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Geomorphology of the Mt. Cusna Ridge (Northern Apennines, Italy): evolution of a Holocene landscape

Guido S. Mariani [a], Mauro Cremaschi [a], Andrea Zerboni [a], Luisa Zuccoli [b] and Luca Trombino [a]

[a]Dipartimento di Scienze della Terra 'Ardito Desio', Università degli Studi di Milano, Milano, Italy; [b]Istituto Comprensivo Statale 'A. Volta', Mandello del Lario, Italy

ABSTRACT
The Mt. Cusna ridge, located in the Northern Apennines (North Italy), is a mountain area of relevant geological interest for the interaction through time of distinct geomorphic processes, acting since the end of the Last Glacial Maximum. A geomorphological map at the 1:10,000 scale was produced to characterise the main landforms and processes identifiable on the ridge. From this, a detailed reconstruction of the Holocene landscape history of the area is drawn. After deglaciation, at the end of the Pleistocene, glacial and periglacial processes left wide deposits and barren surfaces. Slope and running water processes acted cyclically on the landscape through phases of stronger slope denudation and landslide activation followed by stability periods. These processes are related to the main climatic changes recorded for the N Apennines during the Holocene. Since the Late Holocene, the impact of human communities may have played a prominent role as an agent of landscape modification.

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Mountain geomorphology; landscape evolution; slope processes; Holocene; Northern Apennines

1. Introduction

The Northern Apennines are a young and complex mountain chain, heavily bent and deformed by tectonics during the Tertiary and Quaternary, which tectonic evolution is still ongoing (e.g. Molli, 2008; Molli et al., 2010; Vai & Martini, 2001). In such a dynamic geologic environment, surface processes are continuously working and reshaping the landscape in a variety of forms through time. This is especially true at higher elevations, where the tectonic forces are better expressed and geomorphic evolution has been triggered in time by a wider range of factors, both from geological settings and exogenous surface processes (Carton & Panizza, 1988; Giraudi, 2017). Since the Last Glacial Maximum (LGM), when surface processes were largely inhibited by the presence of glaciers, many areas of the Apennines underwent their full reactivation and have been heavily remodelled. During the Holocene, landscape evolution, as a natural phenomenon, also interacted multiple times with human activity: human presence in the area is well established, with the first evidence starting since the Mesolithic period (c. 9000 years BP), when hunt-gather groups exploited the higher part of the chain (Biagi, Castelletti, Cremaschi, Sala, & Tozzi, 1980; Castelletti, Cremaschi, & Notini, 1976; Castelletti & Cremaschi, 1975; Cremaschi et al., 1984). Traces of occasional frequentation during the Chalcolithic and the Iron and Roman Ages are also found (Cremaschi & Nicosia, 2012; Panizza et al., 1982). From the Early Middle Ages (Panizza et al., 1982), human impact increases through the appearance and later expansion of stable pastures and logging activities in the land, which are still present and continuously increasing to this day.

Mt. Cusna, among the other peaks of the Northern Apennines, is a paradigmatic case of study, and was investigated during the 1980s as part of a classic geomorphological work, which produced a 1:25,000 scale map of a larger area of the Appennines including its NE slope (Panizza et al., 1982). However, new data on deglaciation and recent Quaternary studies conducted on the Holocene climate changes and soil development in the area (Compostella, Trombino, & Caccianiga, 2012; Compostella, Mariani, & Trombino, 2014; Mariani, 2016) highlighted the need to improve the knowledge of the Holocene evolution of the whole Mt. Cusna ridge, focusing solely on the higher landscape. Here, a new geomorphological map (Main map) of the Mt. Cusna ridge at 1:10,000 scale is presented, with the aim of completing the geomorphological investigation of this landmark and of reconstructing how and by which processes the landscape of an high altitude Mediterranean region has been reshaped since the end of the last glaciation.

