



Geotourism Route through Trás-os-Montes e Alto Douro University (Vila Real, Galicia-North Portugal Euroregion): a Space of Public Outreach of Geology

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Abstract

Geoconservation, geotourism and geodiversity are concepts that should be taught at all educational levels. The entire society should preserve the natural resources in a sustainable way. Geological processes and quarrying created and still creates cultural heritage in landscapes, villages and cities worldwide. Rock outcrops, historical quarries, forms of extraction and buildings built with stones are a heritage that should safeguard. This work details a geotourism route that would bring new life to Trás-os-Montes e Alto Douro University (UTAD) campus. The proposed route connects a historical quarry located in the UTAD campus with the main church built with its granite and different rock outcrops that show the geological history of the city of Vila Real (Portugal). It envisages a three-points of interest tour from the Fernando Real Geology Museum (UTAD) to a church built with Prezandães granite from Folhadela.

Keywords Geotourism route · Heritage Stones · Historical quarries

Introduction

Stones are interconnected with humans and environment in all cultures (de Wever 2016; Fernández Castro et al. 2021; del Lama and Costa 2022). The first settlements and their areas of influence had a marked geological or

geomorphological control (Kaur et al. 2021). In this sense, historical quarries are part of the tangible heritage of a region. Administrative protection to guarantee the preservation of quarry landscapes, awareness about the conservation of historical quarry fronts, reopening historical quarries for restoration of monuments and enhancing social perception and tourism are some aspects important to heritage defense (Canesin et al. 2020; Machado et al. 2021; Navarro et al. 2022). For this reason, there is a need to heighten the public profile of historical quarries and heritage stones, to develop new methods to highlight their scientific, cultural, aesthetic and social/economic values (Wang et al. 2022; Bert et al. 2022; Berred et al. 2022; Kaur 2022). In this sense, the campus of Trás-os-Montes e Alto Douro University (UTAD) of Portugal has extraordinary potential for the

Highlights

- Abandoned historical quarry of UTAD campus is a resource with tourist and economic potential.
- Natural stones and historical quarries have links to cultural heritage.
- The importance of geological heritage and its relevance in modern society must be disclosed to the general public.
- Geoconservation, geotourism and geodiversity are concepts that should be taught at all educational levels.

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outreach of geology, keeping a balance between geoheritage, local economy and education to achieve sustainable social development.

Education plays a major role to promote responsible citizenship towards its geological environment. An informed society will appreciate its value and will make wise decisions about protecting geoheritage, which is part of the essence of local culture and society (Azman et al. 2010; Khoukhouchi et al. 2018; Freire-Lista and Fort 2019).

Geodiversity, geotourism and geoconservation are concepts that should be taught in all educational levels so that the entire society can safeguard this natural resource in a sustainable way (Kubalíková et al. 2021; Salameh et al. 2021; Crofts et al. 2021).

Geodiversity encompasses the natural range of geological and geomorphological features, including their assemblages, relationships and properties, that should be exploited for geotourism (Insua Pereira et al. 2013; Brilha 2016; Schrodt et al. 2019).

Geotourism is a form of tourism that focuses on geology and landscape (Panizza, 2001; Newsome and Dowling 2010; Dongying et al. 2012; Singh and Subhash 2013). Travelers appreciate natural and anthropic landscapes that are a niche area of the local tourism economy (Insua Pereira et al. 2015; Freire-Lista et al. 2021; Awad et al. 2022). Geotourism routes for public outreach (Freire-Lista et al. 2017, 2022a; Freire-Lista 2020) can include archaeological, natural and cultural sites as historical quarries which attract many tourists and economic prosperity (Kozłowski 2004; Reynard and Panizza 2007; Citiroglu et al. 2017; Medina-Viruel et al. 2019; Hall and Zeppel 1990a, b).

Relationships between geoheritage and cultural heritage are being increasingly explored all over the world for geotourism, environmental conservation purposes and public outreach of geology (Rocha et al. 2019; Freire et al. 2022c; Halbouni et al. 2022; Pijet-Migoń and Migoń 2022).

Geomorphosites have a big importance on geological public outreach around the world. Significant steps have been given to identify, assess and protect many geosites. Some countries like Portugal and Brazil have strong advances in the geomorphological heritage research, the definition of elements and processes of geodiversity, the establishment of quantification methods and country's involvement in the international geoconservation scene (Brilha et al. 2018; Brilha and Pereira 2020; Xavier et al. 2021).

Nominations for UNESCO Global Geoparks generate a public outreach of geology. For example, Orlické-Bystrzyckie Mountains Block in Central Europe shows large geological processes, as geomorphic evolution traced back to the Cretaceous, marine transgression over a weathered land, large scale tilting, origin of mountains fronts and other fault-generated escarpments, stripping of cover deposits, deep fluvial incision and Quaternary periglacial areas (Migoń

and Różycka 2021). Other example is Cabeco da Ladeira (Portugal) that is known as the “Jurassic Beach” (Machado et al. 2021). It contains the large exposures of a Middle Jurassic carbonate tidal flat with an outstanding fossil record. Mondego Cape (Portugal) has a set of outcrops with international stratigraphic relevance given by the establishment of two *stratotypes* (Rocha et al. 2014); Seridó Geopark (northeast of Brazil) which integrates geological features with communities as Quilombola (da Silva et al. 2022) was nominated in 2022; the “Litoral del Biobío” (Chile), one of the most important geopark projects (Ferraro et al. 2021) contributes to local sustainable economic development, education on geological risks, as well as the revaluation of the cultural heritage. Huaynaputina volcano had the largest historical eruption (1600 CE) in Peruvian Andes. It occurred during the transition between the Inca Empire and the Viceroyalty of Peru. It created an important geological and cultural heritage with volcanic geosites, volcanic-cultural geomorphosites and hot springs (Mariño et al. 2021). Another American example where the geodiversity is associated with economic, scientific, social development and public outreach of geology is the Magdalena Medio Antioqueño Valley, in Colombia. (Tavera-Escobar and Álvarez-Ramírez 2019).

Central America is in a dynamic region where tectonics and volcanism, together with the tropical climate and its diverse vegetation, have shaped the landscapes. Volcanic, coastal, karstic, glacial and fluvial geomorphic environments are common in the region. Exhaustive analyses to enhance the knowledge of its geodiversity are necessary. The environmental and touristic policies promote its geoheritage through geotourism and public outreach of geology (Quesada-Román et al. 2022).

