Geoheritage (2022) 14:68
https://doi.org/10.1007/s12371-022-00700-0

ORIGINAL ARTICLE

Culturally Differentiated Paths Towards the Conservation of the Paleontological Heritage at Araripe (NE Brazil) and Arouca (N Portugal) UNESCO Global Geoparks

Maria Helena Paiva Henriques[1] · **Ismar de Souza Carvalho**[1,2]

Received: 17 November 2021 / Accepted: 5 May 2022

Abstract
Fossils are polysemic entities that attract people for very different reasons ranging from scientific to recreational ones. They can therefore display different heritage contents according to the meanings assigned by different social groups. This may endanger the integrity of the fossil record that grounds the development of paleontology (and related sciences) and may affect the enrichment of the paleontological heritage of the Earth. But the source of the paleontological heritage is not limited to academic activities that are trained to put into action top–bottom methods of inventorying, assessment, conservation, valuing, and monitoring procedures to fossils and fossil sites. Other culturally differentiated initiatives of geoconservation, whose meaning is inextricably rooted in both cultural and scientific dimensions, are important contributors to enlarge the data on paleontological heritage. Even among mining activities, normally seen as a big threat to geoconservation, it is possible to recognize examples of distinct practices of preservation and valuation enhancing of the paleontological heritage according to a bottom-up approach where fossils display heritage contents quite far from the contents usually assigned by the experts. The case of two UNESCO Global Geoparks (Araripe, NE Brazil; and Arouca, N Portugal) here presented enables to feature a new approach to the concept of paleontological heritage as a set of natural objects, resulting of culturally differentiated initiatives of geoconservation, whose significance is strongly linked to both cultural and scientific dimensions.

Keywords Paleontological heritage · Mining · Community involvement · Araripe UGGp (N Brazil) · Arouca UGGp (N Portugal)

Introduction

Fossils are natural objects corresponding to expressive representations of Earth's diversity over time and therefore possess heritage value. Like other non-living components of nature, such as rocks and minerals, fossils enable reconstructions of the natural environment at different time spans of the planet's history and the macro-evolution of life on Earth.

However, each geological narrative demands specific types of fossils, which in their multiplicity of possibilities — viruses, bacteria, protozoa, invertebrates, vertebrates, plants, trace fossils, etc. — present different aspects of interest and meaning. Biostratigraphic applications of fossils do not necessarily represent the same interest, meaning, or use for paleoenvironmental interpretation; fossils used in paleoclimatology may not have any function for studies in mineral prospecting. Thus, not just any fossil can be applied to the different geological narratives. Nor can they have a priori a clear function in the field of geosciences.

Like other geological objects, fossils display different contents, reflecting diverse heritage values, and they are not limited to scientific use alone (Lima and Carvalho 2020). In fact, fossils attract other groups of people besides paleontologists (e.g., Duffin 2008; Geer and Dermitzakis 2008; Geer et al. (2008); Moncel et al. 2012; Moura and Albuquerque (2012); Gambim et al. 2017; Nissen et al. 2019). This is

✉ Maria Helena Paiva Henriques
hhenriq@dct.uc.pt

Ismar de Souza Carvalho
ismar@geologia.ufrj.br

1 Geosciences Center and Department of Earth Sciences, University of Coimbra, Rua Sílvio Lima, Coimbra 3030-790, Portugal

2 Department of Geology, CCMN/IGEO, Federal University of Rio de Janeiro, Cidade Universitária - Ilha do Fundão, Rio de Janeiro 21910-200, Brazil

Published online: 17 May 2022

because of the different meanings that are attributed to them; in this sense, they represent a semiotic challenge.