2. Study area

The Northern Apennines are characterised by an extremely complex geological structure. The collision

CONTACT Guido S. Mariani guido.mariani@unimi.it Dipartimento di Scienze della Terra 'Ardito Desio', Università degli Studi di Milano, via L. Mangiagalli 34, I-20133 Milano, Italy

of the Adria and European continental plates (Klingfield, 1979; Vai & Martini, 2001 and references therein) shaped the Apennine orogen into a fold-and-thrust belt verging North to NE in the direction of the main tectonic deformation (Argnani et al., 2003; Bartolini et al., 1982; Vescovi, 1988). As a result, the mountain chain is organised in a series of ridges oriented NW–SE. Mt. Cusna, the second peak of the Northern Apennines (2121 m a.s.l.), represents the culminating fold of one of such ridges. Towards SE, it runs at an elevation of around 2000 m a.s.l. to Mt. La Piella (2071 m a.s.l.), ending at a saddle located at Il Passone. To the North, the ridge connects to the lower Mt. Bagioletto (1758 m a.s.l.), a smaller flat summit degrading more gently into the valleys below (Figure 1).

Other than tectonics, the local morphology is strongly influenced by the lithological features of the outcropping rocks, mainly derived from turbiditic or deep-sea sedimentary deposition (Bortolotti, 1992; Ricci Lucchi, 1986). Sandstones are the most represented lithology in the area, forming all the main peaks and most of the summit of the ridge itself (SGSS – Regione Emilia-Romagna, 2007a, 2007b, 2007c, 2007d). Claystones, sometimes interbedded with limestone levels, are also widespread together with marlstones, outcropping on both sides of the ridge as well as North of it (Figure 1). Due to the active compressional tectonics of this side of the Apennine range (Gelati, 2013; Siddiqui & Soldati, 2014; Vai & Martini, 2001), all these lithologies are widely bent and fractured in folds and thrusts in the whole area. The main active morphogenetic processes are mainly due to gravity and running water, as well as human influence (Bruschi, Coratza, Piacentini, & Soldati, 2012; Piacentini, Ercolessi, Pizziolo, & Troiani, 2015). Glacial and periglacial processes were widespread during the Pleistocene (Losacco, 1982; Panizza et al., 1982)

3. Methods

The geomorphological mapping of the Mt. Cusna ridge was supported by a combination of the available topographic and geological data together with thematic cartography stored in a GIS geodatabase. Digital 1:5000 scale topographical mapping (Regione Emilia-Romagna, 2017) provided the contour lines used for the preliminary identification of the landforms, together with aerial photos (aerial passage AGEA 2012: Ministero dell'Ambiente e della Tutela del Territorio e del Mare, 2017) and a 5 m resolution Digital Terrain Model used to obtain a 3D surface of the area (SGSS – Regione Emilia-Romagna, 2017). Google-Earth™ high resolution satellite images were also consulted for detailed investigations on features visible at the 1:10,000 scale. Lithology of the bedrock formations and structural features were acquired from 1:10,000 scale geological map (SGSS – Regione Emilia-Romagna, 2007a, 2007b, 2007c, 2007d) and included in the map; data on the distribution of Quaternary deposits were acquired from the same source (SGSS – Regione Emilia-Romagna, 2007a, 2007b, 2007c, 2007d) to provide a reference for survey operations. The previous geomorphological investigation by Panizza et al. (1982) was used for a preliminary assessment of the distribution of landform types along the NE slope of the Mt. Cusna ridge.

Geomorphological survey was performed in three different field seasons (2013–2015). All geomorphological features present in the existing cartography were identified and, when necessary, remapped and reinterpreted (Butler, 2013). New features detected from remote sensing or discovered in the field as well as the landforms related to structural elements were mapped and interpreted. Quaternary deposits and soils were described in the field following the guidelines of Gale and Hoare (1991) and FAO (2006) respectively and mapped accordingly. Mapping mainly followed the guidelines from the Italian Geological Survey (Brancaccio et al., 1994; D'Orefice & Graciotti, 2015). From the same guidelines, most of the symbols for the identified landform types were provided, as well as the colour coding for each genetic process with higher or lower intensity according to the active/inactive state of the landform.