In Africa, the Rabat-Tiflet area (north-western Morocco) has a complex geological setting and a high geodiversity, two reasons that justify the geoheritage. A geoconservation strategy should be implemented in this area by national and local authorities to protect and conserve this geological heritage (Mehdioui et al. 2020). In Ngorongoro Conservation Area from Tanzania, a Maasai indigenous community highlight some problems related to tourism development like restrictions to access to land resources, unsatisfactory involvement in decision making and it benefits sharing (Melubo and Lovelock 2019).

Since stones are a strong element in humanized landscape of Trás-os-Montes area of Portugal (Freire-Lista et al. 2022a), the aim of this work is to present aspects of Prezandães granite of Folhadela (Portugal) through a geotourism route for public outreach of geology. Starting at the Geology Museum of Trás-os-Montes e Alto Douro University and going through a historical quarry and the Romanesque church of São Tiago de Folhadela (Fig. 1).

Historical quarries have existed since the Neolithic times in Trás os Montes area (Sanches and Nunes 2005;

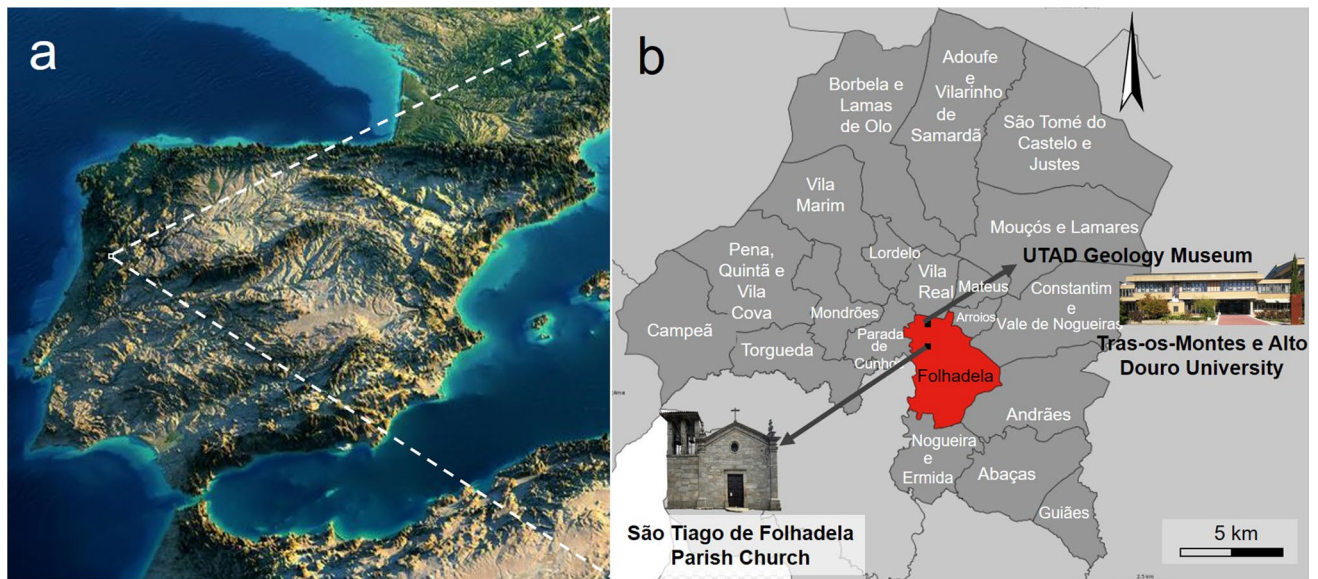


Fig. 1 **a** Map of the Iberian Peninsula indicating the location of the study area. **b** Parishes of Vila Real municipality of Portugal. Folhadela is marked in red

Freire-Lista et al. 2022b). Their conservation and diffusion are a duty of the scientific community. In this way, forms of traditional construction, mason's marks, local building granite types and ashlar decay, would be shown by local guides. Thus, disciplines such as geology, archaeology, history and architecture contribute to the enhancement of Galicia-North Portugal Euroregion's heritage, delving into environmental education and conservation.

Outreach of Geology at UTAD

UTAD's history starts in 1973 when a group of respected members of the community of the city of Vila Real presented the Government a proposal to create a school of higher education. Following that initiative, an installation commission was nominated in March 1974 and the Instituto Politécnico de Vila Real (IPVR) was born. The process accelerated after the 25 of April Portuguese Revolution and consequent regime change that year. IPVR adopted the name of Instituto Universitário de Trás-os-Montes e Alto Douro (IUTAD) in 1975. Less than 10 years later (1986), IUTAD rose to the category of University in recognition of its intense activity in the fields of teaching, and scientific and technological research.

Teaching and research in the Geology field was initially a responsibility of a Division of the Department of Geosciences in the early Institute. Following the creation of UTAD, the Division became the Secção de Geologia (Section of Geology). During 2000, the Geology Section then became the Department of Geology in the School of

Life and Environment Sciences (ECVA). There are courses dedicated to Geodiversity and Geoheritage at three-degree levels—BSc, Master and PhD. Students in the third year of the Biology/Geology BSc have a semester on “Geology Heritage and Geoconservation”, and in Tourism, the option on “Geotourism”. The department also organized a short course on “Technical Guide to Interpretation and Management of Geological and Mining Heritage”.

From the beginning, UTAD had, by statute, a strong connection with the local and regional communities. The University has always encouraged and promoted outreach activities and special programmes for the local population and general public.

“Museum of Geology” (MG) was created in 1986 by the first rector of UTAD, an eminent geologist, Professor Doutor Fernando Real, in collaboration with members of the academy. His private collection and of other colleagues and enthusiasts formed the initial nucleus of the MG. Many donations and deposits of private collections over the years enriched the Museum's collection. Today, the MG is called “Fernando Real Geology Museum” (Coke and Favas, 2010).

From 2019, several items of the collection were placed outside on the campus of Quinta de Prados in different parts of its Botanic Garden. There is a project of creating in the garden a route that will exhibit rocks and geodiversity. Exhibits and collections of the Fernando Real MG are an essential teaching tools for the students of different courses in UTAD.

