serra d'arga

GEOLOGY

FROM THE SERRA D'ARGA
TO THE FOZ DO ÂNCORA

PRODUCED BY

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452581/19

ISBN
978-989-54359-4-4

January 2019

Introduction

The Site of Community Importance 'Serra de Arga' (SCI PTCON0039), classified in accordance with the Decision of the Commission of 7 December 2004, with a total area of 4,493 hectares, is a special conservation area that includes the municipalities of Caminha, Viana do Castelo and Ponte de Lima.

This small brochure is part of a set of materials promoting this region's heritage. The aim is to highlight some of the region's natural and cultural assets while raising awareness about the importance of preserving them.

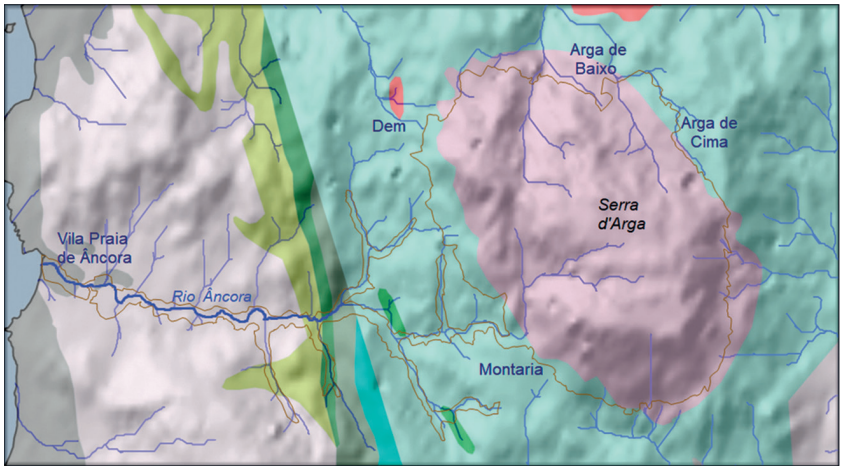
The Serra d'Arga is a prominent granite massif characteristic of the landscape and environment of the north-west of mainland Portugal. The area is of great significance for understanding the geology of the Alto Minho region, and contains innumerable geological curiosities.

The granite of the Serra d'Arga is the result of a magma intrusion that occurred over 300 million years ago, causing high-grade metamorphism in the surrounding rocks. Granite settlement also led (with hydrothermal fluids) to the concentration of ore deposits with economic interest (minerals).

In fact, around the edge of the granite massif of the Serra d'Arga, in the schists and mica schists, there are numerous locations where mining used to take place.

In addition to the Serra d'Arga granite, there are also other former rocky substrates containing metasediments — mainly schists from the Silurian period that completely cover the granite batholith.

Along the River Âncora, from the foothills of the Serra d'Arga to the river mouth, the Silurian metasediments are subjected to a wide variety of different lithologies (rocky substrates and recent deposits): Siluruan black schists, Ordovician slaty schists, Ordovician metaconglomerates, Cambrian banded phyllites, granite from Vila Praia de Âncora (two-mica syntectonic granites) and river and beach deposits.



GEOLOGY

Recent sediments

River and beach deposits - former quaternary and recent Pliocene period

Eruptive rocks

Pegmatite and aplite-pegmatite veins and masses

Two-mica tarditectonic granites

Two-mica non-tectonic granites

Limits of the area studied

Metasedimentary rocks

Metasediments, mainly Silurian schists

Silurian ampelite schists

Variety of metasediments from the upper Ordovician period

Slaty, carbonous and clay schist from the Middle Ordovician period

Pelitic schist metaconglomerates

Phyllites banded with siltstone beds, from the Cambrian period

Scale

0m 2000m 4000m

Simplified geological map of the region

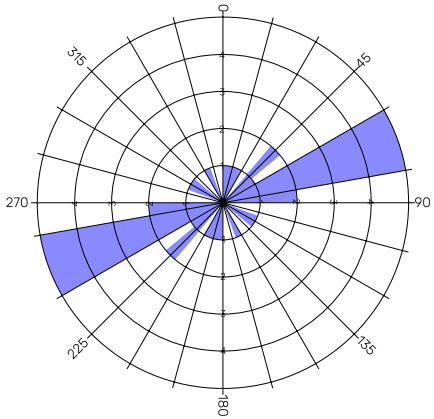
Mining in the Serra d'Arga area dates all the way back to the dawn of human civilization, the Palaeolithic era, and is a fundamental element in the region's heritage. Since then there have been numerous different periods of mining in which minerals such as tin, wolfram, gold, silver, niobium, tantalum, zinc and lithium were extracted.

