Geology of the eastern slopes of the Simbruini Mts. between Verrecchie and Capistrello (Central Apennines – Abruzzo, Italy)

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**1. Introduction**

The present paper is supported by a geological map (Main Map) of a sector of the Simbruini Mountains and the higher Roveto Valley (Central Apennines), in the Latium-Abruzzi geological domain (Figure 1). This is the second of two companion geological maps of the Simbruini Mts., the first (northern Simbruini Mts.) having already been published (Fabbi, 2016). Due to this, obvious similarities occur in the text, concerning the stratigraphic description and the geological setting. The new map covers an area roughly oriented NW–SE and about 70 km² wide, located in the westernmost sector of the Abruzzo region (Province of L’Aquila, Central Italy). The western part of the study area falls within sheets #367 ‘Tagliacozzo’ and #376 ‘Subiaco’ of the official Geological map of Italy on the 1:50,000 scale (Servizio Geologico d’Italia, 1998, 2005), while the eastern part would fall in the sheet #377 ‘Trasacco’ whose realization is still not planned.

The map was conceived originally as a byproduct of a research project whose main target was to investigate the sedimentology of the ‘brecce della Renga fm.’ (Fabbi & Rossi, 2014 – see below) and the paleostructural features of the late Miocene Simbruini structural high (Carminati, Fabbi, & Santantonio, 2014; Fabbi, Galluzzo, Pichezzi, & Santantonio, 2014 – see below). The main differences with the already published geological cartography (Devoto, 1970; Servizio Geologico d’Italia, 1998, 2005) of the area are due to the higher detail of surveying which allowed the accurate mapping of each different lithofacies of the ‘brecce della Renga fm.’, a more detailed representation of the Mesozoic substrate and a reinterpretation of structural features, that were misrepresented or erroneously interpreted in the previous maps.

**1.1. Regional geological setting**

The Central Apennines (Figure 1) is a mountain chain advancing from SW to NE, whose growth and migration is related, since the Miocene, to the W-directed subduction of the Adriatic continental crust under the Italian peninsula (Carminati & Doglioni, 2012; Cosentino, Cipollari, Marsili, & Scrocca, 2010 and references therein).

The Latium-Abruzzi Domain is one of the paleogeographic domains that characterize the Central Apennines since the Jurassic (Figure 1). In the earliest Jurassic, the present-day central and northern Apennines were occupied by a vast shallow-water sea, characterized by carbonate sedimentation (Bosellini, 2004). Since the Hettangian/Pliensbachian, such carbonate platform was fragmented and partly drowned as a consequence of a well-known Early Jurassic rifting phase (Santantonio & Carminati, 2011; Fabbi & Santantonio, 2012 and references therein).

Subsequently to the rifting stage, thus, a distinction between geological domains can be done, based on the different tectono-sedimentary evolution of the
Figure 1. (A) Location and (B) regional geology of the Central Italy; (C) schematic geological map of the Simbruini Mts. and neighboring areas. Modified after Carminati et al. (2014) and Fabbi (2016).
basin. In the Tuscany and Umbria-Marche-Sabina Domains (Figure 1) tectonic subsidence caused the rapid drowning of the carbonate platform and the onset of pelagic sedimentation; differently the Latium-Abruzzi Domain saw continued shallow-water carbonate production throughout the rest of the Mesozoic, and, following a regional hiatus (see below), the Cenozoic (Accordi & Carbone, 1988; Chiocchini, Chiocchini, Didaskalou, & Potetti, 2008; Civitelli & Brandano, 2005; Parotto & Praturlon, 1975). The general stratigraphy of the area consists of a thick (>3 km) Meso-Cenozoic carbonate platform succession, overlain by upper Miocene-Pliocene terrigenous units representing sedimentation in the Apennine chain foredeep basin (Bigi, Costa Pisani, Milli, & Moscatelli, 2003; Gritelli et al., 2007; Milli & Moscatelli, 2000). The terrigenous succession in the study area (Figure 1(C), Figure 2) includes a lithoclastic unit, the ‘brecce della Renga formation’ (Compagnoni, Galluzzo, & Santantonio, 1990; Devoto, 1967; Fabbi & Rossi, 2014 – see below), which was sedimented in response to the erosion of submarine escarpments produced by an extensional phase predating the Apenninic compression (Compagnoni et al., 1990; Fabbi et al., 2014; Fabbi & Rossi, 2014).

