Long-term geomorphological evolution in the Abruzzo area, Central Italy: twenty years of research

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Abstract: The most recent research studies into the long-term landscape evolution of the Abruzzo area, carried out over the last twenty years at the "G. d'Annunzio" University of Chieti-Pescara, are based on an integrated approach incorporating structural geology and geomorphology and, in particular, the geomorphometry of topographic and hydrographic aspects, geological and structural-geomorphological surveys and mapping supported by morpho-stratigraphic and chronological constraints.The geomorphological analyses have allowed us to outline the main stages of geomorphological evolution and to identify the factors that have contributed to the landscape shaping of the Apennine Chain, the Adriatic Piedmont and the fluvial plains and coastal sectors, up to the Tremiti islands. In the Apennine Chain, landscape evolution — in a ridge, valley and basin system — is connected to the regional uplift, local tectonic subsidence and local base level variations, which have led to changes in the drainage systems, from exoreic to endorheic (in the intermontane basins) and then to exoreic again. In the Adriatic Piedmont, landscape shaping is connected to uplifting and eustatic sea-level fluctuations, which have induced the formation of a structure-controlled drainage system and the shaping of systems of entrenched alluvial fans and large consequent river valleys, with flights of river terraces. In the coastal Adriatic area — composed of a coastal plain-coastal slope system (northern and southern coast) and of a cliffed rocky coast (central coast, Tremiti) interrupted by river valleys — landscape shaping is the result of selective erosion due to the interaction between marine geomorphic processes and slope processes connected to Late Quaternary eustatic fluctuations.

Keywords: geomorphological studies, landscape evolution, Neogene–Quaternary, Central Apennine Chain, Adriatic Piedmont, coastal areas.

Introduction

Research studies on the relief landforms and processes that characterize the Abruzzo area are very complex, requiring an interdisciplinary approach that involves structural geomorphology in a broad sense, and must take into consideration the various tectonic events that occurred in the Central Apennines.

The Abruzzo area can be divided into three main morphostructural domains: the Central Apennines Chain, the Adriatic Piedmont, with its large fluvial plains, and the coastal area, each one presenting different morphostructural features in terms of both surface and deep structure. The structural-geomorphological relations, boundaries and internal differentiations between the three domains, which reflect a different morphogenesis at different times, are particularly significant. In this framework, the various stages of evolution (especially the initial ones) and the connections between the domains are not entirely clear. These domains are the result of differentiated geomorphological evolution, which took place after the initial emersion stages: Eocene–?Oligocene to Miocene in the chain areas and late Early Pleistocene in the piedmont and even later in the coastal areas.

The geomorphological research conducted over the last twenty years by the authors — and still under way — has focused on the long-term geomorphological evolution of the Abruzzo area, in connection with the scientific debate (since Castiglioni 1935; Demangeot 1965; Mazzanti & Trevisan 1978) about the evolution of Central Italy. The research has focused on the comparison of the Apennine Chain, the Adriatic Piedmont and the Adriatic sectors, up to the Tremiti islands (Fig. 1), with particular reference to:

- morphogenesis in the chain, piedmont and coastal areas;
- geomorphological evolution of the intermontane basins and the main Abruzzo drainage systems, with reference to tectonic processes and eustatic fluctuations;
- slope processes in relation to morphostructural features.

The research work of the authors was based upon detailed geomorphological analyses carried out at local, catchment and regional scales, including in particular topography and hydrography geomorphometry, bedrock and Quaternary surface deposits mapping, and structural-geomorphological mapping, further supported by the definition of morpho-stratigraphic and chronological constraints (^{14}C, U/Th, Ar/Ar dating). This approach is a key tool for understanding the long-term evolution of the landscape resulting from the combination of the tectonic processes that have built up the relief and the geomorphological surface processes that have dismantled it.

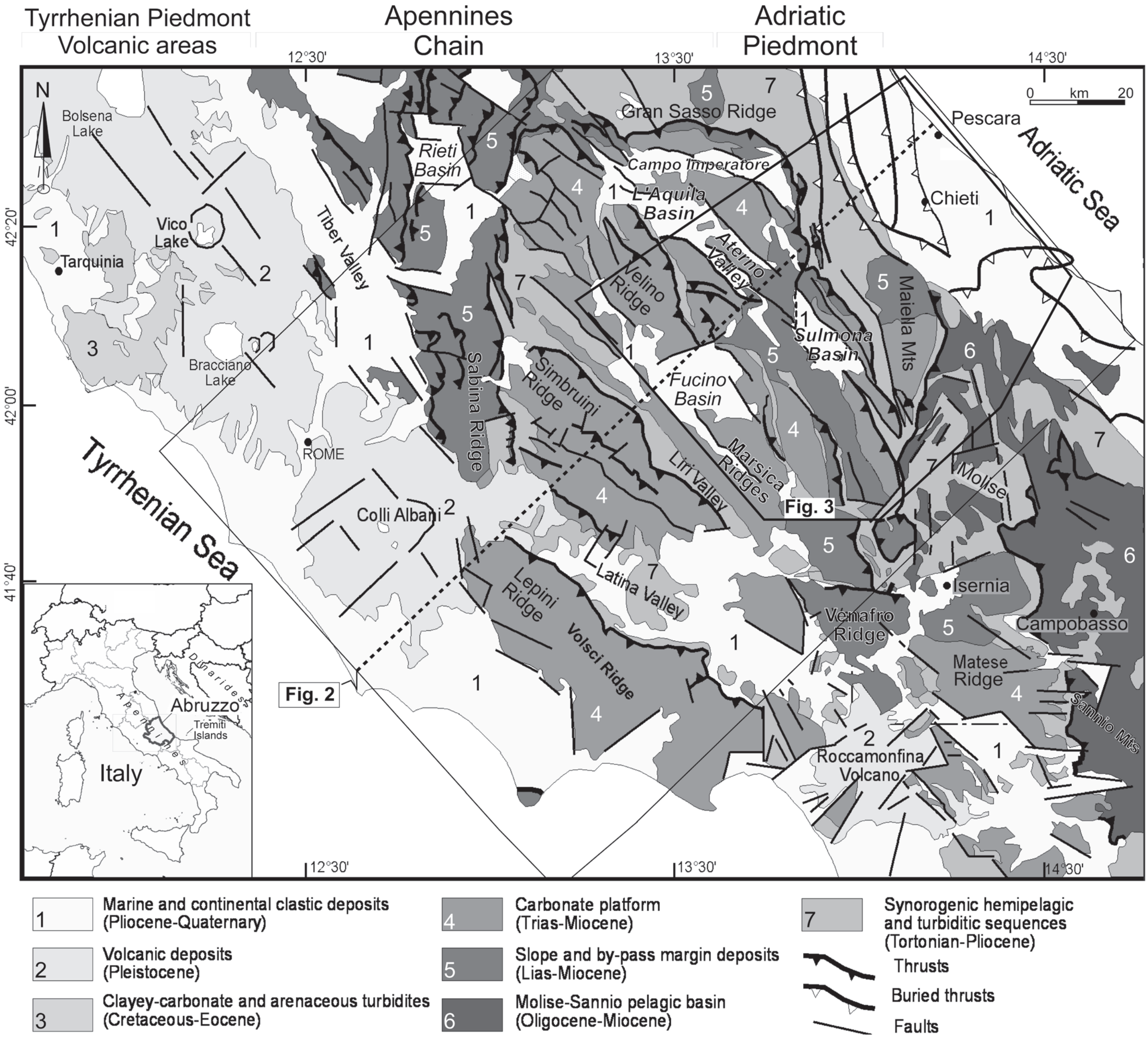

Fig. 1. Location map of the study area and geological scheme of central Italy (modified from Parotto et al. 2004). The boxes show the location of Fig. 2.