A Late Pleistocene to Holocene chronology for the development of the mapped landforms was compiled using several methods. Soils developed on significative landscape units were used as chronological reference according to their development (discussed in Mariani, 2016). Dating and other chronological insights were provided by comparisons with the available literature (Compostella et al., 2012, 2014; Giraudi, 2014; Panizza et al., 1982).

4. Results

4.1. Structural setting and related landforms

The tectonic structure drives the entire geomorphological evolution of the area in subtle, but considerable ways. The Mt. Cusna ridge is characterised by a tight fold overturned NE; normal and subordinately reversed faults are present and show apenninic (NW–SE) and antiapenninic (NE–SW) strikes. To the North, Mt. Bagioletto shows the same anticline structure, this time overturned North. In the whole area, overthrusts are manly directed North and NE, particularly in the northern part and around Mt. Cusna, where they are sometimes associated to cuestas and minor escarpments. In the SE part of the ridge, a particularly evident fault breaks the continuity of the ridge itself in direction E–W, forming a saddle in the ridge crest. Along the ridge many escarpments, especially in

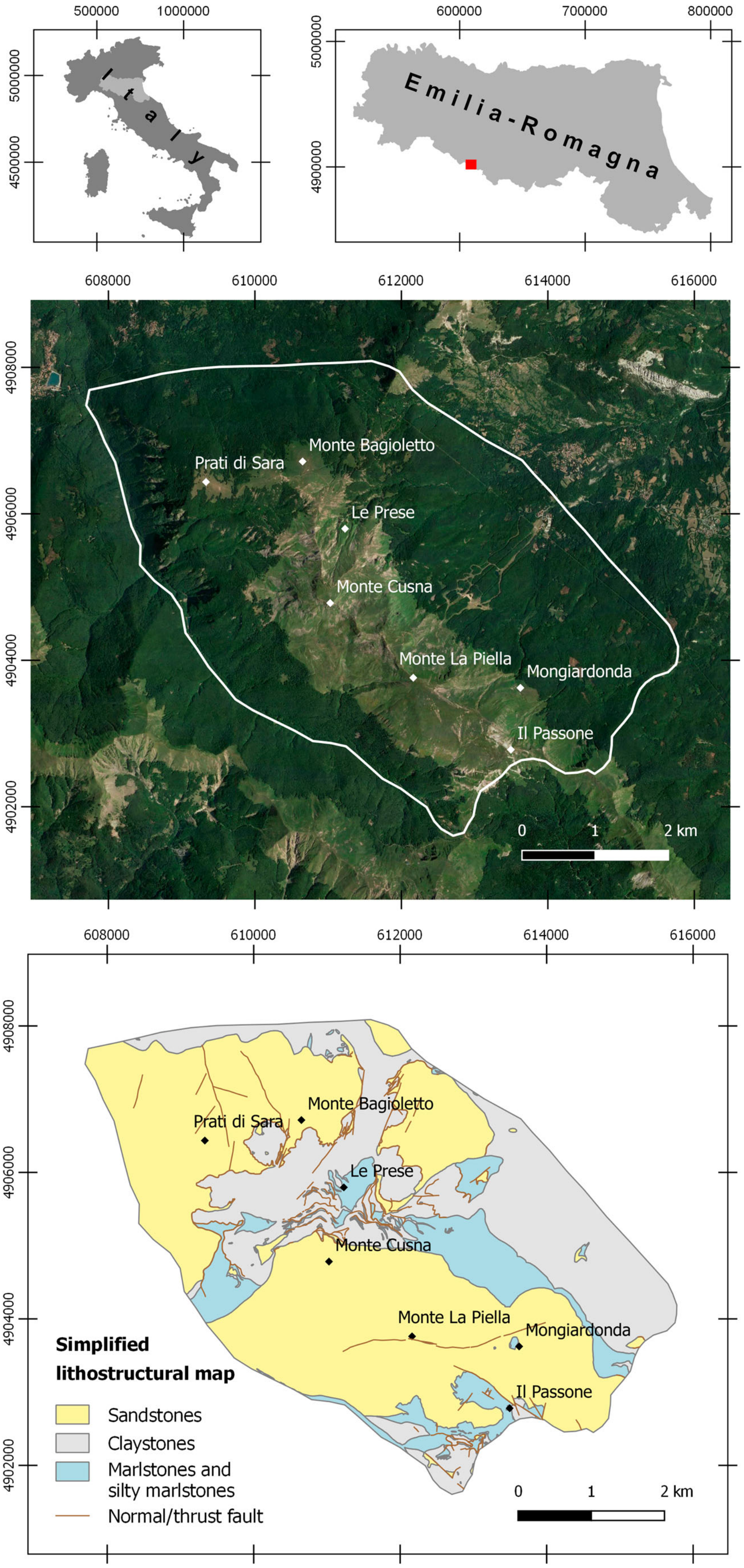

Figure 1. Location, satellite image (GoogleEarth™) and simplified lithostructural map of the study area. Main localities cited in the text are present. UTM Coordinate grid, units in metres.

Figure 2. (a) Southern portion of the ridge seen from Mt. Cusna, with visible structural escarpments and talus heaps. (b) Parallel erosional network of gullies on the northern slope of Mt. Cusna; in the foreground, denudation phenomena due to washout erosion. (c) Parallel faults (in yellow) cutting Mt. Bagioletto (right) in three portions degrading West to Prati di Sara (left).