Fossils are polysemic entities and the multitude of reasons that attract people to fossils may endanger the integrity of the fossil record, the basis for paleontological research (Henriques and Pena dos Reis 2019a, b and references therein). Such concern led to the elaboration and implementation of diversified legal instruments assigned to fossil conservation or land-use planning policies aiming at assuring the integrity of fossiliferous sites and/or specimens. But this point of view, based on a conservationist perspective emanating above all from the scientific communities, has so far not resulted in an effective conservation of the geological heritage. On the other hand, there are several examples of good practices of preservation and valuation of the paleontological heritage carried out by non-academics, namely from the extractive industry sector and/or commercial dealers, normally seen as one of the biggest threats to geoconservation. Even among the academic community, there is a heated debate about outcrop damage, not only by collectors and merchants who collect fossils for private or commercial purposes, but also by geologists for rock sampling (e.g., Druguet et al. 2013; Bétard et al. 2018; Carvalho et al. 2021 and references therein).

As such, the paleontological heritage, as part of the fossil record which requires specific protection and management measures, needs to be redefined considering that fossils are more than scientific objects. As natural objects that can display culturally differentiated meanings, they must be perceived within a new paradigm of sustainability. This requires the bridging of the disciplinary research in paleontology and other knowledge fields and breaking the artificial barrier between natural and human and social sciences, as well as considering non-scientific and non-western forms of knowledge, within a humanistic scientific framework (Werlen et al. 2016).

Considering that the science of paleontology is a partnership of academic, amateur, and commercial actors who need to rely on each other (Larson 2001), this work proposes a new approach to the concept of paleontological heritage as a set of natural objects, resulting of culturally differentiated initiatives of geoconservation, whose significance is strongly linked to both cultural and scientific dimensions.

Some of those initiatives represent unexpected examples of harmonious relations between the preservation of the paleontological heritage and the increasing transformation of the land surface as a result of the exploitation of geological resources. In two UNESCO Global Geoparks — the Araripe (NE Brazil) and the Arouca (N Portugal) — the mining activities, traditionally seen as a threat of the fossil record, have strongly contributed to the deepening of scientific knowledge about ancient biota and substantially enlarged the paleontological heritage of the world. Instead of being seen as worlds apart and in permanent conflict (Brilha 2015; De Miguel et al. 2021), the scientific community and the other communities should invest in another path based on effective communication with each other in order to increase collective awareness for the conservation of natural heritage, which includes the fossils.

The Nature of the Paleontological Heritage

Fossils have been found all over the world and have interested humans since at least the Paleolithic (e.g., Demnard and Neraudeau (2001); Peresani et al. (2013). They have been collected, traded, sold, and even revered as magical, medicinal, and spiritual artifacts, or used as money (Larson 2001; Moura and Albuquerque 2012; Gambim et al. 2017; Vialou and Vialou 2019). Even if fossils exist without human interference, the scientific theories that paleontologists use to advance our understanding of ancient life are human constructions (Besterman 2001), and signs are present in everything that is human (Petrilli 2009).

As geological objects representing signs, fossils raise different meanings produced by different interpretants or codemakers, from experts to amateurs (Henriques and Pena dos Reis 2019b). This multifunctional character of fossils represents the greatest threat to geoconservation of the paleontological heritage and to paleontology as well as related sciences. Awareness of the conservation of the paleontological heritage can be increased if we look at paleontological objects as signs and understand the different meanings assigned to fossils by culturally differentiated interpretants, i.e., through a semiotic perspective (Henriques and Pena dos Reis 2019b). Since everything may be studied from the point of view of its semiotic (Sonesson 2011), semiotics can help us to understand why certain signs (fossils) are interpreted differently in different cultures and different geographies. This is the first step to promote efficient engagement of geoscientists in communication with non-specialists, by sharing and popularizing the results of geosciences in order to promote geoethical values of appropriate behavior and practices when human actions intersect with the Earth system (Drąsutė et al. 2000; Ribeiro et al. 2015).