General geological and geomorphological structure of the Abruzzo area

The current landscape setting of the Abruzzo area, as well as that of the northern and southern Italian peninsula, is the result of the Neogene–Quaternary geological evolution of an east-verging chain-foredeep-foreland orogenic system generated through the westward subduction of the Adriatic microplate (Fig. 1).

Geomorphological evolution began with the emersion of the orogen, forming an initial landscape, at least from the Miocene (possibly Eocene–?Oligocene) in the chain area and from the late Early Pleistocene in the piedmont area, and it is closely connected with a complex combination of endogenous (morphotectonics) and exogenous processes (slope, fluvial, karst and glacial processes), also inducing selective erosion on existing geological structures.

The morphology of the Central Apennine Chain is asymmetric, with its highest peaks (Gran Sasso, 2912 m a.s.l.; Maiella, 2793 m a.s.l.; Figs. 1 and 2) located eastward of the main Tyrrhenian–Adriatic drainage divide, and is characterized by the superimposition of undulations of different wavelengths, comprising a wide bulging (>100 km), intermediate undulations (10–20 km) and minor undulations (<2km) (Fig. 2; D'Agostino et al. 2001; Molin & Fubelli 2005; Piacentini & Miccadei 2014). The chain is made up of thrust sheets that were generated through the deformation of Mesozoic–Cenozoic palaeogeographical domains (carbonate platforms and related margins, slope and basin) consisting of pre-orogenic lithological sequences having different

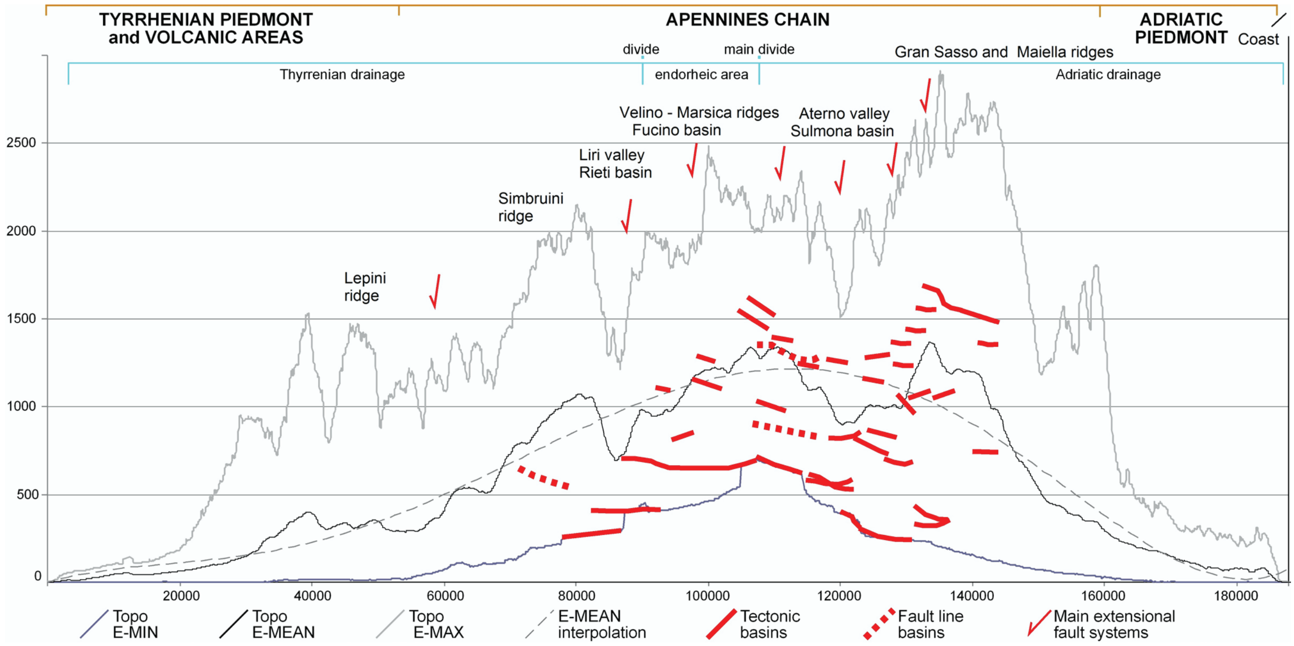

Fig. 2. Swath profile in the SW–NE direction across the central Apennines (from 40 m DEM). Maximum, minimum and average elevations (and the related interpolation) are shown, as well as the main extensional fault systems and the position of the main divides (modified form Piacentini & Miccadei 2014).

thicknesses, rheology and erodibility (mainly limestone and/or alternating limestone/marl). Orogenic compressional tectonics along NW–SE to N–S-oriented thrusts affected the Central Apennines from the Late Miocene (western side) to the Early Pliocene (eastern side). This deformation caused the complex superimposition of the tectonic units one over the other and over synorogenic pelitic arenaceous turbiditic sequences. The consequent tectonic thickening led to the emersion of the chain and the shaping of the incipient landscape composed of low hilly relief, gentle surfaces and islands, bordered by bays and small marine basins (Coltorti & Pieruccini 2000; Parotto et al. 2004; APAT 2006a,b,c,d; Patacca et al. 2008; ISPRA 2010a,b,c,d; Vezzani et al. 2010; Calamita et al. 2012; Miccadei et al. 2012a; Bonini et al. 2014 and references therein). Compressional deformation was followed by strike-slip tectonics along mostly NW–SE to NNW–SSE-oriented faults poorly constrained in age and largely masked by later extensional tectonic events. Strike-slip tectonics contributed to defining a more complex tectonic setting, deforming the compressional tectonic units.

Since the Early Pleistocene (and more intensively during the Middle Pleistocene), the orogen underwent regional uplifting (average rate 0.2–1 mm/a), connected to sublithospheric dynamics and responsible for the long-wavelength bulging of the chain (Demangeot 1965; Cinque et al. 1993; Dramis 1993; Ascione & Cinque 1999; D'Agostino et al. 2001; Mayer et al. 2003; Ascione et al. 2008; Carminati & Doglioni 2012; Faccenna et al. 2014). In connection with regional uplift, local extensional tectonics affected the chain — first in the western areas and then in the eastern ones — and led to the formation of the intermediate topography undulations along the main NW–SE-trending extensional fault systems (Fig. 2) (average slip-rates ~0.1–1.5 mm/a; Papanikolaou et al. 2005 and references therein). This caused the uplifting of the chain system, the formation of the intermontane basins (Cavinato & De Celles 1999; Galadini & Messina 2004; Giaccio et al. 2012; Bonini et al. 2014; Piacentini & Miccadei 2014 and references therein), the ensuing widening of the chain area and the emersion of the Adriatic Piedmont (Dramis 1993; Coltorti et al. 1991, 1996; Aucelli et al. 1996; Centamore et al. 1996; Del Monte et al. 1996; Lupia Palmieri et al. 1996, 1998; Ascione & Cinque 1999; D'Alessandro et al. 2003; Mayer et al. 2003). The present-day tectonic setting is characterized by extensional tectonics still active in the axial part of the chain, which is characterized by intense seismicity and strong historical earthquakes (up to M 7.0; e.g. Fucino 1915; L'Aquila 2009). The Adriatic Piedmont is characterized by moderate uplifting and moderate seismicity, while the Adriatic sea is affected by subsidence and by moderate compression and strike-slip related seismicity (Di Bucci & Angeloni 2013 and references therein).

