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ORIGINAL ARTICLE

Ophiolites: Geological Heritage with Multifaceted Cultural Values

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Abstract

Cultural geomorphology is a very recent discipline that studies the geomorphological component of a territory which embodies both a cultural feature of the landscape and its interactions with cultural heritage: this cultural approach concerns the dialogue and cultural integration between humanistic and scientific disciplines and can be extended to all the fields of Earth Sciences. Ophiolite rock masses strongly characterize the landscape: their greenish-black, sometimes red-brown colour; the steep profile of the slopes, which results from their greater resistance to erosion than the surrounding softer sedimentary rocks; the scarce or even absent vegetation cover. The value of ophiolites is not only related to scientific and aesthetic interests, but is also due to historical–geographical, cultural and socio-economic issues. In this research, we present the elements of cultural and landscape value related to the ophiolites of the Northern Apennines, and how these geological and geomorphological features have led to specific relationships with humankind and human geography. Indeed, ophiolites represent characteristic elements of popular culture with immediate reference to toponymy, local legends and religion. Ophiolites are also an element of great strategic importance, as they are crucial for human settlement, with specific reference to defence, and for mining and quarrying activities. The landscape of ophiolites is of great geological, geomorphological, hydrogeological and pedological interest, resulting in a high concentration of geosites, hence on the one hand the opportunity for enhancement and potential geotourism, and on the other hand the need for their protection and geoconservation.

Keywords Cultural geomorphology · Ophiolites · Geoheritage · Toponymy · Geosites · Geotourism

Introduction

The concepts of cultural geomorphology and, in a broader sense, cultural geology, are relatively young fields within earth sciences (Panizza and Piacente 2003; Caetano and Ponciano 2021). Cultural geomorphology, as defined by Panizza and Piacente (2003), is "the discipline that studies the geomorphological component of a territory which embodies both a cultural feature of the landscape and its interactions with cultural heritage of the archaeological, historical, architectonic etc. type".

The relationships between geology *l.s.* and culture are multifaceted, and recent scientific literauture has extensively analysed this complex relationship from various points of view (e.g. Panizza and Piacente 2009; Reynard and Giusti 2018; Pijet-Migoń and Migoń 2022; Kubalikova and Coratza 2023 and references therein): i) the influence of geomorphological processes and landforms on cultural aspects; ii) the links between geological elements and cultural heritage; iii) the interplay between geomorphological processes and cultural heritage, that can result in damage or even destruction; and iv) how culture affects perception of geological elements.

Several studies have dealt on how geomorphological processes and landforms affect intangible cultural heritage—popular beliefs, legends, religion, mythology (e.g. Vitaliano 2007; Piccardi and Masse 2007; Knight and Harrison 2013; Goemaere et al. 2021; Kiernan 2015; Mostafaei and Moshiri 2015; Sisto et al. 2020; Burbery 2021; Rassios et al. 2022). Geology has an influence on the toponymy (Sellier 2013; Tort i Donada and Sancho-Reinoso 2014; Abdullina et al. 2019), as place names can reflect the appearance of a specific geological feature, the occurrence of geomorphological processes or events, or even past environments (Sousa et al. 2010).

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Geomorphological features are often strongly linked with tangible cultural heritage. Rocky hillocks and tops are preferential place to build castles, fortresses, villages or even monasteries (e.g. Tronkov and Sinnyovsky 2012; Szepesi et al. 2020), due to their defensibility and the opportunity to control a portion of land. Caves and cave dwellings have been used as homes since prehistoric times (e.g. Sardella et al. 2019). Research has dealt with the interaction of cultural landscapes and geomorphology (e.g. Tilley et al. 2000; Migoń and Latocha 2008; Lozić et al. 2012; Pereira and Martins 2016; Štrba et al. 2022). In some cases, the geomorphological context can lead to the conservation of cultural heritage (Brandolini et al. 2011), while in other cases cultural heritage can be affected by geomorphological hazard (e.g. Nicu 2017; Pavlova et al. 2017).

Another significant intersection of geology and culture lies in the realm of construction and ornamental stones (e.g. Cimmino et al. 2004; Del Monte et al. 2013; Borghi et al. 2014; Da Silva 2019; Freire-Lista et al. 2019; Lezzerini et al. 2019; Ballesteros et al. 2021). This connection is ultimately linked with mining and quarrying heritage. Some mines and quarries are considered part of geoheritage due to their rock exposures of stratigraphical or structural interest (Gajek et al. 2019; Prosser 2019 and references therein), their mineralogical value (Coratza et al. 2018), while on the other hand they have been exstensively investigated because of their environmental issues (e.g. Marescotti et al. 2018). Moreover, they are part of the cultural heritage for various reasons. Firstly, the exploited geomaterials significantly shape the cultural heritage of the region (e.g. construction and ornamental stones in cities). Secondly, mines and quarries reflect the expertise and practices of the workers who shaped them (Pérez-Aguilar et al. 2013).

In the Northern Apennines of Italy, ophiolite outcrops stand as prominent and characteristic features in the natural landscape due to of their striking appearance − sharp, dark colours, and stark contrast with the surrounding environment. Ophiolites in the Northern Apennines have a striking scientific value, having been extensively studied for decades for their petrogenetic (e.g. Rampone et al. 1995, 2020; Borghini et al. 2016 and references therein), structural and paleogeographical aspects (e.g. Marroni et al. 1998), and even their ecological (e.g. Vercesi 2005) implications. Many ophiolite outcrops in this area have been recognised as geosites (Ferrando et al. 2021; Giovagnoli 2023), while their cultural and landscape value has been discussed in various papers (Piacente et al. 2001; Bollati et al. 2012, 2018).

This research aims to provide a comprehensive understanding of the cultural value of ophiolites in the Northern Apennines, by analyzing their influence on intangible aspects, such as place names, legends, religious connections as well as tangible cultural heritage like castles, villages, churches, quarries and mines. The research has been framed in an uniform geological context—namely, the ophiolitiferous, non-metamorphic Ligurian Units of the Northern Apennines, that exhibit specific and relatively uniform landscape features. Ophiolites are also present in the nearby standing South-Western Alps, between Liguria and Piedmont, but they have a different petrogenetic history (having been subjected to Alpine metamorphism) and display dissimilar landscape characteristics.

Recognising the cultural value of ophiolite outcrops holds significance in land planning, geoconservation efforts, and presevation of cultural heritage. Furthermore, it serves as means to promote geotourism, as legends, myths or tangible cultural heritage associated with geological feature often intrigue the "general public" to become interested in the geological aspects of these rocks (Khoshraftar and Farsani 2019).

Study Area

The Apennines are a mountain range approximately 1000 km long, stretching from Liguria, in North-Western Italy, to Calabria, in Southern Italy. Thus, they represent a sort of backbone of the Italian peninsula, and are traditionally divided into three sectors—the Northern, Central, and Southern Apennines. The Northern Apennines (Fig. 1) traverse the Italian regions of Liguria, Tuscany, Emilia-Romagna, Umbria, Marche, and include the small enclave of San Marino. The mountain range has a generally NW–SE trend, with two distinct sides—one facing the Ligurian and Tyrrhenian Seas, and the other facing the Adriatic Sea. The highest peaks aren't always situated along the main watershed, but are often located on the Adriatic side of the chain. Notable peaks include Mt. Maggiorasca (1804 m), Mt. Penna (1736 m) and Mt. Lesima (1724 m) in the Ligurian Apennines; Mt. Cusna (2120 m) and Mt. Cimone (2165 m) in the Tuscan-Emilian Apennines; Mt. Falco (1657 m) and Mt. Pianellaccio (1592 m) in the Tuscan-Romagna Apennines. These peaks contribute to the diverse landscape and character of the Northern Apennines.

The Apennines exhibit a marked contrast between their Adriatic and Tyrrhenian sides. The Adriatic side is quite uniform and has a simple orography, while the Tyrrhenian side is dissected by large tectonic depressions bordered by normal faults, with their main axes subparallel to the main Apennine chain, resulting in isolated massifs, like the Apuan Alps (Mt. Pisanino, 1947 m), the Monti Pisani (Mt. Serra, 917 m) and the hills of central Tuscany, culminating in the Colline Metallifere (le Cornate, 1059 m).

For what concerns the hydrography, the mountain chain present distinct characteristics on either side. The north-east side features a drainage pattern roughly parallel to the chain. Most watercourses are tributaries of the Po River,