2. Methods
Field mapping was originally performed on the 1:10,000 scale, using an enlarged 1:25,000 IGM topographic map (Series 25, year of publication 1994. Sections: 367 II ‘Tagliacozzo’; 376 I ‘Castellafiume’; 377 IV ‘Capistrello’).

Stratigraphic units represented in the map have been determined using a lithostratigraphic criterion. The lithostratigraphic study was accompanied by biostratigraphic analysis performed both on microfossil assemblages (essentially benthic forams and calcareous algae in thin section) and nanofossils (on smear slides); the determination of macrofossils (e.g. rudist assemblages) resulted also useful for stratigraphic considerations. In addition, the biostratigraphic study has been integrated with sedimentological analysis for the terrigenous deposits (see Fabbi & Rossi, 2014). No formalized stratigraphic units exist for the carbonate platform succession of the central Apennines, so the stratigraphic units used in this paper are the same described in Compagnoni et al. (2005) and Damiani, Catenacci, Molinari, Panseri, and Tilia (1998), with minor differences discussed in the text.

3. Stratigraphy and geological setting of the mapped area
The stratigraphy of the study area (Figure 2) essentially reflects the evolution of the Latium-Abruzzi carbonate platform, which hosted shallow water sedimentation from the Late Triassic to the middle Miocene (Accordi & Carbone, 1988; Chiocchini et al., 2008; Damiani, 1990; Damiani et al., 1998; D’argenio, 1974; Parotto & Praturlon, 1975, 2004). Since the late Miocene the area was involved in the Apennine Chain building (see below) and the sedimentation style changed from carbonatic to lithoclastic/siliciclastic, and finally, following the emersion from the sea and the uplift of the chain in the latest Messinian-Pliocene (Fabbi &

Figure 2. Stratigraphy of the study area: UAM = ‘unità argilloso marnosa’; BDR = ‘brecce della Renga fm.’; CTLA = ‘complesso torbiditico altomiocenico Laziale-Abruzzese’. Modified after Fabbi and Rossi (2014) and Fabbi (2016).
S. FABBIA, 2018, a further shift occurred from marine to continental sedimentation.

In the following text the description of the stratigraphic units is therefore organized in three different sections, reflecting the main evolutionary steps of the study area:

i. Carbonate platform succession: ‘Saifar limestone’, ‘Campbelliella limestone’, ‘Fioio dolostone’, ‘requieniid limestone’, ‘radiolitid limestone’ and ‘bryozoan limestone’

ii. Terrigenous succession: ‘breccia della Renga fm.’ and ‘compleso torbiditico altomocienico laziale abruzzese’

iii. Continental deposits: valley bottom deposits, landslide and slope debris.

3.1. Carbonate platform succession

While carbonate sedimentation in the region started in the late Triassic (Chiocchini et al., 2008 and references therein), the earliest part of this sedimentary history, up to the middle Jurassic, crops out outside the mapped area.

The ‘Saifar limestone’ (Bajocian-Tithonian) is the oldest unit exposed in the study area (Figure 3); it is a gray wackestone/mudstone organized in dm-thick beds. Although in the literature oolitic-bioclastic intercalations are described, along with abundant micropaleontological assemblages (Damiani et al., 1991, 1998), the outcropping portion of the unit only shows oligotopic assemblages, characterized by abundant Favreina prusensis and Favreina spp., and rare Cladocoropsis mirabilis. F. prusensis is found, in the successions described for the sheet #376 ‘Subiaco’ of the Geological map of Italy (Servizio Geologico d’Italia, 1998), in Berriasian-Valianginian beds (see also Kuss & Senowbari-Daryan, 1992), but in literature it is commonly described in Kimmeridgian-Tithonian strata (Molinari-Paganelli, Pichezzi, & Tilia-zuccari, 1980; Schweigert, Seegis, Fels, & Leinfelder, 1997). The occurrence of Cladocoropsis mirabilis, which is a marker of the lower Callovian – upper Kimmeridgian (Chiocchini et al., 2008), allows to tentatively ascribe this unit to the Berriasian. The thickness is about 100 m.

