



Cantera Gorria and Red Ereño: Natural and Cultural Geoheritage (Basque Country, Spain)

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Abstract

Construction and ornamental stones are important elements of cultural heritage and geoheritage. The quarries, where these materials are extracted, are a type of site that combines these two types of heritage. Both the ornamental character of the rock and its place of origin can be deeply rooted in the local society. *Red Ereño* is a red micritic limestone (Lower Cretaceous) with abundant white rudist fossil shells. This stone has been exploited since Roman times in the north of the Iberian Peninsula (Basque Country, Spain) and exported internationally. The main quarry related to the extraction of *Red Ereño*, *Cantera Gorria*, is currently a cultural and geoheritage site. This emblematic site brings together numerous geologic (palaeontological, petrological, geomorphological and tectonic) and mining features that make it a reference point for both research and teaching activities. The link between geoheritage and cultural heritage that exists in *Cantera Gorria* is evident and makes this place an essential point for dissemination of geology as well as for tourism. The quarry is currently abandoned, and because of this, there is an urgent need for its protection and development, and in order to increase awareness of its importance and potential use.

Keywords *Cantera Gorria* · Quarry · *Red Ereño* · Geoheritage · Ornamental stone

Introduction

Construction and ornamental stones, as part of the geoheritage, are an important element of cultural heritage identity and are part of the landscape of a territory. In fact, stones have been an intrinsic part of the World Cultural Heritage. Projects such as the designation as Global Heritage Stone by the IUGS (International Union of Geological Sciences) Heritage Stones subcommission provide visibility and disseminate the heritage importance of these rock varieties (Pereira and Cárdenes Van den Eynde 2019).

In the case of lithologies used as ornamental stone, they are valued for their aesthetics and their attractiveness and are generally used as a sign of distinction and just sometimes power, such as Roman porphyry (Abu El-Enen et al. 2018). The international interest in certain lithologies is well known, as is the case of *Carrara* marble (Primavori 2015) (Pereira and Cárdenes Van den Eynde 2019). Other rocks are part of several heritage monuments such as the *Villamayor de Salamanca* sandstone (Iñigo et al. 2003) or the *Macael* marble (Navarro et al., 2019) in Spain; Estremoz Marble from Portugal (Lopes and Martins 2015); Bath Stone limestone in England (Marker 2015); Decan Trap basalts and tachytes from India (Kaur et al. 2019); the orthoquartzite known as Piedra Mar del Plata from Argentina (Cravero et al. 2014); and Tennessee limestone from the USA (Byerly and Knowles 2016). *Rojo Ereño* (Damas Mollá et al. 2021a) or *Negro Markina* (Damas Mollá et al. 2012) are two ornamental limestone types, exploited since Roman times in the province of Bizkaia (Basque Country, Spain) and which have been exported worldwide.

The connection between stone as a cultural material and the geological origin of the formation of the different varieties

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is combined in their quarries of origin. This is the case of the ancient quarries of Isaura and the Zengibar Castle in Turkey (Gökçe et al. 2020) or the limestones of Hontoria and the Burgos Cathedral in Spain (<https://info.igme.es/ielig/LIGInfo.aspx?codigo=IB021>). These sites are part of the surrounding communities and are perceived by the inhabitants, so that a strong social component is also integrated into them as the quarries are a symbol of their way of life and the demand for social material in their period of activity (Prosser 2019). The evaluation and dissemination of the places of extraction of singular rocks are a relevant tourist attraction (Mateos et al. 2011). These quarries can be a great potential for local development, such as quarries and abandoned mining sites in Iran that could be used for tourism and educational purposes in degraded rural areas, with activities such as guided tours of the sites (Mehdipour Ghazi et al. 2021). The cuts made for the exploitation of the stone in the quarries leave vertical walls in the landscape that are generally not covered with vegetation, and allow the observation, study and characterisation of numerous geological features. In many cases, these sites have great potential as geosites, as is the case of the *Libero* quarries (Todaro 2019), the ancient quarries of *La Vaglia* (Matera, Italy) (Bonomo et al. 2019) or the *Marès* quarries in Mallorca (Spain) (Mateos et al. 2011). All of them are frequently used for tourist visits or educational and informative excursions. In the *Marès* Quarries (Spain), a tourist space has been created that combines geology, art and history, is open to the public and is used for numerous activities (Lithica 2021).

The main objective of this work is to valorise the main exploitation quarry of the *Red Ereño, Cantera Gorria*. In order to value it, it is necessary to know it, which is why this work includes all the features, both geological and cultural, of *Cantera Gorria*. It also proposes a plan for the use of this space, in educational and informative ways and for tourism and leisure. There are several reasons that support this objective: (a) there are numerous geological features that can be recognised/observed in its different cuts; (b) the antiquity of the exploitation of this rock; and (c) this space is currently used as a place for teaching and research. Furthermore, its vertical red walls and its different squares and buildings generate great curiosity, so it is also an environment with potential interest for tourism and entertainment.

Red Ereño

Location and Geological Context

The study area is located in the North of the Iberian Peninsula, in the province of Bizkaia (Basque Country, Spain), inside the Urdaibai Biosphere Reserve, declared by UNESCO in 1984 (Government of the Basque Country 2021) (Fig. 1). This privileged environment is characterised by an abundant natural

and cultural heritage. The reserve, since its origin, has been regulated by means of a management strategy that respects nature and has a markedly social character. The rich geodiversity of the environment is evident in the numerous Sites of Geological Interest designated in the reserve, both by the IELIG (*Inventario Español de Lugares de Interés Geológico*; Spanish Inventory of Sites of Geological Interest) (IELIG 2021) and by the autonomous community in the inventory of sites of geological interest of Basque Country (Government of the Basque Country 2015). One of them corresponding to the main exploitation quarry of *Red Ereño, Cantera Gorria (Kanteragorria)* (Fig. 1), designated by IELIG (PV015; <http://info.igme.es/ielig/LIGInfo.aspx?codigo=PV015>) and by the Autonomous Community (LIG 15; https://www.ingurumena.ejgv.euskadi.eus/r49-u95/es/contenidos/informacion/lig/es_def/adjuntos/015.pdf) (Mendia et al. 2011). *Cantera Gorria* is located east of the Urdaibai Reserve (43° 21' 34.81" N; 2° 38' 01.81" W; 207-m altitude) (Fig. 1) and is owned by the municipality of Gautegiz-Arteaga (Bizkaia, Spain).

The limestones quarried as ornamental rock under the name of *Red Ereño*, outcrop in a band parallel to the stratification in a WNW–ESE direction, are intimately linked to the Ereño fault, at the base of the Santimamiñe Limestone Unit (Agirrezabala 1996) of Lower Cretaceous age. The exploited sector corresponds to a narrow strip, 1500 m long and 166 m thick, which stands out for its red-coloured micritic matrix, as against the grey-coloured matrix of the rest of the unit (Fig. 2). This calcareous unit was deposited north of the Basque-Cantabrian Basin, on a shallow subtropical marine platform (Damas Mollá et al. 2021a) and in a rift context related to the opening of the Bay of Biscay (Robles 2014).

Main Points of Exploitation

The *Arkeologi Museoa* of Bilbao (Archaeological Museum) conserves a votive altar and a milestone from the roman period (first century), carved in *Red Ereño*, which come from the site of Forua (Bizkaia, Basque Country) (Ybarra y Bergé, 1955) located near the town of Ereño. During the Middle Ages and until the beginning of the twentieth century, small quarries proliferated between the towns of Ereño and Gautegiz Arteaga (Bizkaia) (Damas Mollá et al. 2021a). The history of these quarries was not documented until the end of the twentieth century, because they were family and/or community quarries, with limited rock extraction. Even so, the name and location of several of these quarries are known (Quarries on Mount *Geranda* and *Lucas II* or *Gorri*, on the surroundings of the municipality of Ereño; *Aldekozea*, in the neighbourhood of Atxoste; *Atzarraga* or *Andrabide* to the west). The major quarry, *Cantera Gorria* (Fig. 1), finished its activity in the twentieth century (Pereda García 2004), and so it is the best preserved and documented.