The combination of these processes with Quaternary climate fluctuations led to the most important morphogenetic phases, involving morphotectonic and selective erosion processes, both in the chain area and in the piedmont and coastal areas. This resulted in the reorganization of drainage systems, the dismembering of the palaeo-landscapes generated during the initial shaping stage, the development of consequent valleys with flights of fluvial terraces and the formation of the present-day landscape (D'Agostino et al. 2001; Ascione et al. 2008; Nesci et al. 2012; Piacentini & Miccadei 2014 and references therein).

Main stages of geomorphological evolution in the chain, piedmont and coastal sectors of the Abruzzo area

The present-day relief of the central Apennine Chain area consists of a series of morphostructural elements that form the intermediate undulations of the topography (Figs. 2 and 3):

- ridges resulting from a combination of morphotectonic and selective erosion processes, with variable NW–SE to N–S directions (e.g., thrust ridges, anticlinal ridges, faulted homocline ridges), formed in pre-orogenic Mesozoic–Cenozoic calcareous sequences;
- narrow erosion valleys (e.g., fault line valleys, transversal valleys, radial valleys), longitudinal and transversal to the

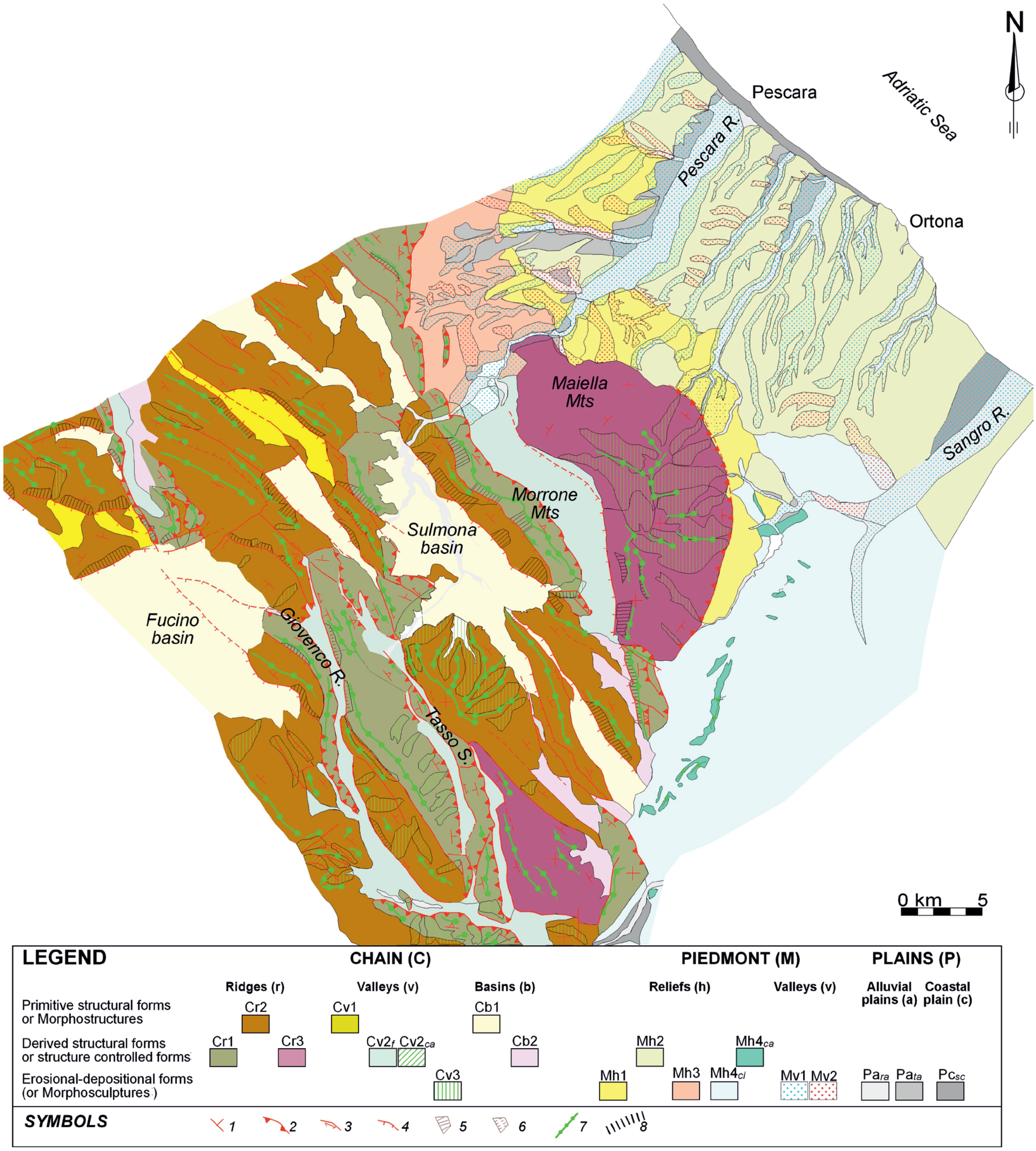

Fig. 3. Scheme of the morphostructural elements of central-eastern Abruzzo (modified from D'Alessandro et al. 2003). **Chain (C) — Ridges:** Cr1) exhumed thrust ridge; Cr2) faulted homocline ridge; Cr3) exhumed anticline ridge. **Valleys:** Cv1) tectonic valley; Cv2) fault line valley; Cv3) radial or transversal valley. **Basins:** Cb1) tectonic basin; Cb2) tectonic-karst basin. **Piedmont (M) — Reliefs:** Mh1) homoclinal reliefs; Mh2) mesa relief; Mh3) exhumed thrust relief; Mh4) relief on chaotic lithological sequences; **Valleys:** Mv1) consequent valley; Mv2) subsequent valley. **Plains (P)** — Pa) Alluvial plains. **Symbols:** 1) dip direction domain; 2) thrust; 3) strike-slip fault ; 4) normal fault; 5) main fault scarp; 6) main fault line scarp; 7) main ridge; 8) divide.

NW–SE-trending chain axis, underlain by synorogenic pelitic-arenaceous sequences (fault line valleys) or carved into the calcareous bedrock (transversal and radial valleys);
- tectonic valleys and large tectonic intermontane basins, mostly NW–SE-elongated and partly filled with Quaternary post-orogenic continental deposits.

These morphostructural elements were affected by the main surface processes (mostly fluvial, slope, lacustrine, karst and glacial) induced and controlled by climate fluctuations, local and regional tectonics and related base level variations.

The analysis of the geomorphological-structural characteristics of the main ridges, valleys and intermontane basins, of the drainage systems and of karst palaeo-landscapes (Ciccacci et al. 1999; Miccadei et al. 1999; Piacentini 2000; Cavinato et al. 2002; Villani 2004; Ascione et al. 2007; Berti 2008; Piacentini & Miccadei 2014; Santo et al. 2014 and references therein) has enabled us to outline the evolution of the landscape in relation to uplifting, extensional tectonics and geomorphological processes (Fig. 4).