The ‘Fioio dolostone’ (Figure 3) overlies the ‘Campbelliella limestone’ in the succession, although no continuous exposures can be observed; it is a thick stack of dolomitic and incipiently dolomitized beds, found essentially along the Fosso Fioio valley (Compagnoni et al., 2005; Damiani, Molinari, Pichezzi, Panseri, & Giovagnoli, 1990). The rare preserved (non-dolomitized) limestone levels contain abundant micropaleontological assemblages, including Salpingoporella annulata and other dasycladaceae (Coptocamphlydon sp.), ostracods, fragments of gastropods, miliolidae and other benthic forams (Istriloculina sp., Valvulineria sp.? Belorussiella sp., Mayncina bulgarica and Campanellula capuensis among others). The age of this unit is late Berriasian- Barremian/earliest Aptian, and the thickness is about 400 m.

Above the ‘Fioio dolostone’ the succession continues with the Aptian – lower Cenomanian ‘requieniid limestone’ (Figure 3). It is a wackestone to coarse packstone, organized in dm-thick beds with common requieniids (rudistid bivalves). In the lower portion of the unit dolomitized beds and green shaly levels are also common, along with rare oolithic horizons. Fossil assemblages are generally very rich and include Archaeovalvea reicheli, Arenobulimina sp., Belorussiella sp., Bolivinopsis sp., Cretaci cladus miner vini, Cribellopsis arnau dea, Cancelina laurienti, C. gr. camposauri, ?C. carrassii, Glomospira urgoniana, G. cf. Watersi, Haplophragmoides cf. globosus, Istriloculina sp., Moesiolina hirsti, Neazazata isabellae, Novalesia sp., Paleocornulina lepina, Paleosigmoilopsis appenninica, Praechrysalidina infra cretaecea, Pseudon nummolucina sp., Sabaudia auruncensis, S. capitata, S. minuta, Salpingoporella dinarica, Sellia vil lii, Spiroloculina cenomana, Thaumatoporella sp., Tro chamninoide cronus, Valvulineria sp., milolacea, ostracods and fragments of bivalves (Fabbri, 2013, 2016). The thickness of this unit is about 600 m.

The ‘radiolitid limestone’ (upper Cenomanian – lower Maastrichtian), which typically follows in the region the ‘requieniid limestone’, is made of dm- to m-thick tabular beds of white packstones and wackestones, along with common lensoid bodies mainly composed of rudists and rudist debris (Hippuritidae and Radiolitidae – Figure 3). The microfossils assemblages include Accordiella conica, Cancolina sp., Decastro nema barattoloi, Moncharmontia appenninica, Neazz zatinella sp., Nummolucina sp., Pseudocydalmmina.
cf. sphæroidea, Pyrgo sp., Thaumatoporella sp., ostracods, discorbacea, nubicularidae and rotaliidae (Fabbi, 2013, 2016). This unit only crops out in limited areas and no complete sections are exposed, so that the thickness (which should exceed 600 m – Damiani et al., 1998; Compagnoni et al., 2005; Fabbi, 2016) cannot be precisely determined.

A long phase of subaerial exposure of the region is believed to have taken place during the Paleogene, producing the so called ‘Paleogene hiatus’ (Cipollari & Cosentino, 1995; Cosentino et al., 2010; Damiani et al., 1990, 1991), although alternative models have recently been proposed (Brandano, 2017).

Carbonate production, characterized by heterozoan assemblages, was resumed starting in the early Mio- cene, producing a paraconformable contact with the Cretaceous substrate (Civitelli & Brandano, 2005).

The ‘bryozoan limestone’ (upper Burdigalian – lower Tortonian p.p. – Civitelli & Brandano, 2005) is the last carbonate platform unit in the region and is a thick to fairly bedded white packstone with abundant bryozoans and bivalves. The rich micropaleontologic
assemblages include abundant benthic forams, serpulids, barnacles, echinoid fragments with syntaxial calcite cement, and rare planktonic forams. Some levels are dominated by rodoliths. The upper portion is characterized by a peculiar lozenge-shaped fracturing pattern. The unit in the study area directly rests above the Cretaceous substrate and exceeds 100 m in thickness.