Geomorphology, resulting from the interaction between rocky substrates and environmental geodynamic agents, has also been significant here. The relief of the Serra d'Arga is unusual in coastal regions, with its granite massif rising to a height of more than 800 metres due to its greater resistance to erosion in comparison with the majority of the adjacent schist formations.

On several slopes in the Serra d'Arga there are views of the beautiful landscape that are also of geomorphological interest, revealing peculiarities of the relief relating to the alternation between rocky substrates.

An aspect that is common to all rocky formations in the region is the presence of simple fractures (joints) and other tectonic structures such as faults and veins. This rock 'cutout' shows that the region suffered intense crustal stress in the past. On the other hand, it has great geomorphological influence, as it promotes the development of erosive areas, for example some watercourses in fault zones.

In terms of outcrops, you can see that the network of fractures (and other structures) exhibit regular orientation patterns, even though the main family (or trend) is shown in a north-east-south-west and ENE-WSW direction, which can be seen in the diagram below.



Rose diagram representing the main orientations of the tectonic structures (joints, faults and veins) seen in the Serra d'Arga.

There are geologically recent decompression fractures on the ridges, which are 'cut' by the same tectonic structures. This fact suggests that they come from a later date and are the result of Alpine orogeny, which is evidenced by faults and joints in the north of Portugal in a north-east-south-west direction.

Deep fractured granite also leads to the development of a wide range of morphologies, including tors, blockfields, pseudo-stratification and disjunctions.

In all rocky substrates, the presence of fractures allows for the circulation and storage of groundwater, providing villages with important water resources that are exploited in the form of mines, wells and natural springs.

The water mines, enabling water to be drained to the places where it is to be used (houses, public fountains and agricultural plots), indicate the ancestral know-how of the local population.

In hydrographic terms, it should be noted that the Serra d'Arga is the source of two major watercourses in the Alto Minho region, the Ribeiro de São João Stream (a tributary of the River Coura) and the River Âncora. The groundwater masses developed as a result of the intense fracturing of the rocks play an important role in keeping them flowing.

A densely fractured schist outcrop

Densely fractured schist outcrop, with quartz veins

Fracture systems in outcrops, often called mesoscopic fractures (Barker, 2001), are a significant feature in the Serra d'Arga. With the exception of the stratification fractures, the mesoscopic ones found in schists are the result of plastic deformation of the Earth's crust.

Most of these fractures are joints but there are also some faults, as well as a complex network of quartz veins. Whilst the quartz veins, consistent with the stratification, are the result of metamorphic fluids (metamorphic exudation), the others are formed by the solidification of hydrothermal fluids.

In rocky massifs, fractures and phylonian bodies facilitate the circulation and storage of groundwater, resulting in fissure aquifers that constitute the region's natural resources.

Fault mirror with landslip streaks

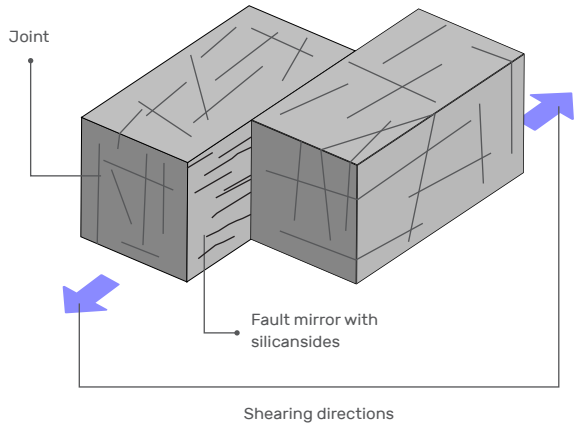
The geological faults in this area, some of which are very large and visually very impressive, are of interest both to scientists and tourists. The biggest can be found on the south side of the Serra d'Arga, between Montaria and Santa Justa.

The prominence of some of these structures is due to the occurrence of large fault mirrors (exposed fracture planes, several metres long), giving the false impression that they are the result of direct human intervention.

In many of these fault mirrors there are well-preserved signs of fracture block movement in the form of silicansides. Some of these streaks have vitreous quartz lenticules, resulting from intergranular thermal stress, and are known as pseudo-tachylites.

The majority of fault mirrors found in the region have horizontal landslip streaks, indicating horizontal movements between fracture blocks. This suggests that they are schist faults, revealing regional 'schist corridors', probably resulting from Alpine deformation of the Earth's crust.