summit positions, have a structural origin: these are particularly evident along the SW slope (Figure 2(a)), where the erosion of the anticline has uncovered structural cliffs several tens of metres high. Another two parallel main faults running NW to SE are located in the northern part of the map. Between these two lines a strong tectonic strain affects the area and its morphology, forming two consecutive valleys characterised by a series of erosional gullies parallel to the fault (Figure 2(b)). Two other main faults, oriented N–S, lie on the North side of Mt. Bagioletto, cutting the entire Mt. Bagioletto anticline perpendicularly in three portions (Figure 2(c)).

4.2. Glacial and periglacial processes and landforms

Glacial and periglacial processes have strongly remodelled this area during the last glacial phases. Although the physical disappearance of the ice cover is probably traceable to the end of the Pleistocene (Losacco, 1949), evidence of the passage of glaciers is still widespread as cirques and till deposits (Losacco, 1982). The shape of cirques is usually clearly recognisable: ample niches are present above the treeline located on the NE ridge, with sharp upper crests and steep slopes more or less eroded and modified by later slope processes. Wide talus sheets connect the bottom of the niches to the extended till deposits below. Till covers most of the lower NE slope of the ridge, forming a continuous deposit 10 km^2 wide and up to 10 m thick (Figure 3(a)). The form and characteristics of glacial sediments are complex: from a geometric point of view, they are characterised by the presence of at least two moraine arcs, attributable to the most recent glacial advances. The uppermost moraine system consists of a series of smaller arcs at elevations between 1400 and 1550 m a.s.l., compatible to the last advance of the ice front, possibly during the Late Glacial period. The lower one is composed by two wide tongues, one partially extending outside the map, located between 1100 and 1300 m a.s.l., and is probably related to the LGM. In between these clearly visible arcs, a series of smaller ridges, sometimes in position geometrically difficult to interpret, is present. Their formation could be caused by a later reworking of the deposits by periglacial processes rather than by a proper glacial advance. Scattered on glacial deposits many erratic blocks several metres wide can be found, often at the foot of moraine arcs. This suggests sliding movements caused by the reworking of the moraines.

