Landscapes and Landforms Driven by Geological Structures in the Northwestern Apennines

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Luisa Pellegrini and Pier Luigi Vercesi

Abstract

The northwestern Apennines present a very complex geomorphology, strictly related to the recent tectonic evolution of the orogenic chain (Upper Oligocene—Lower Miocene to present). In this chapter, some unique and representative landform assemblages related to tectonic structures located in the area between the Scrivia and Trebbia valleys are described. Morphological aspects are also highlighted in relation to lithological/structural elements of local or regional importance, some of which have driven significant river diversion. The peculiar features of these landforms hold the pieces of the geological and geomorphological evolution of the entire area and are spectacularly exposed and clearly visible along beautiful valleys.

Keywords

Selective erosion • Synclinal mountain • River diversion • Entrenched meanders • Northern Apennines

17.1 Introduction

The extremely varied landscape of the northwestern Apennines is the result of geomorphological modelling influenced by the presence of rock types of diverse erodibility in a very complex tectonic setting. The tectonic evolution of the area took place in the Neogene and Quaternary, involving alternating phases of intense activity (e.g. the Tortonian, Intra-Messinian, Mid-Pliocene phases) and phases of relative quiescence. The effects of these phases are clearly visible in the contemporary morphology of mountains and valleys, where a series of different geomorphic features allows for the reconstruction of a complex landscape evolution, including the development of a hydrographic network with a very peculiar pattern. Therefore, fluvial diversions, superimposed rivers (entrenched meanders), steep escarpments, or gorges are common in this sector of the Apennines.

There are many locations where landforms, such as hanging valleys, monadnocks, etc. are strictly related to regional tectonic structures (anticlines and synclines) and to their lithology. Obviously, all these structures had clearly influenced the fluvial morphology, which shows straight trends, aligned elbows, asymmetrical valleys, erosion steps with the formation of paleo-surfaces, polygenic landslides, centrifugal patterns, etc. Selected unique examples will be described and discussed in this chapter, aiming at highlighting how the geomorphological evolution has been conditioned through time by various geological settings.

17.2 Geographical Setting

The area is located in the northern portion of the Apennines, east of the Scrivia Valley, west of the Trebbia Valley and north of the Po River—Ligurian Sea watershed (Fig. 17.1). This watershed runs about 10 km away from the Ligurian coastline and is about 1200 m high (except Mt. Aiona, 1695 m a.s.l.). It should be noted that the highest peaks are not situated along the watershed itself, but they can be found

L. Pellegrini (✉) · P.L. Vercesi
Dipartimento di Scienze della Terra e dell’Ambiente, Università di Pavia, Via Ferrata 1, 27100 Pavia, Italy
e-mail: luisa.pellegrini@unipv.it

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about 25 km north of it, forming a massif about 1600–1700 m high (e.g. Mt. Lesima, 1724 m; Mt. Chiappo, 1699 m; Mt. Ebro, 1700 m; Mt. Antola, 1597 m). North of the massif elevations progressively decrease, the mountains become hills and finally the Po Plain opens up and the altitudes drop to 50–70 m.

The area is crossed by many rivers and streams, which form a kind of radial pattern with the massif formed by Mt. Antola, Mt. Ebro, Mt. Chiappo and Mt. Lesima in the centre. This pattern is due to structural setting and differential uplift. Neotectonic phases, in particular, the uplift of the central area of the chain, and favourable, very wet climatic conditions have caused intense fluvial erosion, many river diversions and captures.

Rivers on the northern slopes of this massif, which flow into the Po River, have two preferential directions: northwest (Staffora, Curone and Scrivia rivers) and northeast (Tidone and Trebbia rivers). This configuration follows the shape of the structural arc in this part of the Apennine area. Only the first reach of the Staffora River and some minor streams (e.g. Versa and Scuropasso rivers) flow northward.

Climate shows an average annual temperature of 12 °C in the less elevated areas and of 8 °C at the highest elevations. Rainfall is about 675 mm/year on the plain, 785 mm/year in the hills and 1420 mm/year in the mountains. The monthly pluviometric regime shows two maxima, in November (absolute maximum) and May, and two minima, in July (absolute minimum) and January (Maggi and Ottone 2003).