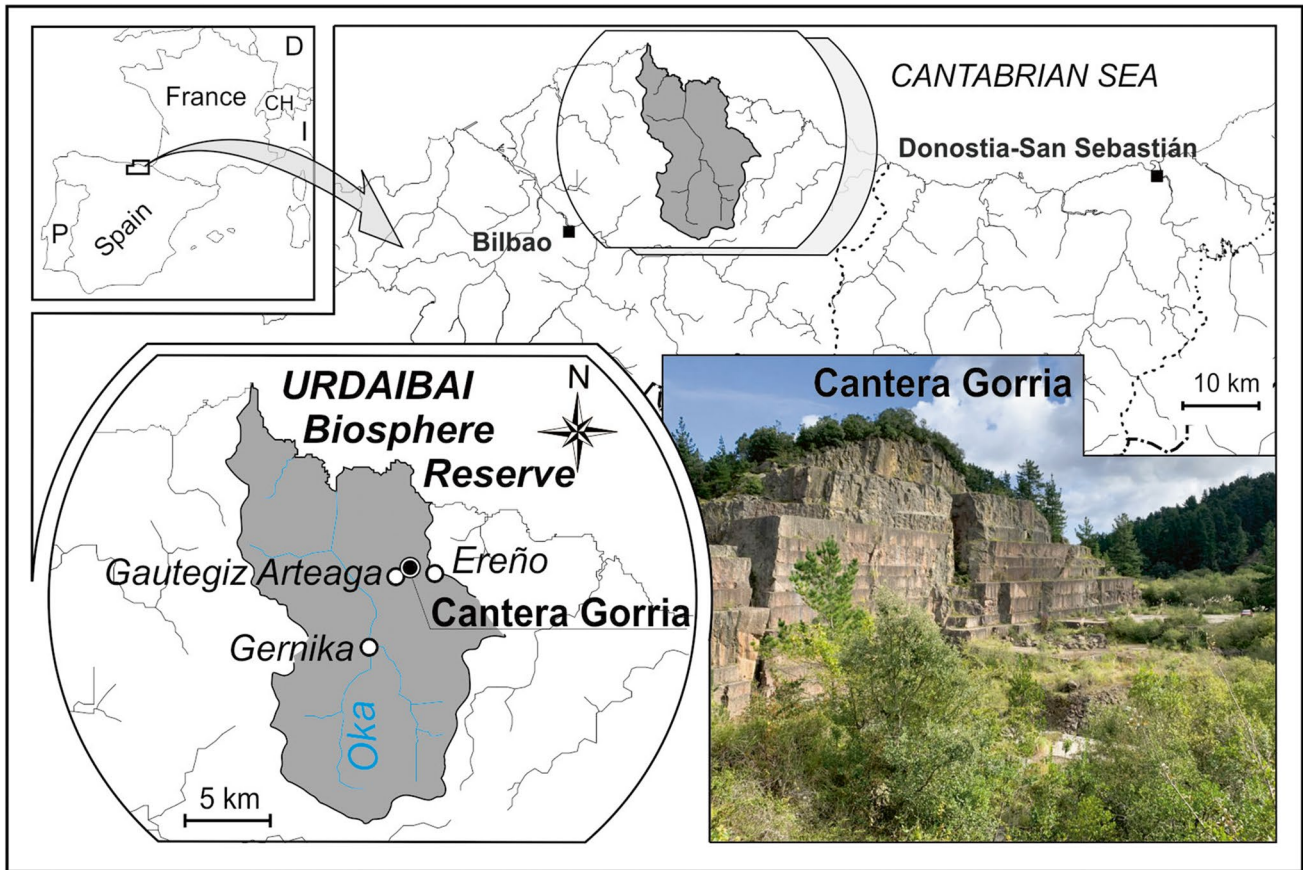
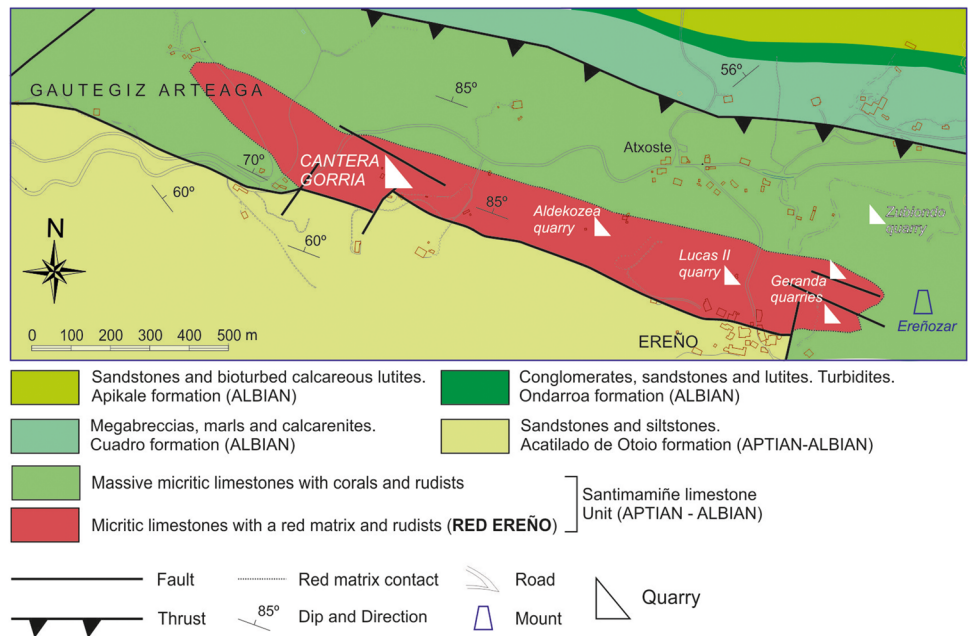


Fig. 1 Geographical location and panoramic photograph of *Cantera Gorria* within the Urdaibai Reserve

Fig. 2 Simplified geological map of the area with the location of the main *Red Ereño* quarries (modified from IGME 2009 and Damas Mollá et al. 2021a)



The Use of *Red Ereño* as an Ornamental and Structural Stone

There are currently numerous examples of architectural heritage elements that use *Red Ereño* as a structural and ornamental material. This lithology is present both in the regions close to its location and throughout the Iberian Peninsula and the Canary Islands. It has even crossed borders and is found in buildings in the Vatican and America (Damas Mollá et al. 2021a). Figure 3 and Table 1 show some examples of the use of Rojo Ereño. This stone has been used as a construction material for decorative elements (fountain of the emblematic *Iturribide* street of Bilbao (Bizkaia) (*iturri* means fountain and *bide* track in Basque language) (Fig. 3a), as a structural material (Church of *San Miguel* in Ereño (Bizkaia), stairs in *Euskal Herria* Museum in Gernika (Bizkaia) (Fig. 3b) or as an ornamental rock (Fronton or pelota court, space for the practice of *Herri Kirolak* (traditional rural sport in basque language) (Fig. 3c), floor of the entrance of St. Peter's Basilica in the Vatican (Italia) (Fig. 3d)).

Cantera Gorria

Cantera Gorria is the name currently used for the space of this old quarry. The origin of this name comes from *cantera* (quarry in Spanish), and the red colour of the stone, as the word *gorri*, means red in *euskera* (basque language, the only surviving language isolate in Europe). This quarry is currently abandoned. When it was active, its activity was also called *Cantera de*

Atzarraga or *Azarraga*, after a previous farmhouse in the area, or *Canteras de Andrabide*, in reference to the original name of this area (Pereda García 2004). In some documents, it is also called *Kanteragorria* but this word has no direct translation. It covers an area of approximately 30,000 m², and is owned by the municipalities of Gautegiz Arteaga, small municipalities with less than 1000 habitants (Basque Country, Spain) (Fig. 1).

Pereda García (2004) summarises the scarce data preserved on the exploitation of *Red Ereño* as an ornamental rock in this area. The origin is unclear; the author bases his work on the documents published by Delmas (1864), which indicate that at the end of the nineteenth century, exploitation was carried out erratically without any control. This type of exploitation, according to this author, could be due to the fact that the land was communal and, therefore, its exploitation has been communal. It was not until the end of the nineteenth century, in 1890, that information was recorded in the Archive of the Provincial Council of Bizkaia (A.D.F.B 1890) about the beginning of the exploitation of this large quarry. *Marmolería Bilbaína*, S.L. was the company in charge of its most intensive phase (1968–1989), until the activity ceased and the quarry was abandoned.

Geological Features

Cantera Gorria is an exceptional place to observe, recognise, study and interpret numerous geological features. They allow us to understand not only the evolution of a shallow carbonate marine platform, but also many aspects related

Fig. 3 **a** Fountain in Iturribide Street in Bilbao (Bizkaia, Spain) from 1894. **b** Stairs of the Euskal Herria Museum in Gernika (Bizkaia, Spain). **c** Floor tiles on the outside of the Ispaster pelota court (Bizkaia, Spain). **d** *Red Ereño* tiles at the entrance of St. Peter's Basilica in the Vatican (Italy)



Table 1 Examples of the use of *Red Ereño* in architecture

Building	Location	Year	Architecture	Use of <i>Red Ereño</i>
Church of <i>San Miguel</i>	Ereño (Bizkaia, Spain)	1560–XVII	Renaissance temple with a nave and side tower	Structural (Plinth for altarpiece support)
<i>Arteaga</i> Castle	Gauteguiz Artega (Bizkaia, Spain)	1856 (Reconstruction of a fifteenth-century tower house)	Neo-medieval palace with neo-gothic tower (French influence)	Structural
Church of <i>Santa Clara</i>	Gernika-Lumo (Bizkaia, Spain)	1890	Neo-Gothic convent (Italian neoclassical). Latin cross plan with a single nave divided into three bays and a side chapel	Structural (on façade and interior segmental arch)
Basilica of <i>Begoña</i>	Bilbao (Bizkaia, Spain)	Siglo XVI	Late Gothic style, and Renaissance main doorway	Structural and furnishings (Stairs to the main altar and baptismal font)
Bilbao Stock Exchange building	Bilbao (Bizkaia, Spain)	1905	Neoclastic	Structural (interior columns first floor gallery)
Palace of <i>Victor Chávarri</i>	Bilbao (Bizkaia, Spain)	1888	Eclectic style (inspired by neo-flamenco revivalism)	Structural (on façade)
Palace of the <i>Cortes</i>	Madrid (Madrid, Spain)	1843	Neoclastic	Cladding. (Interior paving)
Regional Assembly of Murcia	Cartagena (Murcia, Spain)	1991	Modernist style (architectural influences of the Renaissance)	Aplacado (gradas en el interior)
Central Library of Cantabria	Santander (Cantabria, Spain))	1900	Industrial building (former tobacco warehouse)	Cladding. (Interior paving)
Basilica of Santa María la Real	Covadonga (Asturias, Spain)	1877	Neo-Romanesque style (some Gothic elements). Three naves with groin vaults and two slender towers	Cladding. (Exterior paving)
<i>Colón</i> Theatre	Buenos Aires (Argentina)	1908	Neo-Renaissance (Italian influence) and French Baroque	Aplacado (widows' box)
St. Peter's Basilica	The Vatican (Italy)	1626	Renaissance and Baroque	Cladding. (Interior paving)
Faculty of Medicine, University of Valladolid	Valladolid (Spain)	1960	Postmodern	Cladding. (Interior paving)
Residential Building <i>Horreo</i>	Barakaldo (Bizkaia, Spain)	1960	Commercial space	Cladding (façade)
Roman's votive ara and cip	Ereño (Bizkaia, Spain)	Twenty-first century	Recreation of traditional architecture	Structural in stairs
Fountain	Forua (Bizkaia, Spain)	First and second centuries	Decorative	Block
Fountain	Ispaster (Bizkaia, Spain)	1927	Decorative	Structural
Fountain	Lekeitio (Bizkaia, Spain)	1888	Decorative	Structural
<i>Casa de Juntas</i>	Bilbao(Bizkaia, Spain)	1894	Decorative	Structural
<i>Euskal Herria Museum</i>	Gernika (Bizkaia, Spain)	1826	Neoclastic	Block carved coat of arms and holy water font. Decorative
Fronton (Court) <i>Herri Kirolak</i> (traditional rural sport in basque language)	Ispaster (Bizkaia, Spain)	1733	Barroque	Stairs, structural and decorative
		-	-	Decorative, floor tiles