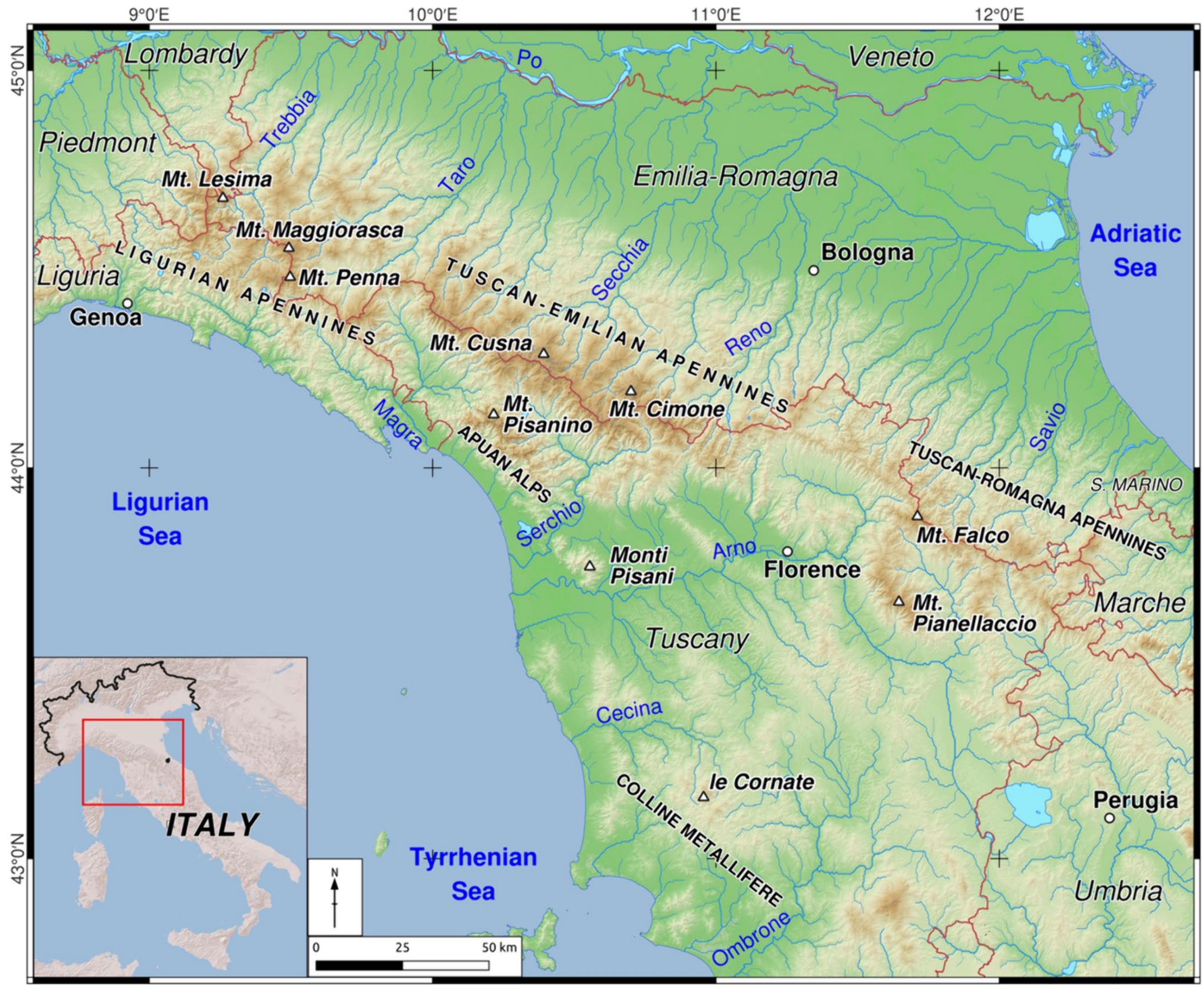

Fig. 1 Geographical map of the Northern Apennines

which in turn flows into the Adriatic Sea, while those in the easternmost part directly flow into the Adriatic Sea. Among the main rivers on this side of the mountains, there are the Trebbia, Taro, Secchia, Panaro, Reno and Savio. On this side, the main watercourses, flowing to the Ligurian and Tyrrhenian Seas, are the Magra, Serchio, Arno, Cecina and Ombrone.

From a geological point of view (Fig. 2), the Northern Apennines are a fold and thrust orogenic belt with northeastward vergence, which originated starting from the Miocene in response to the counterclockwise rotation of the Corsica-Sardinia block (Vai 2001). The nappe pile, from top to bottom, is formed by: i) Ligurian Units, comprising Jurassic oceanic lithosphere overlain by Jurassic-Paleogene deep-sea sediments; ii) Subligurian units, made by suboceanic sediments; iii) the Tuscan nappe, which is a Triassic-Oligocene sedimentary sequence relative to an outer continental margin; iv) the Tuscan metamorphic units, which have a Hercynian metamorphic basement overlain by metasedimentary series, one Lower-Middle Triassic in age (Massa Unit l.s.), the other Late Triassic-Oligocene in age (Apuan Alps metamorphic complex). In the outer part of the orogen, facing the Adriatic side, there are several other units: v) the Cervarola unit, which is similar to the Tuscan nappe but younger in age; vi) the Umbro-Marchean units, made by a Mesozoic-Pleistocene sedimentary sequence (Elter 1960; Ducci et al. 1997; Vai 2001; Molli 2008).

The ophiolitiferous Ligurian Units (4a and 4b in Fig. 2), which are oceanic in origin, are the ones of interest for the present research. They are in turn subdivided in Internal Ligurian Units and External Ligurian Units, referring to the paleogeographical position in the Jurassic oceanic basin in which they were formed. Internal and External Ligurian Units have notable differences in their stratigraphic series.

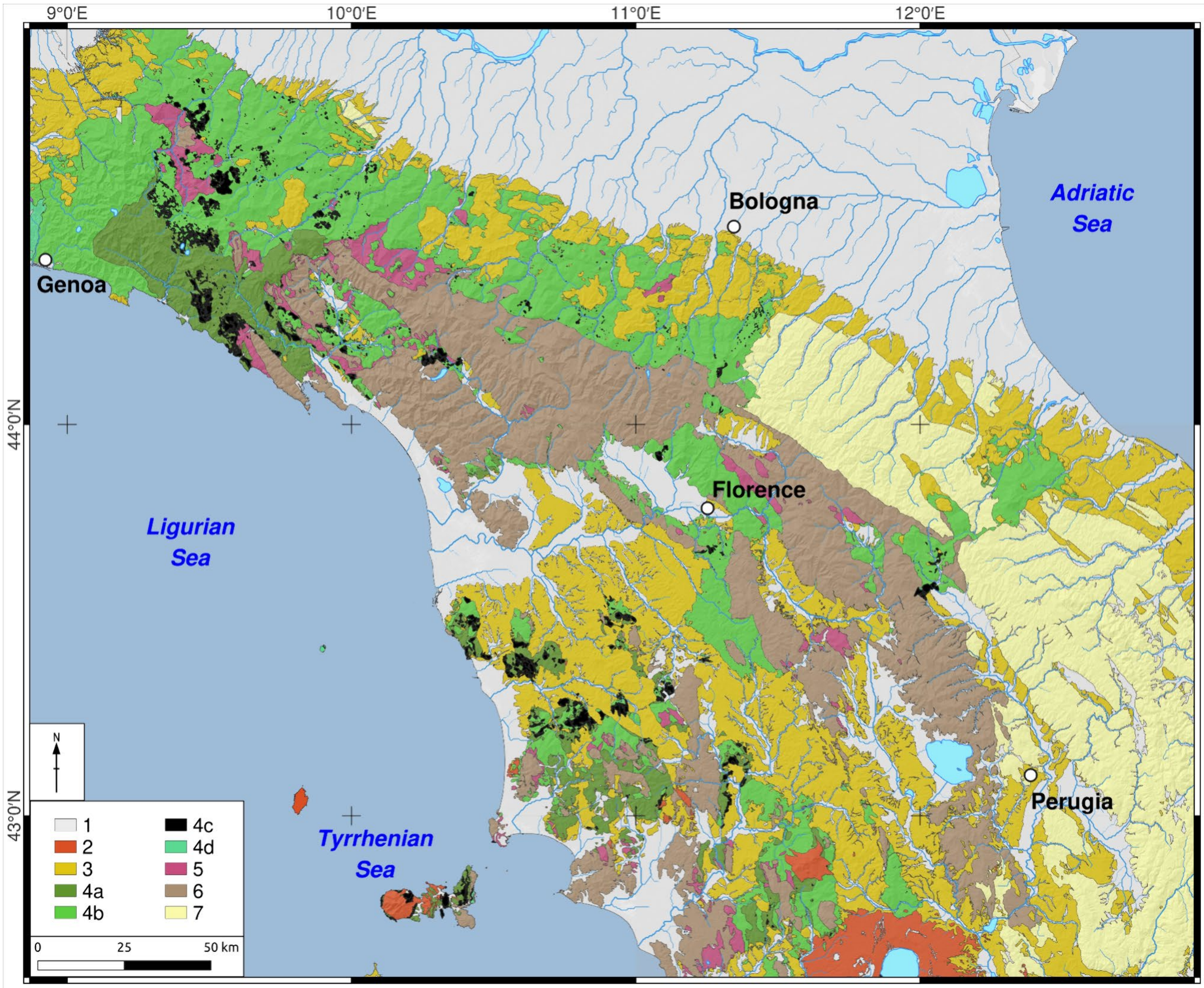

Fig. 2 Simplified geological map of the Northern Apennines. 1) Quaternary deposits; 2) Pliocene–Quaternary magmatic rocks; 3) Late-orogenic and post-orogenic sedimentary series (Oligocene-Pliocene); 4a) Internal Ligurian Units (Jurassic-Early Paleocene); 4b) External Ligurian Units (Late Cretaceous-Middle Eocene); 4c) Ophiolite outcrops belonging to the Internal and External Ligurian Units; 4d) Metamorphic Ligurian Units (Jurassic-Early Paleocene); 5) Subligurian Units (Paleocene-Eocene); 6) Tuscan Units (including the Tuscan Nappe, the Tuscan metamorphic units and the Cervarola Unit; Palaeozoic-Oligocene); 7) Umbro-Marchean Units (Triassic-Miocene)

The Internal Ligurian Units (Fig. 3a) consist of a Jurassic ophiolitic sequence made of: i) serpentinized mantle peridotites; ii) gabbros; iii) a volcano-sedimentary complex, with basalts, both with pillows and massive structures, and various types of ophiolitic breccias, which can be from tectonic to frankly sedimentary in origin. The ophiolite sequence is overlain by Middle Jurassic-Early Cretaceous hemipelagic deposits (cherts, limestones and shales) and then Early Cretaceous-Early Paleocene turbidite deposits, mainly silicoclastic in nature (Abbate et al. 1994; Principi 2004; Marroni et al. 2010; Meneghini et al. 2020).