17.3 Geology and Structure

The Apennine orogen was generated by the closure of the Liguria-Piemonte Ocean (Eoalpine phase) and subsequent continental collision between the European and Adriatic tectonic plates (Mesoalpine phase). This chain has an

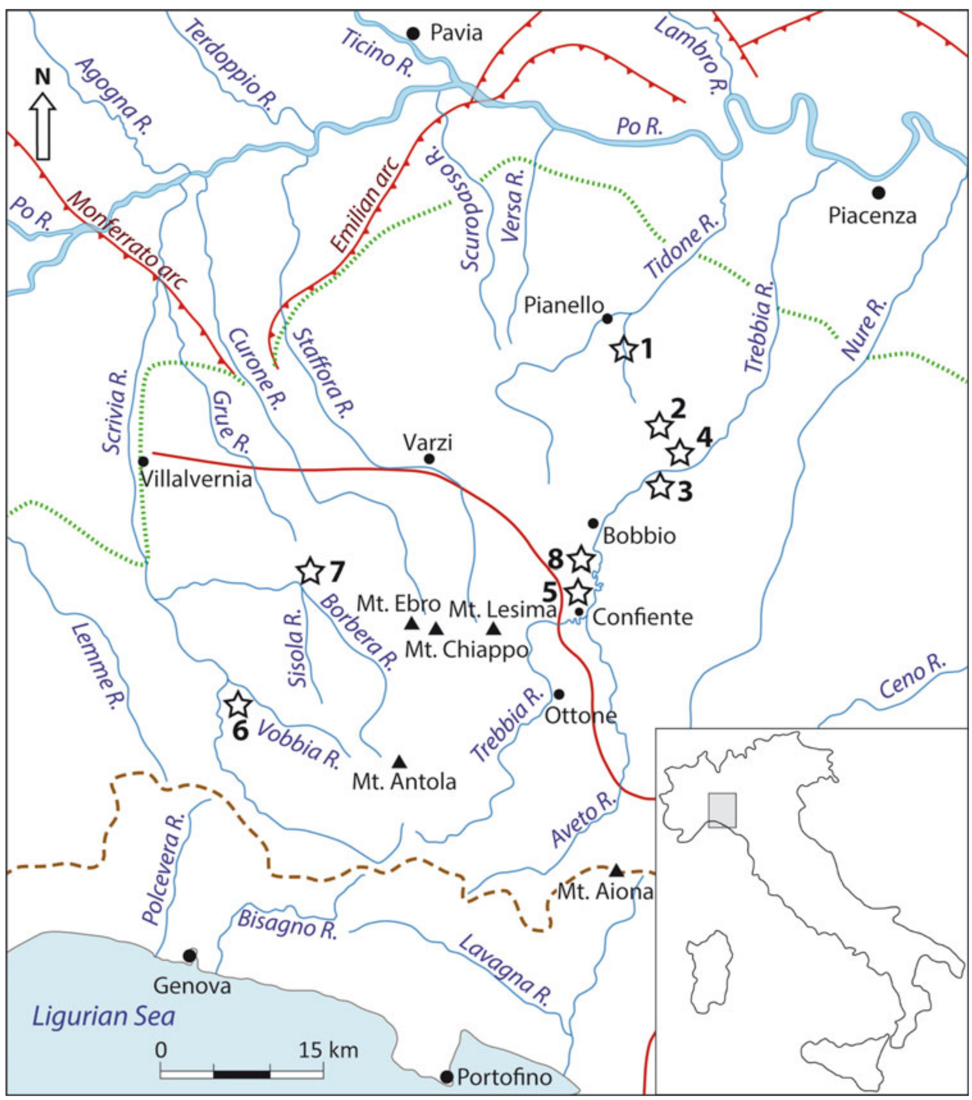

Fig. 17.1 Geographical setting of the northwestern Apennines. The *brown dashed line* indicates the divide between the Po basin and the Ligurian basins; the *green dotted line* shows the Po Plain boundary; the *red lines* represent tectonic lines (*lines with triangles* are main post-Tortonian thrusts, modified after CNR 1991). The *stars* indicate: *1* Rocca d'Olgisio syncline mountain; *2* Pietra Parcellara ophiolite; *3* Mt. Barberino ophiolite; *4* Caverzago slope; *5* Brugnello slope; *6* Castello della Pietra peak; *7* Borbera River diversion; *8* Trebbia River entrenched meanders and Bobbio windows

eastward vergence (Adriatic vergence) which is due to the post-Oligo-Miocene tectonic phases, and related to the westward subduction of the Adriatic plate. According to this model, the opening of the Ligurian-Provenzal Basin in the Upper Oligocene—Lower Miocene, and later opening of the Tyrrhenian Basin (Upper Miocene) can be both explained as back-arc tectonic extensions, induced by the Apennine subduction, and as the source of the *boudinage* structure of the Alpine prism (Laubscher 1988). Today's geological structure of the Apennines, with its northeast-vergent nappes stacked upon the Adriatic plate, arises from these latest geodynamic phases, started in the Upper Oligocene—Lower Miocene and showing landforms very different from one another.