to digenesis. It is these features, precisely, that provide the especial features to this lithological variety and generate the greatest interest, such as, for example, the origin of its red colour (Damas Mollá et al. 2021b).

The outcrops caused by the exploitation of the quarry allow the observation and study of different geological features: (1) the palaeontological content of the limestones; (2) palaeoenvironmental conditions prevailing during their formation; (3) diagenetic features; (4) tectonic features; and (5) geomorphological modelling.

Palaeontological Content

The fossils of bivalves, especially polyconitid rudists, provide the singular feature of this ornamental lithology. The different quarry faces that have been made during the exploitation of *Cantera Gorria* allow us to observe sections of the shells in different

axes, as well as the association of fossils (palaeoecology) of organisms that made up the Aptian-Albian marine platform.

Polyconitid rudists are the most abundant. Their lower shell is conical, about 10 cm long and 5 cm in maximum diameter (V-shaped in longitudinal section and circular in cross section) (Fig. 4a, b and c). Its upper shell is flat, but it is difficult to observe in the quarry. They have two distinct layers, between 0.5 cm and 1 cm thick: an outer calcitic layer with a prismatic microstructure (greyish tones), and an inner layer, which was originally aragonitic, but is currently of sparitic calcite (white) (Fig. 4b and c). Polyconitids are gregarious organisms of carbonate, subtropical and oxygenated platforms, which live sessile to the substrate in areas of active waves (Fig. 5). Thus, they form large accumulations of hundreds of individuals known as thickets (Cestari and Sartorio 1995). In the fronts of the quarry, it is possible to observe these levels in different sections.

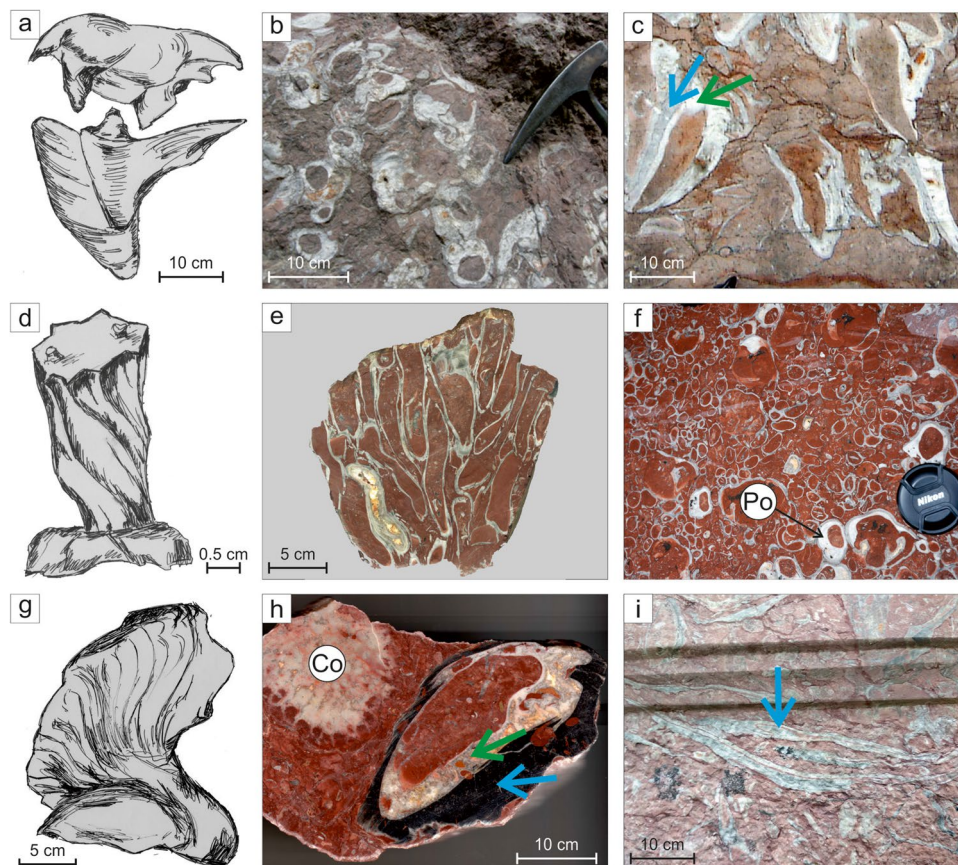


Fig. 4 **a** Illustrative engraving of polyconitid rudist by R. Damas (based on Dechaseaux et al., 1969). **b** Cross-section of a group of polyconitid rudists in *Cantera Gorria*. **c** Longitudinal section of a group of polyconitid rudists in *Cantera Gorria* (the blue arrow shows the calcitic layer; the green arrow shows the aragonitic layer). **d** Illustrative engraving of monopleurid rudist by R. Damas (based on Dechaseaux et al., 1969). **e** Longitudinal section of a bouquet of monopleurid rudists in a sample taken at *Cantera Gorria*. **f** Cross-section of a bouquet of monopleurid rudists in on floor tiles of the

Arriaga Theatre in Bilbao (Bizkaia, Spain). They are surrounded by polyconitid rudists (Po). **g** Illustrative engraving of requienid rudist by R. Damas (based on Dechaseaux et al., 1969). **h** Cross-section of a requienid rudist (Re) and a coral (Co) in a sample taken at *Cantera Gorria* (the blue arrow shows the calcitic layer; the green arrow shows the aragonitic layer). **i** Cross-section of a group of *Chondrodonta* sp. on the steps of the *Euskal Herria* Museum in Gernika (Bizkaia, Spain). The blue arrow marks the separation zone between both shells

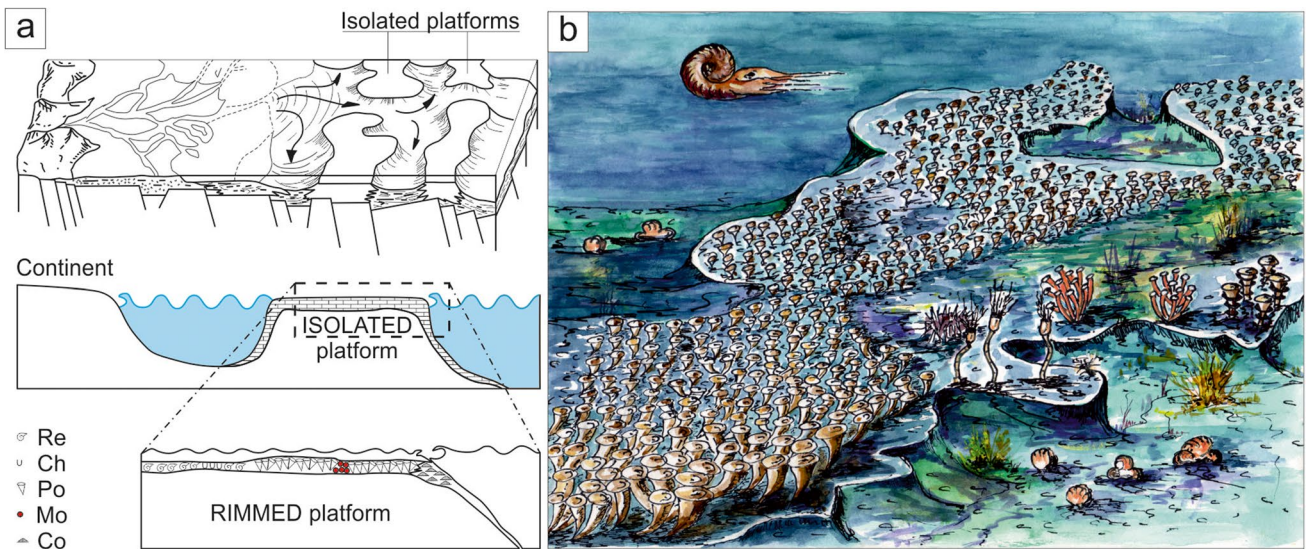


Fig. 5 **a** Top: schematic of the isolated platform model. Middle part: isolated platform type of the Boggs (2009) model which corresponds to the Santimamiñe platform of the Ereño limestones formation. Lower part: isolated platform sector corresponding to a rimmed type

model as defined by Boogs (2009) with the main fossils represented in its environment (Mo: monopleurids; Po: polyconitids; Re: requienids; Ch: *Chondrodonta* sp.; Co: corals). **b** Interpretative drawing of a platform of the Santimamiñe type during the Cretaceous by R. Damas

In the shelter of the polyconitid rudists are small bouquets of tens of monopleurid rudists. They are sessile individuals, with cylindrical elongated shells. Their shells are the same length as the polyconitids, since, like the latter, they grow vertically to compensate for the sediment deposit in the environment, but their diameter is smaller (1–2 cm). They are also much thinner, barely 2 mm, with two distinct light-coloured layers: the outer one generally having vertical ribs, which in cross-section resemble a cogwheel (Figs. 4d, e and f).