The External Ligurian units (Fig. 3b) are made of a Late Cretaceous-Middle Eocene sedimentary sequence. In the External Ligurian units, the ophiolitic substratum is lacking, and ophiolites occur as olistolites within sedimentary melanges known as "base complexes" (*Complessi di base* Auctt.). The ophiolitic olistolites are very heterogeneous in size, from a few tens of meters to more than one kilometer. The base complexes are then topped by thick sequences of Cretaceous limestone-marly flysch (Helmintoid flysch Auctt.) (Elter and Marroni 1991; Marroni et al. 2002; Marroni et al. 2010; Barbero et al. 2020). The ophiolitic olistolites are characterised by a preponderance of ultramafites (peridotites and serpentinites) and subordinate basalts, with related monogenic or polygenic breccias. Olistolites of gabbro are very rare and limited in extent. Small masses of

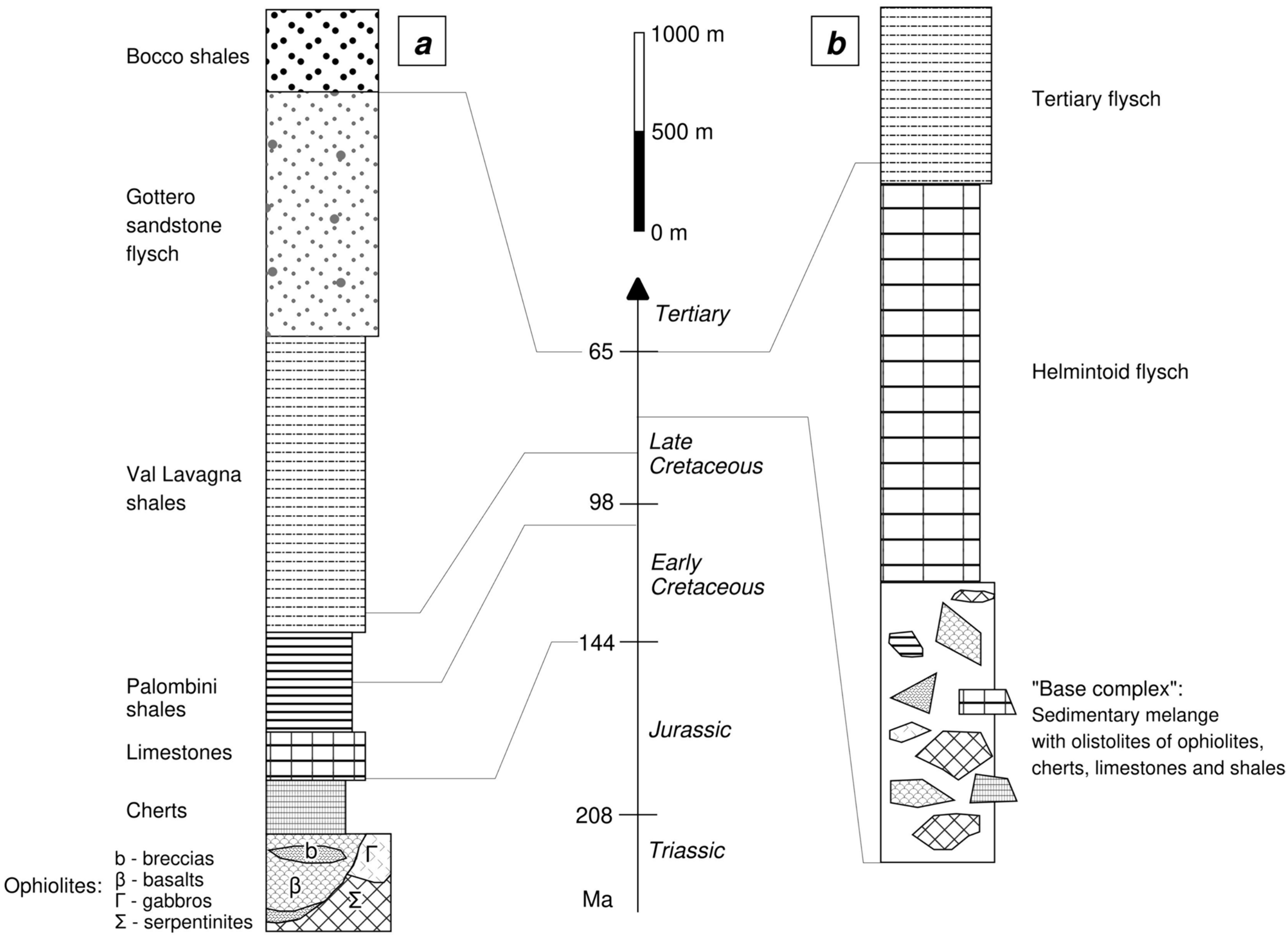

Fig. 3 Stratigraphic succession of (**a**) Internal Ligurian Units and (**b**) External Ligurian Units, redrawn from Marroni et al. (2010)

continental crust rocks (granulites and granitoids) are associated with ophiolites in the base complexes of the External Ligurian Units (Marroni et al. 1998).

Geological and Geomorphological Landscape of Ophiolites in the Northern Apennines

Ophiolitic outcrops constitute remarkable and imposing features in the scenery of the Northern Apennines, defining some of the region's most distinctive and unique landscapes (Bollati et al. 2018; Brandolini et al. 2007). The characteristics of the ophiolitic landscape of the Northern Apennines are essentially related to differential erosion, that has modeled the Appennine relief along the Quaternary. Ophiolitic masses —be they basaltic, gabbroic, or serpentinitic — are more resistant to erosion than the surrounding weak sedimentary rocks, and often remain isolated (Pellegrini and Vercesi 2017). The contrast is also strong in terms of aspect. Ophiolitic outcrops tipically exhibit a rocky, rugged appearance, with sharp edges, high cliffs and stony slopes, constrating sharply with the smoother profiles of sedimentary rocks ridges.

Differential erosion is most evident between ophiolites and surrounding sedimentary rocks, but it's also visible between different ophiolites – for instance, in the emerging of basaltic dykes in gabbroic rock masses. Different types of ophiolites have also a distinct appearance due to their structure and primary petrographic features. Basalts are often characterised by well conserved pillow structures, while in many cases ultramafic rocks show mantle layering consisting of peridotite-pyroxenite associations (Borghini et al. 2020).

Colour is another distinctive trait when comparing ophiolites with surrounding rocks. The term ophiolite is derived from the Greek words "ophis" (snake) and "lithos" (rock), meaning "snake-like rock"; this is indeed the most common aspect of ohiolites which are greenish in colour – they are also known as green stones – with a schist-like, scaly look. Ophiolitic masses often present dark hues ranging from black to greenish and brown, occasionally with reddish or grey undertones, depending on lithology and rock alteration.

Conversely, surrounding sedimentary rocks, predominantly claystones, sandstones or marly-limestones, display light colours, ranging from grey to light brown and white.

These morphological and chromatic contrasts are particularly evident in the case of the External Ligurian Units of northeastern Liguria and Emilia-Romagna. Here, the ophiolitic masses are found as fragmemts within predominantly arenaceous-clayey sedimentary melanges. Because of this, they appear as true dark-coloured "boulders" that stand out in a gentle, undulating context (Fig. 4a). Often, the surrounding gentle slopes are characterised by rural activities (mowed lawns, agriculture, grazing etc.), further enhancing the contrast. The contrasts are less pronounced in the outcrops of the Internal Ligurian Units, where the original ophiolitic sequence is preserved as a true basement within the tectonic units.

Finally, one last prominent feature concerns vegetation. The flora of the rocky ophiolite environment is made up of stress-tolerant species. This is mainly due to the bedrock nature, which lacks essential nutrient matter and are rich in magnesium, which is toxic to many plant species. Moreover, the dark colour of the rock, which in summer is overheated by the sun, makes this environment even more inhospitable for plants. Therefore, ophiolitic outcrops tend to be poor in vegetation, bare, and colonised by a peculiar and very specialised flora (Gambi 1992; Barberis et al. 2004; Vercesi 2005), particularly by "serpentinophytes" species such as *Asplenium cuneifolium*, along with rare species that also thrive on other rocks, such as *Cheilanthes marantae*, and endemic species like *Robertia taraxacoides*.

Structural landforms, such as trenches, rock towers and scarps are widespread among the ophiolites of the Northern Apennines (Fig. 4b) (Pellegrini and Vercesi 2017). These features are then shaped by gravity and the action of running waters. Because of the frequent presence of vertical rock walls, rock falls and toppings are among the most frequent gravitational phenomena, leading to the formation of debris cones and scree slopes at their foot (Fig. 4c). Small debris flows can occur along couloirs and gullies (Chelli et al. 2016).

More extended and complex gravitational phenomena, with very slow kinematics when active, are mainly due to the competence contrast between the ophiolites and the surrounding sedimentary terrain. The competence contrast is particularly strong in the case of the ophiolitiferous sedimentary melanges of the External Ligurian Units. This leads to the formation of complex, slow-moving landslides, block slides, and rock avalanches (Faccini et al. 2012; Chelli et al. 2013).

Deep-seated gravitational slope deformations (DSGSD) are particularly widespread in places where External Ligurian Units outcrop (Capitani et al. 2013). They are exerted by rock-block slide or lateral expansion kinematics at the slope scale, favoured by the contrast between the rigid behaviour of the ophiolitic masses and the plastic behaviour of the embedding sedimentary rock. Slopes characterised by DSGSD show typical geomorphological evidence: stepped profiles, counter slopes and basins often occupied by wetlands, trenches and double ridges in the summit portions of the slopes (Faccini et al. 2009, 2012; Allasia et al. 2021; Godone et al. 2023) (Fig. 4d).

Regarding fluvial landforms and processes, the presence of ophiolites often leads to the entrenching of certain stretches of stream (Fig. 4e). Wide floodplains can be found upstream of the entrenched stretch. Examples of these morphologies can be found along the Ceno and Aveto streams in the Ligurian-Emilian Apennines and along the Serchio River and Pavone Creek in Tuscany. The action of runoff is controlled by the structural features of the ophiolitic rock mass: small gullies tend to form along faults and fractures. Pseudo-badlands are observed only in cases of particularly altered rock (e.g., Monte Menegosa), and are not typical of most ophiolites.

As for ophiolites located at higher elevations (above 1000 m), and especially on the higher ridges of the eastern Ligurian Apennines, relict periglacial landforms can be observed, originated in colder climatic periods (Ribollini and Giraudi 2023). Landforms related to the action of frost and thaw, such as tors, block streams, and block fields are particularly common in these areas, and are especially well preserved where peridotites outcrop (Fig. 4f).

Ophiolites are considered one of the main aquifers in the Northern Apennines (Gargini 2014; Segadelli et al. 2017). Because of the relatively high permeability due to fractures, they act as groundwater reservoirs. Groundwater flow can be further enhanced by local slope conditions, i.e. the presence of DSGSD. The surrounding sedimentary rocks act as aquitards, and permeability threshold are present at the interface between ophiolites and sedimentary rocks (Gargini 2014), giving way to a great abundance of springs.