17.4 Landforms

The landscape of the area is very complex, with contrasting landforms and frequent morphological changes. These changes are mostly related to different lithology and regional tectonic structures, heritage of the tectonic setting of the Apennine chain.

17.4.1 Structural Landforms

In stable tectonic settings, morphology only reflects erosional/depositional processes, which can be more or less intense depending on the climatic condition and the initial topography of the area. By contrast, in the Apennines tectonic evolution is still active and the connection between landforms and tectonics is the primary element that marks the landscape. Examples include faults juxtaposing completely different lithologies on the two sides, resulting in asymmetrical valleys (Staffora Valley); active synclines with deformed highly resistant sedimentary successions, which are fractured in the axial zone (Rocca d'Olgisio syncline); arching and isostatic movements deforming stacked nappes and taking the same stratigraphic units to different topographic levels (Mt. Barberino ophiolitic group).

An exemplary case of a hanging syncline is the Rocca d'Olgisio ridge (cf. Pellegrini et al. 2010) which is located southwest of Piacenza, close to Pianello Val Tidone. It is an extraordinary site of high geological value, cut in the middle by the Chiarone stream, with a SSE–NNW direction. At the western end of the structure, the fortress of Rocca d'Olgisio stands in a striking position, over a high arenaceous spur (Fig. 17.2).

The structural and lithological setting played a fundamental role in shaping the Rocca d'Olgisio syncline, where the "relief inversion" phenomenon is related to the superposition of resistant and weak successions. Therefore, the syncline is built up of turbiditic sediments of the Ranzano Formation in the upper part, and in the Monte Piano Marls in the lower part. The conglomeratic sandstones (Ranzano Formation), highly resistant to erosion, allowed the structure to stand in a dominant position with respect to the general landscape, whereas anticlines can be recognized in the more erodible marls of the Val Luretta Formation to the north, and in the Palombini Shales and the pelitic-arenaceous succession of the Scabiazza Sandstones to the south (Fig. 17.3), both subject to considerable erosion.

Also, topographic maps show peculiar erosional features of the Rocca d'Olgisio syncline, due to central depression of the WNW–ESE-oriented fold axis and the periclinal closures of two lateral culminations. These two terminations display different morphologies: the western one has a very gentle pitch and the limbs of the folds are almost parallel, while the eastern one has a steeper pitch and the pattern of the outcrops is almost circular.

Therefore, the area shows all typical conditions for shaping of a "canoe valley" such as resistant rocks above weak ones, folded structures (with an Apennine trend of their axes), folded structures with a WNW–ESE strain trend, geomorphological evolution that led to the erosion of the upper parts of the relief (axial culminations) and "relief inversion". We can define the elongated shapes as a "canoe valley" because of the similarity with this type of boat. In the above-described area, the anticlines, squeezed and faulted, are more intensely affected by erosion that has reached the weakest rocks. When this happens, erosion increases its intensity and speeds up, while the lower parts of the synclines, formed by competent rocks, are still resistant to erosion. This selective erosion has generated a landscape where synclines are the most elevated morphological features.

The evolutionary model of the area has many similarities with the one proposed in 1965 and taken up in 1985 by Oberlander to explain the morphology of the Zagros Mountains. Although the tectonic evolution has been different, the peculiarity of the frequently undulating axes of the folds (plunging folds), the lithological alternation of resistant and weak rocks, and the young orogenic developments have led to a similar morphological evolution. The drainage pattern is discordant with the geological structure (Chiarone stream) and is comparable to Oberlander's (1985) transverse streams with superimposition controlled by structures such as the "drainage inheritance" of Summerfield (1991).