In other sectors, clusters of tens of fossil shells of requienid rudists can be recognised. They are benthonic organisms, but do not live sessile. The morphology of their shells is coiled, so the cuts generated in the blocks, quarry faces and quarry squares are varied, generally kidney-shaped or triangular (5–8 cm). Their fossil shells were characterized by two layers about 3 to 4 cm thick: the outer layer (calcitic, prismatic) is shiny black and the inner layer (originally aragonitic but nowadays as a mosaic of sparite crystals) is whitish in colour (Fig. 4g and h). They are associated with more reductive and lower energy environments.

Chondrodonta sp. are inequivalve molluscs with flat, thin shells, linked by a hinge in the form of a double hook in longitudinal section. They are common in low-energy, muddy shelf environments. In general, they form associations, in the form of elongated bouquets, with the shells semi-buried in the substrate. Their size is variable, but in *Cantera Gorria*, they are around 10 cm long, with a foliated microstructure of greyish and whitish colours. In section, a thin red line formed by micritic matrix can be distinguished between the two shells (Fig. 4i).

Sedimentary Facies and Palaeoenvironment

In the Basque-Cantabrian Basin, important part of Lower Cretaceous stratigraphy is represented by large units of bioconstructed limestones, known as Urgonian limestones (García-Mondéjar 1990; García-Mondéjar et al. 2004). These Barremian-Albian limestones were most developed on the margins of the Tethys and are characterised by a predominance of shallow marine biogenic carbonates with bioherms and biostromes (lenticular and tabular bioconstructions, respectively) of corals and rudists. Bonvallet et al. (2019) provide an exhaustive study of the Helvetic shelf in Switzerland and present a complete compilation of references from previous studies of outcrops from Spain to Pakistan and from Morocco to the Middle East, with some occurrence in South and Central America and the Pacific coast. Most of them formed isolated platforms, flanked by siliciclastic units (Fig. 5a top and middle part). One of these platforms is the *Santimamiñe* platform, which included the limestones that are currently known as *Red Ereño* (Agirrezabala 1996). This unit lies between the *Acantilado de Otoio* Formation, at its base, and the *Cuadro*, *Ondarroa*, *Apikale* and *Deba* formations, at the top (IGME 2009; Damas Mollá et al. 2021a) (Fig. 2). In detail, the *Santimamiñe* platform could be classified as a rimmed platform (Fig. 5a bottom part) (Boogs 2009). In the middle part of the platform, with moderate energy, bioconstructed banks developed with abundant polyconitid rudists and some monopleurids. In the more sheltered areas, with somewhat greater depth and medium/low

energy, there was a proliferation of rudist requienids and *Chondrodonta* sp. On the outer part, some coral colonies developed, but, in this case, they are not representative of the rock exploited as ornamental, as they are usually found in grey matrix facies (Fig. 5a bottom part). Figure 5b presents a recreation of one such platform.

In the *Cantera Gorria* sector, five types of facies have been identified (Damas Mollá 2011), many of which are related to each other in different repetitive sequences and lateral facies changes. The quarry faces and the quarry squares allow for different sections of these facies and allow for three-dimensional views of the relationships between them. The criteria for classifying each facies are determined according to the predominant larger fossils, their position in the series (living or non-living position) and the degree of reworking of the skeletal material (complete or fragmented). The five facies have been named on the basis of the petrological classification of Embry Klován (1971) or Dunham (1962) and the predominant fossil type. Thus, are defined as follows:

- Facies A—*Framestone and Bafflestone* (Embry and Klován 1971). This is characterised by the preservation of entire skeletal material, in a living position, embedded in a micritic matrix. Two types can be distinguished:
 - A1) *Framestone* (Embry and Klován 1971) of polyconitic rudists, represented by large thickets of hundreds of individuals in direct contact with each other, forming a large continuous lateral framework, like the RFA (Rudist Facies A) defined by Cestari and Sartorio (1995) (Fig. 4b). This facies are the most appreciated in their use as ornamental rock (Fig. 3c and d).
 - A2) *Bafflestone* (Embry and Klován 1971) of *Chondrodonta* sp. These are thin layers between 1 and 2 m thick with the shells of these bivalves in an entire life position. They are less continuous laterally than the previous ones with clusters of tens of individuals in the form of decimetric bouquets.
- - Facies B—*Boundstone* (Dunham 1962). They correspond to micritic facies with whole fossils, but, not in life position, with some transport. Two types can be distinguished:
 - B1) Requienuid *boundstone*. These are entire rudists with a limited transport.
 - B2) *Boundstone* of *Chondrodonta* sp. with whole shells, but not in life position because of external processes, such as storms (Fig. 4d).

The following facies are characterised by different concentrations and sizes of bioclasts embedded in a micritic matrix. Thus, they are differentiated:

- Facies C—*Floatstone* (Embry and Klován 1971). Bioclasts larger than 2 cm with abundant matrix.
- Facies D—*Rudstone* (Embry and Klován 1971). Bioclasts larger than 2 cm in contact with each other.
- Facies E—*Wackestone/Packstone* (Dunham 1962). Bioclasts less than 2 mm with varying proportions of matrix depending on the study area.

Figure 6 shows the main facies and facies associations that outcrop in the largest square of the *Cantera Gorria*.

Diagenetic Features

One of the most striking aspects of *Red Ereño* is the red colour of the matrix and its contrast with the fossil shells, which are generally lighter in colour (Fig. 3d). This is one of the most striking diagenetic features. The red colour is due to the presence of pigmentary haematite, an ultrafine-grained iron oxide that stains the micritic matrix of the rock red. Despite the intensity of the colour, mineralogical analyses by X-ray diffraction have shown that the concentration of haematite is low or hardly detectable due to its size. Haematite is found in greater concentration in areas of stylolitic scars (Fig. 7a). Another aspect related to colour is the absence of red pigmentation in the fossil shells of bivalves. Different magnetic experiments, petrological observations and geochemical analyses have shown that the iron input occurs in an intermediate diagenetic stage, when the rudist shells were already protected/closed by neomorphic processes (crystal growth or transformation into polymorphs without generating porosity (Folk, 1965)) (Damas Mollá 2011), but the compaction of micrite was not yet complete. The formation of stylolites is due to pressure/dissolution processes linked to the mechanical-chemical compaction of the rock (Damas Mollá et al. 2021b; Damas Mollá, 2011). The dissolution of calcium carbonate, therefore, increases the concentration of the red pigment in the areas of the micrite affected by stylolites, so the red micrite is more concentrated in the stylolites (Fig. 7a).

Tectonics

The *Cantera Gorria* area is notable for its very intense syn-sedimentary tectonics (Agirrezabala 1996). But the post-depositional tectonics has also strongly affected the area, verticalising the series to dips of 85° NE. Three main fault systems are recognised and are easily observed in the quarry faces. One of the most vertical cuts is a large fault plane which has the orientation of the major quarry faces and has displacements of up to 30 cm (Fig. 7b). Diaclases perpendicular to the layering are also recognised.