Ophiolites in Popular Culture

Ophiolites, because of their very distinctive appearance and their prominence in the landscape, had a strong impact on the culture of the people who inhabited the Northern Apennines. To prove this point, three particular aspects have been considered in the following sections: toponymy, to highlight the relationship between place names and the appearance of ophiolites, and legends and religious aspects related to them. Ophiolites with relevant toponyms, or with particular relations with local legends and religion are shown in Fig. 5.

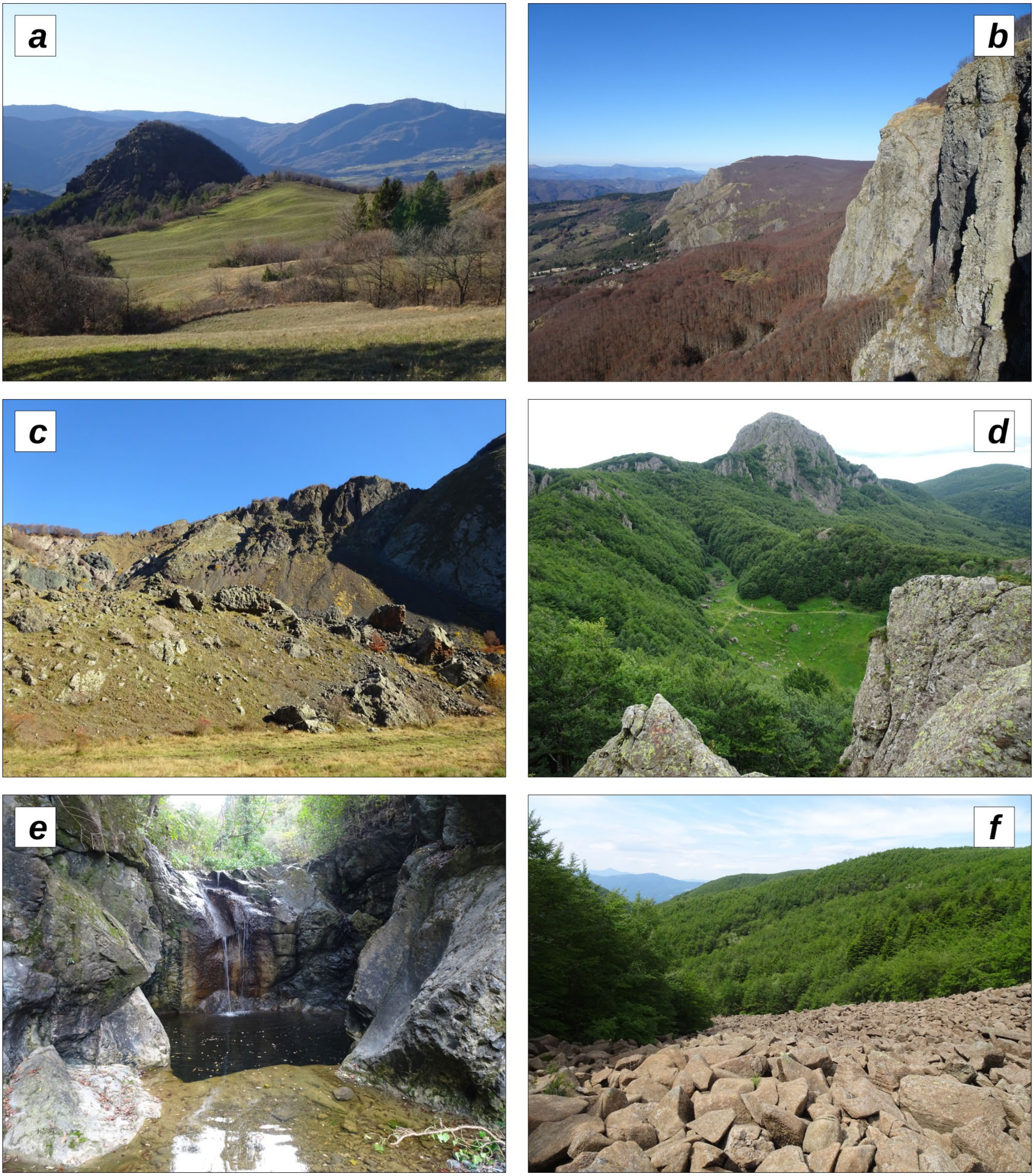

Fig. 4 Geomorphological and landscape features of ophiolites in the Northern Apennines. **a**) Peridotite crag abruptly rising from a gentle rural landscape (Monte il Castello, Coli, Emilia-Romagna); **b**) Vertical basalt cliffs of structural origin (Rocca del Prete, Santo Stefano d'Aveto, Liguria); **c**) Scree slopes (Rocca Marsa, Ferriere, Emilia-Romagna); **d**) A km-long DSGSD trench (la Nave, border between Liguria and Emilia-Romagna); **e**) Fluvial pothole in a gorge carved in gabbros (Fosso di Radicagnoli, Pomarance, Tuscany); **f**) Block stream on the slopes of Monte Nero (Santo Stefano d'Aveto, Liguria)

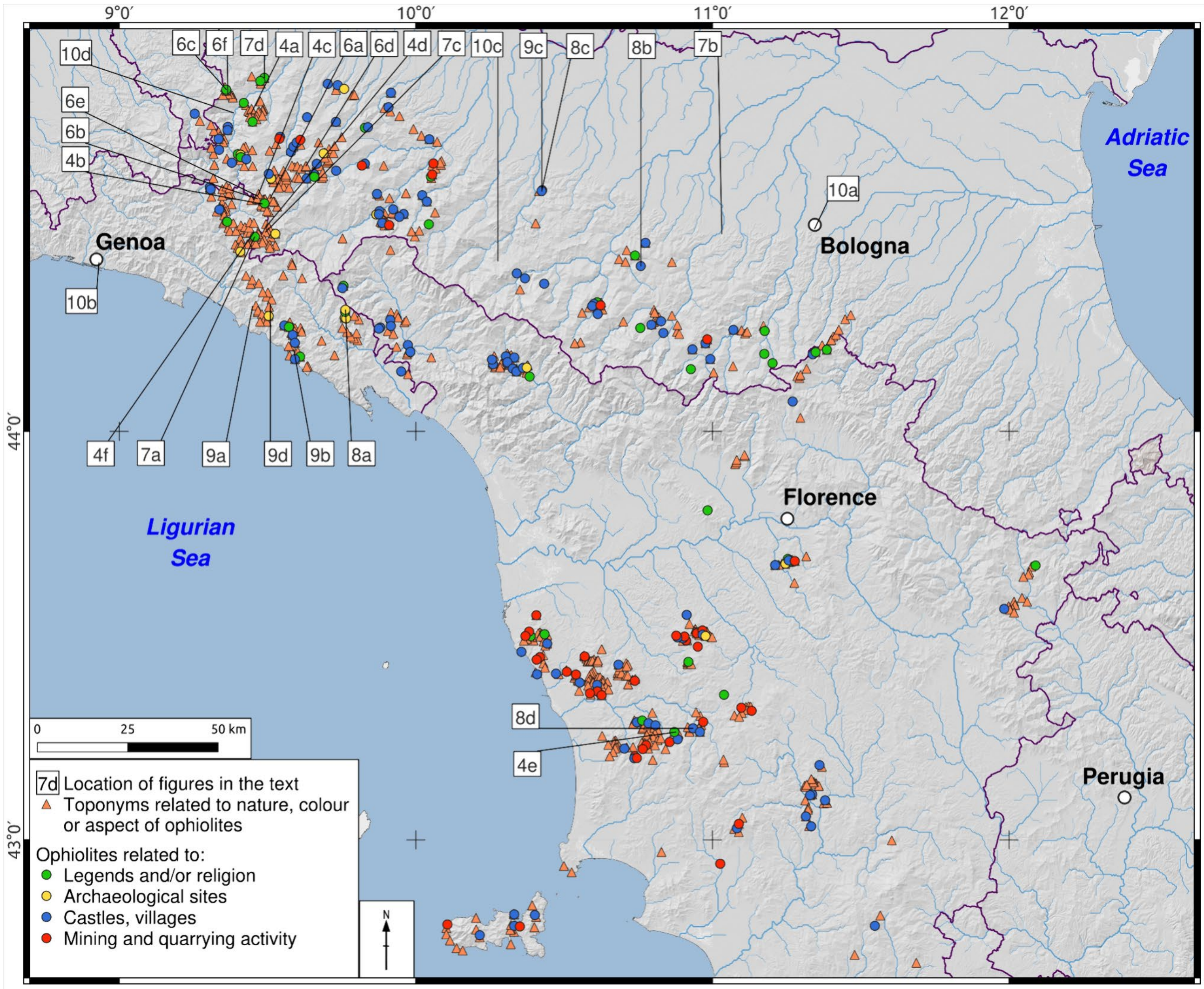

Fig. 5 Position of known examples of ophiolites in the study area with: relevant toponyms, archaeological sites, castles, villages, natural resources, legends and religion. The map also shows the location of the pictures of Figs. 4, 6, 7, 8, 9 and 10

Toponymy

As part of this research, about 850 place names concerning or directly related to ophiolitic outcrops were analysed in order to find any links present between the toponym and the nature or appearance of the ophiolitic outcrop itself (Fig. 6). Toponyms were taken from the regional technical maps of Liguria (scale 1:5000), Emilia-Romagna (scale 1:10,000), Tuscany (scale 1:10,000) and Lombardy (scale 1:10,000). In the following paragraphs, the Italian or Italian dialect toponyms will be written in *italics*, while the english translation will be put between quotation marks.

Many toponyms of ophiolitic outcrops simply refer to the rocky nature of the locality, which contrasts sharply with the surrounding gentle slopes, often covered by forest or characterised by cultivated fields (Table 1).