Although being representations of past forms of life, the heritage content of a fossil can be assessed in different ways by the various social groups (Table 1). Moreover, fossils may collectively possess different contents, thus increasing their global heritage value (Schemm-Gregory and Henriques 2013). For instance, an exceptionally well-preserved fossil can increase its geoheritage value if, besides displaying a clear relation with the original organism, it also represents the holotype of the species where it belongs thus achieving global scientific relevance (Haag and Henriques 2016). The same happens when fossils are preserved for reasons other

Table 1 Heritage content types and corresponding main characteristics displayed by fossils according to the relevance grade and abstract perceptiveness. This perspective integrates expert and non-specialist interpretations of the fossil record. Categories of paleontological heritage mainly based on specialists' assessment (from 1, the most important, to 4, the less important based on Page 2003, 2018, considered only for fossil specimens) and heritage ranks framed within an integrated qualification and evaluation system for paleontological heritage (from I, the less important, to III, the most important; based on Henriques and Pena dos Reis 2015, considered for fossil specimens and ichnofossils). Modified after Henriques and Pena dos Reis (2015)

Content type	Relevance grade	Abstract perceptiveness	Main features	Interpretant	Category/rank
Indicial	Local	Material	Fossils displaying real relationships between original organism and the result of the fossilization process; e.g., exceptionally well-preserved fossils	Experts and non-specialists	2/I
Iconographic	Local	Cognitive	Fossils displaying clear physical relations between a given activity of biogenic origin and its effects; e.g., trace fossils	Mainly experts	II
Symbolic	Local	Social	Fossils appreciated by the public with little or no background in Earth Sciences for reasons other than learning about paleontology; e.g. fossils used as ornaments, offerings and tools	Mainly non-specialists	4/II
Documental	Regional	Demonstrative	Key specimens of stratigraphical or paleobiological significance; e.g., index fossils	Mainly experts	3/II
Conceptual	Global	Cognitive	Specimens of typological importance for the definition of fossil species; e.g., type species	Experts	1/III
Scenic	Global	Social	Fossils with unusual morphological features providing high recreational function; e.g., dinosaurs and other large Mesozoic vertebrates displayed in Natural Museums	Mainly non-specialists	4/III

than scientific and later come to be the object of investigation by paleontologists. It is the case of the Early Cretaceous dinosaur footprints of the Natural Monument of Cabo Espichel (near Lisbon, Portugal), regarded by fishermen as the sacred record of Our Lady, stepping down from the sea and who would have ridden on a mule to the platform above the cliffs (Antunes 1976).

As discussed in previous works by Pena dos Reis and Henriques (2009) and Henriques and Pena dos Reis (2015, 2019b), the fossil heritage content is affected by two main factors:

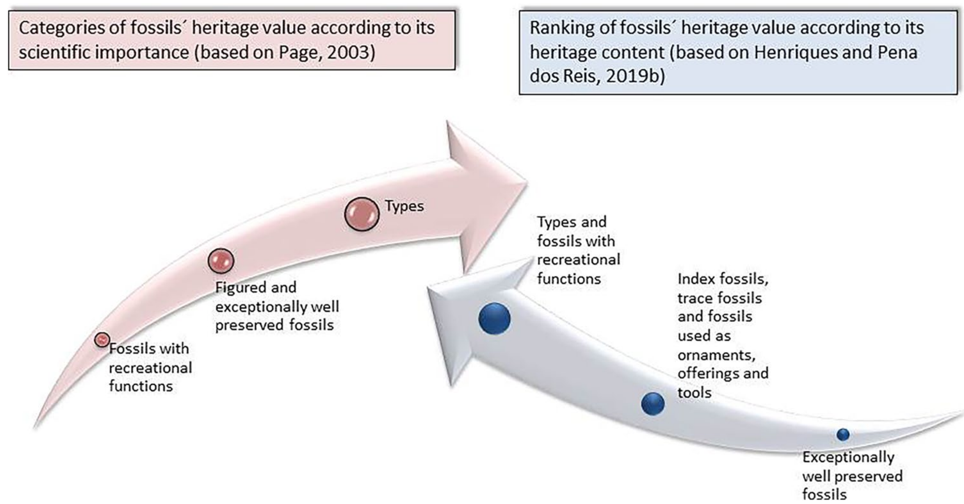
The relevance grade, i.e., the meaning attributed to the fossils by scientific communities like type specimens, which have typological importance for the definition of fossil species, index fossils which are key specimens of stratigraphical or paleobiological significance, or exceptionally well-preserved fossils which display real relations between the original organism and the result of the fossilization process (Page 2003, 2018; Henriques and Pena dos Reis 2019b)