Close-up view of a geological fault - fault mirror



Schematic picture of the formation of fault mirrors

Folds in schist and other metasediments

The folds in the Serra d'Arga correspond to tectonic manifestations that occur in metasedimentary lithologies (e.g. shale, mica schist, quartzite and quartz-phyllites) when they come into contact with the large granite massifs.

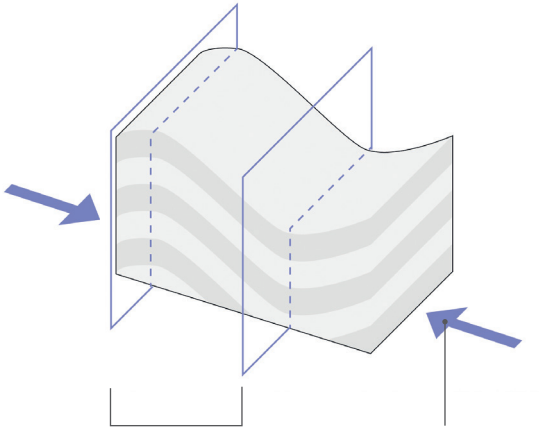
These structures, with orientations perpendicular to their axes, are evidence of crustal tectonic stress that occurred over 300 million years ago, at a time when these rocks were not yet fully consolidated through diagenesis.

The most prominent folds in the region are found in schists and mica schists, but also in quartzites and quartz-phyllites. These structures and their respective lithologies can be found all around the edge of the granite massif of the Serra d'Arga.

Folds in schist

Folds in quartz-phyllite (above)

Diagram showing fold components and formation (right)



Simple fracture in granite - joints

Simple fractures (joints)

Simple planar fractures, occurring in granites, schists and quartz, are one of the most common geological features of the Serra d'Arga. In geology these fractures are often referred to as joints, which are distinguished from geological faults by the absence of displacement between rocks.

Due to their nature and origin they are widespread in the region, and particularly common in road embankments, slopes and valley floors.

Normally these fractures are the result of tectonic stresses of the Earth's crust (compression and traction) exerted on hard rocks. In granite areas, some joints come from mechanical anistrophies caused when magma cools.

The proliferation of several fracture systems influences the region's geomorphology and environment, to the extent that it causes meteorisation and disintegration of the rocky substrate, soil development, root expansion and the development of groundwater reserves.

Quartz microdiorite outcrops

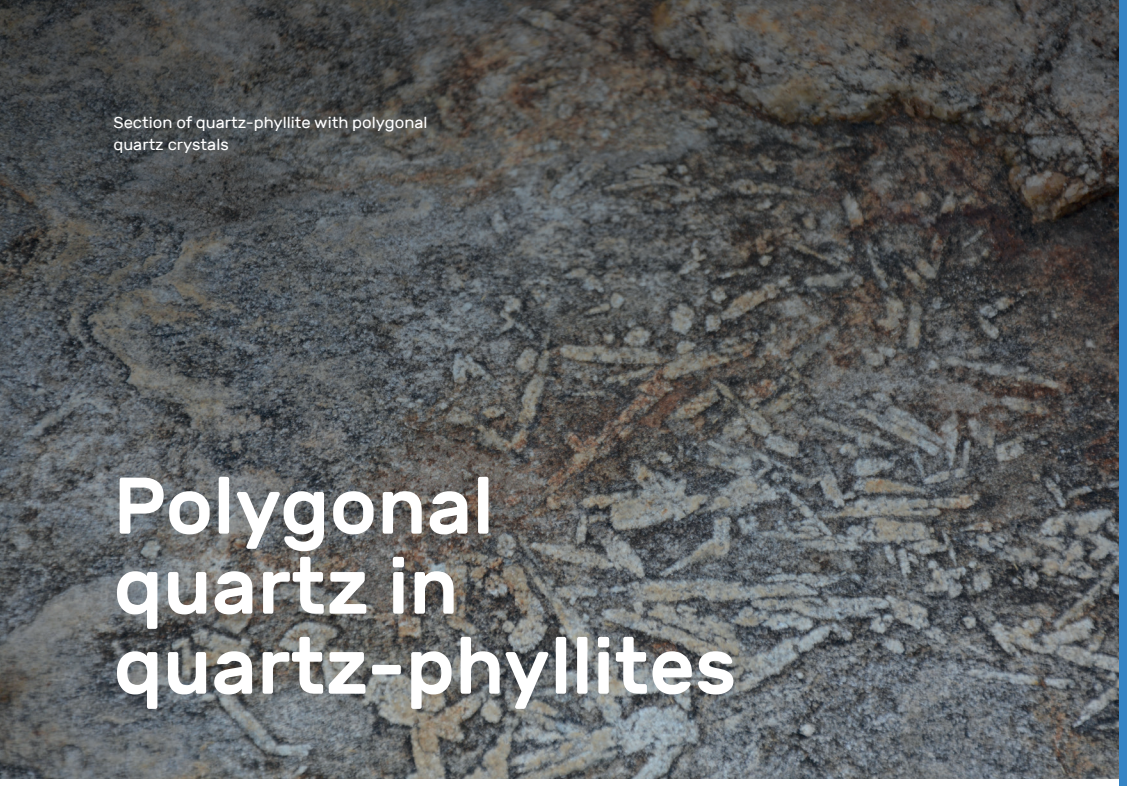
Microdiorite is an igneous rock with a moderately coarse texture comprising minerals very similar to diorites, although it is richer in quartz. In the areas where it is found, it shows irregular distribution patterns because it seems to intercalate with the granite of the Serra d'Arga. However, when observed from above, it shows a general distribution with phylonian contours, as it is totally surrounded by this granite. It is found only on ridges and hilltops to the east of the village of Trás-Âncora (Montaria).