The earliest evidence of local erosion, probably due to karst processes, dates back to the Eocene–Oligocene (Miccadei et al. 2012a), bearing witness to the early emersion that took place when the area was still in the foreland of the Apennine orogenic system. Between the Late Miocene and the Pliocene, the Abruzzo area was progressively affected by compressional tectonics. The landscape was gradually transformed into a series of islands, separated by some marine sedimentary basins, where deposits were laid down over the deformed pre-orogenic sequences (piggy-back, thrust-top basins;

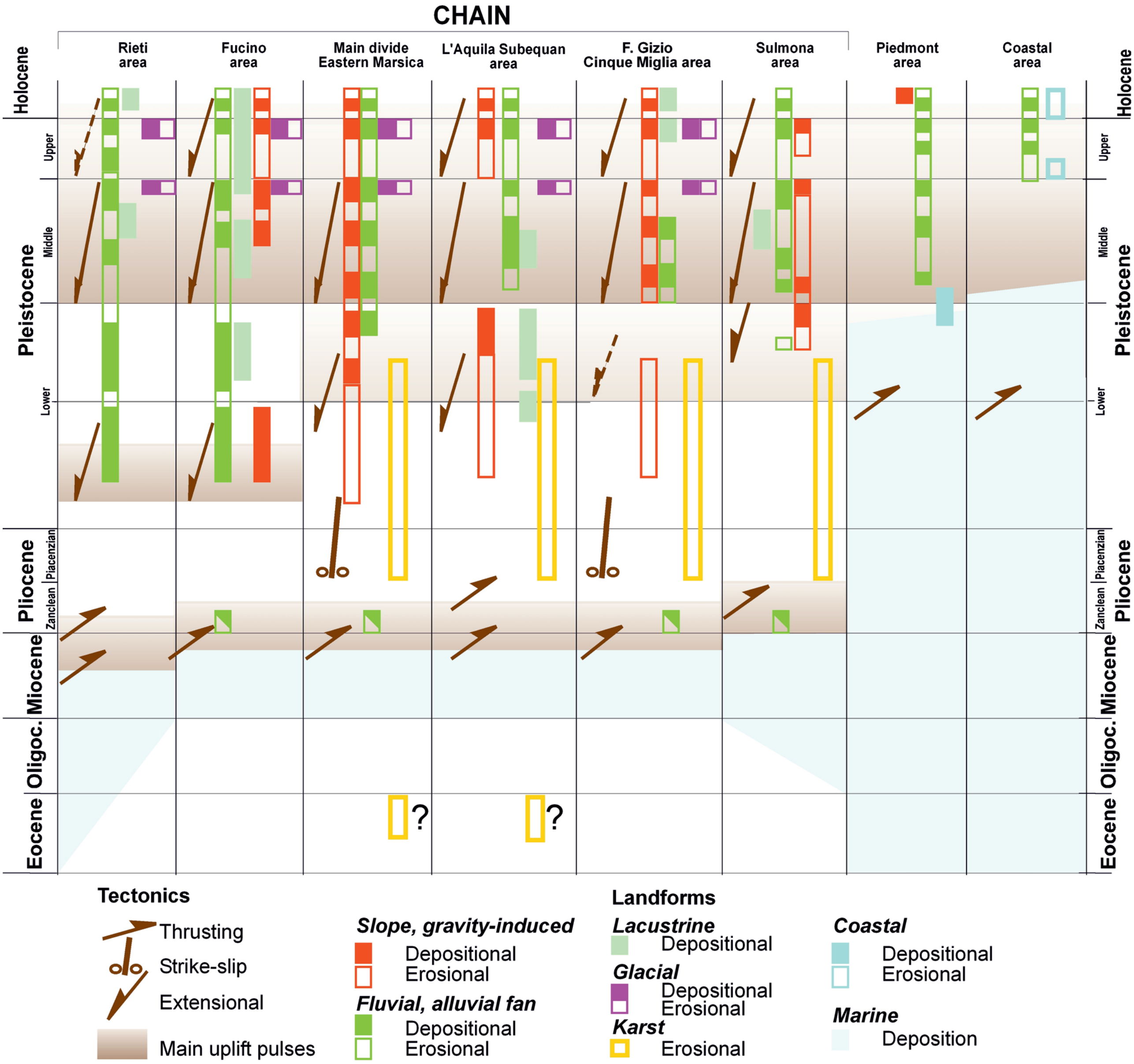

Fig. 4. Distribution of the geomorphic processes in the chain, piedmont and coastal plain sectors of the Abruzzo area.

Cipollari et al. 1999; Miccadei et al. 2012a and references therein). This initial landscape was characterized by minor topographic undulations related to karst and fluvial erosion, the remnants of which have been preserved at the top of the relief; patches of conglomerates with allochthonous elements found at high elevations and in large hanging valleys provide evidence of a pre-existing drainage system originating from the western sectors (Marsica area; Miccadei & Parotto 1999; Miccadei et al. 2012a).

In the chain area, since the Early Pleistocene (Fig. 4), anticlinal ridges, thrust ridges (e.g., Monte Morrone, Montagna Grande) and fault line valleys (e.g., the Giovenco River Valley, Sangro River Valley and Tasso Stream Valley) have been shaped by the geomorphic processes controlled by the lithostructural features of compressional structures. The presence of palaeosurface remnants on top of the relief and the arrangement of continental deposits on the valley slopes show various stages in the deepening of the hydrographic network and in the incision of the landscape that started in the Early Pleistocene, when part of the relief had probably already developed (Galadini & Messina 2004; Ascione et al. 2008; Aucelli et al. 2011; Giaccio et al. 2012). This led to the outline of the current chain configuration.

Intermontane basins, tectonic valleys and homoclinal faulted ridges started to be shaped diachronically in connection with extensional tectonics: from the Early Pleistocene in the western portion of the Apennines and from the late Early Pleistocene in the axial and eastern sides (Figs. 3 and 4) (Cavinato & De Celles 1999; D'Agostino et al. 2001; Galadini & Messina 2004; Carminati & Doglioni 2012; Bonini et al. 2014; Mazzoli et al. 2014; Piacentini & Miccadei 2014). Large intermontane basins were formed, elongated in a NW–SE to NNW–SSE direction and bounded by normal faults mostly on their eastern sides (Fig. 4). These basins were progressively filled with sequences of alluvial fan, fluvial and lacustrine deposits. The tectonic subsidence of the basins led to the rearrangement of the drainage systems and the formation of endorheic areas in the axial part of the chain (Fucino, L'Aquila).

During the Early–Middle Pleistocene, intermontane basins were filled primarily by sequences of lacustrine deposits. These bear witness to the formation of a large system of lacustrine basins within low-lying areas bordered by fault related escarpments and fault slopes. These basins developed mostly along NW–SE and WSW–ENE-oriented fault systems, with complex deformation histories (including strike-slip movements) and a last stage characterized by extensional tectonics. During the latter, the local tectonic subsidence rate was higher than the regional uplift rate, thus preserving an endorheic drainage system in the basins.

Extensional tectonics induced the formation of large sets of tectonic landforms and of slope-alluvial fan deposits. At the same time, variations in local base levels (within the intermontane basins) and the deepening of the hydrographic network induced intense surface processes and controlled the development and exhumation of thrust and anticlinal ridges (Ciccacci et al. 1999; Miccadei et al. 1999, 2004; Cavinato et al. 2002; Galadini & Messina 2004; Giaccio et al. 2012; Piacentini & Miccadei 2014; Santo et al. 2014; for the surrounding areas see also Coltorti et al. 1991, 1996; Amato et al. 2014; Aringoli et al. 2014; Giano et al. 2014; Labella et al. 2014 and references therein).