Groups from local schools and other parts of Portugal are regular visitors of the Fernando Real MG. Guided visits and special activities are available by appointment. Open days

and special events when temporary exhibitions open attract a steady flow of viewers. Presently, the Fernando Real MG is part of the MuD – Rede de Museus do Douro (Douro Museums network) (<https://www.museudodouro.pt/rede-museus-douro>). It is also a partner of the “Route of Mines and Points of Mining and Geological Interest in Portugal” (<https://roteirodasminas.dgeg.gov.pt/apresentacao/>), an initiative of two organizations: the General Directorate of Energy and Geology (DGEG), part of the Ministry of Economy, Innovation and Development; Empresa de Desenvolvimento Mineiro SA – EDM.

Since the 1990s, members of the area of geology, often in cooperation with colleagues from other departments, organized and participated in many activities and outreach programmes. These include *Geologia no Verão* (Geology in the Summer) and “Scientific Occupation of Young People”, both promoted by the *Ciência Viva* Agency. In the first, guided by members of the Department, members of the general public from all over the country and even abroad were invited to visit places of geological heritage interest all over the region of Trás-os-Montes and Alto Douro. Guidebooks and other documentation were specially written for these visits. The “Occupation of Young People” gave youngsters an opportunity to participate in research and conservation related activities in the MG and countryside. Members of the department and MG have taken part in other activities for the general public that include *Ciência Viva* Mini-forums, Science Technology (every November) and *Universidade Júnior* (in the summer) for children aged twelve to sixteen.

MG organizes a “Fair of Rocks and Minerals” in the UTAD campus every year. Members of the academy and general public can buy minerals, gems and fossils and other items (necklaces, rings and other decorative objects) made in the most diverse and raw materials of geological origin.

In the last years, the programme *À descoberta da Geologia* (Discovering Geology) has the aim of offering teachers, students and the general public field trips that promote integrated scientific knowledge of the region. Various activities include visits to sites of geological, mining or archaeological interest, with a view to interpreting the landscape and geological resources.

Geological Settings

The city of Vila Real is in the north of Portugal, in the district of Vila Real in Trás-os-Montes region (Galicia-North Portugal Euroregion). The Galicia-Tras-os-Montes Zone (GTMZ) is one of the geological units into which the Iberian Massif is subdivided. It is in the northern part of the Central Iberian Zone (CIZ), in the Iberian sector from the Variscan belt. It is the result of an assemblage history of continental collision and extension (Gomes, et al. 2011). GTMZ is

characterized by siliciclastic metasedimentary rocks. These metasediments once were sediments accumulated in the Tethys sea basin and metavolcanic rocks, interpreted as the outermost part of the Gondwana continental margin. CIZ is characterized by a large volume of Variscan granitic plutons (Roda-Robles et al. 2018).

Continental plates collided in the Lower Paleozoic, which produced the Variscan Orogeny (Matte 2001; Ribeiro et al. 2007; Arenas et al. 2016; Veludo et al. 2017). The later Mesozoic rifting and breakup of Pangea into Laurasia and Gondwana had a profound effect on the continental crust of the western border of Iberia since the metasedimentary materials present in this area are the product of sedimentation in the Tethys Sea, which was between these two supercontinents (Pereira et al. 2016).

The granite historical quarry of UTAD campus is near the boundary between metasedimentary rocks and granites (S1). These S1 granites are interpreted to derive mainly from the partial melting of highly peraluminous, Ca-poor and P-rich metasediments during Variscan orogeny. Different types of two-mica syntectonic granites from Variscan Vila Real Composite Massif intruded the metasedimentary rocks (Martins et al. 2009; Villaseca et al. 2009). These small-size intrusive bodies are either porphyritic or not, biotite-rich and sometimes very leucocratic.

A decompression followed immediately after the emplacement of the allochthonous terranes during the major Variscan collision (D1 and D2 deformation phases, *ca.* 387 to 352 Ma). Peraluminous granite magmas were generated by crustal anatexis of metasediments and metavolcanoclastic rocks during the initial steps of this decompression phase (Noronha 2017).

Two-mica granites were emplaced during the D3 deformation phase (*ca.* 320–310 Ma). They are peraluminous with aluminium-potassium affinity and represent the crystallization of magmas derived from the partial melting of pelitic metasediments.

“Tardi-D3” (*ca.* 310-305 Ma) includes moderately peraluminous biotitic monzogranites/granodiorites and aluminium-potassium affinity resulting from the crystallization of magmas generated by partial fusion of metagranites and/or meta-igneous felsic materials. The group “late to post-D3” (*ca.* 300 Ma) is dominated by two-mica peraluminous leucogranites and aluminium-potassium affinity. “Post-D3” (*ca.* 296-290 Ma) is different from all the previous ones, comprising of compositionally evolved subalkaline ferro-potassium granitoids resulting from crustal partial fusion (Mateus and Noronha 2001). Quartz veins are widespread in the granite outcrops of UTAD campus. Several stages of fluid percolation following contact metamorphism can be recognized. At each stage, the contact zone, characterized by quartz veins, related faults and fractures, focused the hydrothermal flow and were conduits for hydrothermal fluids. These hydrothermal fluids, together with the meteoric

waters, cause mineral oxidation and granite weathering. The shallow part of the granite plutons, relatively fractured by joints and exfoliation microcracks, has been exploited by historical quarries for building granite. Precisely the presence of fractures facilitated the extraction of blocks for carving (Freire-Lista and Fort 2016, 2017; Freire-Lista et al. 2015, 2016).

Methodology

Geological mapping, petrographic analysis, scanning electron microscope (SEM) and Raman spectroscopy have been performed to obtain didactic material for this geotourism route.

A block of Prezandães granite from Folhadela was extracted from the historical quarry located in UTAD campus. This block was cut at low speed (120 rpm) and low strain and two thin sections were made and characterized under a polarized light microscope. A Leica DM750P microscope equipped with a Leica MC 120 HD digital camera and LAS 4.3 software was used.

An in situ search has been carried out on UTAD campus and its surroundings to set the route path. In this way, a geotourism route was drawn along part of the pedestrian path that runs along the old train tracks.

A visual inspection was performed on the granite ashlar of buildings and monuments of Folhadela (Vila Real). To determine the origin of granite spots, small chips of speckled granite from the historical quarry were dried and coated with carbon to perform surface observations using SEM by secondary and backscattered electrons, and X-ray maps were created in a JEOL JSM 6400 Scanning Electron Microscope at 16 keV coupled to an electron dispersive spectroscopic analyser (EDS) Oxford 200 Inca Energy EDS.