Thus we find many occurrences of *Rocca* (= "rock"), *Sasso* (= "boulder") or *Pietra* (= "stone"), with the related diminutives (e.g., *Rocchetta*, = "little rock") or accrescitives (*Roccone* = "big rock"). These three main terms can be used independently (e.g. *la Rocca*, = "the rock"), or as an apposition (e.g. *Rocca Bruna* = "brown rock", *Pietra Perduca* = "Perduca stone") instead of the more generic *Monte* (= "mount"), *Punta* (= "peak") or *Poggio* (= "knoll"), which are also very common.

A very particular term, used between central Liguria and western Emilia often to define ophiolitic mountains, is *groppo*. This term, derived from Germanic, can be roughly translated as "crag" (Ferro 1979; Petracco-Siccardi and Caprini 1981). It can be found as an independent toponym (e.g., *il Groppo* = "the crag") or as an apposition (e.g., *Groppo Rosso* = "red crag").

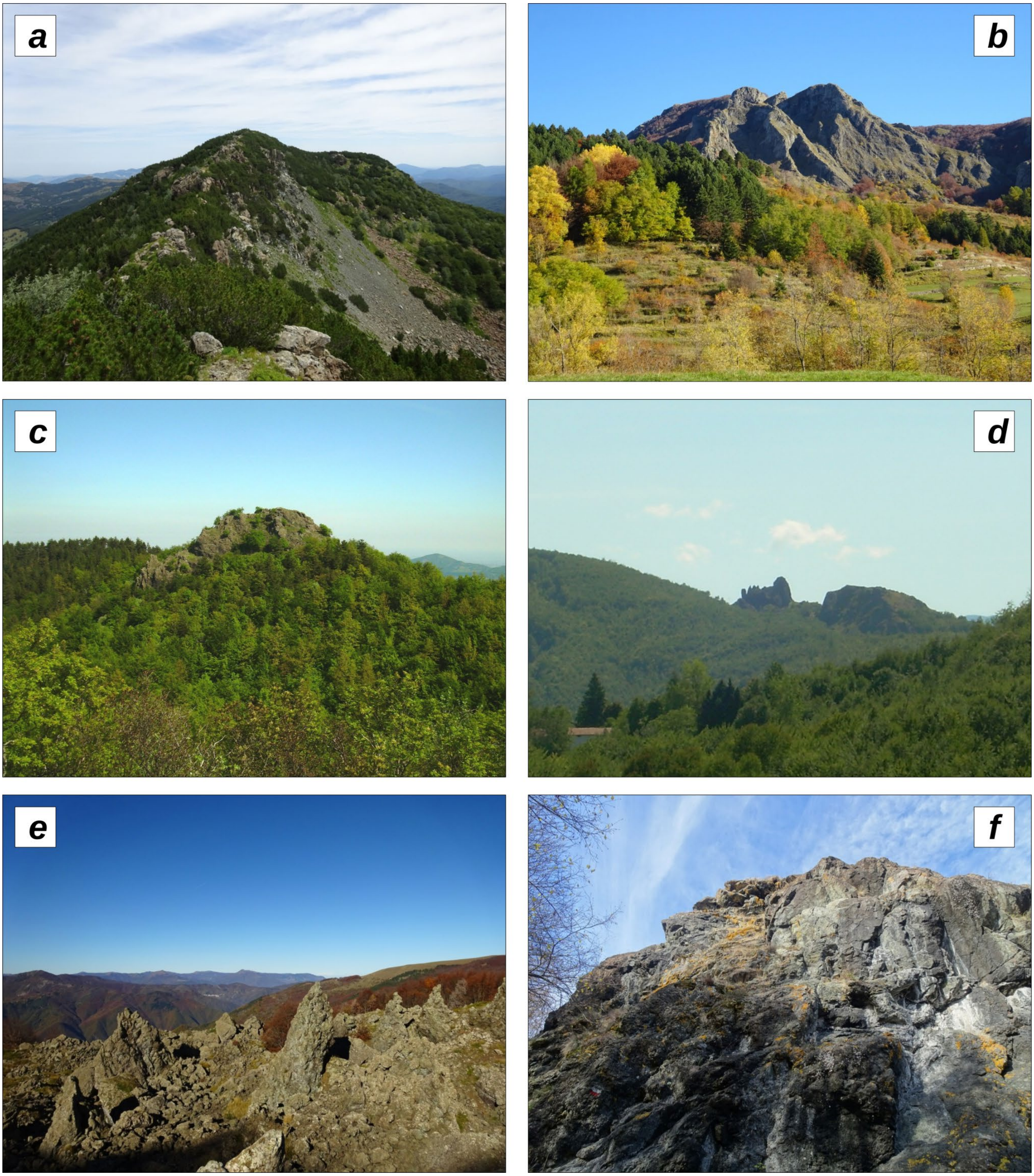

Fig. 6 Ophiolitic outcrops with notable toponyms. **a**) Monte Nero ("Black Mountain"), on the border between Ferriere and Bedonia (Emilia-Romagna); **b**) Groppo Rosso ("Red Crag"), Santo Stefano d'Aveto (Liguria); **c**) Pietra di Corvo ("Crow's Stone"), on the border between Lombardy and Emilia-Romagna; **d**) Roccia Cinque Dita ("Five Fingers Rock"), Farini (Emilia-Romagna); **e**) Valle Tribolata ("Troubled Valley"), Ferriere (Emilia-Romagna); **f**) il Groppo ("the Crag"), Bobbio (Emilia-Romagna)

Table 1 Toponyms influenced by the appearance of the ophiolite outcrop

Toponym	Translation	Occurrences
Rocca *Variants:* Rocchetta, Roccone, Roccia	Rock	69
Pietra	Stone	40
Sasso / Scoglio / Masso	Stone/Boulder	51
Groppo *Variants:* Groppetto, Groppone, Greppo	Crag	46

Table 2 Toponyms influenced by the colour of the ophiolite outcrop

Colours	Examples	Occurrences
Nero (black)	*Monte Nero* (Black Mountain)	29
Corvo, moro, scuro (dark)	*Monte Moro* (Dark Mountain) *Pietra di Corvo* (Crow Stone)	15
Rosso (red)	*Groppo Rosso* (Red Crag) *Monte Rosso* (Red Mountain)	18
Bruno (brown)	*Rocca Bruna* (Brown Rock)	2

In a limited area between southeastern Liguria and northern Tuscany, the term *gruzzo* or *gruzza*, also derived from Germanic and translatable as "crag", is also widespread (Petracco-Siccardi and Caprini 1981). This term occurs in about twenty local toponyms, mostly referring to ophiolitic outcrops (e.g., *Monte Gruzzo*, *la Gruzza di Veppo* etc.).

Numerous place names are influenced by the colour of ophiolitic rocks, which can have different shades (Table 2). Among the colours indicated in place names, the most common is *nero* (= "black")—there are frequent examples of *Monte Nero* (= "Black Mountain") or *Pietra Nera* (= "Black Stone") and the like. In other cases, the blackish or brownish colour of the outcrop is reflected in a generic *scuro* ("dark") or even *moro*, which has about the same meaning. In other cases, the blackish colour is juxtaposed with the colour of the crow, so there are places named *Pietra di Corvo* o *Pietra Corva* (= "Crow's Stone").

In order of occurrence, the second colour mentioned is *rosso* (= "red"), due to the reddish hues that ophiolitic outcrops take on due to the formation of iron oxides—either by surface alteration or by metamorphic processes of oceanic environment. Toponyms such as *Monte Rosso* (= "red mountain") or *Groppo Rosso* (= "red crag") are relatively frequent.

Curiously, there are few toponyms that refer to brown (*bruno* or *marrone* in Italian), which, on closer inspection, is a very common colour in ophiolitic outcrops, especially for weathered peridotites and serpentinites. Moreover, there is no occurrence of "green" in ophiolite toponyms. Even if ophiolites are popularly known as "green stones" (*pietre verdi*), in local toponyms the green colour is mostly associated with forests and meadows, and not to the dark shades of green that are characteristic of ophiolites.

Numerous toponyms are influenced by the morphology of the ophiolite outcrop. Among them, one can name *i Campanili* (= "the Bell Towers"), the *Valle Tribolata* (= "Troubled Valley"), the *Roccia Cinque Dita* (= "Five Fingers Rock"), il *Monte Tre Sorelle* (= "Three Sisters Mountain"), il *Poggio Corno al Bufalo* (= "Buffalo Horn Hill"), and the *Pietra Spaccata* (= "Broken Stone").

In other cases, the name refers to the detrital, unstable appearance of the ophiolitic outcrop, perhaps in the case of rocks that are particularly fractured or affected by gravitational phenomena. In this category fall toponyms such as *Pietra Marcia* (= "rotten stone") or *Rocca Marsa* ("rotten rock"), where the "rottenness" of the rock could be related not only to its detrital aspect, but also to its reddish-brown colour. Other examples may be *Sassaia* or *Pietraia* (= stony ground), but also *Monte Petroso* (= "stony mountain") or *la Ruina* (= "the ruin").

There are frequent occurrences of place names related to the iron aspect of the ophiolites, when not actually to the presence of metal deposits within them (e.g. *Poggio Monteferrato*, *Poggio al Ferro*, which may be translated as variations of "Iron Hill"). Also related to this aspect are another series of place names, often of villages or groups of houses, where there was a mine or furnace for metalworking (e.g. *la Miniera* = "the mine", *la Fornace* = "the Furnace" etc.).

A widespread toponym, especially in central Tuscany, is *Gabbro*, with its many variants (e.g. *Gabbri*, *Gabbra*, *Gabriggioli* etc.). It is a dialect term, derived from the Latin *glabrum*, meaning "bare". It is often assigned to ophiolite reliefs, which have a bare, rocky appearance with little vegetation. The name of the gabbro, i.e. the intrusive magmatic rock, comes precisely from these Tuscan toponyms, even if the toponym *Gabbro* is also indifferently assigned to serpentinitic or basaltic heights.

Toponyms such as "Monte Castellaro," "Monte Castello," and "Poggio Castiglione" are widespread among ophiolites in the Northern Apennines. They derive from the latin *castrum*, which stands for "castle" or "fort". For the most part they refer to the presence of ancient fortified settlements (see Sect. "Defense and Surveillance"), but in some cases they derive from the appearance of the ophiolite outcrop, which reminds of a ruined castle.