### 3.2. Terrigenous succession

In the late Miocene, the Latium-Abruzzi platform was involved in the Apennine building chain (Bally, Burri, Cooper, & Ghelardoni, 1986; Centamore, Rossi, & Tavarnelli, 2009; Doglioni et al., 1999; Mostardini & Merlini, 1986; Patacca, Scandone, Bellatalla, Perilli, & Santini, 1991, 1992; Royden, Patacca, & Scandone, 1987), which resulted in the shift from shallow-water carbonate to hemipelagic, to turbiditic foredeep sedimentation (Figure 2) (Bigi et al., 2003; Carminati, Corda, Mariotti, & Brandano, 2007; Centamore & Rossi, 2009; Cipollari & Cosentino, 1991; Critelli et al., 2007; Milli & Moscatelli, 2000; Patacca & Scandone, 1989). The hemipelagic interval (i.e. ‘Orbulina marls’ auctt. - Fabbi et al., 2014; Fabbi & Rossi, 2014; Pampaloni, Pichezzi, Raffi, & Rossi, 1994) does not crop out in the area, while the siliciclastic turbidites belonging to the ‘compleso torbiditico altomiocenico laziale abruzzese’ (late Miocene Latium-Abruzzi turbiditic complex) and the above mentioned ‘brecce della Renga fm.’ are extensively exposed.

The ‘compleso torbiditico altomiocenico laziale-abruzzese’ represents the foredeep sedimentation of the Latium-Abruzzi region. It is a very thick (several hundred meters) turbidite succession, dominated by sandstone intervals (Figure 4) organized in T_{a-b} to T_{a-e} Bouma sequences. The sandstones are composed almost exclusively of siliciclastic grains (quartz, micas, K-feldspar, plagioclase) along with rare bioclasts and very rare bioclasts. Rare graded/ laminated calcarenites, mainly composed of indeterminable bioclastic debris, occur interbedded with the sandstones. The age of this unit is early Messinian p.p. (Compagnoni et al., 2005; Fabbi et al., 2014).

In the northeastern Simbruini Mts. a peculiar unit, the ‘brecce della Renga fm.’ (Devoto, 1967) represents the lateral equivalent of the ‘unità argilloso-marnosa’ and the ‘compleso torbiditico altomiocenico laziale abruzzese’ (Fabbì & Rossi, 2014 and references therein; Fabbi, 2016). This unit is markedly clastic and results from the dismantling of the margins of a prominent structural high existing in the area during the late Miocene (Figure 5) (Carminati et al., 2014; Critelli et al., 2007; Fabbi, 2013, 2016; Fabbi et al., 2014; Fabbi & Rossi, 2014).

The ‘brecce della Renga fm.’ was subdivided in three lithofacies and six sublithofacies by Compagnoni et al. (1990, 1991, 2005), based on field geometries, rudite/arenite/pelite ratio, and a diverse array of sedimentological features.

A detailed description of each lithofacies and sedimentology of the ‘brecce della Renga fm.’ can be found in Fabbi and Rossi (2014).

Only lithofacies 2 and 3 of the ‘brecce della Renga fm.’ are found in the study area.

The lithofacies 2 of the ‘brecce della Renga fm.’ crops out extensively and is subdivided into a massive sublithofacies (2-a) and a well bedded sublithofacies (2-b). The sublithofacies 2-a has a total thickness of more than 300 meters (Fabbi & Rossi, 2014) and is made of clast- supported carbonate breccias. The bioclasts are markedly heterometric, ranging from sand to boulder (up to tens of meters across) size. Lithoclasts are Miocene and Cretaceous carbonates, with Miocene granules also comprising isolated coeval echinoids, bivalves, benthic forams and bryozoans. Yellow pelite intercalations (already described by Compagnoni et al., 1990, 2005; Devoto, 1967, 1970; Fabbi et al., 2014; Fabbi & Rossi, 2014; Parotto, 1969) are common (Figure 4), and provide the essential biostratigraphical elements to determine the age of the rudites (early Tortonian-
early Messinian – Fabbi & Rossi, 2014). This massive lithofacies commonly lacks any stratal organization and rests unconformably on the Cretaceous bedrock (Fabbi, 2013; Fabbi & Rossi, 2014). At Cima Bertina the well bedded sublithofacies 2-b of the ‘brecce della Renga fm.’ displays a typical fining upwards trend coupled with an increase of siliciclastic components (Compagnoni et al., 1990). The matrix of the breccia is composed of skeletal grains (barnacles, bryozoans, bivalves, echinoids, red algae, rare benthic forams) and abundant siliciclastic grains (mainly quartz).