The abstract perceptiveness, i.e., the public understanding of such meanings in relation to social use of the fossils which is based on culturally particular values, norms, beliefs, and attitudes that we have learnt and acquired during our socialization and education programs (Henriques et al. 2012; O'Brien et al. 2013; Table 1)

This holistic approach to the heritage value of fossils can help scientists to identify the social groups that may be attracted by fossils and the type of fossils that may interest them from a non-scientific point of view (Fig. 1). Scientists place a different value on fossils from non-specialists because each group assigns its own significance to them. Considering the ex situ collections in a museum, type specimens are of great value for a paleontologist, while the museum exhibitions of large vertebrates have a similar impact for the general public. Figured specimens as a result of field work are essential referents for taxonomic, taphonomic, biostratigraphic, and paleoecological studies. But the same fossiliferous localities can be of similar interest for people who use fossils for other reasons such as ornaments, offerings, and tools.

Such wide interpretation of the same objects among totally different codemakers is a key aspect in establishing efficient communication strategies among them in order to bridge culturally differentiated interpretants and to increase collective awareness for the conservation of the

Fig. 1 Fossils can have different interpretations according to different codemakers, resulting in different heritage values. Left: categories of fossils' heritage value according to its scientific importance (based on Page 2003); right: ranking of fossils' heritage value according to its heritage content (based on Henriques and Pena dos Reis 2019b). Note that fossils and/or fossil collections may collectively possess different contents, thus increasing their global heritage value



fossil record and achieve its geoconservation. As pointed out by Larwood (2001), more communication and cooperation among all groups concerned in the conservation and use of fossil resources are still required. Paleontologists are specifically trained to put into action only top–bottom methods of inventorying, assessment, conservation, valuing, and monitoring procedures to fossils and fossil sites. But valuing and monitoring the fossil record independently of who discovered or collected it (i.e., whether amateurs, mining, or trade agents) must be considered a complementary path to feed inventory and assessment procedures of the fossil record performed by the scientific community (Fig. 2).