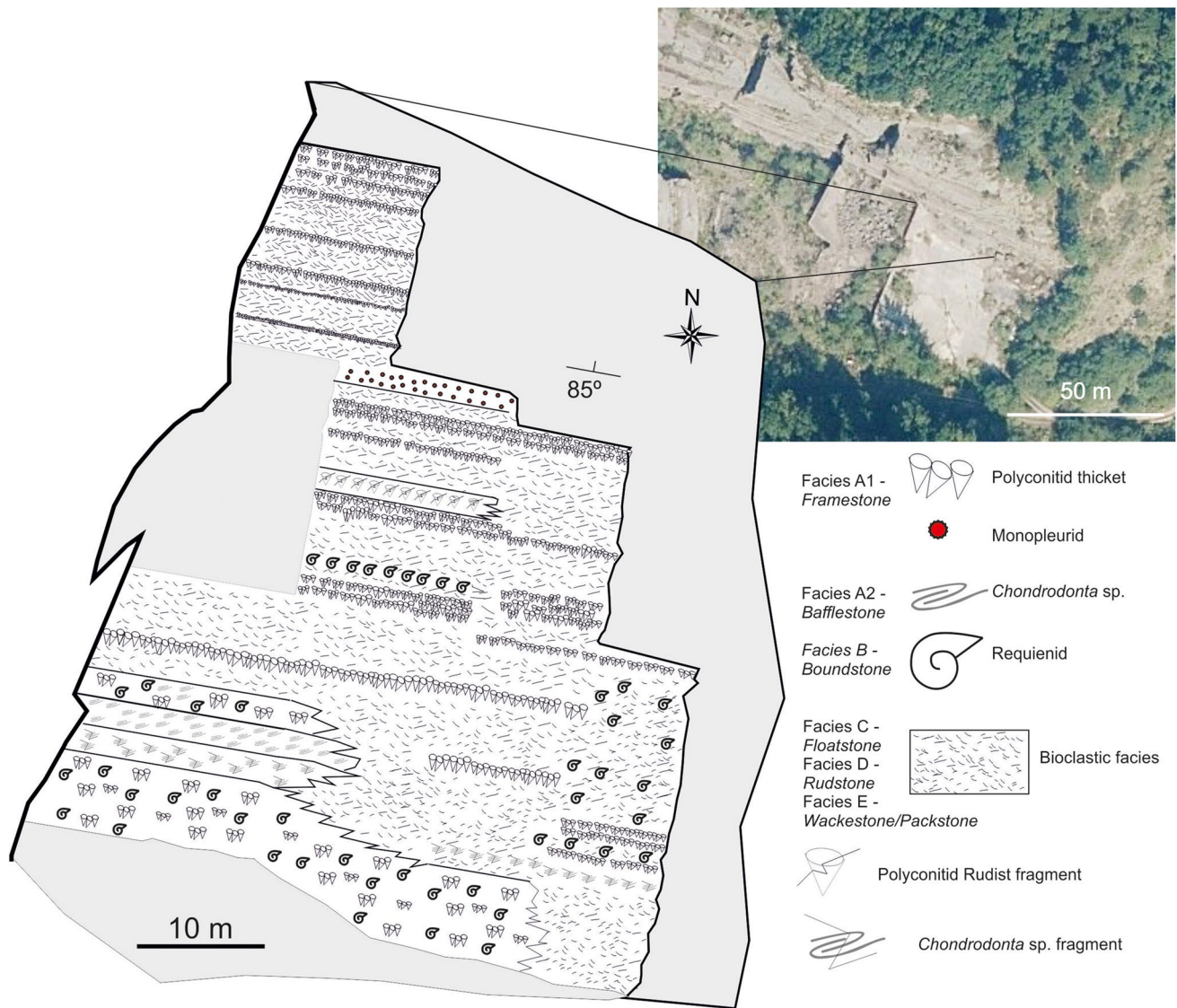


Fig. 6 Distribution of the fossil associations and the facies present in the upper square of the main front of *Cantera Gorria* (modified from Damas Mollá 2011)

Geomorphological Modelling

The main geomorphological feature in the area is karst. On the scale of *Cantera Gorria*, the exokarst features have generated a pronounced lapiaz almost completely covered by vegetation. In the areas where the limestones are most exposed, such as in the areas that have been left uncovered as a result of the quarrying activity, subvertical water filtration conduits can be recognised, developed along the previous diaclastic system. It can be inferred, therefore, that the evolution of the karst (endokarst) in the Ereño limestones has a clear structural control.

In the upper section of the quarry, a section of a karstic cavity (gallery) of a phreatic water channel with a sub-horizontal development in a north–south direction, 5 m in

diameter and about 30 m in length, is preserved (Fig. 7c and d). Inside it, subparallel erosion lines with a horizontal arrangement and a regular spacing between them can be recognised, marked on what were once the walls of the cavity, reflecting the different palaeo-levels of the water. At the same time, deposits of both siliciclastic and chemical material (carbonate) can be seen in the form of speleothems (Damas Mollá 2011).

Geoheritage

It should be highlighted that this unique place is part of the geoheritage. In 1990, it was included in the list of Points of Geological Interest in Bizkaia, under the name of Mármol de Ereño (Ibargutxi and Bombín 1990). It is presently included

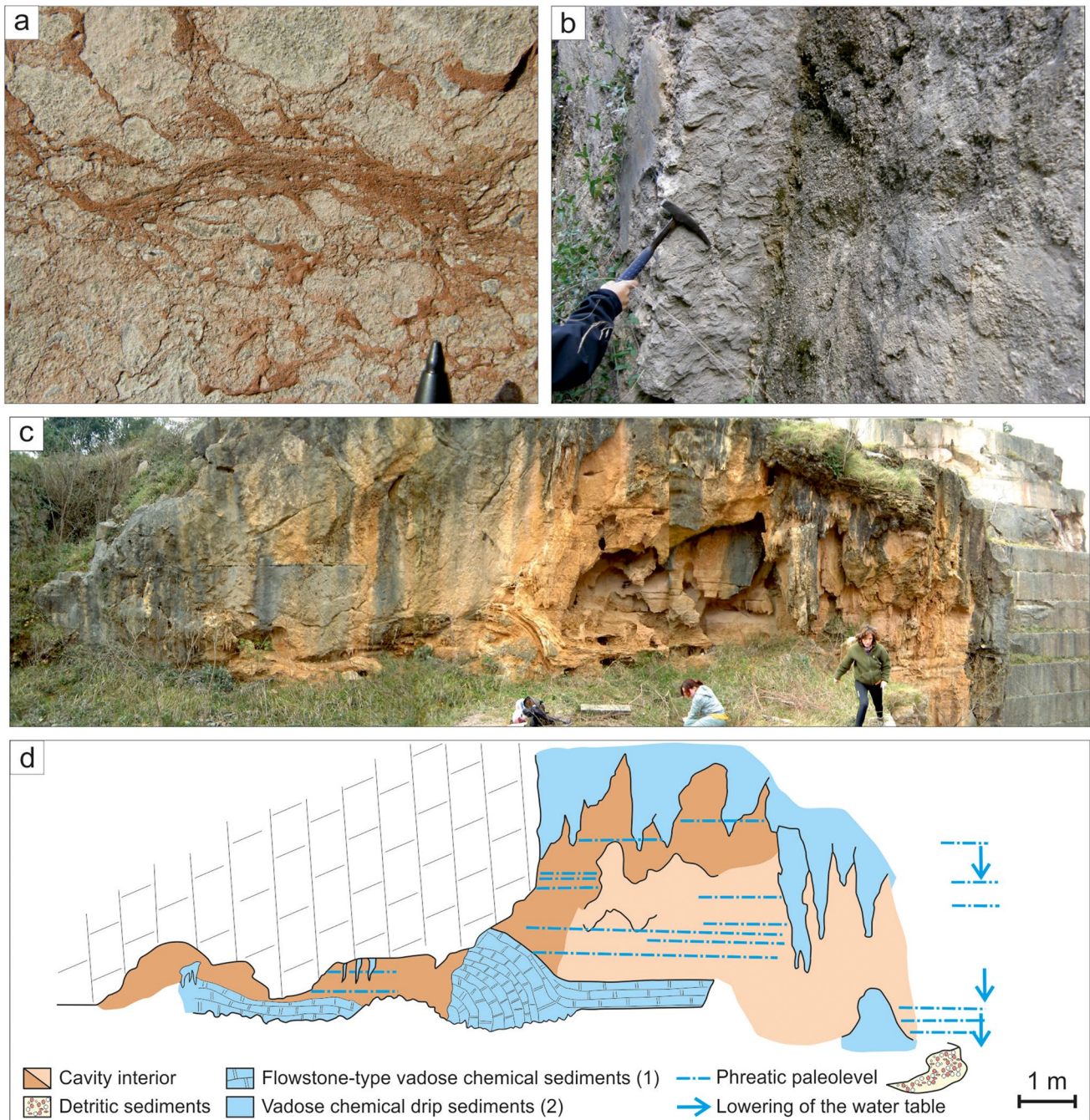


Fig. 7 **a** Stylolites with a high concentration of iron minerals at *Cantera Gorria*. **b** Fault scarp of 30 cm in one of the fronts of *Cantera Gorria*. **c** Phreatic channel developed in the upper part of *Cantera*

Gorria with the formation of speleothems. **d** Interpretative diagram of the previous image

in the inventory of Places of Geological Interest of both the Autonomous Community (Government of the Basque Country 2015) and the State (IELIG 2021).

The evaluation of *Cantera Gorria* has been conducted according to the methodology of the IGME (2018) in order to be able to make a comparison with other similar Places of

Geological Interest of Spain. There are three criteria used in the evaluation: its importance or scientific value, its didactic value and its tourism potential. In order to calculate the value of the Places of Geological Interest, a series of tables with different parameters are used, which are ranked from 1 to 4, and which are also weighted according to the case to

be assessed. When applying this methodology, the values will be less than 10, so that the value obtained according to the scientific parameters is 5.88, the didactic value is 7.25 and the tourist value is 6.13. These values include *Cantera Gorria* within a Places of Geological Interest of very high didactic value and high scientific and tourist value (Table 2).