The lower Messinian lithofacies 3 of the ‘brecce della Renga fm.’ crops out along the NE slopes of the Simbruini Mts., and consists of stacks of dm- to m-thick breccia beds and associated arenites, interbedded with the siliciclastic turbidites; the breccias often form disorganized intervals, up to some tens of meters thick (Figure 4) also bearing large boulders of the carbonate substrate. Graded and laminated turbiditic calcarenites are commonly organized in stacks up to some meters thick. The fossil content of the calcarenites include fragments of echinoids, balanids, bryozoans, molluscs, and red algae, along with benthic forams (Amphistegina sp., Elphidium sp., Planulina sp., Anomaliniidae, Cibicididae, Rotaliidae, Textulariidae). The abundant siliciclastic fraction is essentially composed of quartz and micas. The maximum estimated thickness is a few hundred meters.

### 3.3. Continental deposits

The studied sector of Central Apennines was finally uplifted and became emergent through the late Messinian – late Pliocene (Carminati & Doglioni, 2012;
Cosentino et al., 2010; Doglioni et al., 1999; Gueguen, Doglioni, & Fernandez, 1998).

Post-emersion continental deposits are essentially Quaternary in age. Being the mapping project focused on the substrate, continental deposits have been separated only on the basis of sedimentological and positional features, and they are subdivided into three separate categories:

i The deposits cropping out at valley bottoms (i.e. the Liri river alluvial sediments); the thickest soils (> 1 m) which commonly hide the bedrock in the inner valleys of the Simbruini Mts.; the volcaniclastic (essentially cineritic) deposits belonging to the Alban Hills or the Oricola volcanoes (Compagnoni et al., 2005; D’oreifice et al., 2014) which occasionally are up to >5 meters thick (Figure 6) in the inner valleys of the Simbruini Mts.;

ii a wide landslide which affects the slope whose toe host the village of Petrella Liri, which is partly built on and around large fallen limestone boulders;

Figure 4. Upper Miocene terrigenous units (A) Vertical beds of turbiditic thick sandstone/thin pelite alternations (‘complesso torbiditico altomiocenico laziale-abruzzese’ at Verrecchie; (B) typical aspect of the lithofacies 3 of the ‘brecce della Renga fm.’ near Castellafiume (after Fabbi et al., 2014); (C) verticalized decametric breccia bed (arrows) outcropping at Verrecchie; (D) load deformations in sandstones at the base of the thick breccia bed shown in ‘C’ (lithofacies 3 of the ‘brecce della Renga fm.’ outcropping at Verrecchie – modified after Fabbi & Rossi, 2014); (E) S. Antonio lake, one of the sites where lower Messinian pelites outcrop intercalated to the sublithofacies 2-a of the ‘brecce della Renga fm.; (F) lower Tortonian pelites intercalated to the sublithofacies 2-a of the ‘brecce della Renga fm.’ along the Camporotondo ski slope (after Fabbi & Rossi, 2014).
iii slope debris, mainly composed of pebbles and boulders belonging to the carbonate succession and to the ‘breccia della Renga fm.’

4. Tectonics

At least three main tectonic phases in Miocene to recent times affected the study area: (i) A late Miocene extension, which originated the structural high whose dismantling produced the spectacular clastic deposits of the ‘breccia della Renga fm.’; (ii) a latest Miocene-Pliocene compressional phase which gave origin to the Apennine chain; (iii) a Pleistocene post-orogenic extensional phase, which is still active in the Region, as confirmed by recent strong earthquakes.

Pre-orogenic paleo faults are largely sealed by the ‘breccia della Renga fm.’, and are mapped with a different symbol. The best exposure of pre-orogenic extensional faults is to be found at Colle la Fossa, where the Cretaceous substrate is cut by SW-dipping faults (with total throw of a few hundred meters) sealed by the sub lithofacies 2-a of the ‘breccia della Renga fm.’ (Figure 7 – Carminati et al., 2014). A similar situation, with the breccias onlapping a SW – dipping normal fault paleoescarpment can be observed at Monna Rosa (Figure 8 – Carminati et al., 2014; Fabbi & Rossi, 2014). For a detailed description and analysis of pre-orogenic faults and of the paleogeographic setting of the area the reader is referred to the papers of Carminati et al. (2014) and Fabbi and Rossi (2014).