Parts of the landscape not reached by glaciers were still subject to intense periglacial processes, testified by the general rounded and hilly aspect of the slopes, especially in the area of Mt. Bagioletto. Its northern slope hosts a wide expansion of glacis deposits formed by a regularised layer of angular blocks and gravel, sometimes oriented downslope, embedded in a silty matrix. The deposits occupy elevations from 1400 to 1200 m a.s.l. down to the foothill outside the map limits. Solifluction has probably been cyclically present after the LGM, following the fluctuations of the climate, and is presently active in summital or steep positions, where the snow cover is thinner and easily removable by gravity or wind action (Figure 3(b)). In these areas, including the summit of Mt. Cusna, it is

Figure 3. (a) Front view of a moraine arc colonised by forest. (b) Surfaces interested by frost creep in the highest part of Le Prese. (c) Protalus rampart on the slope of a cirque. (d) Stabilised talus heaps on the southern slope of the ridge.

possible to see lobes and steps produced by frost creep. Protalus ramparts are often found inside cirques (Figure 3(c)). Their formation is favoured by the heavy accumulation of snow in this area, though it is sometimes difficult to outline proper nivation hollows from the cliffs above, indicating a more widespread active phenomenon of continuous detachment of materials.

On the SW slope of the ridge, glacial and periglacial landforms are completely lacking. This is not unexpected, since in this part of the Apennines glacial activity is always associated with northern and eastern slope aspects and very rarely elsewhere (Federici, 1977; Federici & Tellini, 1983; Losacco, 1949). The only recognisable traces of glacier influence on this side are cliff edges in the southernmost part of the valley, at elevations between 1800 and 1700 m, probably carved by a glacial tongue originated on the other side of the valley (outside the map) and spared from later slope processes. Periglacial processes are also almost lacking and limited to few possible scattered inactive rock glaciers, located on the higher part of the slope.

4.3. Gravity-induced processes and landforms

On steeper slopes, mainly present at higher elevations and usually associated with sandstone outcrops, the main denudational slope process leads to the formation of talus. Talus deposits derive from rock and debris fall below active scarps: here, they are organised in a layering of successive cones, forming in time continuous scree-like forms representing the majority of the deposits in the whole area. Cones still retain their shape only when isolated or recently deposited. Active talus deposition is currently limited to higher elevations (above the treeline), and past deposits located below are today covered in vegetation (Figure 3(d)). On the upper ridge, the presence of linear gullying is mainly related to the deposition of debris flows. These movements get reactivated periodically by detachments possibly triggered by avalanches or snowmelt, and leave deposits at the foot of the slopes sometimes visible as distinct cones on the SW side of the ridge. On the other slope, these gullies lay at a lower angle: channels here tend to collect into the water system with continuity transporting the flowing materials to lower elevations. This system, once formed, becomes the preferential way for snowmelt discharge and gets progressively deepened by water erosion.

The Mt. Cusna area, like many parts of the Northern Apennines, is subject to extremely active slope morphodynamics (Bertolini & Pellegrini, 2001 and references therein). In fact, rock and debris slides are widespread on the slopes of the ridge with varying dimensions and positions (Figure 4(a)): sometimes, their movement is complex and difficult to understand. Especially large deposits are found on the SW slope, where the energy of steeper slopes and the potential for slide detachment are higher. When not clearly active, these forms can always be considered dormant and subject to potential reactivation, in accordance with the dynamic setting of the area (Dramis & Bisci, 1998; Piacentini et al., 2015). Slope instability and landslide reactivation phases are recorded in connection with past changes in the climate regime (Bertolini & Tellini, 2001; Soldati et al., 2006; Tellini & Chelli, 2003): datings on landslide deposits from this sector