In the late Middle Pleistocene, the Appenines area underwent an extensive landscape modification. A sudden change occurred, from closed drainage systems and lacustrine basins to open through-going drainage systems connected to the Adriatic Piedmont. This is indicated in the sedimentary sequence of the intermontane basins by the transition — with erosional contacts and unconformities — from lacustrine deposits to mainly fluvial and alluvial ones. In this stage, the effects of regional uplift and geomorphic processes overcame the local tectonic subsidence, inducing the incision and deepening of the drainage network. The connection between the basins and the Piedmont was the result of the incision of both longitudinal (along tectonic or fault line valleys) and transversal deep gorges (along transversal valleys crossing fault slopes, faulted homocline ridges and thrust ridges).

The front of the Apennine Chain experienced extensive modifications connected with the evolution of the chain. From the Miocene to the Pliocene, the front migrated from west to east, inducing the gradual emersion of the chain. Since the Early Pleistocene, it has been located in its present position near the outer and more superficial thrusts. In this area, geomorphological studies and mapping (D'Alessandro et al. 2008; Della Seta et al. 2008; Miccadei et al. 2012c, 2013) have shown the development of intense selective erosion processes induced by the regional uplift and controlled by the passive role of morphostructures and lithology in terms of hardness, fracturing and erodibility. These processes resulted in the formation of major thrust ridges (Gran Sasso, eastern Morrone) and exhumed anticlinal ridges (Maiella) along the chain front. From the Middle to the Late Pleistocene, these morphostructures were incised by radial valleys (Maiella) and transversal valleys. The main transversal valleys (e.g., Popoli gorges, Pescara River) defined the connection of the drainage system of the Apennines Chain with the one in the piedmont area. Along the front of the chain, a sequence of alluvial fans and terraced fluvial deposits provides evidence that the incision occurred as a result of uplifting and drainage network deepening (see also Demangeot 1965; Dufaure et al. 1989; Coltorti et al. 1991, 1996; Aucelli et al. 1996; Del Monte et al. 1996; Nesci & Savelli 2003).

The Adriatic Piedmont landscape (D'Alessandro et al. 2003, 2008; Paron 2004; Della Seta et al. 2008; Buccolini et al. 2010; Miccadei et al. 2012c, 2013; for surrounding areas see also Coltorti et al. 1991, 1996; Giannandrea et al. 2014: Gioia et al. 2014) started to develop more recently, during the emersion phase that occurred in the late Early Pleistocene (Fig. 4). Its morphostructural setting is the result of the late evolution of the Adriatic foredeep domain of the Apennine orogenic system, with a coarsening-up sequence of marine clayey-sandy-conglomeratic rocks (Late Pliocene–Early Pleistocene) characterized by a slightly NE-dipping homoclinal setting. After the emersion, uplifting led to the shaping of cuestas, mesas and plateaux incised by approximately SW–NE-oriented consequent valleys. Some of these valleys lie within the piedmont area. Others originate from the chain front and cut across the whole piedmont. The main ones originate at the core of the chain, cross its front through the main transversal valleys and run across the piedmont within large alluvial plains. The latter are characterized by fluvial deposits arranged in flights of at least four orders of terraces that formed in the Middle Pleistocene–Holocene interval. The slopes are extensively covered by landslide and colluvial deposits (Della Seta et al. 2008; D'Alessandro et al. 2008; ISPRA 2010a,b,c,d; Miccadei et al. 2013; for the surrounding areas see also Coltorti et al. 1991, 1996; Bracone et al. 2012; Nesci et al. 2012; Giannandrea et al. 2014; Giano & Giannandrea 2014 and references therein). Secondary valleys show clear geomorphological evidence of tectonics, such as river bends, hanging valleys and counterflow confluences. The correlations between the above-mentioned geomorphic features and the various generations of alluvial fans and river terraces in the main and secondary valleys, together with the chronostratigraphic constraints, outline the shaping of a rectangular hydrographic network and its possible timing. This network developed in the late Middle Pleistocene and was influenced by mainly SW–NE, N–S, NW–SE-oriented minor faults and main joints associated with uplifting processes. It was gradually incorporated in the hydrographic network rearrangement up to its current configuration, which indeed still shows a number of anomalies (network orientations, counterflow confluences, knick points, stream captures, etc.; D'Alessandro et al. 2008; Della Seta et al. 2008; Miccadei et al. 2012c, 2013). Finally, rapid slope and fluvial plain dynamics are also recorded in more recent times, mainly connected to anthropic factors (e.g. Coltorti et al. 1996; Capelli et al. 1997; Buccolini et al. 2007; Piacentini et al. 2015).

Therefore, the piedmont area is mainly characterized by selective erosion processes, while the control of tectonics on landforms is less present, although it strongly contributed to defining the arrangement of the drainage network.

The Abruzzo coastal belt borders the mesas and plateaux sloping down from the piedmont area. It features a narrow, elongated coastal plain bounded by palaeocliffs (northern part) and a rock coast with cliffs of variable height and small pocket beaches (southern part). Landscape shaping is controlled by the geological setting of the Adriatic foredeep and induced by uplifting, climate changes and Late Quaternary eustatic sea-level fluctuations. In order to better understand the landscape evolution of foreland areas, this sector was compared with the Tremiti area (Ricci 2005; Mascioli 2008; Miccadei et al. 2011a,b, 2012b; Parlagreco et al. 2011). Large stretches of the Abruzzo coastal slopes are characterized by palaeo-landslides, which involved entire slope portions (e.g., Ortona, Vasto), leading to the current coast configuration. Colluvial deposits and calcretes (dating: U/Th 30–50 ka) covering the landslide deposits allow us to date these phenomena to the first part of the Late Pleistocene, in low sea level stands (Calamita et al. 2012; Della Seta et al. 2013; Piacentini et al. 2015). The Holocene post-glacial sea-level rise induced the filling of Late Pleistocene palaeo-valleys, the shaping of the present cliffs and coastal slopes and the formation of a narrow coastal plain. The coastal area is also characterized by recent system of coastal dunes largely removed by urbanization and anthropic activities (Miccadei et al. 2011b). The prevailing role of selective erosion and morphosculptures can be assessed in the coastal area too, in spite of the role played by tectonic features, which have passively controlled the development of cliffs and landslides.

Conclusions

The beginning of the morphogenesis and Quaternary geomorphologic evolution of the Apennine Chain and of the related piedmont and coastal areas has always been at the centre of lively scientific debate. The geomorphological analysis carried out by the authors in the Abruzzo and surrounding areas have allowed us to outline the main evolutionary stages and to identify the factors that have contributed to the landscape shaping of the main morphostructural domains (Fig. 4). The geomorphological evolution of these domains has varied over space and time and has been influenced by climate changes and the effects of regional uplift, with different consequences related to local tectonics or litho-structural control. The main evidence is recorded in the morphostructures located at the boundaries between the chain, piedmont and coastal domains and in the internal variability of these domains (Fig. 4).

The Abruzzo Apennine Chain is characterized by a complex geological setting and landscape that evolved as a result of the continuous combination — from Neogene to Quaternary times — of tectonics and selective erosion, which are strongly influenced by the juxtaposition of different lithological sequences due to polyphasic (compressive, strike-slip and extensional) tectonics and regional uplift. Landscape shaping — in a ridge, valley and basin system — was thus controlled by the combination of regional uplift and local tectonic subsidence, which induced changes in the drainage base levels of the intermontane basins and changes in the drainage systems, from exoreic to endorheic and then to exoreic again. Climate changes have affected the distribution of glacial and karst landforms as well as the variation in landslides and debris production on the slopes and sediment transport in river valleys. The overall morphostructural setting of the landscape is the result of the active role of tectonics (which is prevalent in the central and western sectors) and the passive role of the structure in selective erosion processes (which prevails in the southern and eastern sectors; Fig. 4).

