# The Geomorphological Landscape of Trás-os-Montes and Alto Douro

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**Abstract**

The main geomorphological features of the eastern part of the Trás-os-Montes and Alto Douro region are presented, namely the Iberian Meseta, the residual ridges, the Serra de Montesinho, the tectonic landforms and the Douro River incision. The Iberian Meseta is represented by extensive plateaus shaped in pre-Mesozoic rocks of the Iberian Massif. Above the Meseta plateaus, Appalachian-type reliefs are built in metamorphic rocks, testifying an older planation surface. Below the plateaus, the incised river network and the canyon-type Douro River Valley in the Portugal–Spain border region reveal a recent Atlantic capture of the northern interior of Iberia. Nonetheless, it is the Vilariça NNE-SSW trending strike-slip fault system that is the main source for the push-up elevations and strike-slip tectonic basins bordered by pop-up type mountains that define the tectonic landscape of the region.

**Keywords**

Tectonics • Fluvial geomorphology • Iberian Meseta • Trás-os-Montes • Douro River

## 11.1 Introduction

Trás-os-Montes and Alto Douro are the historical province of north-east Portugal. The names mean ‘behind the hills’ (Trás-os-Montes) and ‘high Douro’ (Alto Douro), the latter referring to the steep-sided and deep Douro Valley, contrasting with the valley of the same river near the city of Porto. Although no longer a formal province, this territory is still known by that name.

The eastern part of the region belongs to the “plateaus and mountains of northern Portugal” (Pereira et al. 2014, 2015), one of the three units that compose the major morphotectonic unit known as the Iberian Massif. The latter is the largest morphotectonic unit of Iberia and consists of a basement of Proterozoic and Palaeozoic metamorphic and plutonic rocks (dominated by granites), affected by Variscan and Alpine tectonic deformation (Arthaud and Matte 1975; Ribeiro et al. 1990; De Vicente et al. 2011; Pereira et al. 2015).

Pereira et al. (2015) described the most significant geomorphological elements of the Iberian Massif as (Fig. 11.1):

- Large residual landforms, including plateaus and quartzite crests. The general, low-relief, vast planation surface known as the Iberian Meseta is differentially uplifted by tectonics and represented by plateaus at different elevations. Quartzite crests rise around 250–300 m above the extensive plateaus of the Iberian Meseta and are the best morphological expression of an Appalachian-type relief. The crests’ tops represent an older planation surface, probably of early Mesozoic age known as the “Initial Surface” (Martín-Serrano 1988, 2004; Pereira 2010; Pereira et al. 2015).
- Granite landforms, prevailing in northern and central Portugal, typical of temperate climate zones. In north-eastern Portugal, particularly in the Serra de Montesinho, granite landscapes reflect the diversity of mineralogical and geochemical facies, as well as features related to Variscan and Alpine tectonics that have affected extensive granite areas (Pereira 2010; Pereira et al. 2015).
- Tectonic landforms, which formed in relation to the compressive intraplate deformation of Iberia since the Campanian, causing differentiation of several morphotectonic blocks controlled by major faults (Cloetingh et al. 2002; De Vicente et al. 2007, 2011; Pereira et al.