Legends and Religion

Over the millennia, curious legends have arisen around many ophiolite outcrops. Most of them are due not only to the raw and sullen appearance of ophiolite, but also to some of its physical properties. Particular fascination comes from the magnetic properties of peridotites and serpentinites, which in folk beliefs have been associated with the magic and the supernatural. These rocks can deflect the needle of the compass and are said to attract lightning (e.g., the Pietra del Fulmine, that is, the Lightning Stone, Val d'Aveto). A very special case is the Pietra Borghese (Liguria; Fig. 7a), in the Ligurian Apennines, which, because of these curious properties, has long been considered a meteorite. Among the local folk, it is still known as "the Meteorite," although this popular belief has long since dissipated.

Because of their properties, ophiolites have also been used as amulets, both for personal use and for magical or religious rites. Among the most important prehistoric findings is the Savignano Venus — a famous archaic female statuette, ascribed to the last Palaeolithic phase (Dixon and Dixon 2011), made of a serpentine rock common in the Modena district — seems to be connected to ancient magical-religious functions (Fig. 7b). In other cases, ophiolitic outcrops were regarded as extinct volcanoes, an aspect that was later taken up in early scientific research in the nineteenth century.

In many cases, legends and folk beliefs are mixed with religious aspects. Often, the sullen appearance of ophiolites has meant that in popular culture they have been linked to the devil or demonic events. An example of this is the Sassi Neri ("black stones") near Bobbio: according to tradition, these ophiolite masses were thrown by the devil in an attempt to stop St. Columbanus, the saint who

Fig. 7 Examples of ophiolites related to legends and religion. **a**) The peridotite tor of the Pietra Borghese (Borzonasca, Liguria) was believed to be a meteorite; **b**) The Savignano Venus, a statuette in serpentinite rock dating from the Paleolithic; **c**) Mt. Penna (border between Liguria and Emilia-Romagna) was considered a sacred mountain by ancient Ligurian tribes; **d**) Pietra Perduca (Travo, Emilia-Romagna) also was a sacred mountain for pagan tribes, before being christianised with the building of a small oratory

evangelised the area in the Middle Ages (Tosi 1978; Boccaccia et al. 2000).

Another similar legend concerns Sasso della Mantesca and Sasso di San Zenobi, located in Firenzuola (Tuscany). Here, too, we have an evangelizer, San Zenobi, who is thwarted by the devil, who proposes an endurance challenge to him: whoever carried a huge boulder the farthest would win the souls of the valley. In the end, St. Zenobi won it, thanks to the strength given to him by the Lord, and carried his rock farther. Instead, the fatigued devil brought his boulder crashing down, shattering it and giving rise to the adjacent Sasso della Mantesca.

Since pre-Roman times, some prominently shaped ophiolite mountains have been considered sacred mountains. One example is Mt. Penna (Fig. 7c), among the most characteristic and recognizable mountains of the Ligurian Apennines. Due to its prominence and regular pyramidal shape, Mt. Penna was considered by ancient Ligurian tribes to be the abode of Penn, the ancient Ligurian god of the mountains.

With the arrival of the Christian religion and the evangelization of these territories, beginning in the early Middle Ages, many of these sacred mountains were evangelised themselves. Religious symbols (altars, crosses etc.) and sometimes chapels, churches or shrines were placed on or near the peaks.

One case that represents this evolution well, complete with accompanying folk legends, is that of Mt. Dragnone (Zignago, Liguria). Mt. Dragnone was a place of worship as early as the Ligurian Apuanians (apparently as early as the fourth century BC); the small church, on the other hand, was built in the Middle Ages, by Benedictine monks fleeing from Luni. According to one legend, the stones for the construction that had been temporarily deposited halfway up the slope miraculously reached the top of the mountain by themselves. The devil, angry that the little church was taking shape, allegedly threw a paw at a rock, where the imprint would still be visible today. This rock, known as Zampa du Diavu (Devil's Paw) is actually a block of jasper with the layers densely folded, appearing to form the imprint of a giant paw. The small church was later rebuilt in 1863, when it took its present form.

Another such example is represented by the Pietra Perduca (Travo, Emilia Romagna), which is a crag made by serpentinitic breccias (Fig. 7d). The Pietra Perduca has been frequented since the Neolithic, probably for pagan rites related to Penn. In the 10th Century, with the christianisation of the area, there was built a small church, which was then modified several times leading to the current St. Anna Oratory. On the top of the crag there are two small tubs carved in the rock. According to beliefs, the water in them never dries up (Panarello 2021).

Strategic Importance of Ophiolites

Ophiolitic outcrops, as also remarked in previous chapters, are often emergent and dominant forms on the landscape, and represent more or less pronounced topographic highs. Due to this nature of theirs, they have been designated since ancient times as strategic points in the territory, first of all for the surveillance and control of the same: that is why lookout points, castles, fortresses are found there. Secondly, these often steep and rocky topographic highs are easy to defend, which is why they have become favourite places for building settlements, villages and towns. This can be deduced from some local placenames (see Sect. "Toponimy"), such as Pietramogolana (from *petrum*), Sassomorello (from *saxum*), Roccaprebalza and Roccamurata (from *rauca*).

The emergence of settlements around ophiolites since ancient times depends not only on their dominance or defensibility. It also depends on the fact that the ophiolite itself has been regarded as a natural resource since prehistoric times. Ophiolites have been exploited since the Paleolithic (Sanmartino 2005; Maggi and Campana 2008)—at first to extract stones for simple manufacts and weapons, then, over the next millennia, for several other purposes, such as to obtain metals (from ore deposits contained in the ophiolites), ornamental or construction stones (Bargossi et al. 2004). Ophiolite crags also constitute important aquifers, so they have been frequented since ancient times due to the high availability of spring waters.

The position of ophiolite outcrops with known relevance to defense and surveillance and natural resources is given in Fig. 5.

Defense and Surveillance

The first settlements of some importance to arise in the Northern Apennine area are the so-called *Castellari*, which developed in the Bronze Age (2000–1150 BC) and Iron Age (1150–180 BC) in the territory populated by the tribes of the ancient Ligurians (Liguria, western Emilia-Romagna and northwestern Tuscany). These settlements, which began as primitive groups of a handful of huts, developed over the centuries, in some cases becoming true small fortified villages. Some of them are also frequented during the period of Roman rule, and in some cases even the early Middle Ages (Bellatalla et al. 1991; Delfino et al. 2008; Delfino and Del Lucchese 2020).

Generally, *Castellari* were built on the top of hills, so that they had surveillance over the surrounding territory and any communication routes (De Pascale et al. 2006) and so that they were easily defensible. In the generally gentle landscape of the Northern Apennines, the optimal conditions for the emergence of *Castellari* occurred at ophiolitic cliffs, which then became a preferred location.

Numerous examples include Monte Pan Perduto (Emilia-Romagna) and Poggio Castiglione (Tuscany). A very special place in this regard is the valley of the Gravegnola Stream, divided between the municipalities of Zignago and Rocchetta di Vara (Liguria). As many as four such pre-Roman settlements have been recognized in this valley: the Monte Castellaro of Zignago (Fig. 8a), the Monte Castellaro of Veppo, the Poggio Castellaro of Vezzola, and the Pianaccia of Vezzola (Ferrando Cabona et al. 1978; Fossati et al. 1982). Each of these four *Castellari* is situated on the top of a hillock of ophiolite nature.

In more recent times, especially from the late Middle Ages onward, there is the emergence of larger and more developed settlements, often dominated by a castle that sits on top of the ophiolite outcrop. Notable examples of medieval towns, often dominated by a castle, include Bardi, Pompeano and Rossena in Emilia-Romagna (Fig. 8b and c), and Pietranera (Liguria). In other cases, the castle stands unrelated to the popular settlement, perhaps with purely military or surveillance functions, e.g., Rocca Sillana (Tuscany; Fig. 8d), Roccalanzona (Emilia-Romagna).

As can be seen, the presence of more or less ancient and more or less fortified settlements—whether *Castellari*, fortresses of Roman or medieval times, towers or actual castles—is also reflected in toponymy (see Sect. "Toponimy").

Fig. 8 Examples of ophiolites used for defence and surveillance. **a)** Remains of a *Castellaro* from the Bronze Age (Mt. Castellaro di Zignago, Liguria), with Mt. Dragnone on the foreground, another ophiolite mountain with a chapel on the summit; **b)** The medieval castle of Pompeano (Emilia-Romagna), built on a serpentinite crag; **c)** The medieval castle of Rossena (Ciano d'Enza, Emilia-Romagna), located on a basaltic outcrop; **d)** The medieval castle of Rocca Sillana (Pomarance, Tuscany), situated on the top of a serpentinite hill

Mines and Quarries

The economic exploitation of the ophiolites goes back to the mid-Palaeolithic, when cherts were used for making weapons and tools and is further developed in the Copper and Iron Ages, with the exploitation of ore deposits related to ophiolites. The most important mineral deposits associated with ophiolites are iron and copper sulphide deposits, which are generally found within basalts and, to a lesser extent, in serpentinites (Zuffardi 1977; Ferrario and Garuti 1980; Moroni et al. 2019 and references therein). Within these ore deposits, small quantities of Au, Ag and U have been found (Garuti and Zaccarini 2005). The presence of iron and copper in fair quantities and easily obtained certainly played a role in the development of some of the earliest pre-Roman settlements (the *Castellari*, see Sect. "Defense and Surveillance").