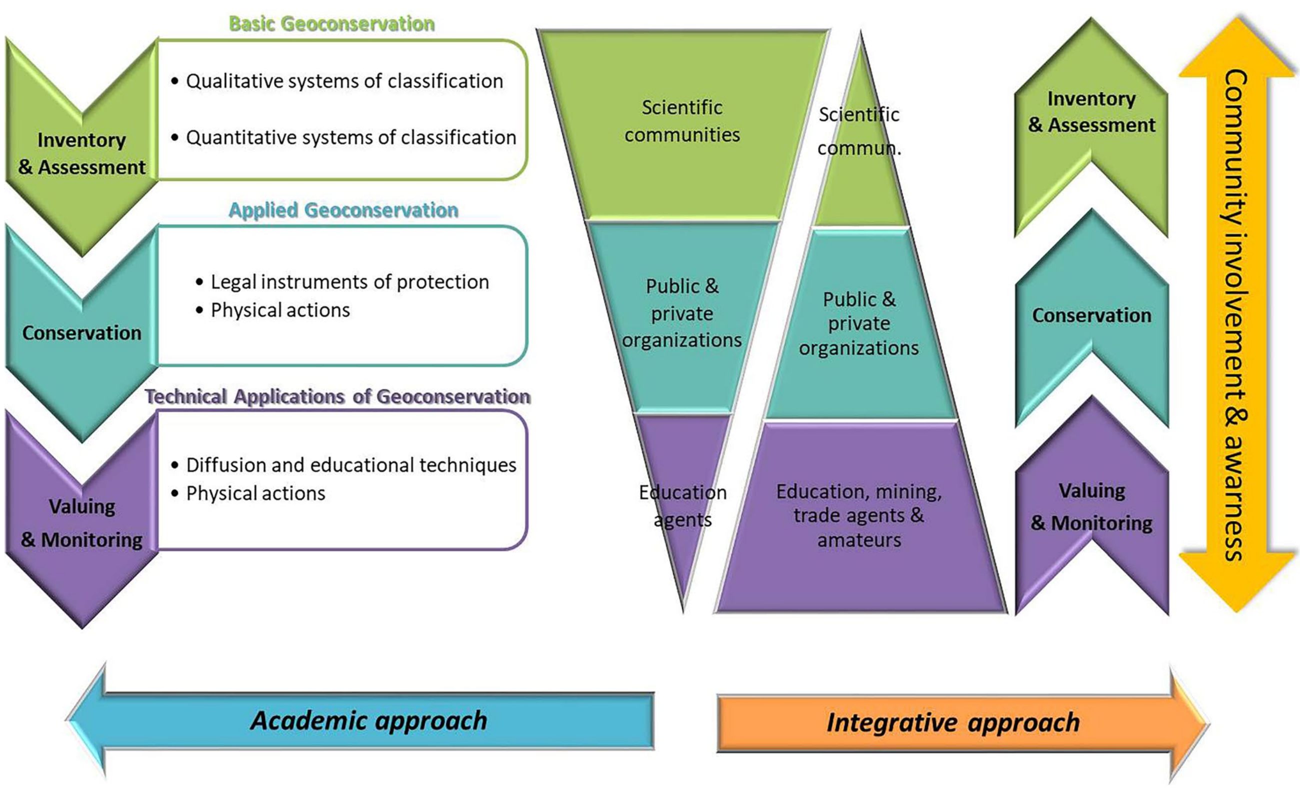


Fig. 2 Two complementary paths towards the geoconservation of the fossil heritage. Within the top-down approach, the scientific communities are the main agents who start the geoconservation procedures. But awareness regarding fossil preservation can start from non-specialists' groups according to a bottom-up approach

Geoconservation in Mining Scenarios

The increasing consumption of resources, including energy, materials, and land, imposes new challenges for all sectors of society, such as politicians, businessmen, educators, and media but namely to geoscientists. They face new dilemmas emerging from the need of promoting sustainable exploration and use of the geological resources in order to respect the fragility of the physical environment. Geoconservation is related to this new social responsibility towards the use of Earth's resources (Henriques et al. 2011), including the fossil record. Geoconservation concepts, methods, and techniques, namely assessment methodologies for all kinds of geological objects displaying heritage value, such as fossils and integrating specimen-based with site-based approaches, have been discussed in a previous work (Henriques and Pena dos Reis 2015). Such substantive knowledge of geoconservation can be applied to promote conservation and valuation of the paleontological heritage of the Earth by means of inventory and assessment procedures (Basic Geoconservation; Henriques et al. 2011).

Geoconservation must take the scientific requirements into account, usually provided by the scientific community, but the ethical dimension of geoconservation also has to be considered, as the concern regarding the sustainable use of the geological resources requires the support of local inhabitants through the respect of their cultural background and economic needs (Martins and Pereira 2018). As pointed out by Peppoloni and Di Capua (2021), similar ethical issues and dilemmas that arise in different contexts and circumstances may require different choices, and any intervention imposed on its management without considering the conditions and characteristics of the local contexts risks provoking opposing, even violent, reactions from the communities involved in fossil sampling.

Mining activity is traditionally considered big threat for fossil conservation, and in many countries, highly restrictive laws were created for the use of sites where fossiliferous rocks outcrop for the extractive industry, for amateur fossil collection, and even for scientific purposes. However, such extreme conservationist positions lead to a great paradox about fossils. In fact, the mining of fossiliferous formations is, quite frequently, an important source of fossil occurrences of great scientific importance (De Miguel et al. 2020). In fact, knowledge about the fossil record does not result only from the sampling of specimens by paleontologists as part of their scientific activities. It results from other sources that can recognize in fossils other contents than those usually assigned by the scientific community, and who also aim to preserve it; in this case, they promote a bottom-up approach to geoconservation (Fig. 2).