According to Allaby (2008), diorite rocks normally have a quartz content of just over 10 percent. But in fact, given their whitish hue, it is probable that their quartz content is significantly higher. They are also likely to contain significant amounts of other whitish minerals such as pyroxene and chlorite.

These rock formations are the result of the late rise of magma through geological faults or other tectonic discontinuities in the Earth's crust.

An unusual aspect related to some outcrops of quartzodiorite involves pseudo-stratification, which also occurs in granite and is derived from the conjugation of mechanical anisotropies (natural cleavage) with litostatic decompression. This decompression is derived from rocky material and surface soil due to erosion.

Quartziferous microdiorite rocks



Section of quartz-phyllite with polygonal quartz crystals

Polygonal quartz in quartz-phyllites

The occurrence of polygonal quartz on rocks is a metamorphic phenomenon that occurs in the region in the form of quartz-phyllites. These types of rocks are sometimes similar to grey schists, although they have the typical hardness of quartz formations. They are actually quartz sandstones produced by higher-grade metamorphism, which is why they are called quartz-phyllites. They are distinguished from common quartzites due to their banded appearance (metamorphic foliation) with alternating dark and light grey levels.

In this specific case, metamorphic banding is frequently interrupted by polygonal quartz crystals resulting from the solidification of hydrothermal fluids caused by metamorphic exudation (or metamorphic perspiration).

There are also many signs of deformation of the Earth's crust here in the form of small folds, fractures and quartz veins.

Quartz-phyllites can be seen in the region along a narrow metasedimentary belt to the north of the village of Cerquido, between the granite of the Serra d'Arga and the Silurian schist formations.

Dune formations

Dunes develop along coastal strips of land of various dimensions. They occur in virtually all climates and are formed through a combination of different natural processes, with wind an essential factor in the processes of erosion and deposition.

Beach dunes normally have convex and vegetated ridges, forming strands parallel to the coastline (Hesp, 2002) and dynamic systems very susceptible to environmental and climatic changes.

Dune formations occur near the outfall of the River Âncora in a strip about 1,500 metres long, covering an area of about half a square kilometre.

Adjacent to the dune formations there are other sediments from current or relatively recent periods (quaternary), as is the case of river and estuary deposits.

Dune formations beside the outfall of the River Âncora

Granite basins

These are circular or oval cavities, often found in granite massifs in the north and centre of Portugal, that are often formed as a result of chemical weathering, induced by water, in minerals such as feldspars, biotite and plagioclase. These minerals cause different levels of erosion in their more concentrated forms in sections of granite due to constant contact with water (temporary retentions). This process may also be due to the presence of cracks in the granite and acidification of water caused by bacteria.

These cavities are a geomorphological phenomenon that occurs in almost all the areas of granite in the region.

They are particularly common at the top of the Serra d'Arga but can also be seen on hillsides and valley floors.

Granite basin with a pronounced cavity

Connecting granite basins

Watercourse running through
a geological fault zone

Watercourse running through a possible fault zone

Many primary and secondary watercourses in the Serra d'Arga and surrounding areas are signs of preference erosion (linear) that normally occurs in large linear tectonic zones, such as geological faults and shear zones.