The Simbruini Mts. are essentially a wide NE-dipping monocline. This monocline is cut to the E and NE by the Simbruini thrust front, and is fragmented to the W by a large system of regional SW-dipping extensional faults (Figure 1), largely exposed outside the study area (Carminati et al., 2014 and references therein).

The main compressional fault in the study area is the Simbruini thrust front, one of the most important thrusts in the region, which trends NW–SE along the Roveto valley, and becomes a blind structure south of Cappadocia. In the field, it is possible to observe at least two main splays and several minor lineaments. Good exposures of the westernmost lineament are at Verrecchie and along the Verrecchie-Cappadocia road. The best exposure of the easternmost lineament occurs near the Cappadocia cemetery (Figure 9), where the most external outcrop of the lithofacies 3 of the ‘breccia della Renga fm.’ is severely deformed, and overthrusts the siliciclastic sandstones of the ‘com plesso torbiditico altomiocenico laziale abruzzese’. Kinematic indicators measured along the whole structure, including minor fault planes, show a general apenninic vergence (N 60° E – Fabbi, 2016). A minor reverse fault trends NW–SE and crops out along the Fioio valley, at the southwestern boundary of the study area, causing the overthrusting of the ‘Saifar limestone’ above the ‘Fioio dolostone’. In addition, several low angle reverse planes cut the verticalized breccia beds at Verrecchie and along the Capistrello-Piani della Renga-Filettino road, evidencing that the breccias should be already lithified when the region experienced compressional tectonics (Fabbi, 2013; Fabbi & Rossi, 2014).

As was mentioned above, the main extensional faults of this sector of the Apennines are located outside the mapped area, where, however, a number of...
minor faults can be observed. It is worth noting that the pattern of faults affecting the substrate is more dense than the pattern seen in the ‘breccia della Renga fm.’, which suggests that the substrate records subsequent superimposed tectonic phases, including the one which generated the breccias (Carminati et al., 2014; Fabbi, 2013), while the breccias record only orogenic compression and subsequent Quaternary extension.

A major regional tectonic lineament observed in the study area is the left-lateral transpressive fault system which borders the left side of the Roveto valley (Compagnoni et al., 2005; Montone & Salvini, 1993; Smeraglia, Aldega, Billi, Carminati, & Doglioni, 2016). According to Galadini (1999) and Roberts and Michetti (2004), this fault is now reactivated as an extensional fault and it is still active and seismogenic. Subvertical fault planes are well exposed along the valley (Figure 9), generally striking N 140° E.

5. Conclusions

A geological map on the 1:20,000 scale displays the geology of the eastern sector of the Simbruini Mts., in Central Apennines. Following a common picture for the Central Apennines, this sector of the Chain is characterized by a thick (> 3000 m) succession of Mesozoic and Miocene shallow-water carbonates, belonging to the Latium-Abruzzi carbonate platform Domain.

The carbonate sedimentation ended in the late Miocene, because of the involvement of the region in the Apennine chain building phase. The ongoing foreland flexure caused the gradual shift from carbonate to
siliciclastic sedimentation of the region, that became a complex foredeep basin, facing the Apennine orogenic system.

A result of the foreland flexure was a strong pre-orogenic extensional tectonic phase that affected the northern Simbruini Mts., producing a complex structural high within the basin. The dismantling of the flanks of such a high produced a thick lithoclastic unit (brecce della Renga fm.) which is widely exposed in the study area. This clastic unit is a *unicum* in the region and is partly lateral to the more typical foredeep succession of Central Apennines, represented here by turbiditic sandstones.

Since the Messinian the whole sedimentary succession was deformed and uplifted by the NE-verging Apennine building compressional phase. The final uplift of the chain caused the definitive halt of marine sedimentation in the region since the latest Messinian-Pliocene, and the sedimentation of continental deposits. The main orogenic structures in the map are the Simbruini thrust front, which becomes a blind structure south of the Cappadocia village, and the Roveto valley left transpressional system. The last tectonic event affecting the area is a SW-directed extensional phase, which is still active in the Central Apennines. Several normal faults cropping out in the area are interpreted as secondary lineaments related to such post-orogenic extension.

**Software**

The map has been drawn using the Adobe Illustrator CS2 software, on scanned hand-drawn maps. The topographic base map is the Abruzzo Region D.B.T.R. on the 1:25,000 scale (sheets 367E, 376 and 377W), available online.

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No potential conflict of interest was reported by the authors.

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