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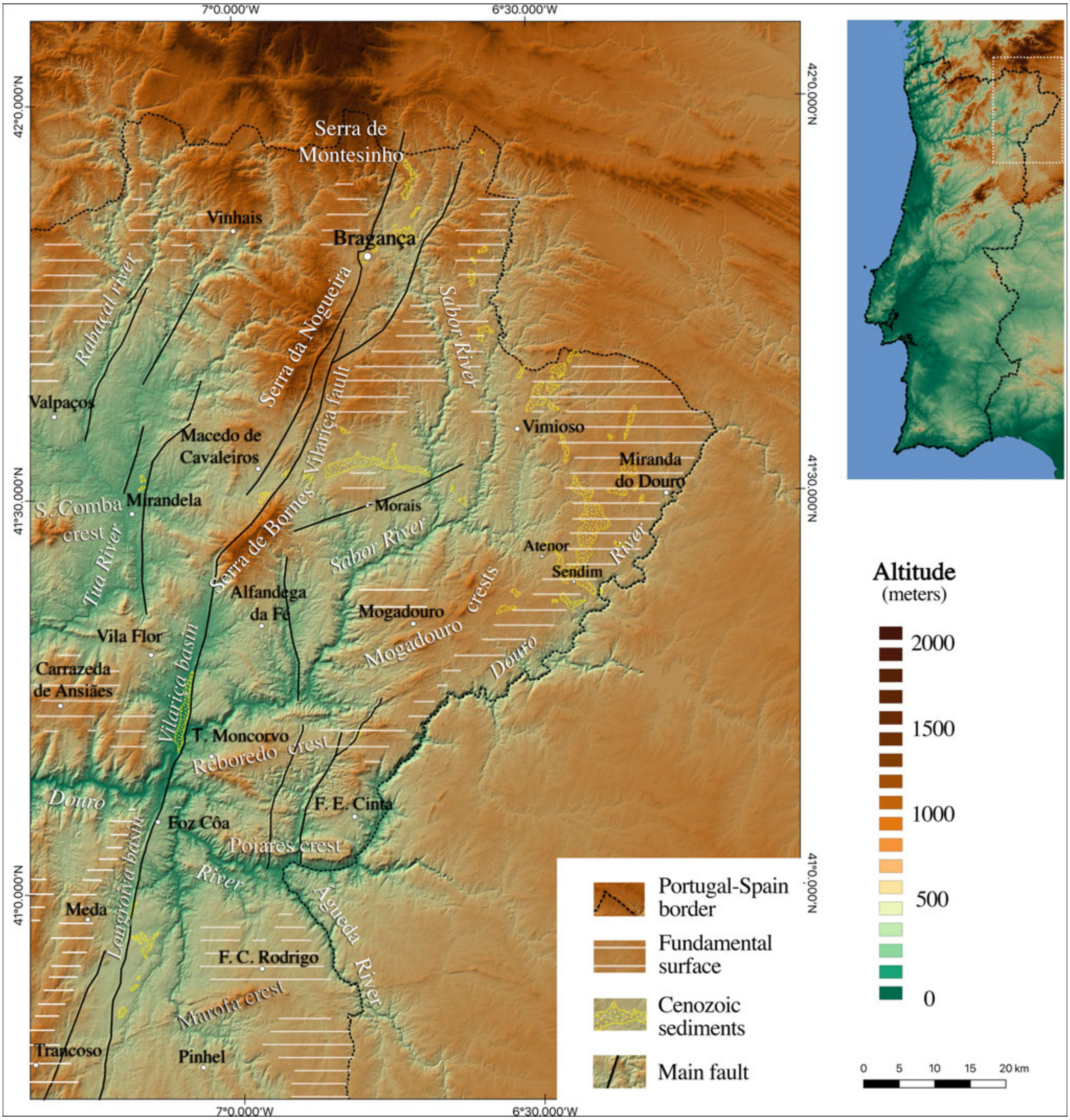


**Fig. 11.1** Main geomorphological features in the eastern part of Trás-os-Montes and Alto Douro

2015). From the late Miocene to the Quaternary, the climax of the tectonic compression was responsible for the origin of major tectonic landforms such as push-up and strike-slip tectonic basins bordered by pop-up type mountains, whilst the Iberian Massif was generally uplifted (De Vicente et al. 2007, 2011; Pereira et al. 2015). The most representative tectonic landforms of the Iberian Massif in Portugal can be seen along the Vilariça fault, a NNE-SSW structure that crosses this region.

- Cenozoic fluvial sediments occur over the Iberian Massif, mainly in small, late Cenozoic tectonic basins and palaeovalleys carved in the Palaeozoic basement. These sediments record tectonic events and characterise several weathering and erosional cycles that are responsible for the multifaceted geomorphology (Cunha 1992; Pereira et al. 2015). In the east Trás-os-Montes and Alto Douro region, these sediments record the geomorphological evolution and environmental conditions of different stages between Paleogene and Gelasian (Pereira 1997, 2004, 2010; Pereira et al. 2000, 2015; Pereira and Azevêdo 1995; Pais et al. 2012).

- Fluvial landforms of the Iberian Massif, induced by the Alpine tectonics, differential resistance of the bedrock, and the late Cenozoic climatic and sea-level evolution. The combination of these factors is particularly clear in the Douro Valley at the Portugal–Spain border, a region with international scientific value recognised in the Spanish and Portuguese geoheritage inventories (Pereira 2010; García-Cortés 2008; Pereira et al. 2015).