Some of the geological faults and other small structures present in rock outcrops in the Serra d'Arga are aligned with these watercourses. This indicates the existence of larger structures (large geological faults and shear zones) that condition the geology, hydrology and evolution of the region's landscape.

In the Serra d'Arga there are various places where you can see watercourses 'inserted' in a fault zone, particularly in several sections of the Ribeiro de São João Stream valley and some subsidiary brooks, and also in tributaries of the River Âncora.

Polygonal disjunction in
a granite outcrop

Polygonal exfoliation (disjunction)

Granite exfoliation involves the development of short fractures in rocky massifs. This phenomenon occurs periodically in the granite of the Serra d'Arga as a result of the litostatic decompression to which the granite masses are subjected, after long periods of erosion of soil layers and/or overlying rocks.

Usually these fractures have irregular shapes and patterns, but in sections susceptible to granite flaking they may have polygonal or planar patterns.

Exfoliation is a phenomenon that can be seen in almost all the granite areas of the Serra d'Arga, but it only appears in the form of polygonal flakes on a few outcrops on slopes facing north and north-west, and on hilltops, near Cerquido.

Pseudostratified granite

The pseudostratification of granite, one of the most curious morphologies in the Serra d'Arga, is quite common in the region, particularly on ridges and plateaux. The phenomenon derives its name from the horizontal bands that normally resemble the stratification typical of sedimentary rocks and some metamorphic ones.

In granitic rocks, this 'false stratification' is related to crustal decompression (reduction of litostatic load) resulting from successive episodes of erosion of the surface soil and rock layers. The characteristic planar flaking is a result of petrographic pressure anisotropies induced in a magmatic chamber during the solidification of granitic magma.

The pseudostratified rock is occasionally 'cut' by posterior vertical fractures, giving the impression of small, man-made terraces. These vertical fractures are an indication of Alpine orogeny, the most recent phase of crustal deformation to have occurred in the Northern Hemisphere.

Granitic pseudo-stratification

Pseudo-stratification fractures 'cut' by vertical fractures

Round granite megablocks

Isolated, round rocks are one of the most abundant granite morphologies in the Serra d'Arga. The largest of them tend to be found at the bottom of slopes and on valley floors, in some cases close to villages.

They are a result of two geomorphological processes: spheroidal disjunction and the abrasive action of the wind when it carries solid particles (sands). Wind erosion, a long process of physical wearing down, is the more important and frequent factor.

These round rocks are often of unusual and impressive dimensions — so-called megablocks that play a role in some of the popular beliefs and legends of the Alto Minho region.

In some of the villages closest to the Serra d'Arga there are houses alongside or even attached to the megablocks — a remarkable way of exploiting the area's natural resources.

Granite megablocks

Blockfields

Blockfields are one of the most abundant granite morphologies in the Serra d'Arga. These landforms are often assumed to be more advanced stages of erosion of previous morphologies, as is the case with the granitic tors. This conception is based on the greatest morphological irregularity and the highest degree of rounding of the rocks through erosion.

In the Serra d'Arga, a significant aspect of these morphologies is the occurrence of heaps of large rocks, which tend to be located on slopes and along watercourses.

As is the case with the large, isolated rocks, blockfields occur throughout the Serra d'Arga, particularly along watercourses, on valley floors and hillsides, and at the foot of granite ridges.

Blockfield on a hillside

Granitic tor in a ridge area

Granitic tors

The tor is one of the most prominent morphologies in granitic environments, and the Serra d'Arga is no exception.

In geomorphological terms they are often seen as residual areas, meaning that they are a result of different types of erosion by erosive agents.

In these rocky areas, the predominant morphology is characterised by cubic or polygonal disjunction of the granite, where several families of fractures (with different orientations and slopes) stand out. The rocks resulting from this fracturing process are rounded due to wind abrasion.

In the Serra d'Arga, granitic tors are mainly located on ridges and peaks but also on slopes and are often surrounded by other morphologies (e.g. blockfields and isolated rocks).

The general aspect of the ridges with a tor is sometimes reminiscent of castle ruins. This is due to the irregular patterns of the rock fractures in the main outcrop and the presence of groups of rocks in the periphery.

Pedunculated rock

Pedunculated rocks (knight rocks)

Knight rocks are scientifically described as a derivation of pedunculated rocks. They are generally formed by rocks protruding from a base block that is normally smaller, giving the impression of instability.

In fact they are vertical stacks of two or more rounded rocks, the base rocks being subjected to more intense erosion from sands carried by the wind.

Pedunculated rocks can be found in most of the granite batholith of the Serra d'Arga, either standing alone or 'embedded' in other morphologies such as tors and blockfields. According to some local myths, these rocks have been placed on top of one another by supernatural forces.