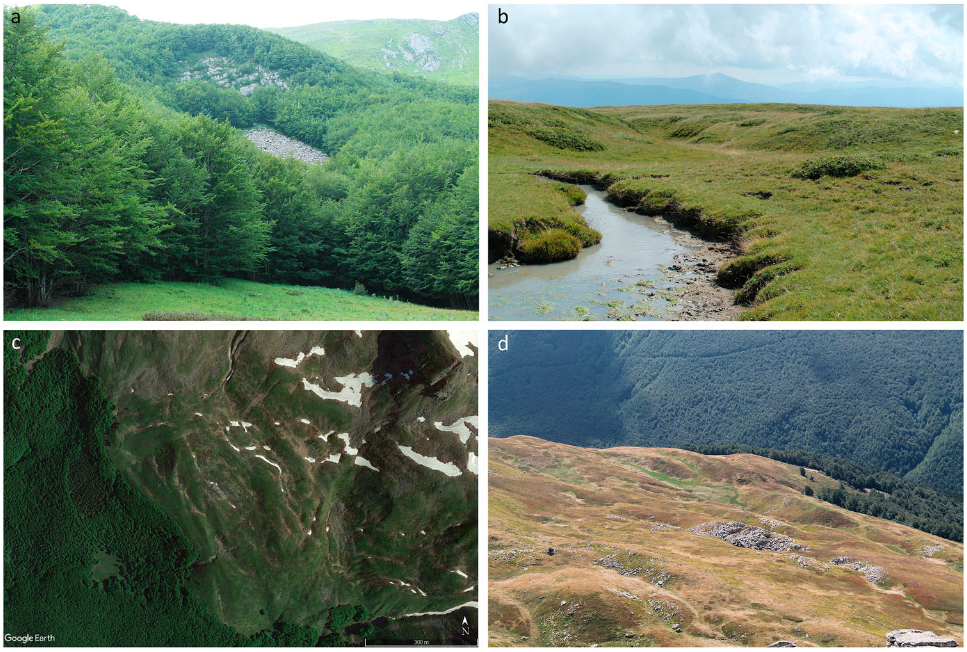

Figure 4. (a) Recent rock-slide on the Northern side of the Mt. Cusna ridge. (b) DGSD summit trench partly occupied by an ephemeral pond. (c) Satellite image (GoogleEarth™) of a DGSD in the southern slope of the ridge with visible trenches and counterscarps running NE to SE. (d) Counterscarp system of (c) seen from the North.

of the Apennines clearly show a peak in slope activity following a period of climate cooling during the transition to the Neoglacial (c. 4000 years BP: Soldati et al., 2006; Bertolini, 2007). It might also be the case here: evidence from dated soil sequences (Compostella et al., 2012; Giraudi, 2014) suggests a period of partial reactivation of slope processes at the beginning of the Late Holocene and an extant more complex phase, with erosive processes related both to running water action and slope instability. Other periods of instability during the Early Holocene, related to postglacial warming, have also been detected at lower elevations (Panizza et al., 1982).

Deep-seated gravitational slope deformations (DSGSD or DGSD: Goudie, 2004) and their surface features are common in the area, as in most of the Apennines (Della Seta et al., 2017; Dramis & Sorriso-Valvo, 1994; Gori et al., 2014; Taramelli & Melelli, 2009). They are usually made visible by the presence of two valleys diverging from a summit point and marking the upper and side boundaries of the deformation itself. These valleys occupy the intersection between the detachment surface and the slope (unloading valleys) and sometimes become preferential waterways connected to the main catchments. On the summit area of the deformation trenches and piping forms are often present, usually collecting water as ephemeral ponds (Figure 4(b)). Three separate systems, however, show different features. The first, placed at about the middle section of the SW slope of the ridge (Figure 4(c)), is a very large deformation occupying the entire slope from below the crest to the bottom of the valley. Differently from the other landforms, its main body has moved downwards by more than 200 m, forming several double crests and counterscarps (Figure 4(d)) and a vast flatter area at its top covered by talus and other deposits. Parallel to this, another large landform is present on the same slope in the northernmost part of the map characterised by a clearly cut step on the body of the deformation. In this case, though, instead of a pattern of counterscarps, the release of the form from the bedrock caused the formation of dilatation cracks perpendicular to the valley, following the dip of the strata. The last important system is found on Mt. Bagioletto, where three different deformations located side by side can possibly be separate portions of a single widespread movement involving the entirety of its northern slope. In fact, the bottom of the slope, outside the map, shows a peculiar convexity that could be interpreted as the initial formation of a foot.