The identification of the iron oxide present in the millimetre brown cubes of Prezandães granite from Folhadela was recorded using a Renishaw InVia model Raman microscope with a 785-nm laser and in static mode (focused on 520 cm^{-1} , taking an area of approximately $213\text{--}800\text{ cm}^{-1}$). The laser exposure time was 0.3 s with 1500 accumulations, the laser power was 0.4 mW and a 50× objective was used.

Results

Petrographic Analysis of Prezandães Granite from Folhadela

Prezandães granite from Folhadela is a medium-crystal-size granite. The mineralogical composition is: quartz ($\approx 35\%$), potassic feldspar ($\approx 23\%$), plagioclase ($\approx 29\%$), biotite ($\approx 2\%$), muscovite ($\approx 9\%$) and goethite ($\approx 2\%$); therefore, the

rock is classified as a monzogranite. K-feldspars (K-Fsp) are subhedral, orthoclase (around 1.5–4.5 mm), usually kaolinized and with perthite textures. Quartz (Qz) is anhedral. Plagioclase (Pl) is presented in oligoclase type subhedral crystals, being slightly alkaline at the edges (Freire-Lista et al. 2022c). The sample contains randomly distributed laminar crystals of muscovite (sericite). Opaque minerals are distinguished, in euhedral to subhedral crystals, whose shape resembles that of pyrite (iron oxides in Fig. 2). These minerals are brownish in colour and highly altered. That is, the pyrites were altered to iron oxides and they have pores inside. From these minerals a network of oxides is spreading out by through intercrystalline fractures and minerals of very fine crystal size (indicated with an ellipse in Fig. 2).

Raman Spectroscopy of Brown Cubes from Prezandães Granite from Folhadela

Analyses with Raman spectroscopy have identified the iron oxide present in the brown cubes of Prezandães granite from Folhadela as goethite (Fig. 3). That is, the originally pyrite cubes present in the Prezandães granite from Folhadela have been altered to goethite.

Geotourism Route Through UTAD Campus (Vila Real-north Portugal)

The geotourism route is approximately 3 km long and consists of 3 points of interest (Figs. 1 and 4). This route begins at the UTAD Geology Museum (Fig. 5). The second point of

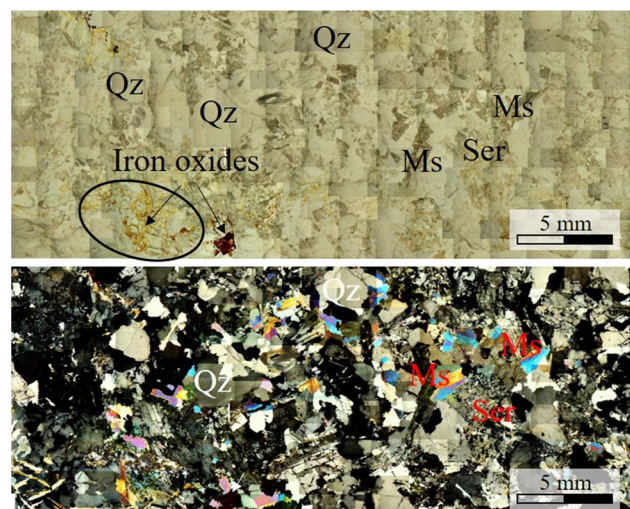


Fig. 2 Petrographic micrographs mosaic (≈ 200 micrographs) of Prezandães granite from Folhadela with parallel and cross Nicols (above and below respectively). Qz: quartz; Ms: muscovite; Ser: sericite

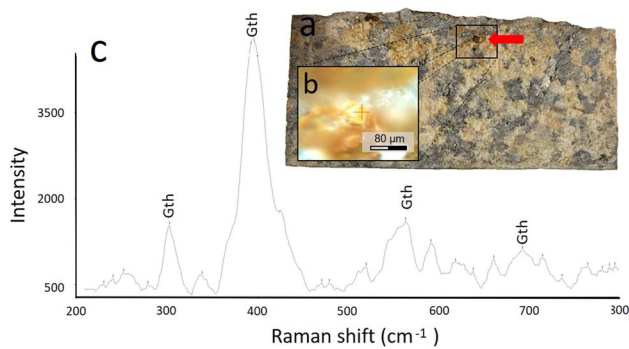


Fig. 3 **a** Hand sample of Prezandães granite from Folhadela. The rectangle indicates the area measured with Raman spectroscopy (brown cube). **b** Image of the measured point with Raman spectroscopy. **c** Raman spectrum of a brown cube of Prezandães granite from Folhadela. Gth: Goethite

interest is the UTAD historical quarry of Prezandães granite from Folhadela. It is an excellent example to teach the traditional techniques of splitting and carving granite. Vestiges of historical stonework and stonecutting wedges can be seen in this granite historical quarry (Figs. 6 and 7). Its granite has brown spots due to the oxidation of pyrites (Figs. 8, 9, and 10). This quarry supplied the main building granite for the Romanesque church of São Tiago de Folhadela.

The third and last point of interest is São Tiago de Folhadela Church, it is a sample of the main granites of

★ Main points of interest on the geotourism route

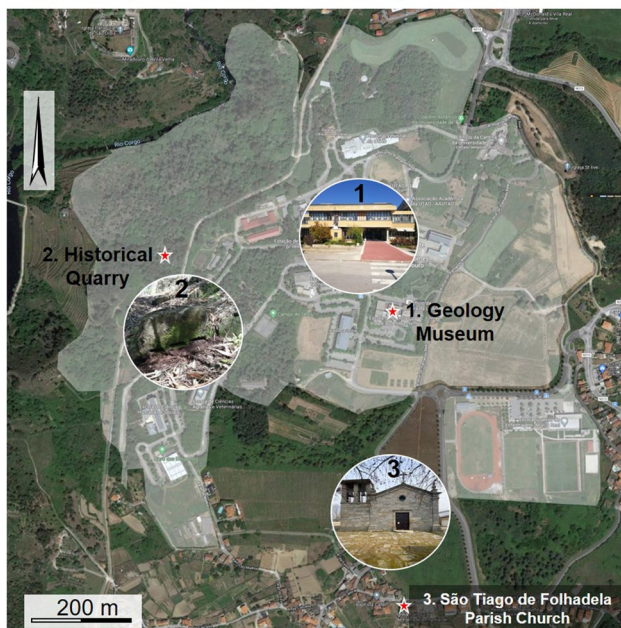


Fig. 4 Main points of interest of the geotourism route for public outreach in Folhadela, Vila Real. (1) Entrance of UTAD Geology Museum “Fernando Real”; (2) Historical quarry of São Tiago de Folhadela Parish Church; (3) Parish Church of São Tiago de Folhadela