In addition, the susceptibility and risk of degradation of the space, both natural and anthropic, have been evaluated. The susceptibility to degradation, i.e. the ease with which the area can be degraded according to its size, fragility and vulnerability, is both natural and anthropic. It is also calculated according to a series of parameters listed

Table 2 Valuation of *Cantera Gorria* as a Place of Geological Interest according to the methodology established by IGME (2018) (very high value > 6.65 points; 3.33 < high value < 6.64; medium value < 3.32 points)

		Scientific value (V_C)	Didactic value (V_D)	Touristic/recreational value (V_T)	
Representativity (R)	Useful as a model to represent, in its totality, a feature or process	2×30	60	2×5	10
Locality character type (T)	It does not comply with the three premises indicated	0×10	0	0×5	0
Degree of scientific knowledge of the site (K)	Researched by several scientific teams and the subject of doctoral theses and internationally referenced published works	4×15	60	4×0	0
State of conservation (C)	Favourable with alterations: some deteriorations that do not decisively affect its value or interest	2×10	20	2×5	10
Observation conditions (O)	Perfectly observable practically in its entirety with ease	4×10	40	4×5	20
Rarity (A)	One of the few known examples at regional level	1×15	15	1×5	5
Diversity (D)	The site presents three or more interest rates in addition to the main interest rate, or only two but both are relevant	4×10	40	4×10	40
Didactic content (C_{DD})	It is commonly used in teaching activities at all levels of the education system	4×0	0	4×20	80
Logistics infrastructure (I_L)	Accommodation and restaurants for groups of 40 people less than 5 km away	4×0	0	4×15	60
Population density (D_P)	More than 1,000,000 inhabitants within a radius of 50 km	4×0	0	4×5	20
Accessibility (A_C)	Direct access by unpaved track, but passable with vehicles	1×0	0	1×10	10
Site size (E)	Decametric features	1×0	0	1×5	5
Association with other elements of natural and/or cultural heritage (NH)	Presence of other elements of both cultural and natural heritage within a radius of 5 km	4×0	0	4×5	20
Spectacularity or beauty (B)	It coincides with two of the three premises (wide relief and remarkable chromatic variety), and in addition, it has attractive fossils	2×0	0	2×5	10
Divulgative content (C_{DV})	It is being used regularly for outreach activities	4×0	0	4×0	0
Potential for tourism and recreational activities (P_{TR})	There are organised activities	4×0	0	4×0	0
Proximity to recreational areas (Z_R)	Site less than 2 km and more than 500 m from a recreation area	2×0	0	2×0	0
Socio-economic context (E_S)	Location in a county with per capita income, education and employment rates similar to the regional average	1×0	0	1×0	0
		$\sum V_C/40 = 5.88$	$\sum V_D/40 = 7.25$	$\sum V_T/40 = 6.13$	

in the aforementioned document (IGME 2018). Thus, the natural susceptibility value obtained for *Cantera Gorria* is 0.38, within the low/medium threshold (<0.75 points), and the anthropic susceptibility value is 2.85 points, within the high threshold (> 2.5 points) (Table 3). With these values, the risk of degradation has been calculated and the results

obtained indicate that protection measures should be taken in the short term in *Cantera Gorria* as it has a high risk of anthropic degradation (2.07 points), although the risk of natural degradation is low (0.27 points) (Table 3). This may be due to the fact that it is a public space and access to it is completely free, without any measures or delimitation.

Table 3 Evaluation of the susceptibility, natural (S_{DN}) and anthropic (S_{DA}), of *Cantera Gorria* according to IGME (2018) (very high/high > 3.5; 3.4 < high/medium < 1.5; medium/low < 1.4). Assess-

ment of the risk of degradation, natural (R_{DN}) and anthropic (R_{DA}) in *Cantera Gorria* according to IGME (2018) (very high/high > 2.5; 2.4 < high/medium < 1; 0.9 < medium/low < 0.5)

		Susceptibility to natural degradation (S_{DN})
Size factor (E_F)	Decametric features (not vulnerable to visiting but sensitive to more aggressive anthropogenic activities)	6/400
Fragility (F)	Resistant or very resistant lithologies but with high fracturing and/or weathering	5
Natural hazards (A_N)	Space affected by natural processes of little relevance	5
$S_{DN} = E_F \times F \times A_N = 0.38$		
		Susceptibility to anthropic degradation (S_{DA})
Interest for mining or water exploitation (V_{UM})	Substance of great interest and of which there are no alternative exploitations	100
Vulnerability to spoliation (V_{UEX})	There are no palaeontological or mineralogical deposits, or they are difficult to extract	0
Proximity to anthropic activities (infrastructures) (V_{UI})	Place located less than 100 m from a main road, 1 km from an industrial or mineral activity, less than 2 km from urban land in cities with less than 100,000 inhabitants or less than 5 km in larger towns	15
Accessibility (potential aggression) (A_C)	Direct access by unpaved track, but passable for passenger cars	10
Site protection regime (P)	Site located in national or nature parks, nature reserves or other protected areas with a management plan and guards	5
Physical or indirect protection (P_F)	Place lacking any kind of physical or indirect protection	20
Land ownership and access regime (T_S)	Site located in open access areas (public or private property)	20
Population density (potential aggression) (D_p)	More than 1,000,000 inhabitants within a 50-km radius	20
Proximity to recreational areas (potential aggression) (Z_R)	Location more than 5 km from recreational areas (campsites, beaches...)	0
$S_{DA} = E_F \times [V_{UM} + V_{UEX} + V_{UI} + A_C + P + P_F + T_S + D_p + Z_R] = 2.85$		
Natural degradation risk (R_{DN})	$R_{DN} = \max (R_{DNC}, R_{DND}, R_{DNT})$	$R_{DNC} = 1/10 (V_C \times S_{DN})$ 0.22 $R_{DNC} = 1/10 (5.88 \times 0.38)$ $R_{DND} = 1/10 (V_D \times S_{DN})$ 0.28 $R_{DND} = 1/10 (7.25 \times 0.38)$ $R_{DNT} = 1/10 (V_T \times S_{DN})$ 0.23 $R_{DNT} = 1/10 (6.13 \times 0.38)$
Anthropic degradation risk (R_{DA})	$R_{DA} = \max (R_{DAC}, R_{DAD}, R_{DAT})$	$R_{DAC} = 1/10 (V_C \times S_{DA})$ 1.67 $R_{DAC} = 1/10 (5.88 \times 2.85)$ $R_{DAD} = 1/10 (V_D \times S_{DA})$ 2.07 $R_{DNC} = 1/10 (7.25 \times 2.85)$ $R_{DAT} = 1/10 (V_T \times S_{DA})$ 1.74 $R_{DAT} = 1/10 (6.13 \times 2.85)$

Mining Heritage Features

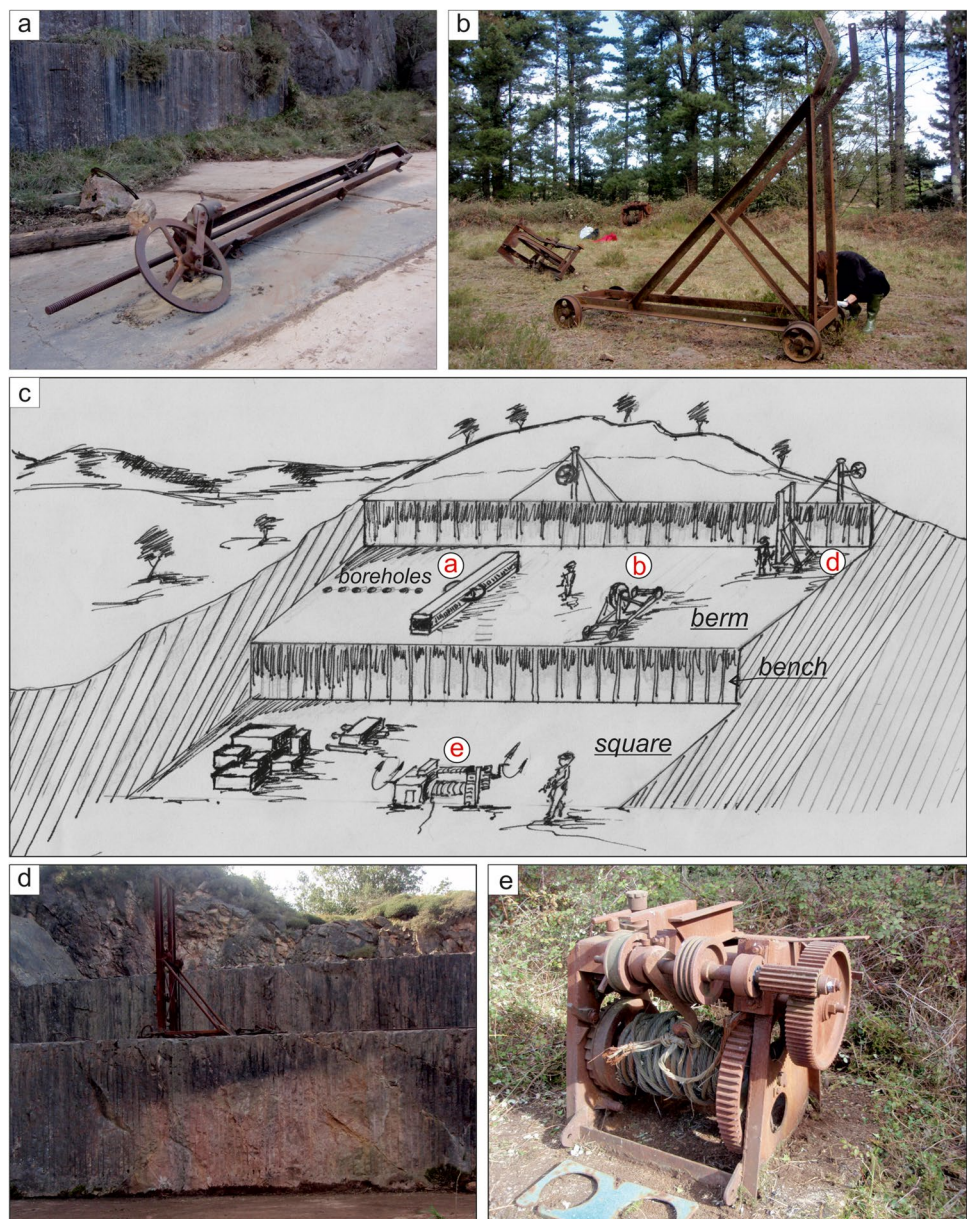
Red Ereño was exploited as an ornamental stone in *Cantera Gorria* by drilling auger (using hydraulic hammers in the last phase) and cutting with helical steel wire guided by flywheels strategically placed throughout the quarry (Damas Mollá et al. 2011). Most of the quarry’s machinery, especially the metal ones, have been plundered and are no longer preserved. On the other hand, some buildings used during mining persist, as well as numerous features related to the extraction method, are preserved in the quarry walls. In other adjacent private quarries (Fig. 8), however, elements in a good state of preservation have been documented, such as, for example, flywheels (Fig. 8a, c), trestles (Fig. 8b, c), block

pulling machines (Fig. 8c and e) and rails and jackhammer trestles (Fig. 8c and d), which could be used with the corresponding agreements if the case arose (Damas Mollá 2011). Figure 8c shows a recreation of the work in this type of quarries during the exploitation period of *Cantera Gorria*.