In the scope of the Portuguese geoheritage inventory, eleven geosites were considered under the "Iberian Massif Landscape and Fluvial Network in Portugal" framework in the Trás-os-Montes and Alto Douro territory.

## 11.2 The Iberian Meseta

The Iberian Central Range divides the extensive peneplain known as the Iberian Meseta (Ferreira 1978) into the Northern and the Southern Mesetas. The Northern Meseta is best developed on the sediments of the Douro Cenozoic basin in Spain, extending towards the west with some regularity in the Iberian Massif basement until the Vilariça fault. The Northern Meseta surface has, therefore, an extensive presence in Portugal, both in the eastern sector of Trás-os-Montes and to the south of the Douro River (Fig. 11.1). Detailed geomorphological analyses allowed for the recognition of the polygenic nature of the Iberian Meseta and the individualisation of multiple stepped surfaces, in some cases, tectonically displaced (Martín-Serrano 1988; Galve et al. 2020).

Under the general Iberian Meseta concept, the term "Fundamental Surface" (Martín-Serrano 1988) is used to designate the most regular and representative plantation level, which is well preserved around 800 m asl in the Miranda do Douro region in north-east Portugal. Southwards, this surface occurs in the geological allochthonous units known as the Morais Massif (Pereira and Pereira 2020) and it is disrupted by the presence of the quartzite crests of Mogadouro and Reboredo (Torre de Moncorvo) (Fig. 11.1). South of the Douro River, the northern plateau has its larger expression until it reaches the Iberian Central Range.

Cenozoic fluvial sediments related to the polygenic evolution of the Iberian Meseta have ages ranging from the Eocene to the Pliocene, revealing the presence of several tectonic episodes in the regional landscape evolution. In the Miranda Plateau, Mio-Pliocene sediments filled the N-S-oriented Sendim tectonic palaeovalley along 2.5 km. Considering the sedimentary infill of this palaeovalley, the plateau surface is continuous and includes both the erosion surface and the infill surface. An organised river network was recognised joining this and other palaeovalleys located in the south and west (Pereira 1997) (Fig. 11.1).

The "Fundamental Surface" is a key element in the interpretation of the other regional geomorphological units, namely the residual ridges, the tectonic landforms and the present river network incision.

## 11.3 The Residual Ridges

Some of the best examples of quartzite resistant ridges in Portugal are located in the Trás-os-Montes and Alto Douro region. In some places, these ridges define the boundary line between Portugal and Spain. Their tops usually correspond to the "Initial Surface", thought to occur between 900 and 1000 m asl. This surface is easier to interpret where the tops of the prominent quartzite crests stand out from the Meseta "Fundamental Surface".

Although the quartzite ridges normally follow a NW-SE Variscan direction, broad Variscan folds occur in this region (Fig. 11.1), as in the Reboredo hills (Torre de Moncorvo). Further south, the Poiares syncline, located in nearby Freixo de Espada à Cinta (Fig. 11.2), reveals the two flanks of the Armorican Quartzite Formation (Lower Ordovician) over the Cambrian schists and greywackes (Douro Group). The periclinal closure of this fold in the Penedo Durão scarp is an excellent viewpoint over the Douro River canyon in this Portugal–Spain border region. South of the Douro River, the crest of Marofa stands out and establishes a clear contrast with the more regular portion of the Iberian Plateau in Trás-os-Montes and with the canyon of the Águeda River, a tributary of the Douro.

Despite the prevalence of Armorican quartzite crests, there are some exceptions in the region. The NE-SW Mogadouro Hills that stand out from the Meseta "Fundamental Surface" in the Miranda Plateau consists of Upper Ordovician quartzites, located on the peripheries of the Morais Massif (Pereira and Pereira 2020) and further west, Silurian quartzite ridges emerge on the Santa Comba Hill.