Fig. 5 General view of Fernando Real Museum of Geology (UTAD).

traditional construction used in Vila Real. Five types of traditional building granite can be distinguished on its walls (Freire-Lista et al. 2022c), although the main building granite is the Prezandães granite from the historical quarry located on the UTAD campus. In addition, the ashlar of the first construction phase of this church show mason’s marks and different types of decay that allow us to explain the mechanisms of deterioration that affect the heritage stones. (Zalooli et al. 2020; Campos et al. 2021a; Campos et al. 2021b; Germinario and Oguchi 2022).

Point of Interest Number 1: Fernando Real Museum (UTAD campus)

Fernando Real Museum of Geology (GM) is on the ground floor of the School of Life and Environmental Sciences (ECVA) of the UTAD (Fig. 5), at Lat. 41.286367, Long. -7.739248. Exhibits are displayed of geological processes that occur on the Earth. It occupies an area of 250 m² dedicated to a permanent exhibition, and a temporary exhibition room of 100 m².

Its permanent collection is distributed across four sections:

- Life evolution through geological eras, with fossil and ichnofossil pieces.
- Mineral collection systematically ordered.
- Collection of rocks ordered by their genesis.
- Collection of stones related to the main Portuguese mines.

Point of Interest Number 2: Historical Quarry of Prezandães Granite of Folhadela at (UTAD Campus)

Most of the granitic outcrops in Folhadela are of weathered Prezandães granite. However, there is a rocky outcrop that presents a less weathered granite. This outcrop

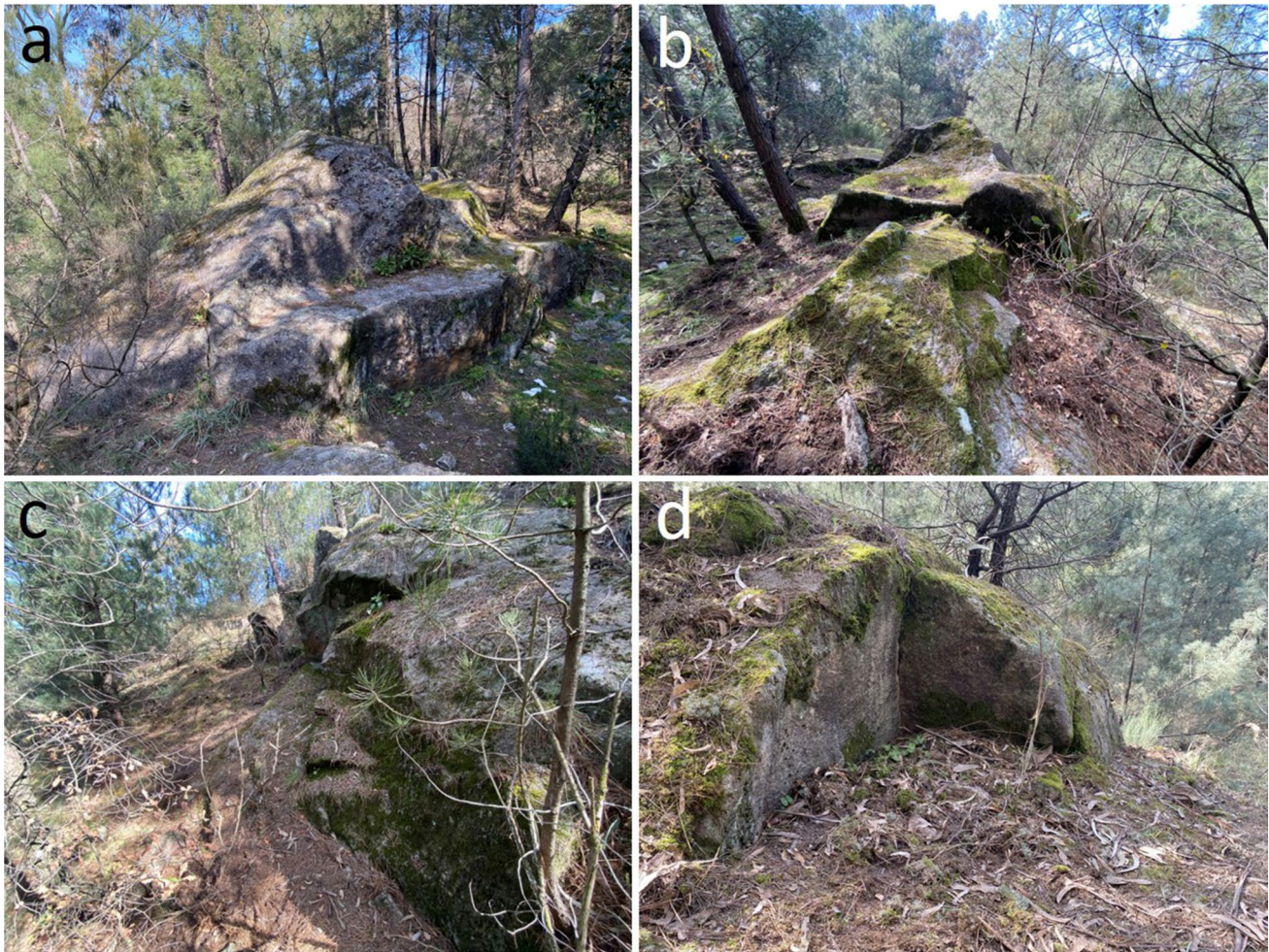


Fig. 6 Fronts of the historical quarry located on the UTAD campus showing three traditional splitting planes.

is in the coordinates Lat. 41.287385, Long. -7.745139 . Many vestiges of historical stonework exist in the historical quarry present in this outcrop. The historical quarry, today unexploited, is located on a small ridge. Its exploitation fronts are distributed at various heights (Figs. 6 and 7). Horizontal detachment planes can be seen together with other vertical planes, following the three traditional splitting directions of granite (Rift, grain and hardway) (Freire-Lista and Fort 2017).