The Adriatic Piedmont has mainly a homoclinal morphostructural setting, incised by large consequent river valleys. Landscape shaping has mostly resulted from the combination of uplifting and eustatic sea-level fluctuations, together with climate changes and the related variation in sediment transport in slopes and rivers. These processes have controlled the selective erosion on hills and slopes and the shaping of river valleys, with the formation of a series of wide alluvial fans and fluvial terraces. From a morphostructural standpoint, the landscape is mainly influenced by selective erosion (cuestas, mesas, plateaux) and uplift/fluvial incision processes (river valleys and terraces), while the active role of local tectonics is less evident, although the main tectonic elements essentially controlled the development of the hydrographic network.

The coastal area is characterized, in the northern part, by a narrow and elongated coastal plain with remnants of palaeocliffs, interrupted by wide river valleys and, in the central-southern part, by a rock coast with active and inactive cliffs and large landslides. From a morphostructural standpoint, landscape shaping is the result of selective erosion, due to the interaction between marine geomorphic processes (and Late Quaternary eustatic sea-level variations) and slope processes (major landslides). These processes have been induced by uplift and passively controlled by the litho-structural setting of the mesa and plateaux reliefs bordering the coast as well as by the presence of tectonic elements. More recently, the above-mentioned long-term processes have interacted, especially in the piedmont and coastal areas, with variations in river and coastal plain dynamics, mainly related to both natural and anthropic processes.

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References

Amato V., Aucelli P.P.C., Cesarano M., Jicha B., Lebreton V., Orain R., Pappone G., Petrosino P. & Russo Ermolli E. 2014: Quaternary evolution of the largest intermontane basin of the Molise Apennine (central-southern Italy). Special Issue: Intermontane Basins: Quaternary morphoevolution of Central-Southern Italy. In: Aucelli P.P.C., Della Seta M., Giano S.I. & Schiattarella M. (Eds.): *Rendiconti Lincei — Scienze Fisiche e Naturali* 25, 2, 197–216.

APAT 2006a: Geological Map of Italy, scale 1:50,000, Sheet 359 "L'Aquila". *APAT Servizio Geologico d'Italia*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/359_LAQUILA/Foglio.html (in Italian with English abstract and legend).

APAT 2006b: Geological Map of Italy, scale 1:50,000, Sheet 360 "Torre de' Passeri". *APAT Servizio Geologico d'Italia*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/360_TORRE_DE_PASSERI/Foglio.html (in Italian with English abstract and legend).

APAT 2006c: Geological Map of Italy, scale 1:50,000, Sheet 368 "Avezzano". *APAT Servizio Geologico d'Italia*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/368_AVEZZANO/Foglio.html (in Italian with English abstract and legend).

APAT 2006d: Geological Map of Italy, scale 1:50,000, Sheet 369 "Sulmona". *APAT Servizio Geologico d'Italia*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/369_SULMONA/Foglio.html (in Italian with English abstract and legend).

Aringoli D., Cavitolo P., Farabollini P., Galindo-Zaldivar J., Gentili B., Giano S. I., Lòpez-Garrido A. C., Materazzi M., Nibbi L., Pedrera A., Pambianchi G., Ruano P., Ruiz-Constàn A., Sanz de Galdeano C., Savelli D., E. Tondi & Troiani F. 2014: Morphotectonic characterization of the quaternary intermontane basins of the Umbria-Marche Apennines (Italy). In: Aucelli P.P.C., Della Seta M., Giano S.I., Schiattarella M. (Eds.): *Rendiconti Lincei — Scienze Fisiche e Naturali* 25, 2, 111–128.

Ascione A. & Cinque A. 1999. Tectonics and erosion in the long term relief history of the Southern Apennines (Italy). *Z. Geomorphol. Suppl.* 118, 1–16.

Ascione A., Miccadei E., Villani F. & Berti C. 2007: Morphostructural setting of the Sangro and Volturno rivers divide area (Central-Southern Apennines, Italy). *Geogr. Fis. Dinam. Quat.* 30, 13–29.

Ascione A., Cinque A., Miccadei E., Villani F. & Berti C. 2008: The Plio-Quaternary uplift of the Apennine chain: new data from the analysis of topography and river valleys in Central Italy. *Geomorphology* 101–102, 105–118.

Aucelli P.P.C., Cavinato G.P. & Cinque A. 1996: Geomorphological evidence of Pliocene-Quaternary tectonics in the Adriatic piedmont of the Abruzzi Apennines. *Il Quaternario – Ital. J. Quat. Sci.* 9, 1, 299–302 (in Italian with English Abstract).

Aucelli P.P.C., Iannantuono, E. & Rosskopf, C.M. 2009: Recent evolution and erosion risk of the Molise coast (southern Italy). *Boll. Soc. Geol. Ital.* 128, 3, 759–771.

Aucelli P.P.C., Amato V., Cesarano M., Pappone G., Rosskopf C., Ermolli E. & Scarciglia F. 2011: New morphostratigraphic and chronological constraints for the Quaternary paleosurfaces of the Molise Apennine (southern Italy). *Geol. Carpath.* 62, 1, 17–26.

Berti C. 2008: The Neogene-Quaternary morphotectonic analysis of the Marsicano-Peligna region (Central Appenines). *PhD in Geology and evolution of the Lithosphere*, 21st Cycle, Università "G. d'Annunzio" di Chieti-Pescara (in Italian with English abstract).

Bonini L., Di Bucci D., Toscani G., Seno S. & Valensise G. 2014: On the complexity of surface ruptures during normal faulting earthquakes: Excerpts from the 6 April 2009 L'Aquila (central Italy) earthquake (M w 6.3). *Solid Earth* 5, 1, 389–408.

Bracone V., Amorosi A., Aucelli P.P.C., Rosskopf C.M., Scarciglia F., Di Donato V. & Esposito P. 2012: The Pleistocene tectono-sedimentary evolution of the Apenninic foreland basin between Trigno and Fortore rivers (Southern Italy) through a sequence-stratigraphic perspective. *Basin Research* 24, 2, 213–233.

Buccolini M., Gentili B., Materazzi M., Aringoli D., Pambianchi G.

& Piacentini T. 2007: Human impact and slope dynamics evolutionary trends in the monoclinal relief of Adriatic area of central Italy. *Catena* 71, 1, 96–109.

Buccolini M., Gentili B., Materazzi M. & Piacentini T. 2010: Late Quaternary geomorphological evolution and erosion rates in the clayey peri-Adriatic belt (central Italy). *Geomorphology* 116, 1–2, 145–161.

Calamita F., Piacentini T., Pizzi A., Rusciadelli G. & Trincardi F. 2012: Explanatory notes to the Geological Map of Italy (scale 1:50,000), Sheet 372 "Vasto". *Servizio Geologico d'Italia, ISPRA*, Roma (in Italian with English abstract).

Carminati E. & Doglioni C. 2012: Alps vs. Apennines: The paradigm of a tectonically asymmetric earth. *Earth-Sci. Rev.* 112, 67–96.

Castiglioni B. 1935. The morphological research in the Pliocene terrains of the Central Italy. *Pubblicazione Istituto Geografico Università di Roma* s. A, 4 (in Italian).

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 subducting slab in retrograde motion. *Geology* 27, 955–958.

Cavinato G.P., Carusi C., Dall'Asta M., Miccadei E. & Piacentini T. 2002: Sedimentary and tectonic evolution of Plio-Pleistocene alluvial and lacustrine deposits of Fucino Basin (central Italy). *Sediment. Geol.* 148, 1–2, 29–59.