Granitic plain on a plateau

Granitic plains

Granitic plains are one of the most interesting geomorphological aspects of the Serra d'Arga. These landforms are topographically flattened and sometimes slightly undulating as a result of the erosion of their weathered upper layers (soil and/or rocky material).

Though granitic plains are more common in tropical regions, in the Serra d'Arga they can be found on hilltops, valley floors and floodplains.

In some of the villages close to the Serra d'Arga, small granitic plains are used for agricultural activities such as the drying and stripping of cereals.

A view of geological and geomorphological interest

In the Serra d'Arga there are numerous vantage points from which to enjoy views of great geomorphological interest. One of the best is on the hillside facing the village of Estorãos (Ponte de Lima), from which a spectacular sequence of geological and geomorphological features can be seen.

In fact, between this spot and the valley of the River Lima you will be able to see granitic hilltops; a break (or furrow) in a schist floor; a cross-ridge line consisting of quartzite layers; a depression in a schist floor; a granitic ridge; and, finally, an extensive sedimentary plain around the River Lima.

This topographic alternation is a direct result of the different degrees of erosive resistance by different lithologies.

It should be emphasised, by way of an example, that protruding ridges or domes are only formed on granite substrates and quartzite layers. This is a geomorphological principle with great influence on the landscape of the Serra d'Arga and Alto Minho, which is also evident in other regions of the Portuguese Maciço Antigo (Ancient Massif).

Panoramic view of geological and geomorphological interest

Granite ridge with a variety of morphologies

On the numerous ridges of the Serra d'Arga you can see different types of granite forms, although not always does a prominent landform stand out. In fact there is a special tendency for the occurrence of transition forms or 'collection' of different morphological typologies.

However, there is a tendency for the main 'rocky body' to exhibit cubic or polygonal disjunction, where three or more fracture systems (families) can be found. Rocks resulting from this fracturing process are often round due to abrasion caused by wind-blown sand.

These granitic ridges represent land protrusions found on the top of slopes, on plateaux or hillsides (forming secondary ridges).

Various granite morphologies on ridges

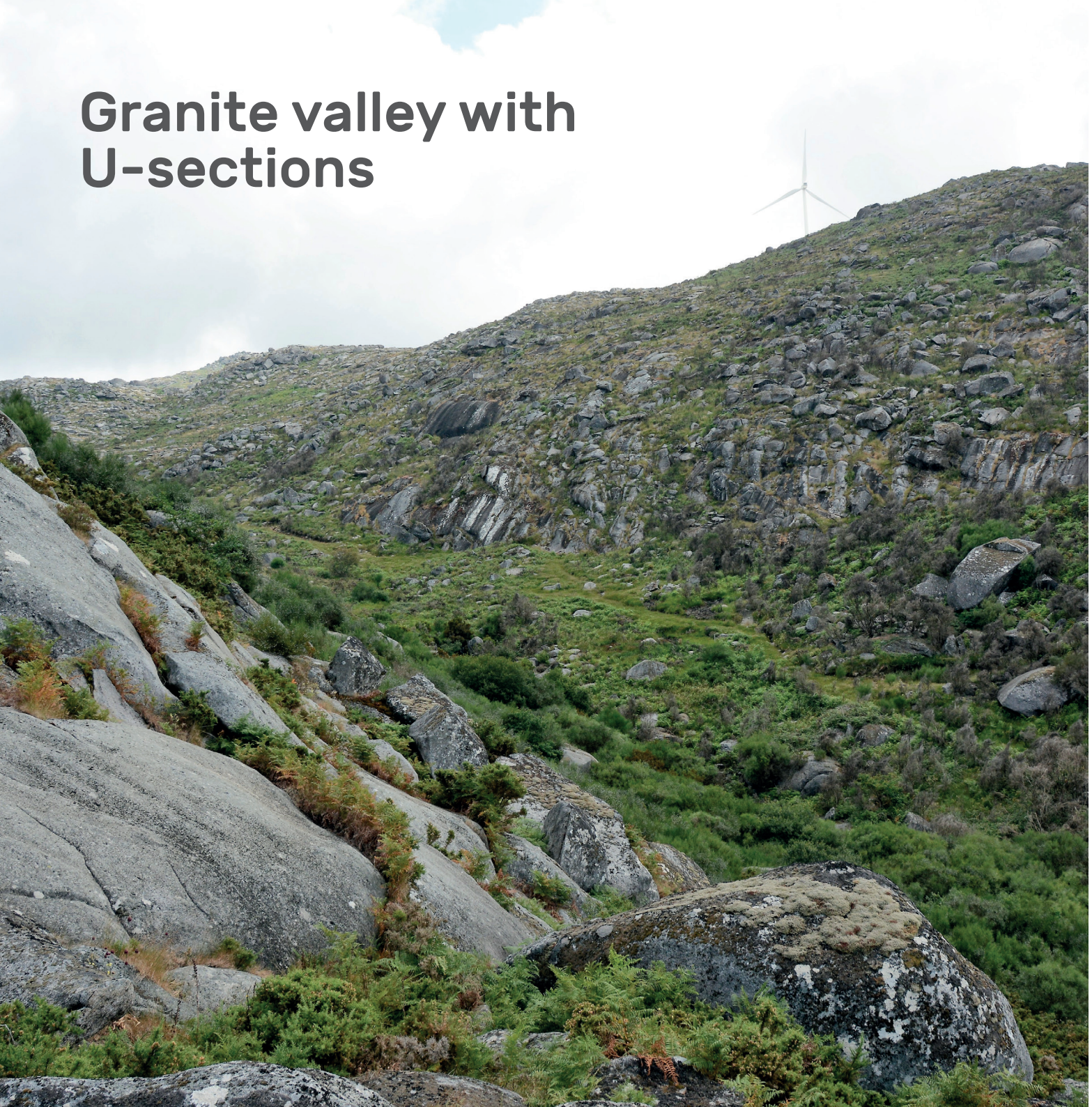
Cavity on a vertical surface (tafoni)