The stonemasons have been shaping the landscape, initially exploiting the large granite boulders, with the bites of the ground, and later with the quarries. The extraction process was not an easy task, especially considering the tools and knowledge of past times. It was common practice to separate the desired block by using wooden or iron wedges. First the dimensions of the stone to separate are defined. Then, some grooves were drawn on the limits of its perimeter, whose width and depth used to range between 5 and 10 cm. Afterwards, wedge slots of between 20 and 30 cm are made inside each groove (Fig. 7a).

One of the most characteristic aspects of this quarry is that its granite has brown spots of iron oxides due to pyrite oxidation (Fig. 7b). It occurs whenever pyrite-bearing stones are aerated (Ling et al. 2021, Wang et al. 2021; Zhang et al. 2021). Therefore, the oxygen recharge is the most important factor controlling the pyrite decomposition process (Alacalı and Savaşçın 2015). Such conditions are induced by denudation and quarrying, which allow the circulation of oxygen through stone cracks and microcracks. Pyrite decomposition is limited by the depth in which this circulation occurs. The result are redox reactions that consume oxygen and release large amounts of iron, sulphate and protons. By this process, water with pH values below 1 and iron and sulphate concentrations in the range of moles per litre may develop, resulting in dissolution and desorption reactions. Under these conditions, pyrite can be oxidised by both oxygen and ferric iron. Reaction rates are limited by either the available pyrite surface or by the oxygen supply depending upon environmental conditions, following two equations:

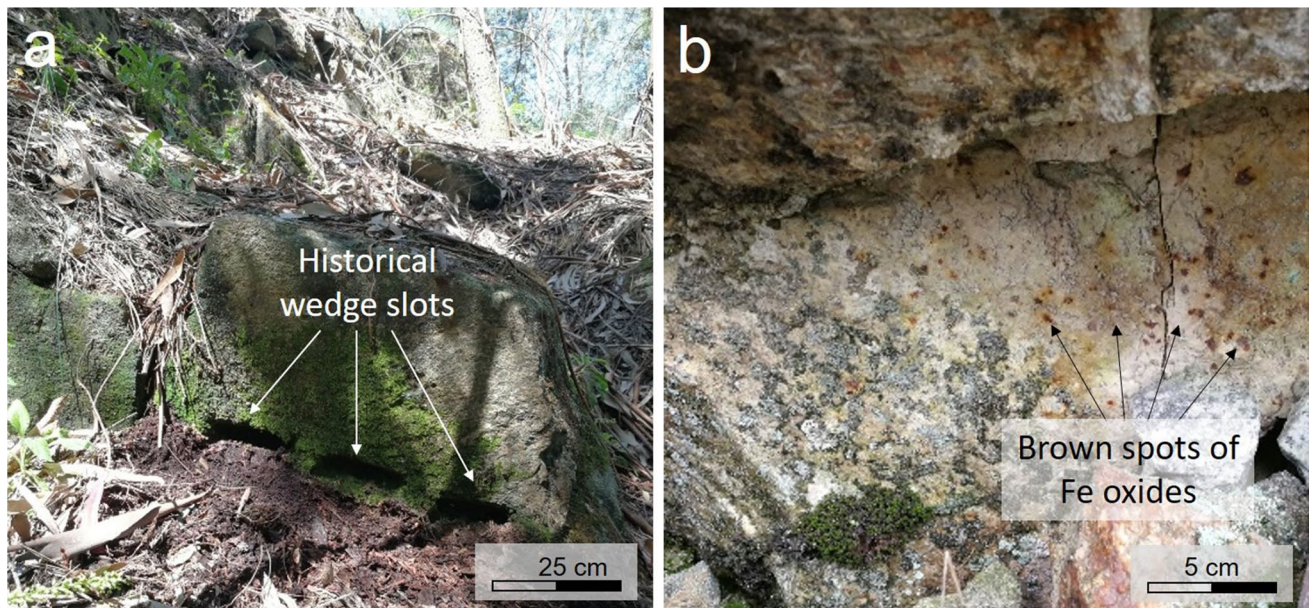
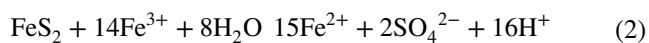
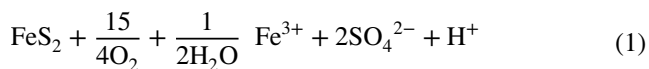


Fig. 7 Historical quarry of Prezandães granite from Folhadela at UTAD campus. **a** Vestiges of historical quarry (wedge slots). **b** Detail of weathered Prezandães granite outcrop in the historical quarry of the UTAD campus



Equation (1) describes pyrite decomposition at low pH values that is microbologically catalysed by *Thiobacillus ferrooxidans* (Gleisner et al. 2006). It is the sum reaction of the pyrite oxidation by ferric iron and the subsequent oxidation of the evolving ferrous iron with oxygen.

Equation (2) shows the pyrite oxidation with ferric iron and it is of importance if the reaction products of Eq. (1) get into an anoxic pyrite-bearing system. In this case, no oxidation of the evolving ferrous iron is observed. In the unsaturated zone, different processes are involved in oxygen transport. Diffusion is the major process balancing concentrations in stone air.

The original pyrite of Prezandães granite from Folhadela has been altered to goethite preserving its original form, creating a pseudomorph of goethite (Fig. 8). The inner part of the cubes has been partially hollowed out and the iron oxides migrated to the cubes perimeter area, creating a brown halo (Fig. 8b). Botryoidal goethite has grown on the inside of the cubes (Fig. 8c, d).

Point of Interest Number 3: São Tiago de Folhadela Parish Church

São Tiago de Folhadela Church settles on metasedimentary materials. It is a Late Romanesque church, described in the “Censual da Terra de Panoias” (Census of Panoias Land)

from the 13th century. It is made up of five volumes: apse, nave, sacristy, bell tower and access stairs built with granite ashlars and masonries (Fig. 9).

This church is located at Lat. 41.280258, Long. -7.738849, approximately 1 km from the historical quarry of UTAD campus. Prezandães granite from Folhadela is the main building granite of São Tiago de Folhadela Parish Church (Fig. 9). Therefore, most of its ashlars have iron oxide stains (Fig. 10) although in total there are 5 types of building granite (Freire-Lista et al. 2022c).

The side walls of the nave façades have ashlars and granite masonry that indicate successive modifications of the nave. Ashlars and granite masonry filling arches are observed in the nave.