## 11.4 The Serra de Montesinho

At 1486 m asl, the Serra de Montesinho is the highest mountain in the region. It is the southernmost segment of the León Mountains, which reach more than 2000 m asl in Spain, a few kilometres to the north (Fig. 11.1) and constitutes the southwest branch of the Cantabrian Range. The uplift of the Cantabrian Mountains is related to the

**Fig. 11.2** Residual quartzite ridge in the south flank of the Poiares syncline, Freixo de Espada à Cinta

subduction of the European plate under the Iberian plate in the Bay of Biscay, with compressive tectonic episodes affecting the Iberian Peninsula since the end of the Cretaceous (Pereira et al. 2015). Recently, it was suggested that the main uplift of the Cantabrian Mountains occurred between ~27 and −2 Ma (Conway-Jones et al. 2019).

A granite batholith crops out in the most elevated part of Serra de Montesinho, extending to the northern mountains (Pereira et al. 2002). However, the presence of a thin cover of Silurian schists reveals the proximity of the intrusive dome (Meireles 2000). Two main planation surfaces are defined, namely a higher level above 1500 m asl (Gamoneda) corresponding to the mountain peaks in the Spanish sector, and a lower level between 1300 and 1400 m asl (Montesinho), which occurs essentially in the Portuguese sector (Pereira 2006).

Granite landforms have almost no expression in the Gamoneda sector, being limited to small boulders, not very rounded, and covering the slopes (Pereira et al. 2005). On the Montesinho surface, by contrast, a typical granite weathering landscape occurs, with frequent tors and pedestal blocks, as well as minor landforms such as weathering pits (gnammas) and pseudobedding that concentrate in the Serra Serrada and Cheira da Noiva sectors (Fig. 11.3). The diversity of minor granite landforms and their unusual concentration in this area led to the selection of the Cheira da Noiva as a representative geosite of minor granite landforms in the Portuguese geoheritage inventory (Pereira et al. 2015; Brilha and Pereira 2020).

## 11.5 Vilariça Fault-Induced Landforms

The Bragança-Vilariça-Manteigas fault, also known as the Vilariça fault, is one of the major NNE-SSW trending strike-slip fault systems that can be recognised in West Iberia (Cabral et al. 2010; Cabral 2012) (Fig. 11.1). It affects the Variscan basement rocks of the Iberian Massif in north-east Portugal, extending for over 220 km from the southern border of the Portuguese Central System in the south to Puebla de Sanabria (Spain), in the north.

This structure has been interpreted as a strike-slip fault generated in the Late Variscan phase of deformation (Cabral 1989). The regional geomorphic expression, the presence of young fault gouges, and the occurrence of faulted Cenozoic sediments preserved in subsided areas along the fault zone indicate that this structure was reactivated during the late Cenozoic due to NNW-SSE to NW-SE compression (Cabral 1989, 1995; Ribeiro et al. 1990), namely since the middle Tortonian (~9.5 Ma) (Cunha et al. 2000). According to De Vicente et al. (2008), it behaved as a transference zone for the stress and deformation between the Cantabrian Mountains and the Iberian Central System since the Pyrenean Orogeny, in the Eocene (Cabral 2012; Cabral et al. 2010).

The Vilariça fault displaces the Variscan basement rocks with a maximum left-lateral offset of 9 km in the Vilariça segment, 1 km being attributed to the late Pliocene to Quaternary movement of the fault (Cabral 1989, 1995). There is evidence of a predominant left-lateral strike-slip

**Fig. 11.3** Examples of minor granite landforms in the Serra de Montesinho: blocks with gnammas (**a**) and pseudobedding (**b**) nearby the Serra Serrada dam; pedestal blocks with gnammas, gutters (**c**) and pseudobedding (**d**) in the Cheira da Noiva sector

component during Plio-Quaternary time in the form of fault outcrop kinematic indicators, the presence of basins along the fault zone that may be interpreted as strike-slip tectonic basins, and compressive structures that may be interpreted as push-ups developed on restraining bends (Cabral 1989, 1995, 2012; Cabral et al. 2010). Further evidence that points towards this interpretation includes offset of river terraces, left-lateral stream deflections, beheaded streams, aligned saddle-like depressions, triangular facets and linear valleys (Cabral 1989, 1995; Rockwell et al. 2009).

Palaeoseismic studies on the Vilariça fault (Rockwell et al. 2009) identified two or probably three $M > 7$ earthquakes during the last 14.5 ka and estimated a slip rate of 0.3–0.5 mm/year and 2–3 m of displacement per event. The slip rate is consistent with the estimation of 0.2–0.5 mm/year in the last $\sim$2 Ma based on the geomorphological displacement and the stratigraphic references (Cabral 1989, 1995, 2012; Cabral et al. 2010; Perea et al. 2010).