Centamore E., Ciccacci S., Del Monte M., Fredi P. & Lupia Palmieri E. 1996. Morphological and morphometric approach to the study of the structural arrangement of the North-Eastern Abruzzo (Central Italy). *Geomorphology* 16, 127–137.

Ciccacci S., D'Alessandro L., Dramis F. & Miccadei E. 1999: Geomorphologic Evolution and Neotectonics of the Sulmona Intramontane Basin (Abruzzi, Apennine, Central Italy). *Z. Geomorphol.* 118, 27–40.

Cinque A., Patacca E., Scandone P. & Tozzi M. 1993: Quaternary kinematic evolution of the Southern Apennines. Relationships between surface geological features and deep lithospheric structures. *Annali di Geofisica* 36, 2, 249–260.

Cipollari P., Cosentino D., Esu D., Girotti O., Gliozzi E. & Praturlon A. 1999: Thrust-top lacustrine-lagoonal basin development in accretionary wedges: Late Messinian (Lago-Mare) episode in the Central Apennines (Italy). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 151, 1–3, 149–166.

Coltorti M. & Pieruccini P. 2000. A late Lower Pliocene planation surface across the Italian Peninsula: a key tool in neotectonic studies. *J. Geodyn.* 29, 323–328.

Coltorti M., Consoli M., Dramis F., Gentili B. & Pambianchi G. 1991: The geomorphological evolution of the alluvial plains of central and southern Marche. *Geogr. Fis. Dinam. Quat.* 14, 1, 87–100 (in Italian with English abstract).

Coltorti M., Farabollini P., Gentili B. & Pambianchi G. 1996: Geomorphological evidence for anti-Apennine faults in the Umbro-Marchean apennines and in the peri-Adriatic Basin, Italy. *Geomorphology* 15, 1, 33–45.

D'Agostino N., Jackson J.A., Dramis F. & Funiciello R. 2001: Interactions between mantle upwelling, drainage evolution and active normal faulting: an example from central Apennines (Italy). *Geophys. J. Int.* 141, 475–497.

D'Alessandro L., Miccadei E. & Piacentini T. 2003: Morphostructural elements of central-eastern Abruzzi: contributions to the study of the role of tectonics on the morphogenesis of the Apennine chain. *Quat. Int.* 101–102, 115–124.

D'Alessandro L., Miccadei E. & Piacentini T. 2008: Morphotectonic study of the lower Sangro River valley (Abruzzi, Central Italy). *Geomorphology* 102, 145–158.

Della Seta M., Del Monte M., Fredi P., Miccadei E., Nesci O., Pambianchi G., Piacentini T. & Troiani F. 2008: Morphotectonic evolution of the Adriatic piedmont of the Apennines: an advancement in the knowledge of the Marche-Abruzzo border area. *Geomorphology* 102, 119–129.

Della Seta M., Martino S. & Scarascia Mugnozza G. 2013: Quaternary sea-level change and slope instability in coastal areas: Insights from the Vasto Landslide (Adriatic coast, central Italy). *Geomorphology* 201, 462–478.

Del Monte M., Di Bucci D. & Trigari A. 1996: The morphotectonic setting of the region between the Majella and the Adriatic Sea (Abruzzese Apennines). *Mem Soc Geol Ital* 51, 419–430 (in Italian with English abstract).

Demangeot J. 1965: Geomorphologie des Abruzzes Adriatiques. *Edition du Centre National de la Recherche Scientifique (Paris)* 15, 1–403.

Di Bucci D. & Angeloni P. 2013: Adria seismicity and seismotectonics: review and critical discussion. Special issue: In: Bigi S., D'Ambrogi C. & Carminati E. (Eds.): The geology of the Peri-adriatic basin and the Adriatic Sea. *Mar. Pet. Geol.* 42, 182–190.

Dramis F. 1993: The role of long-range tectonic uplift in the genesis of the Apennine relief. *Studi Geol. Camerti* vol. spec. 1992/1, 9–15 (in Italian with English abstract).

Dufaure J.J., Bossuyt D. & Rasse M. 1989: Deformation Quaternaire et morphogenese de l'Apennin Central adriatique. *Phisio-Geo* 18, 9–46.

Faccenna F., Becker T.W., Auer L., Billi A., Boschi L., et al. 2014: Mantle dynamics in the Mediterranean. *Rev. Geophys.* 52, 3, 283–332.

Galadini F. & Messina P. 2004: Early-Middle Pleistocene eastward migration of the Abruzzi Apennine (central Italy) extensional domain. *J. Geodyn.* 37, 57–81.

Giaccio B., Galli P., Messina P., Peronace E., Scardia G., Sottili G., Sposato A., Chiarini E., Jicha B. & Silvestri, S. 2012: Fault and basin depocentre migration over the last 2 Ma in the L'Aquila 2009 earthquake region, central Italian Apennines. *Quat. Sci. Rev.* 56, 69–88.

Giannandrea P., Marino M., Romeo M. & Schiattarella M. 2014: Pliocene to Quaternary evolution of the Ofanto Basin in southern Italy: An approach based on the unconformity-bounded stratigraphic units. *Ital. J. Geosci.* 133, 1, 27–44.

Giano S.I. & Giannandrea P. 2014: Late Pleistocene differential uplift inferred from the analysis of fluvial terraces (southern Apennines, Italy). *Geomorphology* 217, 89–105.

Giano S.I., Gioia D. & Schiattarella M. 2014: Morphotectonic evolution of connected intermontane basins from the southern Apennines, Italy: the legacy of the pre-existing structurally controlled landscape. In: Aucelli P.P.C., Della Seta M., Giano S.I., Schiattarella M. (Eds.): Special Issue: Intermontane Basins: Quaternary morphoevolution of Central-Southern Italy. *Rendiconti Lincei – Scienze Fisiche e Naturali* 25, 2, 241-252.

Gioia D., Gallicchio S., Moretti M. & Schiattarella M. 2014: Landscape response to tectonic and climatic forcing in the foredeep of the southern Apennines, Italy: Insights from Quaternary stratigraphy, quantitative geomorphic analysis, and denudation rate proxies. *Earth Surface Processes and Landforms* 39, 6, 814–835.

ISPRA 2010a: Geological Map of Italy, scale 1:50,000, Sheet 361 "Chieti". *Servizio Geologico d'Italia, ISPRA*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/361_CHIETI/Foglio.html (in Italian with English abstract and legend).

ISPRA 2010b: Geological Map of Italy, scale 1:50,000, Sheet 361 "Chieti". *Servizio Geologico d'Italia, ISPRA*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/351_PESCARA/Foglio.html (in Italian with English abstract and legend).

ISPRA 2010c: Geological Map of Italy, scale 1:50,000, Sheet 372 "Vasto". *Servizio Geologico d'Italia, ISPRA*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/372_VASTO/Foglio.html (in Italian with English abstract and legend).

ISPRA 2010d: Geological Map of Italy, scale 1:50,000, Sheet 378 "Scanno". *Servizio Geologico d'Italia, ISPRA*, Roma. Retrieved from http://www.isprambiente.gov.it/Media/carg/378_SCANNO/Foglio.html (in Italian with English abstract and legend).

Labella R, Capolongo D., Giannandrea P., Giano S.I. & Schiattarella M. 2014: Morphometric analysis of fluvial network and age constraints of terraced surfaces of the Ofanto basin, Southern Italy. Special Issue: Intermontane Basins: Quaternary morphoevolution of Central-Southern Italy, Aucelli P.P.C., Della Seta M., Giano S.I., Schiattarella M. Eds. *Rendiconti Lincei - Scienze Fisiche e Naturali* 25, 2, 253–263.