The lintel of the main door is made of Vale das Gatas granite, less altered than the main construction granite from the historical quarry previously visited.

The sacristy has ashlars carved in Ragais granite, and the balustrade of the stairs are carved in Amarelo Real granite (Fig. 9). A corbel is carved in Sanguinhedo granite (Freire-Lista et al. 2022c). The existence of reddish and isolated Vale das Gatas granite ashlar (Fig. 11a) produces a greater chromatic contrast and is possibly due to the reuse of building stones. The rubefacient-aspect ashlar of Fig. 11a has a hole in its centre, possibly used to fit the pincers of a Roman crane and move the ashlar more easily. Vale das Gatas granite outcrops in the Roman sanctuary of Panoias (Fig. 11c, d). This sanctuary is approximately 6 km away of São Tiago de Folhadela Church. What remains today of the sanctuary is an enclosure with three large rocks, where cavities of various

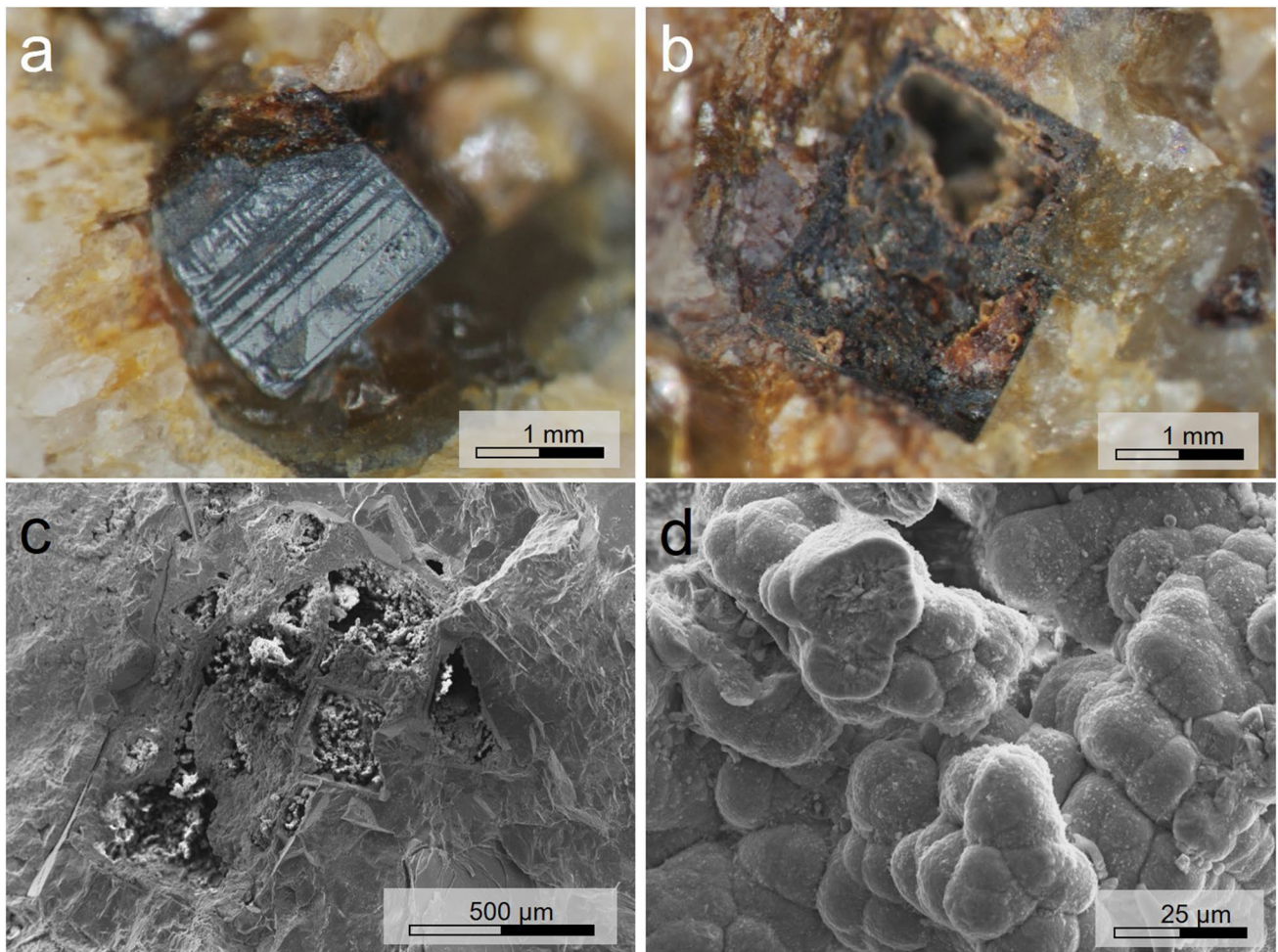


Fig. 8 **a, b** Binocular-magnified image of a sample of Prezandães granite from Folhadela at UTAD before being coated with carbon for SEM observations. Image **a** shows a cube of goethite formed after a cube of pyrite. Image **b** shows the interior of a semi-empty pseudo-

morph of goethite after pyrite cube. **c** SEM image showing pseudo-morphic goethite with a semi-empty interior with botryoidal goethite; **d** Detail of the botryoidal goethite that has grown into the interior of the cubes

sizes and shapes and access stairs carved on the rock exist (Fig. 11c, d). But the temple’s walls have already disappeared, which means that once the sanctuary lost its ritual function, it served as a quarry. That is, there was a looting of the ashlar to reuse them in later constructions (Freire-Lista et al. 2023).

Closing Remarks

Documentary search, cartography, petrographic characterization and chemical analysis are necessary to create a geotourism route aimed at disseminating geology to the general public. This geotourism route highlights the value of local stones used in traditional construction and their historical quarries.

The cultural heritage of Folhadela is closely linked to the geology of Galicia Tras os Montes Zone. The historical quarry of the UTAD campus forms part of Folhadela tangible heritage. Traditional stonemasonry techniques are part of its intangible heritage. These resources are of geotouristic interest.

UTAD historical quarry of Prezandães granite from Folhadela has easy access and many vestiges of historical stonework give this place exceptional possibilities to create hiking trails and an open-air museum.