Vertical surfaces, or taphonomonic cavities, are not very common in the Serra d'Arga. Lateral or basal holes develop in specific granitic bodies, originating from the action of several natural processes. In fact they are cavities resulting from a combination of environmental factors (climatic, biological and chemical) and mechanical heterogeneities in rocks, so the end result are normally very peculiar morphologies.

Though not easy to find in the granite of the Serra d'Arga, there is a good example in an outcrop of metagranitic rock (blockfield) between the villages of Gândara and Arga de Baixo.

Taphonomic cavity in metagranitic rock

Granite valley with U-sections



In granitic environments, normal erosion patterns are evident in a wide variety of morphologies that are mostly determined by mechanical heterogeneities produced during magma solidification.

On a broader scale, the evolution of the landscape leads to the development of v-shaped cross sections, but in the Serra d'Arga it is possible to see some U-shaped valleys. In fact, there could be a tectonic control in the areas where these valleys are located.

However, there are smooth surfaces in line with the topography between the different granite morphologies (e.g. blockfields, polygonal disjunctions and tors).

The combination of these geomorphological aspects may be a sign of glacial erosion. Areas with typical patterns of glacial erosion have been found at the source of the Ribeiro da Arga Stream (tributary of the Ribeiro de São João Stream) close to Arga de Cima.

Granite valley with
U-sections

Giant's kettles

Water is one of the principal elements that has moulded the landscape and rocks of the Serra d'Arga, and this is particularly obvious along the primary and secondary watercourses.

In some of these places very peculiar morphologies are developed — such as the so-called giant's kettles that form as a result of the swirling movement of the waters and the abrasive action of the sands and pebbles they transport. This is actually one of the principal physical erosion processes in the region.

Along the main rivers and streams bordering the Serra d'Arga you can see many spots with giant's kettles, characteristic of low and intermediate levels (below 300 metres), where larger flows can be found.

However, there is an exception to this rule at an altitude of 520 metres, at the source of one of the tributaries of the River Âncora (Regueiro da Lapa Brook).

Giant's kettles in a schist substrate

Pincho waterfall

Waterfalls and natural lagoons

In some of the rivers and streams adjacent to the Serra d'Arga there are many sections with large level differences in watercourses. In several places these different levels produce beautiful waterfalls that terminate in breathtaking natural lagoons.

These are true natural works of art that deserve to be classified as natural monuments not only for their beauty but also because of their scientific importance and their specific characteristics that help us understand the geology and natural history of the region.

In fact, the waterfalls are associated with considerable differences in level in rivers and streams, where the rocky substrate is occasionally more resistant to erosion by water (e.g. alternating with quartzite levels, stratification perpendicular to the water line and a greater concentration of quartz veins), or the existence of tectonic activity occurring in geologically recent periods.