In more detail, the canoe valley of the Rocca d'Olgisio is 4.5 km long and 1 km wide in the central part and reaches the maximum altitude of 610 m in the northwestern periclinal culmination. The effects of selective erosion can be recognized at different scales, from relief modelling in the topographic outline to the tiny details of sculpting and

Fig. 17.2 View of the structural landform of Rocca d'Olgisio from southeast (*photo* L. Pellegrini)

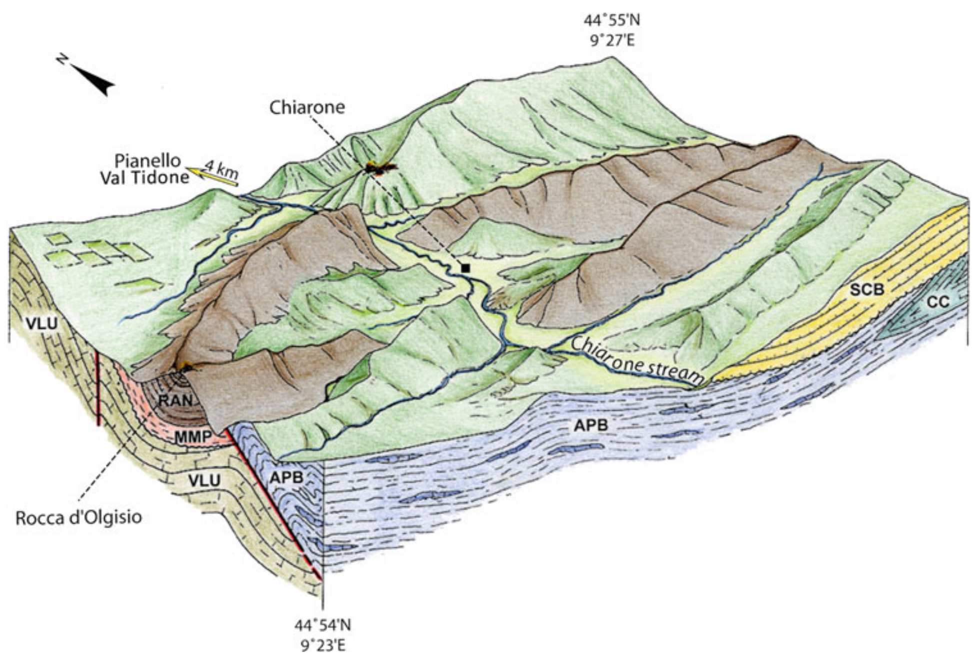

Fig. 17.3 The Rocca d'Olgisio "canoe-shaped" syncline. Three dimensional sketch of the structure. *RAN* Ranzano Formation; *MMP* Monte Piano Marls; *VLU* Val Luretta Formation; *SCB* Scabiazza Sandstones; *APB* Palombini Shales; *CC* Calpionelle Limestone (modified after Pellegrini et al. 2010)

chiselling. The inner side of the "canoe" corresponds to the pelitic facies of the Ranzano Formation and has gentle morphology, while the outer rocky faces are steep, with escarpments up to 200 m, carved in the conglomeratic-arenaceous strata. Lithological features of these strata, partially lightly diagenized, the exposure of the face scarp slope, together with the particular microclimate of the area, have led to the excavation of variously sized hollows, such as tafoni, caves, and alveolar structures with honeycomb appearance, due to differential weathering.

This area is also of high naturalistic interest, because some rare and unusual vegetable species, not found elsewhere in the Northern Apennines, grow here spontaneously thanks to the particular microclimate and soil conditions, consequence of the southward exposition, and local geometry of the arenaceous slopes. A southward exposition, or a nook, protected from winter rain, develops a microclimate that is excellent for these plants, which need warmth and plenty of sun. Moreover, degradation of the arenaceous terrain has produced favourable soil (sandy or very well drained, with a pH about 6–7.5) for the growth of some vegetable species uncommon in this portion of the Apennines. Therefore, it is possible to see the unusual presence of dwarf Indian figs (*Opuntia compressa,* Salisb.) of North American origin, some cork oaks (*Quercus pseudosuber,* Santi) and amaryllis, protected by the current laws, the yellow amaryllis (*Sternbergia lutea,* L.*)* very rare in the Emilian region, some species of wild orchids, like the "spider flower" (*Ophris Sphegodes,* Miller) and the "pyramidal orchid" (*Anacamptis pyramidalis,* L.).