The small Bragança, Vilariça, and Longroiva Cenozoic basins are associated with the Vilariça left-lateral strike-slip fault and related to transpressional tectonic regimes (De Vicente et al. 2011; Pais et al. 2012). To the west, the borders of the larger Mirandela basin are imprecise (Fig. 11.1), though a wider interpretation suggests a tectonic basin developed between the referred main faults. According to Pais et al. (2012), all these small basins could be seen as tectonically preserved outcrops in the vicinity of transtensional/transpressional faults that crosscut the large domain of the Douro Cenozoic basin.

The Vilariça basin is the largest of the strike-slip basins, 20 km long and 3 km wide. The depression closes in the north against the Bornes push-up. In the south, the Vilariça fault controls the Douro River path generating the Vale Meão incised meander (Fig. 11.4). The basin's flat bottom is tilted eastwards to the Vilariça scarp, which imposes a difference of 300–400 m relative to the Iberian Meseta surface (Pereira and Azevêdo 1995) (Fig. 11.5).

The Serra de Bornes is the clearest compressive structure interpreted as a push-up developed on the restraining bends of the Vilariça fault (Cabral 1989, 1995, 2012) (Figs. 11.1 and 11.6). It has maximum altitude of 1200 m and an asymmetric shape caused by the fault scarp on the western border (Cabral 1985; Pereira 1997; Pereira et al. 2000). The Serra da Nogueira, with a similar NNE-SSW disposition (Fig. 11.1), though located on the western margin of the Vilariça fault, is also interpreted as a compressive structure. It reaches 1320 m asl and also presents an asymmetric profile, limited by the Vilariça fault scarp in the east and by a smooth surface slightly incised by rivers in the west.

The Vilariça strike-slip basin is one of the geosites of the "Iberian Massif Landscape and Fluvial Network in Portugal" framework, in the context of the Portuguese inventory of the geological heritage (Pereira et al. 2015). It is the best example of a strike-slip basin including sediments, a clear scarp fault and the tectonic control of the drainage system in Portugal.

The Longroiva strike-slip basin, located south of the Douro River, is also induced by the Vilariça fault. Despite

**Fig. 11.4** Panoramic view of the Vilariça basin to the south, where the Vilariça fault controls the Douro River course


**Fig. 11.5** Vilariça fault scarp limiting the Vilariça basin to the east and imposing a difference of 300–400 m between the flat valley and the Iberian Meseta surface

**Fig. 11.6** Bornes Mountain, a push-up relief developed on the restraining bends of the Vilariça fault

being smaller, 6 km long and 600 m wide, the NNE-SSW basin has similarities with the Vilariça basin regarding landforms and deposits. It is bounded by steep granite slopes in the east and by a shale slope that expresses the western part of the Meseta surface in the west (Ferreira 1978). A clear NW-SE fault scarp also limits the Longroiva basin to the south (Cunha and Pereira 2000).

These small basins preserve Cenozoic sediments, mostly accumulated in response to tectonic movements that occurred between the Tortonian and the Gelasian. Older sediments, probably of Paleogene age, are referred to in the Vilariça and Longroiva basins by the designation of Vilariça Formation (Cunha and Pereira 2000; Pereira and Azevêdo 1995; Pais et al. 2012). It is assumed that the Vilariça Formation reflects the inefficient drainage towards the large Douro Cenozoic Basin in Spain. These alluvial mantles were supplied by a granite source and developed on low-gradient surfaces, whose exhumation is represented by the Iberian Meseta surface (Ferreira 1978; Cunha and Pereira 2000; Pais et al. 2012). In the Vilariça and Longroiva basins, this unit can display pronounced tectonic tilting, and in the basin borders, there is an over-thrust of the Variscan bedrock through faults with both reverse and horizontal components (Cunha and Pereira 2000) (Fig. 11.7). These characteristics are compatible with very intense regional Tortonian compression (Betic episode) and are responsible for the conservation of the Vilariça Formation in the depressions (Pereira 1997; Cunha and Pereira 2000; Pais et al. 2012).