The major mining poles of this type are found in the Internal Ligurian Units, where ophiolitic outcrops are more continuous and extensive; especially, one can find them in eastern Liguria and central Tuscany. In eastern Liguria, some mines have been exploited since the Copper Age (3600–2000 BC), e.g., the Libiola Mine (Fig. 9a) and the Masso Mine, both of them located in the hinterland of Sestri Levante (Maggi and Pearce 2005). Some examples of prehistoric exploitation of iron-copper mines are present also in Emilia Romagna (Cardarelli et al. 2018). These mines survived with alternating phases of exploitation and abandonment during the period of Roman rule and the Middle Ages. In the nineteenth century the real industrial exploitation of the Fe-Cu deposits began, and the ancient Masso and Libiola mines were transformed into real industrial hubs—between 1878 and 1954, a total 6×10^8 kg of pyrite and 4×10^8 kg of Cu minerals were extracted from Libiola (Galli and Penco

Fig. 9 Mines and quarries in ophiolites. **a**) Mine dumps at Libiola (Sestri Levante, Liguria); **b**) A quarry of ophicalcites of the "Levanto Red Marble" variety (Bonassola, Liguria); **c**) A quarry with pillow basalts exposed on the front (Rossena, Ciano d'Enza, Emilia-Romagna); **d**) The entrance of a tunnel of a Fe-Cu mine on the slopes of Mt. Pu (Casarza Ligure, Liguria)

1996). In Tuscany, the main mine of this type is located in Montecatini Val di Cecina.

In the External Ligurian Units, due to the more fragmentary nature and smaller extent of the ophiolite outcrops, mining activity was less intense, relegated to a few mining poles of local importance. In Roman times iron mines were opened in the upper Nure valley near Ferriere (Emilia-Romagna), where the extraction of ore continued until the First World War. Other important mining poles were located in Rovegno (Liguria), Corchia (Emilia-Romagna) and Poggio Dragone (Emilia-Romagna). Other mining sites were often limited to a few tunnels or even only a few surface assays.

The mineral interest of the Internal Ligurian Units is not limited to ophiolitic outcrops in the strict sense, but also to the overlying cherts (Diaspri di Monte Alpe Formation), which constitutes one of the terms of their sedimentary cover. Within the cherts, there are Manganese oxide mineralizations, which have equally been the subject of intense mining exploitation (Marchesini and Pagano 2001). In eastern Liguria, therefore, there is the coexistence of Fe-Cu mines, mainly in basalts, and Mn mines, carved in cherts. Among the latter, the most important is the Gambatesa Mine (Nè, Liguria), which contained Europe's largest manganese oxide lens, and has now been turned into a mining museum.

Cherts are also of some importance to prehistoric folk, who exploited it to make flint tips. In this regard, a number of chert quarries dating back to the Copper Age have been recognized in the Northern Apennines. The most important of them is the Valle Lagorara Quarry (Maissana, Liguria), which is assumed to have been already in communication with the mining settlements of Masso and Libiola at the time (Campana et al. 1998). Interestingly, in the twentieth century, a small Fe-Cu mine was also opened in Valle Lagorara next to the prehistoric quarry, exploiting a small outcrop of basalts. Another prehistoric quarry of some importance has been recognized at Monte di Lama (Morfasso, Emilia-Romagna).

Ophiolites have been utilized as decorative elements in churches, as well in funerary architecture or on the exteriors of mountain buildings, owing to their chromatic nuances and distinct patterns, exemplified by the red hues of basalts, the green tones of serpentines, and the intricate designs of ophiolitic breccias (Fig. 10). The most famous ophiolitic ornamental stone is perhaps the Levanto Breccia (ophicalcites s.s.), a tectonic breccia composed by more or less hematitised serpentinite clasts (red in colour, with green shades), cemented by a dense network of white calcite veins (Cortesogno et al. 1978). The particular design of the Levanto breccia was particularly appreciated during the nineteenth century. During this period, numerous ophicalcite quarries were opened in eastern Liguria, especially around Levanto (Fig. 9b). The stone material was marketed as "Levanto red marble," and can be found in 19th-century buildings throughout Europe. Other ophiolitic breccias (ophicalcites l.s.) of different nature, and with different colour patterns, were quarried and marketed at around the same time.

Second, ophiolitic rocks have long been used as building stone or to make aggregates. Of the quarries opened for this reason, some basalt quarries that are now inactive are particularly interesting (e.g., Cava Molana, Né, Liguria; Cava di Rossenella, Ciano d'Enza, Emilia-Romagna), on the face of which some of the best exposures of pillows-textured basalts in the entire Northern Apennines can be observed (Brandolini et al. 2007; Piacente et al. 2003).

Protection and Potential for Tourism

The naturalistic importance, in the broadest sense, of these outcrops has led to the establishment of numerous protected areas centred on ophiolitic areas, many of them located in the study area. Eleven parks and nature reserves formed the Coordination of Ophiolitic Protected Areas (Coordinamento Aree Protette Ofiolitiche—C.A.P.O.) in 2001. This coordination includes eight protected areas located in the study area (Fig. 11), joined by three natural parks located in the Alps. The coordination was created with the aim of creating a collegial point of reference on issues related to ophiolitic areas, and developing common projects in the areas of management, research and promotion. Unfortunately, the initiative has not had much follow-up, and the coordination has largely remained only on paper.

To the aforementioned parks and nature reserves one should add the Technological and Archaeological Park of the Colline Metallifere Grossetane (Technological and Archaeological Park of the Colline Metallifere Grossetane), which became part of UNESCO's Global Geopark Network in 2005 under the name Tuscan Mining Geopark. In this geopark, however, the "geological" focus is not on ophiolites (which outcrop here and there in its area) but on mineral deposits, exploited since Etruscan times to extract lead, zinc, silver, copper and iron, and geothermal manifestations, also exploited for electricity production.

Among the geosites which are recognised at the national level by the Superior Institute for Environmental Protection and Research (ISPRA), and included in the Italian National Inventory of Geosites (http://sgi.isprambiente.it/GeositiWeb/default.aspx?ReturnUrl=%2fGeositiWeb%2fricerca_geositi.aspx, *accessed on July 2024*; see Giovagnoli 2023), 33 are directly related to the presence of ophiolites in the study area (Fig. 11). These geosites are of various types: some include a single ophiolite of particular scientific and landscape value, others include entire large-scale ophiolite areas, or are related to particular morphologies developed on ophiolite substrate; finally, some quarries and mines have also been included in the National Inventory.

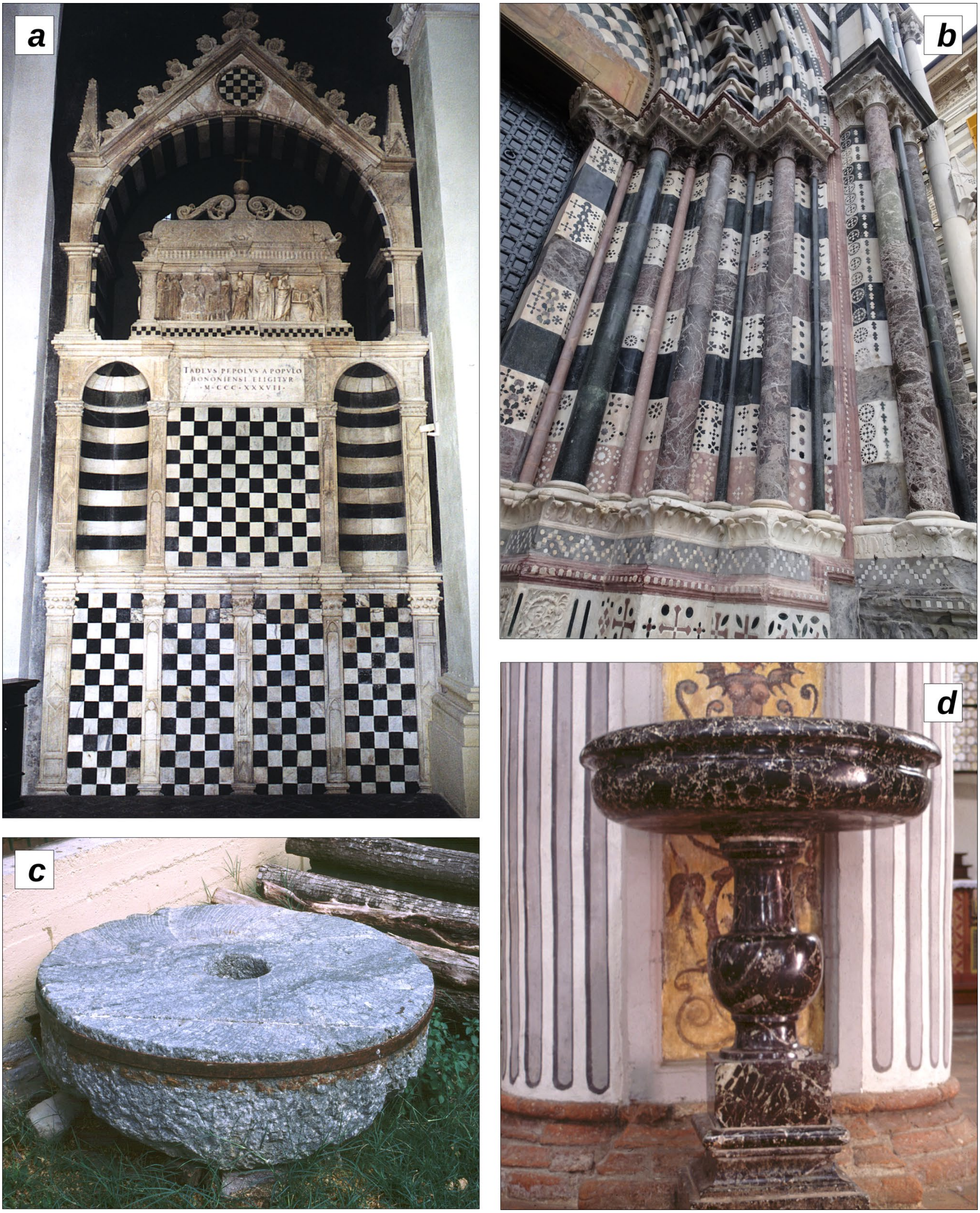

Fig. 10 Use of ophiolites as ornamental and construction stones. **a**) Funerary monument of Taddeo Pepoli, Church of San Domenico (Bologna, Emilia-Romagna); **b**) Columns in ophicalcites ("Levanto Red Marble" and "Polcevera Green Marble") on the face of St. Lawrence Cathedral (Genoa, Liguria); **c**) Millstone for chestnuts in ophiolitic breccia (Ramiseto, Emilia Romagna); **d**) Stoup in ophiolitic breccia at the Abbey of Bobbio (Piacenza, Emilia-Romagna)