17.4.2 Lithological Control on Erosion: Relief Due to Selective Erosion

Lithology and structures strongly influence erosional processes that are much faster if the rock is erodible. Resistant rocks usually emerge as isolated peaks when they are in contact with weak rocks. The selective erosion of Pietra Parcellara, Pietra Perduca (very close to Pietra Parcellara), Mt. Barberino, Caverzago, Brugnello and Castello della Pietra peak are very significant examples.

17.4.2.1 The Pietra Parcellara Ophiolite

The Pietra Parcellara (Fig. 17.4), Pietra Perduca and Mt. Barberino elevations in the Trebbia Valley are large fragments of serpentinized lherzolites (ophiolites) which stand out against the mild landscape of the Palombini Shales Formation. Effects of selective erosion are very clear when related to lithological changes and have repercussions in making use of the soil and in the spontaneous vegetation distribution.

Groundwater reservoir originated in the ophiolitic masses leaks and soaks the clays underneath. This downgrades the geotechnical properties of the pelitic rocks, together with the erosion at the base of the slope, due to lateral erosion of the Trebbia River. Erosion and degradation of the pelitic rocks have caused the formation of some huge landslides.

17.4.2.2 Mt. Barberino Ophiolitic Relief

Mt. Barberino (Fig. 17.1) ophiolitic relief is also surrounded by pelitic deposits with gentle and moderately inclined slopes and is deeply carved by the Trebbia River, which flows in a gorge. This gorge is the result of a superimposed/antecedent phenomenon. It was a consequence of the latest phases of rising of the chain that did increase the stream power enough to deeply erode these more resistant rocks. Upstream of the obstruction, the valley, carved in weak rocks, is wide and terraced alluvial deposits fill its bottom (Bobbio plain). Phases of deposition and incision of these alluvial deposits were emphasized by the ophiolitic obstacle and by the phases of its erosion.

17.4.2.3 Caverzago Slope

Elevated position, which made the neighbouring areas more visible, has affected human behaviour in choosing where to settle since ancient times. In fact, worship or defensive churches and castles have been built on the top of structural landforms.

Fig. 17.4 The Pietra Parcellara ophiolitic relief stands out in the *background*; in the *foreground*, the foot of a large landslidein clays (*photo* P.L. Vercesi)

In the Trebbia Valley, for example, the oratory of Pietra Perduca is nestled in the fracture of an ophiolitic block, close to Pietra Parcellara, and the church of Caverzago (Fig. 17.5), northeast of Barberino, is located on the edge of a steep scarp. This scarp was shaped in turbiditic successions and, even if they are relatively easy to crumble, they have relatively endured through time.

17.4.2.4 The Brugnello Slope

Similarly, south of Bobbio, in the Trebbia Valley, the church of Brugnello (Figs. 17.6 and 17.9a) stands on the edge of a precipitous scarp, more than 150 m high and shaped in the erodible Brugnello Shale Member (the arenaceous components prevail against the shales). The position of this church, and those of Caverzago and the Castello della Pietra, underlines just how the religious or strategic settlement choices are linked to specific landforms.

17.4.2.5 Castello Della Pietra Peak

In the Vobbia Valley, a right tributary of the Scrivia River, there is a spectacular and dramatic peak and on top of it, the Castello della Pietra towers (Fig. 17.7). The peak is similar to the Meteora in Thessaly (Central Greece). In this case, selective erosion focused on planes of weakness, in correspondence to vertical faults. The latter have irregularly cut the highly resistant rocks belonging to the Savignone Conglomerates Formation, which have been intensely fractured and are now arranged in bands of variable thickness, from a few centimetres up to some metres; in some cases, the

Fig. 17.6 Church and village of Brugnello built on an ancient fluvial surface at the edge of a high scarp carved by the Trebbia River (*photo* L. Pellegrini)

Fig. 17.5 The Caverzago church, dominating the Trebbia River bed, is set on an ancient fluvial surface that has been partially eroded. Beside the church, the ruins of the castle, collapsed because of the scarp retrogression, are still recognizable (*photo* P.L. Vercesi)

Fig. 17.7 The Castello della Pietra was built on top of the lower of the two rocky peaks. The highest reaches an altitude of 625 m a.s.l. and rises up 210 m from the valley bottom (*photo* L. Pellegrini)

formation is shaped in huge isolated spurs. The Castello della Pietra has been included among the list of Italian national monuments.