4.4. Processes and landforms due to running water

Surface running water effects are constrained essentially by the characteristics of the bedrock. Two different types of water erosion contributed in shaping the ridge. On outcropping sandstones, the drainage system exploits already available conduits such as debris flow channels, fault lines and unloading valleys. Erosion phenomena and alluvial deposition mainly follow these preferential ways as in the case of the fault on the NE slope of the ridge between Mt. La Piella and Mongiardonda. Here, the formation of a valley along the fault, with ongoing removal of material and its deposition downstream, formed in time three successive alluvial fans. Runoff and washout phenomena are effectively limited by the semi-permeable behaviour of the intensely fractured underlying rocks, which allows passage of water underground weakening the intensity of surface processes (Manzi et al., 2004). On the other hand, clays and marlstones, albeit as well diffusely fractured, remain mostly impermeable. Consequently, the resulting enhanced runoff often exposes surfaces: large washout areas are visible both south of the ridge and between Mt. Cusna and Mt. Bagioletto, where dense networks of hierarchical pseudo-gullies are found (Figure 5(a)). Related to water are also a series of badlands-like forms mapped south of Prati di Sara and in the southern portion of the ridge (Zanicchi, 2005). These represent the more advanced stage of erosion, when plant cover is not sufficient to stabilise slopes: gullying starts deepening cuts (Figure 5(b)) forming wide, steep valleys where plants fail to resettle (Bryan & Yair, 1982; Howard, 2009; Torri et al., 2013). Denudation phenomena seem to have been enhanced in the last centuries: many of these features are clearly still active, pointing to a recent phase of reactivation of diffuse erosive processes (Compostella et al., 2012).

Deposition by surface running water is confined to flat areas, where washout processes are somewhat reduced, especially in correspondence of vegetation or soil cover. Until streams stay ephemeral, or do not fit into an established washout system, they produce short-range colluvial deposits of mainly fine (sandy-silty) material, settling in continuous surfaces along the sides of the slopes or, more often, to their foot. When conditions allow, instead, the formation of gullies inserted directly into the water system, sediments are rapidly discharged below. Many of the counterscarps and hollows present on the slopes, and in particular on till deposits, have been progressively filled in time by decantation, forming marsh deposits that in some cases are still active. Particularly, interesting are the areas located between Mt. Bagioletto and Mt. Cusna, where stable flatter slopes were covered by several tens of centimetres of colluvial material. The formation of these deposits belongs to a time-frame compatible to the Little Ice Age (Kleber & Terhorst, 2013; Mariani, 2016). Here, the same reactivation of the erosive processes cited above, possibly related to recent changes in land use, caused the onset of intense washout processes and formed a diffuse system of rills and gullies, progressively dismantling by lateral erosion this old surface into separate shards (Figure 5(c)). The potential future evolution of these landforms could shift towards steeper gullying and progressive denudation, as described above, with a consequent weakening of surface stability and increase in landslide hazard.

5. Chronological framework

In the absence of a quantitative dating of most of the landforms, it is difficult to draw conclusions on the morphoevolutionary chronology of any landscape. Nevertheless, considering the geomorphological characteristics of the area and the support of soil and paleosol data from recent literature (Compostella et al., 2012; Mariani, 2016), it is anyway possible to give a reasonably reliable reconstruction of the landscape history of the ridge during the Holocene.

The extant landscape of the Mt. Cusna ridge is the product of a series of processes periodically reactivated during the Late Quaternary and especially in the Holocene (Table 1). Before the retreat and disappearance of the glacial cover at the end of the LGM (Losacco, 1982; Panizza et al., 1982), glacier erosion and till deposition, as well as periglacial shaping of the uncovered surfaces, interested the landscape as a whole. Since deglaciation, slope dynamics were subject to periodical phases of reactivation. At the beginning of the Early Holocene, slope denudation and continuous talus deposition, with phases of landslide detachment, were probably favoured by the end of a cooler phase (c. 13–12,000 years BP: Giraudi, 2017). Glacier retreat also possibly triggered the activation of DGSD detachment. Afterwards, approaching the warmer Early and Middle Holocene climatic conditions, a decrease in denudation and in landslide events is recorded (Bertolini, 2007). The shift to warmer conditions allowed the expansion of a more stable vegetation, strengthening slope stability through the development of a continuous soil cover (Compostella et al., 2014). In this period, soil formation is probably the most common surface process. Denudation started dismantling these soils only afterwards, during the onset of the Neoglacial and through

Table 1. Chronological framework of the Late Quaternary activation phases for the various form types in the area.