Fig. 9 North façade of São Tiago de Folhadela Parish Church (Lat. 41.280258, Long. -7.738849)

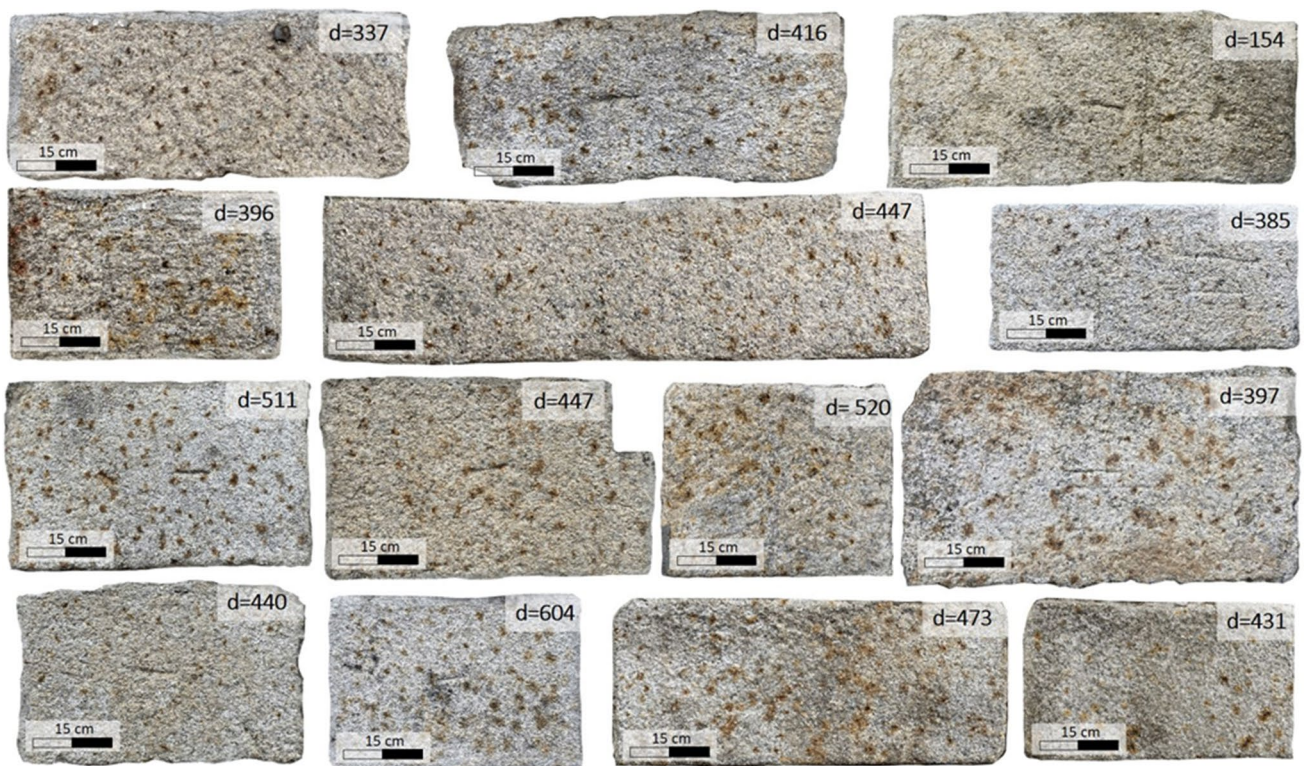


Fig. 10 Ashlars of São Tiago de Folhadela Parish Church. These ashlars are carved in Prezandães granite from Folhadela and it is speckled with brown spots

Prezandães granite from Folhadela presents goethite. It is a pyrite cubes alteration product. Goethite can be observed both in the UTAD historical quarry, and in the ashlars of São Tiago de Folhadela Parish Church.

The main building granite of São Tiago de Folhadela Parish Church is Prezandães granite. However, the ashlars of this church are of five types of traditional building granites,

the most used in Vila Real. Roman ashlars from the archaeological site of Panoias sanctuary are reused in São Tiago de Folhadela Parish Church.

Geoconservation, geotourism and geodiversity are concepts worthy of being taught at all educational levels so that the entire society and entities can safeguard this natural resource in a sustainable way.

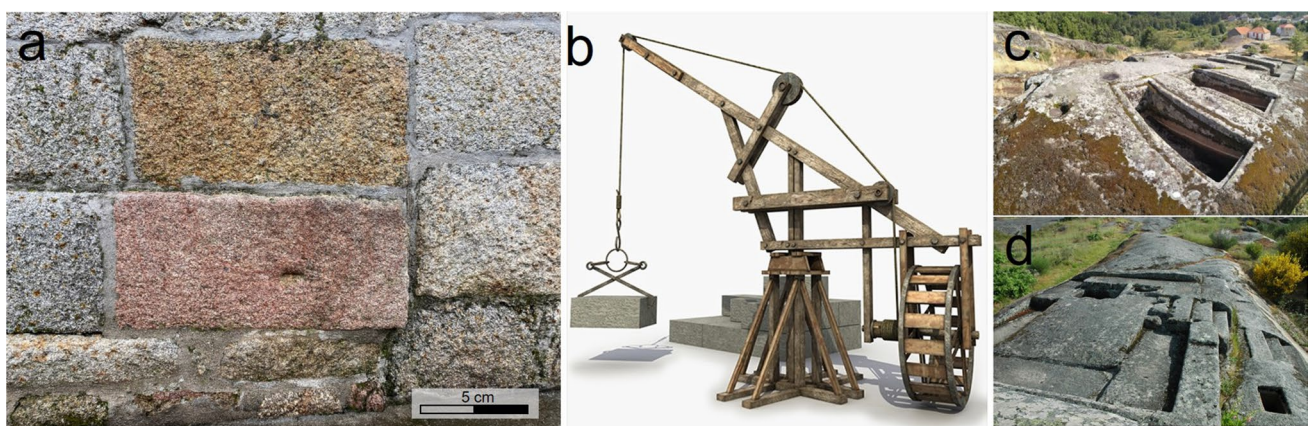


Fig. 11 **a** Ashlars on the South facade of the Folhadela Church; **b** Roman crane; **c**, **d** Sanctuary of Panoias, Vale de Nogueiras, Vila Real (Portugal)

The raising of public awareness of the value of heritage stones and their historical quarries as a cultural asset are necessary for their conservation.

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Declarations

Conflict of Interest The authors declare no competing interests.

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