17.4.3 River Diversion

The Villalvernia-Varzi-Ottone-Levanto tectonic lineament (Fig. 17.1) influences the evolution and the trend of the Staffora Valley. The influence is very clear in the medium reach of the Staffora River, where the river suddenly drifts towards west and then north. From a general point of view, the river axis shows abrupt drift-diversion, or a fluvial elbow, mimicking the trends of other rivers of the same sector (Fig. 17.1). These common features in the river are visible in the collisional zones of the tectonic arcs, such as the Emilian tectonic arc and the Monferrato tectonic arc (CNR 1991).

The Borbera Valley has a very peculiar hydrographic pattern (Pellegrini et al. 2003). The Borbera River, a right tributary of the Scrivia River, flows in a SE–NW direction. Near Pertuso, 1.5 km north of the confluence with the Sisola River, it twists sharply to the west (Fig. 17.8). Changing its direction, the stream abandons a zone of weak rocks and crosses more resistant ones. Moreover, the Borbera Valley (downstream from the confluence with the Sisola River to Pertuso) shows a rather wide riverbed (Fig. 17.8a) and very asymmetric valley slopes. The right side of the valley, carved in flysch, has a gentle slope; the left one has a much steeper slope and is developed in more resistant conglomerates.

Along the valley floor, extensive terraced alluvial deposits stretch out. Where the Borbera River crosses the conglomerates, in the east-to-west reach, "young" landforms can be seen with entrenched meanders and gorges.

Comparative analysis of the morphological and morphotectonic elements described above allowed to propose a scheme for the recent evolution of the area. An original river flowed from SSE towards NNW, going on to the valley of the present Grue River (Fig. 17.8b). The headward erosion of a stream flowing to west, and located west of Borbera Valley, caused capture of the Borbera River. In all likelihood, this capture have been helped by differential tectonic uplift of Mt. Gavasa area and by a tectonic lineament located in the present Borbera gorge close to Pertuso. The evidence of the former Borbera Valley is represented by the scarp flanking the Merlassino area and which is the continuation of the scarp south of the Pertuso elbow (Fig. 17.8b, c). Since the scarp height is generally the same southward and northward of the elbow, the diversion must have occurred quite recently. Traces of the bottom of the former Borbera Valley is no longer visible because of the earth flows affecting the Merlassino area.