	Pleistocene	Holocene			
	<LGM	Early	Middle	Late	
Form/deposit				Pre-LIA	Post-LIA
Glacial					
Till deposits	++				
Periglacial					
Glacis deposits	++	?			
Rock glaciers	++	?			
Protalus ramparts	++	+		–	+
Frost creep forms	++	+		–	+
Gravitational					
Talus deposits		+	–	+	+
Debris flows		+	–	++	–
Debris/rock slides		+	–	++	+
DGSD		++	+	+	+
Running water					
Alluvial deposits		+	–	+	+
Colluvial deposits		?	–	+	++
Washout and gully erosive forms		++	–	+	++
Badlands		?	–	+	++

Note: Compilation is based from field observation and comparison with cited literature. LGM is Last Glacial Maximum; LIA is Little Ice Age.
Key: ++: very active; +: active; –: weakly active; ?: possibly active.

Figure 5. (a) Diffuse denudation and washout forms on Le Prese area. (b) Denudation surfaces from intense gullying with formation of badland-like forms South of Prati di Sara. (c) Lateral erosion from washout on colluvial deposits and soils on the Northern slope of Mt. Cusna.

the Late Holocene, in the form of slope movements and surface water erosion. Successive colluvial deposition and gullying events suggest multiple cycles of slope reactivation, which could be explained by the onset in this period of cooler and more fluctuating climatic conditions, affecting vegetation and consequently slope stability. Frost creep at higher elevations is also related to cold phases. The appearance of human communities and their impact on the Mt. Cusna landscape also need to be considered, especially their contribution in enhancing denudation phenomena through the overexploitation of the plant cover and, later, flocks grazing (Butler, 2012, 2018). Evidence of wide forest fires was found for both the Mesolithic and the Middle Ages (Compostella et al., 2012, 2014; Cremaschi et al., 1984). After the Little Ice Age, a more recent pastoral use of the territory, in combination with more intensive forestry, added even more pressure on slopes, increasing instability, denudation and the potential for unpredictable destructive events, which entity is still to be completely understood.

6. Conclusions

This survey allowed the identification and characterisation of lesser-investigated, but critical aspects of geomorphology and Quaternary geology of the Northern Apennines, such as DGSDs, colluvial deposition and denudation, mostly overlooked or under-represented in previous works. Compared to the previous geomorphological mapping efforts, the higher resolution, the focus on the higher portion of the landscape and the inclusion of the whole of the Mt. Cusna ridge allowed to discover substantial differences in landscape dynamics between different lithologies and slopes, while still finding continuity with the past survey and interpretation. The various landforms could be considered as the result of overlapping surface processes, constrained by the local geology and topography and triggered by climatic variations. This approach brought to the reconstruction of a possible chronological morphoevolution of the area, in which each process could be placed as part of a dynamic system changing through time. In this sense, mapping the activity and diversity of the High Apennines landscape can also become a detailed assessment of the present and future geomorphic hazards for the local communities, as well as a potential guideline in land planning and safety.

Software

Cartographic design, including geodatabase production, photo and DEM analysis, digitisation and georeferentiation, was conducted in QGIS 2.4. QGIS 2.18 was used for the final revisions and layout.

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Disclosure statement

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ORCID

Guido S. Mariani http://orcid.org/0000-0002-8456-3964
Mauro Cremasch http://orcid.org/0000-0003-2934-3210
Andrea Zerboni http://orcid.org/0000-0002-6844-8528
Luca Trombino http://orcid.org/0000-0002-7714-2686

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