Regarding the exploitation of stone in *Cantera Gorria*, the different quarry fronts stand out for their intense red colour. The quarry has been divided into three main zones:

The canyon is a narrow cut (39 m wide by 70 m long) parallel to the bedding of the rock (N110° E), with almost vertical walls up to 50 m high (Fig. 9a). The south wall has up to 20 mining benches with a height of 1.5 m, but no berm between them (Fig. 9a and b), while the north wall corresponds to an extensive fault plane with well-marked

Fig. 8 Machinery preserved in the Aldekozea Quarry (small private family quarry) and a representative diagram of this type of quarry during its exploitation period in the mid-twentieth century. **a** Mobile floor wheel to guide the helical steel wire. **b** Trestle and mobile wheel to guide the wire. **c** Representation of the quarry (letters a, b, c and d represent the position of the elements in the photographs in the quarry). **d** Easel and mobile wheel to guide the wire. **e** Block pulling machine



striations and a step of about 30 cm (Fig. 9a and b). This canyon is located between the BI-2238 road and the main front (zone 2). Between the north wall of the canyon and the road, there are two walls parallel to each other and to the direction of the canyon, which form part of the exploitation, the lower one of ashlar and the upper one of masonry, both made of reddish Ereño limestone (Fig. 9b and c).

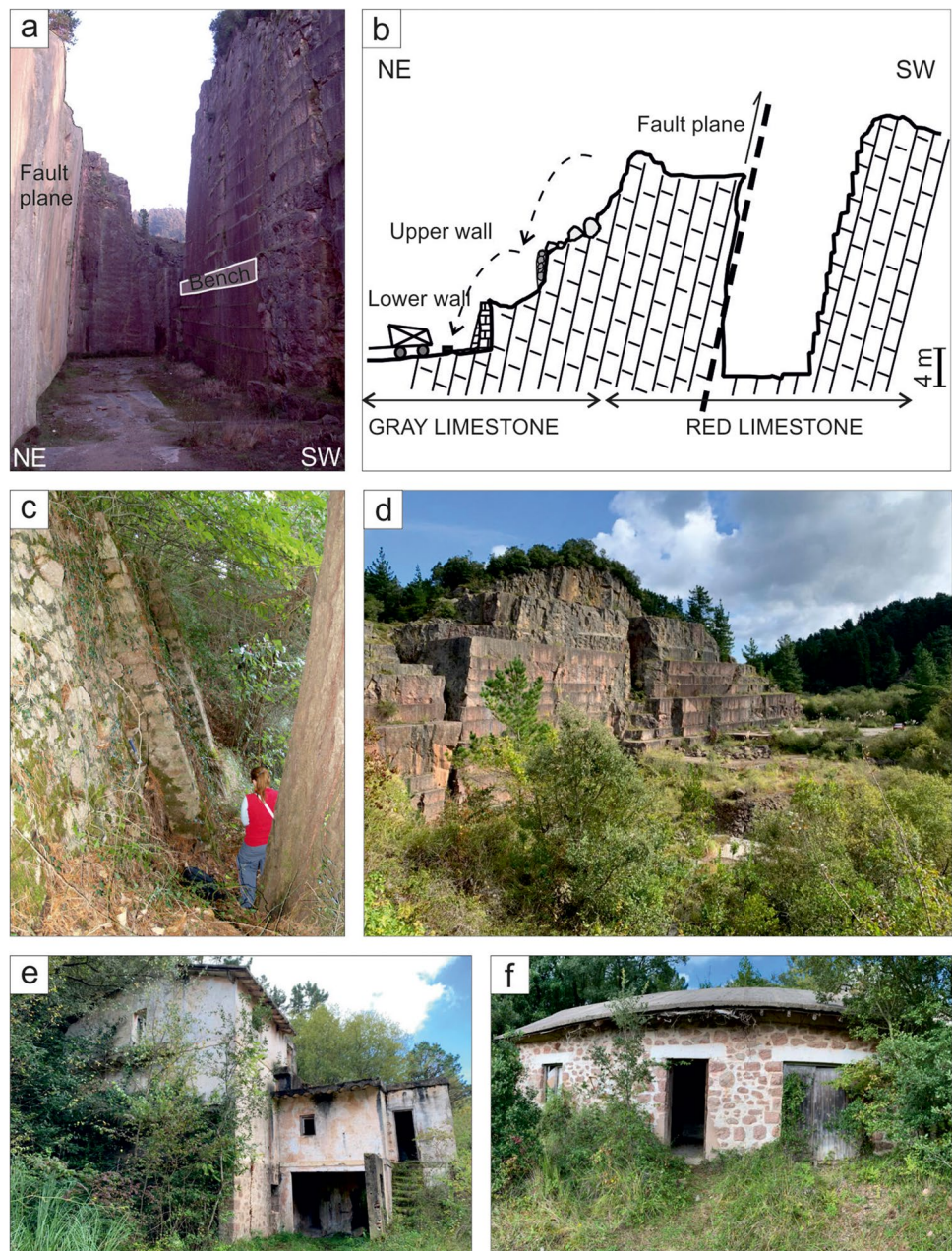
The main face (Figs. 1 and 9d) is the largest area of the quarry (with an area of approximately 10,000 m²) and is divided into three squares, positioned in a staggered manner, the lowest being the closest to the canyon. The direction of the quarry face is parallel to the stratification and has 14 benches, the 7 upper ones without a berm

between them and the other 7 with a berm. The height of the benches is about 2 m (Fig. 9d).

The method used for the extraction of blocks was based on the combination of augers and helicoidal wire. In the quarry, it is possible to observe the holes left by the drilling and the arrangement of these holes to cut the blocks, as there are some that are prepared for extraction. In addition, the marks of the helicoidal thread can be seen. In some areas, fragments of augers driven into the rock and the remains of the steel wire are preserved.

The zone 3 is located to the south of the exploitation and is the highest. It has two different heights, and its exploitation was neglected, as the floor of the main plaza

Fig. 9 **a** The canyon from the road. **b** Diagram representing a cross-section of the canyon with the load-bearing walls in Fig. 9c. **c** Lower load-bearing wall made of Ereño limestone masonry. **d** Panoramic view of the main front of *Cantera Gorria*. **e** Building of *Cantera Gorria* located in the lower part. **f** Red Ereño masonry building located in the upper part, between zones 1 and 3. It housed the main wheel and different machinery



shows irregularities typical of the unstressed steel wire. In this area, the rock is not as deep red as in the previous ones. It stands out because it is located in an elevated area and it is here that the different buildings of the exploitation are seen (Fig. 9e and f). The building where the machinery was located and the main wheel is located in the highest part together with a water tank, and it is built with masonry of this stone (Fig. 9f).

The state methodological guide of Spain for the integration of mining heritage in the Environmental Impact Assessment (IGME 2012) assesses this type of heritage by means of a series of intrinsic and use parameters, weighted according to different coefficients. This methodology has been applied to *Cantera Gorria* (Table 4), obtaining a score of 165, which is included within the medium range of interest in terms of mining heritage at state level.

Cultural and Dissemination

Cantera Gorria, in addition to being Geoheritage and Mining Heritage, is part of the Historical Heritage of the province of Bizkaia, with the denomination of Quarries of Andrabide (Provincial Council of Bizkaia 2021) and, as such, is an element that combines the culture and nature of the environment. Moreover, in the Basque Country, rock, as such, forms an intrinsic part of the intangible heritage of society, for example, the so-called *Idi-probak* (ox tests in basque language: <https://www.youtube.com/watch?v=tnOgB-DPem8>), *harrijasotzaileak* (stone lifters in basque language: <https://www.youtube.com/watch?v=RiItKksyavA>) and *harri-zulatzaileak* (stone borers in basque language: https://www.youtube.com/watch?v=_vc0nJTjoG8), which are part of the rural sport of this territory. In addition, numerous cultural, teaching and dissemination activities take place in *Cantera Gorria*: (1) field trips as part of university degrees; (2) excursions with scientific groups; (3) guided tourist visits; (4) climbing and vertical

sports activities; and (4) cultural activities such as vertical dance shows (DIMEGAZ 2021: <https://www.youtube.com/watch?v=PzOUYoSxvnm>) or art exhibitions.