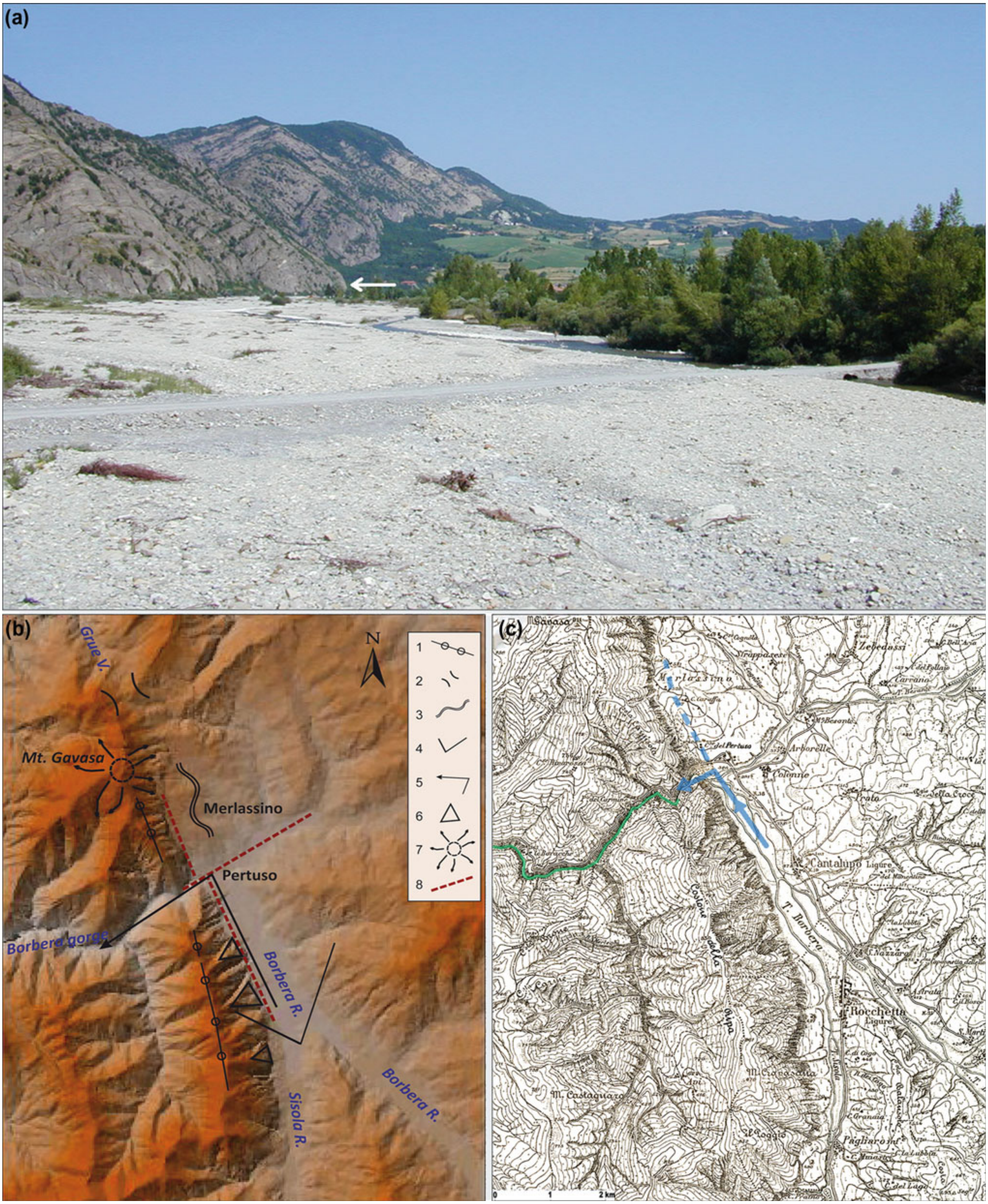

Fig. 17.8 **a** In the foreground, the Borbera River large channel that carries flows towards the background of the photo (by L. Pellegrini) and then turns to the *left* (*white arrow*). **b** Lineaments and morphotectonic elements on hillshaded terrain model, related to diversion (Pertuso area): *1* rectilinear crest or spur; *2* saddle; *3* landslide; *4* asymmetric valley; *5* diversion elbow; *6* triangular facet; *7* centrifugal drainage pattern in the uplift area; *8* lineament (modified after Pellegrini et al. 2003). **c** Topographic map (after Marinelli 1948) of the area of the Borbera diversion. The *blue arrow* indicates the Borbera diversion and the *dashed blue line* is its ancient course. The *green line* highlights the headward erosion of the captor river

Fig. 17.9 **a** Aerial image of entrenched meanders of the Trebbia River from Marsaglia to Bobbio (*photo* G. Bertolini). **b** terrestrial view of the San Salvatore meander cut in the San Salvatore Sandstone of the Lower Miocene (Tuscan nappe) in the heart of the Bobbio tectonic window (*photo* L. Pellegrini)

17.4.4 Incised Meanders

The deep gorge carved by the Trebbia River (Fig. 17.9a), south of Bobbio, not only has displayed important geological structures to the view, such as the tectonic window of Bobbio, but also shows extraordinary entrenched meanders.

The origin of these meanders is related to the reactivation of erosional activity of the Trebbia River, after the relief had undergone levelling (pediplanation), likely during the middle-late Pliocene. This levelling is proven by widespread ancient surfaces, located on top of the water divides or along the slopes. The surfaces are now isolated but well recognizable (see, for example in Fig. 17.9a, Moglia, Rossarola, Brugnello, Telecchio).

Flowing across a gentle and slightly undulated paleolandscape, the Trebbia River channel was a meandering one, with a very high sinuosity index. When the tectonic uplift forced the Trebbia River to start downcutting again, the river did not change its style; it remained meandering highlighting in this way the phenomenon of superimposition.

The magnificent meanders of Confiente, Brugnello and of San Salvatore (Fig. 17.9b) are carved in highly resistant lithology, such as siltstone and sandstone, or sandstone and conglomerate. The high slopes exhibit evidence of several stages of erosion with stronger gradients towards the valley floor (rock-cut terraces).