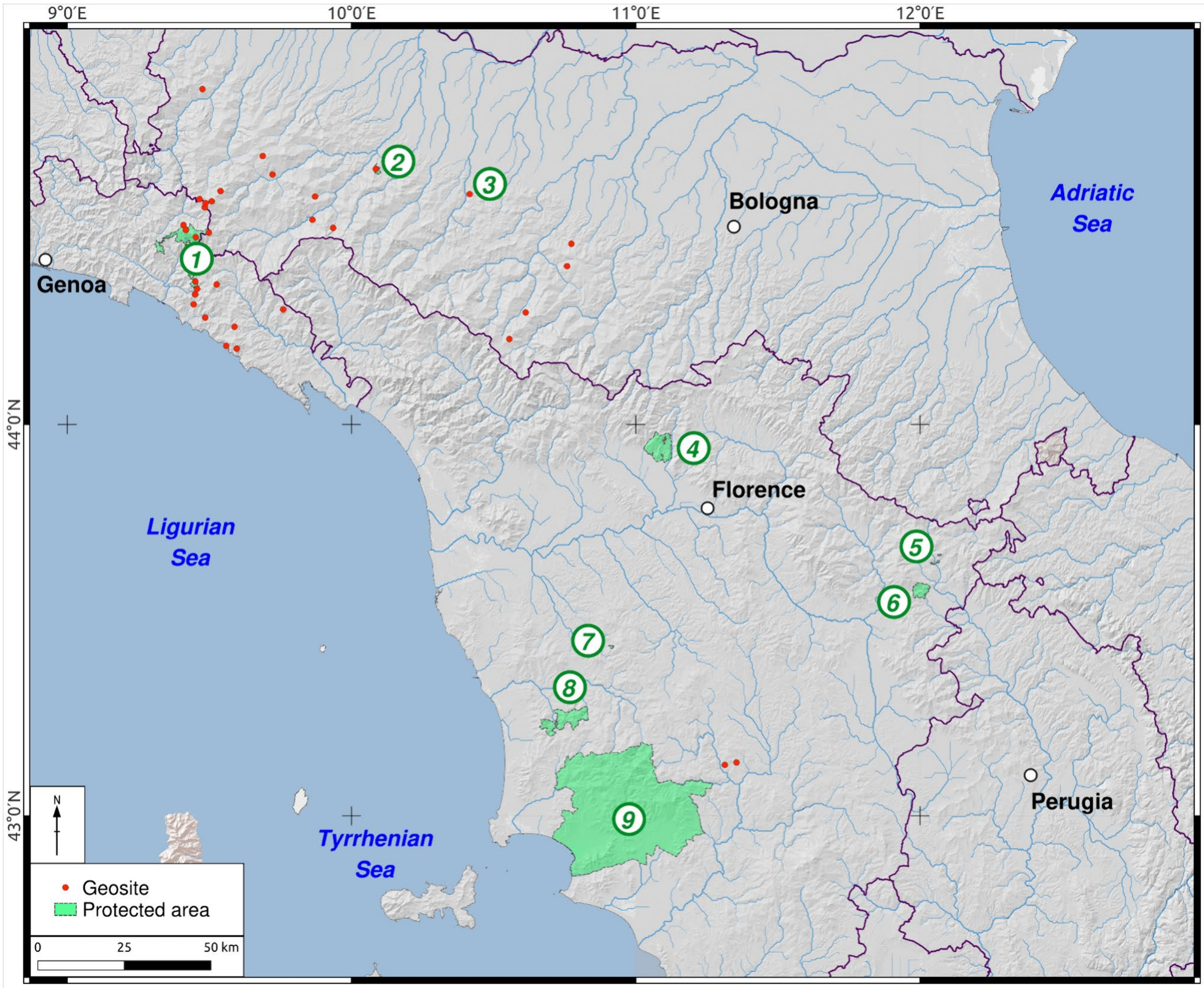

Fig. 11 Geosites and protected areas related to ophiolites in the study area. 1–8 are part of the Coordination of Ophiolitic Protected Areas. 1) Aveto Nature Park; 2) Mt. Prinzera Nature Reserve; 3) Rupe di Campotrera Nature Reserve; 4) Monteferrato Protected Area; 5) Serpentines of Pieve Santo Stefano Protected Area; 6) Monti Rognosi Nature Reserve; 7) Montenero Nature Reserve; 8) Monterufoli-Caselli Nature Reserve; 9) Tuscan Mining Geopark. Other protected areas and geosites not related to ophiolites are not shown in this map

Tourism that develops around the ophiolites of the Northern Apennines can be roughly divided into two categories. The first, much broader category includes all those activities that may be laterally related to the presence of ophiolites, but are ultimately not directly related to the geological aspect: these include cultural tourism in medieval villages and castles, hiking, and climbing. The second, much narrower category includes what can be defined as geotourism in the narrower sense-i.e., tourism devoted to the discovery and appreciation of the geological element and its distinctiveness.

In general, the Northern Apennines can be considered a marginal area (Danzi and Figini 2023; Arata et al. 2023). They are not (and never have been) affected by mass tourism, due to the lack of really famous locations, and the lack of infrastructure that could hold up to mass tourism. Most of the area's tourism is devoted to the discovery of historical and cultural features, such as villages and castles, which, as mentioned in previous sections, are often linked to the presence of ophiolites-or of local products, whether culinary or handicrafts.

Throughout the Northern Apennines, hiking is a popular activity, and one that has been growing during the last decade, thanks to a dense network of marked trails maintained by the Italian Alpine Club and other local associations. Some of the most popular areas for hiking are ophiolitic areas, because of their naturalistic and scenic value. This aspect is particularly developed in the Ligurian Apennines, between eastern Liguria and western Emilia-Romagna, where ophiolitic outcrops are more extensive and characterise the highest and most naturalistically relevant part of the mountain range. Many of the most frequently visited peaks in the Ligurian Apennines (Mount Maggiorasca, Mount Penna in Fig. 7c) are actually ophiolitic. In a mostly gentle and rounded landscape, ophiolite crags represent one of the few places on which outdoor rock climbing and alpinism are possible. Some ophiolite mountains have a local notoriety for hosting *vie ferrate* and climbing routes.

Geotourism in the narrow sense has developed mainly in the protected areas listed above. Outside the protected areas, it struggles to establish itself, except for a few local initiatives. Among the protected areas mentioned above, the best known and most visited are the Aveto Regional Nature Park (Liguria) and the Tuscan Mining Geopark. The geological focus of the Aveto Park is precisely the ophiolites; there are a number of themed trails in the park's territory (Faccini et al. 2012), the most important of which is the "Ophiolite Trail," which allows visitors to visit and learn more about the rocks that are part of the ophiolite sequence. As for the Tuscan Mining Geopark, it has already been mentioned that the geological focus is another; however, there are thematic trails and signage at some of the ophiolitic geosites (Costantini 2015, 2016).

Some of the mines mentioned in this paper have actually been restored and enhanced, turned into mining museums (Garofano and Govoni 2012). Of these, the main ones are located in Liguria: the Gambatesa Mine, in the Aveto Regional Natural Park, and the Masso Mine, located near the well-known coastal tourist centre of Sestri Levante.

Final Remarks

Ophiolitic rock masses are of great scientific importance as they represent fragments of oceanic lithosphere, and are key indicators of plate tectonics. The economic importance of ophiolites has been appreciated since ancient times, both because of the abundance of ore deposits and because of the use of some types of these “green rocks” as natural stone, sometimes of great ornamental value.

Due to complex geodynamic events, ophiolites are distributed within mountain chains of different ages, from the Appalachians to the Ural Mountains and the Himalayas; in Europe, ophiolites can be found in Portugal, Spain, Corsica, France, Eastern Europe, former Yugoslavia, Albania, and Greece. In Italy, ophiolites dotted throughout the central-western Alps, in the Ligurian, Piedmontese and Tuscan-Emilian Apennine ranges to the Tiber valley, southern Tuscany and the Tuscan archipelago.

Outcrops of ophiolitic rock masses represent for all purposes "ecological islands," harboring a wealth of environmental diversity that has been studied for more than fifty years worldwide.

Ophiolitic substrate territories, given their landscape, dimensional and geographical heterogeneity, are characterized by a common and absolutely original naturalness. They offer, among other things, opportunities to study theoretical and applied scientific topics such as the quality and characteristics of circulating and spring waters, geochemical conditioning on vegetation, and identification of plant ecotypes resistant to toxic elements.

They also offer an exceptional field of study for landscape interpretation and methods for the preservation, enhancement and utilization of geodiversity, which is closely tied to biodiversity. The historical, artistic and cultural expressions of human settlements related to ophiolites are also extremely interesting. This research highlighted the close relationship between ophiolites and cultural and landscape aspects, the relationships between the geological nature of the area and geography, both physical and human: toponymy, legends, and religion, are themes intertwined with the history of these particular “green rocks”.

The study also highlighted the strategic importance of ophiolites, both because of the characteristics of the area in terms of defense and surveillance and because of their importance in terms of economic geology.

The results obtained from this research are encouraging, and it is hopeful that the methodology adopted here for the ophiolites of the Northern Apennines will be exported to other similar contexts, both Mediterranean and extracontinental.

In recent times, the landscape of ophiolites has been rightly extolled for its exceptional geological, geomorphological, hydrogeological and pedological interest, thus leading to an exceptional concentration of geosites and often the establishment of geoparks.

With this in mind, we highlight on the one hand the opportunity for the enhancement of these rock masses from a geotouristic and geoexcursionist perspective, and on the other hand the need for appropriate protection and conservation plans. Although endowed with a strong self-preservation capacity, ophiolite outcrops are ecological systems that are considered fragile; therefore, it is necessary to carefully evaluate in terms of costs and benefits the perspectives of spatial planning and management of these areas.

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Declarations

Competing Interest The authors declare no competing interests for this research.

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