Lupia Palmieri E., Ciccacci S., Civitelli G., Corda L., D'Alessandro L., Del Monte M., Fredi P. & Pugliese F. 1996: Quantitative geomorphology and morphodynamics of Abruzzoarea: I. The River Sinello drainage basin. *Geogr. Fis. Dinam. Quat.* 18, 31–46 (in Italian with English abstract).

Lupia Palmieri E., Centamore E., Ciccacci S., D'Alessandro L., Del Monte M., Fredi P. & Pugliese F. 1998: Quantitative geomorphology and morphodynamics of the Abruzzo area: II-the Tordino River drainage basin. *Geogr. Fis. Dinam. Quat.* 21, 113–129 (in Italian with English abstract).

Mayer L., Menichetti M., Nesci O. & Savelli D. 2003. Morphotectonic approach to the drainage analysis in the North Marche region, central Italy. *Quat. Int.* 101–102, 157–167.

Mascioli F. 2008: Geomorphological characteristics of the high coasts: forms and evolutionary processes in southern Abruzzo and northern Apulia. *PhD. in Earth sciences for the assessment of earth dynamics, geological risks, and resources*, 20th Cycle, *Università "G. d'Annunzio" di Chieti-Pescara* (in Italian with English abstract).

Mazzanti R. & Trevisan L. 1978: Evoluzione della rete idrografica nell'Appennino centro-settentrionale. *Geogr. Fis. Dinam. Quat.* 1, 55–62.

Mazzoli S., Ascione A., Buscher J.T., Pignalosa A., Valente E. & Zattin M. 2014: Low-angle normal faulting and focused exhumation associated with late Pliocene change in tectonic style in the southern Apennines (Italy). *Tectonics* 33, 9, 1802–1818.

Miccadei E., Barberi R. & Cavinato G.P. 1999: La geologia quaternaria della Conca di Sulmona. *Geol. Romana* 34, 59–86.

Miccadei E., Paron P. & Piacentini T. 2004: The SW escarpment of the Montagna del Morrone (Abruzzi, Central Italy): geomorphology of a fault-generated mountain front. *Geogr. Fis. Dinam. Quat.* 27, 55-87.

Miccadei E., Mascioli, F. & Piacentini T. 2011a: Quaternary geomorphological evolution of the Tremiti Islands (Puglia, Italy). *Quat. Int.* 232, 3–15.

Miccadei E., Mascioli F., Piacentini T. & Ricci F. 2011b: Geomorphological features of coastal dunes along the central Adriatic coast (Abruzzo, Italy). *J. Coastal Res.* 27, 6, 1122–1136.

Miccadei E., D'Alessandro L., Parotto M., Piacentini T. & Praturlon A. 2012a: Explanatory notes to the Geological Map of Italy (scale 1:50,000), Sheet 378 "Scanno". *Servizio Geologico d'Italia, ISPRA*, Roma (in Italian with English abstract).

Miccadei E., Orrù P., Piacentini T., Mascioli F. & Puliga G. 2012b: Geomorphological map of Tremiti Islands Archipelago (Puglia, Southern Adriatic Sea, Italy), scale 1:15,000. *Journal of Maps* 8, 1, 74–87.

Miccadei E., Piacentini T., Gerbasi F. & Daverio F. 2012c: Morphotectonic map of the Osento River basin (Abruzzo, Italy), scale 1:30,000. *Journal of Maps* 8, 1, 62–73.

Miccadei E., Piacentini T., Dal Pozzo A., La Corte M. & Sciarra M. 2013: Morphotectonic map of the Aventino-Lower Sangro valley (Abruzzo, Italy), scale 1:50,000. *Journal of Maps* 9, 3, 390–409.

Molin P. & Fubelli G. 2005: Morphometric evidences of the topographic growth of the central Apennines. *Geogr. Fis. Dinam. Quat.* 28, 47–61.

Nesci O. & Savelli D. 2003: Diverging drainage in the Marche Apennines (central Italy). *Quat. Int.* 101–102, 203–209.

Nesci O., Savelli D. & Troiani F. 2012: Types and development of stream terraces in the Marche Apennines (Central Italy): A review and remarks on recent appraisals. *Geomorphologie: relief, processus, environnement* 2, 215-238.

Papanikolaou I.D., Roberts G.P. & Michetti A.M. 2005: Fault scarps and deformation rates in Lazio-Abruzzo, Central Italy: Comparison between geological fault slip-rate and GPS data. *Tectonophysics* 408, 1–4, 147–176.

Parlagreco L., Mascioli F., Miccadei E., Antonioli F., Gianolla D., Devoti S. & Leoni G. 2011: Holocene Relative Sea Level Rise along the Abruzzo coast (western central Adriatic). *Quat. Int.* 232, 179–186.

Paron P. 2004: Geomorphological evolution of the drainage network in the north-eastern Abruzzo, with GIS applications. *PhD. in Earth sciences for the assessment of earth dynamics, geological risks, and resources*, 17th Cycle, *Università "G. d'Annunzio" di Chieti-Pescara* (in Italian with English abstract).

Parotto M., Cavinato G.P., Miccadei E. & Tozzi M. 2004: Line CROP 11: Central Apennines. *Memorie Descrittive della Carta Geologica d'Italia* 62, 145–153.

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.

Piacentini T. 2000: The Neogene-Quaternary evolution of the area between the Marsica and the northeastern Peligna region (Abruzzo): Paleogeographic and structural analysis. *PhD. in Geodynamics*, 12th Cycle, *Universita di Roma Tre* (in Italian).

Piacentini T. & Miccadei E. 2014: The role of drainage systems and intermontane basins in the Quaternary landscape of the Central Apennines chain (Italy). In: Aucelli P.P.C., Della Seta M., Giano S.I., Schiattarella M. (Eds.): Special Issue: Intermontane Basins: Quaternary morphoevolution of Central-Southern Italy. *Rendiconti Lincei – Scienze Fisiche e Naturali* 25, 2, 139–150.

Piacentini T., Sciarra M., Miccadei E. & Urbano T. 2015: Near-surface deposits and hillslope evolution of the Adriatic piedmont of the Central Apennines (Feltrino Stream basin and minor coastal basins, Abruzzo, Italy). *Journal of Maps* 11, 1, 1–15.

Ricci F. 2005: The Late Quaternary geomorphological evolution of the Abruzzo coast. *PhD. in Earth sciences for the assessment of earth dynamics, geological risks, and resources*, 18th Cycle, *Università "G. d'Annunzio" di Chieti-Pescara* (in Italian with English abstract).

Santo A., Ascione A., Di Crescenzo G., Miccadei E., Piacentini T. & Valente E. 2014: Tectonic-geomorphological map of the middle Aterno River valley (Abruzzo, Central Italy). *Journal of Maps* 10, 3, 365–378.

Vezzani L., Festa A. & Ghisetti F.C. 2010: Geology and tectonic evolution of the Central-Southern Apennines, Italy. *Special Paper, Geological Society of America* 469, 1–58.

Villani F. 2004: Morphostructural analysis of the Pliocene-Quaternary vertical movements between the Gulf of Gaeta (Lt) and Vasto (Ch): the Sangro-Volturno watershed area (Central-Southern Apennines). *PhD. in Geology and evolution of the Lithosphere*, 17th Cycle, *Università "G. d'Annunzio" di Chieti-Pescara* (in Italian with English abstract).