17.4.4.1 The Tectonic Window of Bobbio

The «Bobbio tectonic window» (Ludwig 1929; Elter 1994) in the Trebbia Valley extends from about Ponte Organasco (close to Marsaglia) to Bobbio and offers a view of the Northern Apennine structural frame.

The Northern Apennines developed through successive tectonic phases and their structure shows various tectonic units piled upon one another, stacked up and shifted towards the northeast (from the Lombardy to the Emilia-Romagna regions), whilst they were originally located in more southwestern areas. The result of this stacking and migration was a fold and thrust tectonic style of the chain.

The internal structures, migrated from west to east, now lie in the western part of the continental margin of the Apula plate. The allochthonous Ligurian Units of oceanic origin currently form the uppermost nappe system of the Northern Apennine stack and have migrated on the Tosco-Umbrian Unit, which represents the deformed and unstuck foreland of the Apula plate.

The Ligurian Units nappe is locally incised, giving the chance to observe the underlying units. This is the case of the tectonic windows of Bobbio, and the other ones such as Salsomaggiore, in the Parma Apennines to the east.

Along the valley bottom of the Trebbia River, which is deeply incised into all the tectonic units, it is possible to see all lithologies and structures of the tectonic window of Bobbio along the slopes of the valley, with the younger unit in the lower part and the progressively oldest lithologies towards the top, separated from one another by thrusts.

17.5 Conclusions

An area characterized by very diverse geological and morphological features, which gave birth to a very unusual landscape, has been described in this chapter. It is interesting to recognize and understand the connections between landforms and tectonic and lithological setting of the area. Therefore, an analysis of local landforms inserted and linked within the regional geological context of the area can be very helpful in understanding landscape evolution.

Many landforms described here can be considered as geomorphosites and therefore included in valorisation programmes. Actually, there are two parks in the area: the Antola Park and the Trebbia Fluvial Regional Park. The Antola Park was established in 1995, based on regional law. The protected area includes the high Trebbia Valley and the Vobbia Valley, with specific reference to the "Castello della Pietra". The Trebbia Fluvial Regional Park is located in the lowest reaches of the valley and is aimed primarily at protecting relict environments in plain and hilly settings, which are important natural habitats for native flora and fauna.

A project for the establishment of a geotouristic itinerary in the Trebbia Valley (particularly referred to the middle section of the valley) is ongoing, aiming at the assessment of sites with high scientific and aesthetic values such as the entrenched meanders, the Pietra Parcellara and others, described in this chapter.

References

CNR (1991) Structural model of Italy, scale 1:1,000,000. S.EL.CA., Firenze

Elter P (1994) Introduzione alla geologia dell'Appennino ligure-emiliano. In: Zanzucchi G (ed) Appennino Ligure Emiliano, 10 itinerari. Guide Geologiche Regionali, Società Geologica Italiana. BE-MA Editrice, Milano, pp 17–24

Laubscher HP (1988) The arcs of the Western Alps and the Northern Apennines: an updated view. Tectonophysics 146(1–4):67–78

Ludwig O (1929) Geologische Untersuchungen in der Geden von Bobbio im Nordapennin. Geol Rundsch 20:36–66

Maggi I, Ottone C (2003) Spatial–temporal precipitation analysis in the area between Scrivia T. and Nure T. (Northern Italy). Quatern Int 101–102:149–156

Marinelli O (1948) Atlante dei tipi geografici. Istituto Geografico Militare, 2nd Edition. Firenze, 320 pp

Oberlander TM (1965) The Zagros streams, a new interpretation of transverse drainage in an Orogenic Zone. Syracuse Geographical Series No. 1, Syracuse University Press, New York, 168 pp

Oberlander TM (1985) Origin of drainage transverse to structures in orogens. In: Hack JT, Morisawa M (eds) Tectonic Geomorphology. Allen & Unwin, Boston, pp 155–182

Pellegrini L, Boni P, Carton A (2003) Hydrographic evolution in relation to neotectonics aided by data processing and assessment: some examples from the Northern Apennines (Italy). Quatern Int 101–102:211–217

Pellegrini L, Boni P, Vercesi PL (2010) Geotourism and geomorphological hazard: the Rocca d'Olgisio case study (Northern Apennine, Italy). Geology Adriatic Area GeoActa, Special Publication 3:179–187

Summerfield MA (1991) Global geomorphology. Longman Singapore Publishers, Singapore, 537 pp