## 11.6 The Douro Valley

The natural and cultural heritage on the Douro Valley is remarkable and has already deserved attention and international recognition. The World Heritage sites of the Cultural Landscape of Alto Douro Wine Region, related to the Port wine vineyards and the Palaeolithic rock art of Côa Valley Archaeological Park, near Vila Nova de Foz Côa, are the best examples of that recognition (Pereira 2004).

Specific characteristics of the Douro River in the Portuguese territory and geology of its valley were decisive for the social and cultural evolution of local populations. In general, these singularities are due to deep fluvial incision into the hills and plateaus and are the reason for the sequence of dams in the valley and for distinctive historical floods.

In the Portugal–Spain border region, steep cliffs, locally named "Arribas do Douro", are the major fluvial landscape features (Fig. 11.8). This canyon-type valley is about 600 m deep and is carved mostly in granite into the well-preserved surface of the Northern Iberian Meseta (Antón et al. 2012). The canyon sidewalls host diverse flora and fauna habitats that justified the designation of the area as a Natural Park in 1998 (Alves et al. 2004; Pereira 2004).

This section of the Douro River, with a steep longitudinal profile and numerous rapids and waterfalls, currently not visible due to the dams, establishes the link between an older Atlantic Douro and a previous endorheic basin, the Douro

**Fig. 11.7** Outcrop at the southern limit of the Longroiva basin documents the reverse movement of the Vilariça fault, with the Variscan bedrock (Cambrian) over the Vilariça Formation (Paleogene)

Cenozoic Basin, located in the east (Galve et al. 2020). The transition from the former internal drainage (endorheic stage) to Atlantic Douro drainage (exorheic stage) is best explained by a combination of two drivers: i. increasing intraplate compression, that progressively tilted the Douro Cenozoic Basin towards the west and ii. a major climate change by ~3.7 Ma (transition to a wetter climate stage), from the generally dry and hot climate during the Miocene and Zanclean to the humid and hot climate of the late Zanclean to Piacenzian. A latest stage (last ~2 Ma), marked by enhanced fluvial incision, is related to continuous regional low crustal uplift, cooler climatic minima and associated lowering of sea level (Cunha et al. 2019).

In the intermediate sector of the Alto Douro, Cambrian schists and greywackes induced a slightly wider valley, but still with steep slopes. Here, the fluvial network promoted extensive erosion of the Meseta surface, which only remains preserved in small areas. Occasionally, the Douro River carves down to granite bedrock, resulting in small sections of canyon-type valley and waterfalls at the granite-schist contacts.

The Alto Douro landscape, involving the Douro Valley and its tributaries, is characterised by terraces, built row upon row with retaining walls—the so-called socalcos. In this cultural landscape developed by the local population over decades of hard work, vineyards prevail next to olive and almond groves (Fig. 11.9). The steep valley, the tough schist and the scarcity of water do not appear to be obstacles in the creation of such a cultural landscape (Andresen et al. 2004; Pereira 2004).

**Fig. 11.8** Douro River canyon in São João das Arribas, Miranda do Douro

**Fig. 11.9** Vineyards of the Cultural Landscape of Alto Douro Wine Region, a World Heritage site

## 11.7 Conclusions

The landforms that make up the north-east region of mainland Portugal cannot be grouped into a single landscape model. In fact, at least two distinct types of geomorphic landscape are represented. In the easternmost sector, the contrast of three different types of landforms is evident: the continuous surface of the Iberian Meseta, the residual ridges and the incised valleys. After a long period of continuous and slow uplift that allowed the preservation of the Meseta and the residual crests, the Douro River canyon was quickly cut during the Quaternary in a process that connected the Atlantic drainage and the inner sector of the Iberian Peninsula.

Towards the west, the relief becomes more complex, with the Meseta surface losing regularity and dome blocks reaching around 1000 m asl near the Vilariça fault. Along the fault, the tectonic origin of landforms is clear, shown by the push-up reliefs and small depressions limited by steep scarps and filled by Cenozoic sediments.

Several of the mentioned landforms have high scientific value and were selected as part of the inventory of the Portuguese geological heritage, especially the ones related to the Vilariça fault and the Douro River canyon (Pereira et al. 2015). Some landforms also show remarkable educational and aesthetic values, important for human well-being and for the development of tourism activities based on the unique natural characteristics of the region.

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