Proposed Use of *Cantera Gorria*

The proposal for the use of *Cantera Gorria* must take into account not only different uses, both educational and cultural, but also for leisure and recreation. Figure 10 shows a general plan with the proposed reuse of different areas of the quarry. When designing this proposal, the three main parameters that make this space a unique environment have been taken into account: geological, use and exploitation of the stone and, finally, cultural and leisure. For this reason, the area of *Cantera Gorria* has been divided into three main zones, each of these zones would have a building themed in one of the three parameters.

– Zone 1: *geological centre*

In this zone, all the geological parameters that have been developed in previous sections and that are identifiable in the quarry, palaeontological, sedimentological, diagenetic, geomorphological and tectonic, would be addressed.

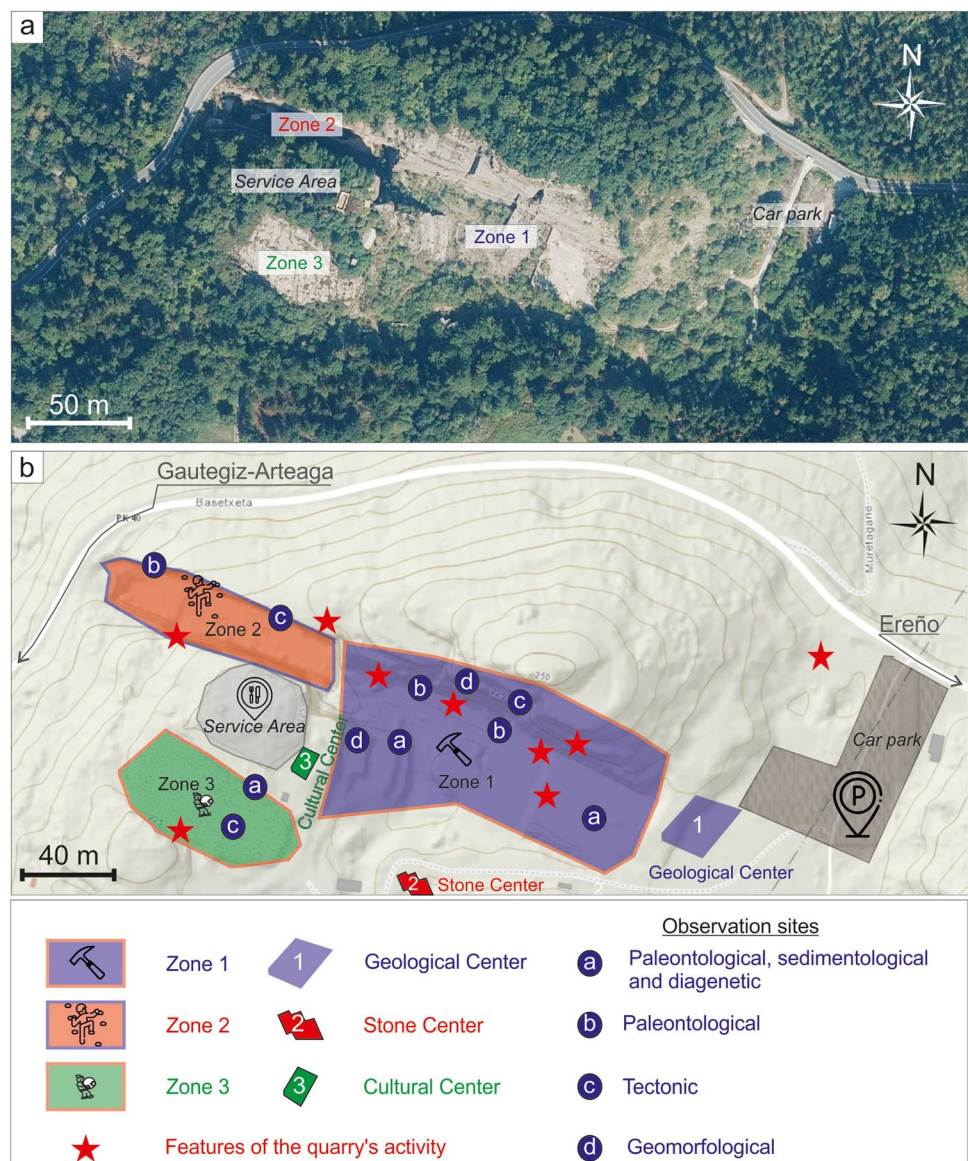
It is the largest zone, about 10,000 m², and it is distributed from the access to *Cantera Gorria* to the road that leads to zone 3 to the south, the benches of zone 3 and the cut of zone 2 to the west, the highest part of the quarry to the north.

A new multipurpose building (*geological centre*) should be built to provide access to the site, as well as to house different exhibitions, models, educational and informative content, focusing on the geological parameters of this sector and others in the Urdaibai Biosphere Reserve area and their importance within the geoheritage.

Table 4 Assessment of the overall interest of *Cantera Gorria* as an element of mining/industrial heritage according to the criteria defined in IGME (2012) (very high value > 300 points; 299 > high value > 200; 199 < medium value < 100)

		Points	
Representativity	Is the mining element useful to represent a mining archetype and illustrate its overall characteristics?	2 × 20	40
Relevance	Can the mining element be considered a local landmark in any of the following fields: technological, architectural or historical and socio-economic?	2 × 20	40
State of conservation	Is the mining element badly deteriorated?	1 × 20	20
Singularity	Is the mining element one of the few known examples at regional level?	1 × 20	20
Relationship to other heritage elements	Are there any other heritage elements within 1 km?	4 × 5	20
Didactic content	Does it illustrate curricular content at any level of education?	2 × 2.5	5
Dissemination content	Is it being used regularly for dissemination activities?	4 × 2.5	10
Accessibility	Is it being used regularly for dissemination activities?	1 × 10	10
Global interest = 165 points			

Fig. 10 Zoning proposal for the informative, cultural and tourist use of the area of *Cantera Gorria*. **a** Aerial photograph taken from <https://www.geo.euskadi.eus/geobisorea/>. **b** Modified topographic map from



The geological parameters can be divided into 4 main typologies, whose most suitable observation points have been identified in Figure 10: (a) observation sites for palaeontological, sedimentological and diagenetic features (such as the main square of the quarry presented in Figure 6); (b) observation sites for palaeontological features, where fossils are well observed; (c) observation sites for tectonic features, mainly faults and diaclases; and (d) observation sites for geomorphological features, such as the karst cavity presented in Figure 7.

Itineraries defined in this zone allow to reveal the geological history of this lithology from its formation to the beginning of its exploitation as an ornamental stone.

– **Zone 2: stone centre**

This zone would address all the parameters relating to the use of the *Red Ereño* and its exploitation. It cor-

responds to the area of the canyon with an extension of about 2630 m². As in the previous area, the building located on the south road (Figures 9e and 10) would be used to present the issues related to these parameters (*stone centre*). Figure 10 presents (marked with a red star) some of the best points to observe features of the exploitation, such as augers, or marks of the helicoidal steel wire. In addition, it would be convenient to recover the existing machinery presented in Figure 8 from the small quarries in the surroundings and to locate these elements in strategic places in the quarry.

As in the previous area, itineraries defined by the quarry, as well as models and other informative supports, would serve to value not only *Cantera Gorria*, but also *Red Ereño* as an ornamental and construction stone.

Numerous vertical sports and other leisure and cultural activities are practised in this area, as described in the previous section. The adaptation of the area would allow these activities to be carried out more safely.

– **Zone 3: cultural centre**

This zone groups together all aspects related to culture and leisure, with special emphasis on rural sports. It occupies an area of about 2600 m² and is located to the west of the quarry. The building shown in Figure 9f would house the exhibitions and the material necessary for the dissemination of these parameters (*cultural centre*).

This proposal has considered the accessibility of *Cantera Gorria* and its suitability for tourist activities. For this reason, the following have been defined: (i) a space accessed from the main road, to the east, which could be used as a car park and (ii) a service area, where tables and other necessities would be set up, located to the west, between zone 3 and the building known as the *cultural centre*.

Although the area of *Cantera Gorria* has been divided into three main zones according to the main themes presented, the interaction of these three parameters is evident throughout the area. The exploitation of the stone cannot be understood without taking into account the geological features that have given rise to this unique lithology, just as leisure activities, such as climbing, for example, cannot be carried out without the existence of the vertical walls caused by the quarry's exploitation.

Conclusions

Cantera Gorria, in itself, is an attractive space, and this intrinsic quality should be enhanced to make it a focus for dissemination, teaching and recreational geology. The relationship between the natural and cultural heritage of this quarry and the *Rojo Ereño* as an ornamental stone also makes it possible to enrich the discourse and events that can take place in its different spaces.

The proposal to transform *Cantera Gorria* is possible, because of the following:

1. It is already being used as a space for research, education, entertainment and culture at specific events.
2. The Urdaibai Biosphere Reserve regulations can provide the administrative tools for managing this space.
3. It is one of the best-known Places of Geological Interest in the community, and its strategic position makes it a privileged place for geological dissemination.
4. It is a space that links geoh heritage with mining heritage.
5. As the main point of exploitation of the *Red Ereño*, it also combines cultural heritage with geoh heritage.

For all these reasons, the proposal for use presented in this study is to value the different geological and mining aspects for transform *Cantera Gorria* into a social and cultural environment, where tourism, entertainment and, of course, research activities can continue to be carried out, but adapting the space to integrate it into the Urdaibai landscape without losing its geological identity. *Cantera Gorria* could become a place of conjunction between geological and cultural heritage where the focus would be the use of rock throughout history and the importance of geology in the development of societies.

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Data Availability Not applicable.

Declarations

Conflict of Interest The authors declare no competing interests.

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