Some lagoons are important waterbodies in the region due to their dimensions and can be used for sports and leisure activities. One example is the Pincho waterfall lagoon, also known as the Frida Má waterfall. Some of the most interesting morphologies and lithological sequences are preserved in this lagoon, located in the River Âncora, including giant's kettles and other erosion cavities, differences in level of river beds and alternating schist and quartz vein areas.

To the north-east of the Serra d'Arga, along the Ribeiro das Pombas Stream, there are other small waterfalls of touristic, geological and geomorphological interest, along with natural lagoons.

Natural lagoons

Evidence of ore deposits exploitation in a vein

In addition to elements of lithological (rocky substrates), tectonic and geomorphological interest, the geology of the Serra d'Arga is also evident from numerous historical and cultural features.

These include the history of mining in the area — occasionally evident in the form of linear furrows in the land where veins of minerals were once extracted.

These can only be seen in locations where a form of open-cast mining used to take place. In these spots there are also other, smaller furrows that are now invisible among the vegetation. A good example is on a slope just over 100 metres (to the NNW) from Alto de Santa Justa.

At the foot of a slope to the north of Cerquido, just over 1,100 metres away, other furrows are also evident, though they are less defined.

Sometimes, in areas surrounding the spots where mineral veins were extracted, secondary veins can be seen (with similar orientations to the furrows), some of which have disseminated and oxidised mineralisation.

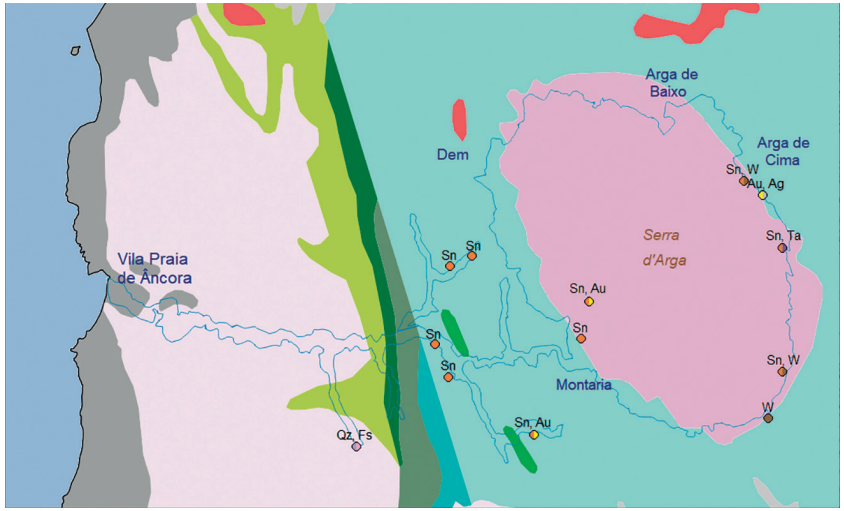
Old mining sites

The Alto Minho region is very well known for its natural heritage, which includes geodiversity, water and mineral resources. This is the location of the mining region of Serra d'Arga that witnessed the exploitation of several mineral deposits, particularly tin, over several centuries.

The exploitation of these resources reached its peak during the twentieth century, when the Portuguese Government granted numerous exploration licenses and mining concessions. At present there are no mines operating, although there are licenses for mineral prospecting and research in the region of Arga and other areas of the Alto Minho.

The archaeological-mining heritage is still evident from the remaining structures and signs of past work and deserves to be preserved and promoted in an integrated and sustainable fashion.

The adjacent map contains geological information as well as the locations of the old mining sites. There are others in the Arga region of different dimensions, typologies and importance.



Simplified geological map of the Arga region and surrounding areas, showing the location of mineral occurrences where mining took place

GEOLOGY

Recent sediments

- Current silting
- River and beach deposits - former quaternary and recent Pliocene period

Eruptive rocks

- Pegmatite and aplite-pegmatite veins and masses
- Tarditectonic two-mica granites
- Two-mica non-tectonic granites

Metasedimentary rocks

- Metasediments, mainly Silurian schists
- Silurian ampelite schists
- Variety of metasediments from the upper Ordovician period
- Slaty, carbonous and clay schist from the Middle Ordovician period
- Pelitic schist metaconglomerates
- Phyllites banded with siltstone beds, from the Cambrian period

MINERAL OCCURRENCES

- **Sn** - Tin
- **W** - Wolfram
- **Sn**, **Au** - Tin and gold
- **Sn**, **W** - Tin and wolfram
- **Sn**, **Ta** - Tin and tantalum
- **Au**, **Ag** - Gold and silver
- **Qz**, **Fs** - Quartz and feldspar

Limits of the area studied

Scale

0m 2000m 4000m

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