It is mainly through the various stages of the extractive production process, which includes the opening of the mine, rock revolving, extraction, mineral processing, and generation of large volumes of waste that enhances the potential discovery of new fossils. Brito et al. (2021) recently reported the occurrence of marine Late Cretaceous coelacanth from Morocco obtained from a commercial fossil source, a sector that is also commonly seen as a damager of the paleontological heritage by the scientific community. This is despite the fact that the majority of the illegal trade in fossils and artifacts is from poor third-world countries to rich first-world ones (Besterman 2001).

The discovery of fossils is often a product of chance or serendipity (Duque and Mateos 2006; Henriques 2010), and mining increases such chances by expanding the exposure of the rocks. The action of paleontologists is to give scientific meaning to the discoveries, and only through their study can they produce a redefinition of fossils that transform them into ex situ heritage.

The conflict between mining activity and fossil preservation is a serious problem. But it can be overcome if a constructive network can be established between local communities and experts. To underestimate the role of non-experts who somehow deal with the fossil record, it does not lead to an increase in the probability of finding new taxa for instance and therefore deepen the knowledge in paleontology and enlarge the paleontological heritage.

A geoconservation strategy that seeks to engage the different communities around the fossils is certainly more successful in terms of guaranteeing the integrity of the fossil record, and, therefore, of the paleontological heritage. Only knowledge leads to the awareness and preservation of a fossil, whether it results of popular culture or is academically produced. The articulation between all the actors in a framework aiming at the geoconservation of any kind of geological object that displays heritage value depends on communication effectiveness. This is a major component in all the steps of the process, and not just at the end when local populations are expected to actively participate in safeguarding the geological objects' physical integrity (Tavares et al. 2015). Meanings are socially produced and have a dynamic nature. It is therefore up to the academic community to try to understand the different meanings that non-specialists attribute to the fossil object and cooperate with them in its valorization, i.e., in assigning other meanings to the same object. Thanks to their knowledge and expertise, geoscientists have competence and experience to better understand the Earth system, its elements, and dynamics; therefore, they play a crucial role as special informer and educators of the general public as part of their geoethical responsibility towards society (Drąsutė et al. 2000).

Brazil and Portugal have very different legal frameworks regarding fossil collection and mining. But the UNESCO

Global Geoparks Network (GGN) requirements about this issue are very demanding with regard to the management of the paleontological heritage of the territories included in the network. If this heritage results from extractive activities, a conflict may arise between the mine owners and the geopark administration, which, in this way, will not be able to fulfill the requirements imposed by the GGN. The positive articulation between the scientific community and the quarry owners provided new opportunities in two UNESCO Global Geoparks (UGGp) — Araripe (NE Brazil) and Arouca (N Portugal) — to implement sustainable mining practices that made it possible to guarantee the integrity of its paleontological heritage and therefore promote effective geoconservation.

Current Practices of Conserving the Paleontological Heritage at Araripe and Arouca UNESCO Global Geoparks

The Araripe and Arouca UGGp share with all the UGGp the fact that they are single, unified geographical areas where sites and landscapes of international geological significance are managed with a holistic concept of protection, education, and sustainable development (UNESCO 2021a). But they also share another important feature: their extraordinary paleontological heritage. While the Araripe UGGp is characterized by important fossil records from the Early Cretaceous times between 100 and 140 million years old, the Arouca UGGp provides giant trilobite fossils up to 70 cm in size of Ordovician age between 460 and 470 million years ago (UNESCO 2021b,c). Moreover, despite the unavoidable conflict between mining activity and fossil preservation, in both cases, the extractive industry played a crucial role in making accessible many tons of material containing fossils, many of which were later studied by experts and scientifically validated.

The Araripe UNESCO Global Geopark

The Araripe UGGp is located in the Northeast region of Brazil (S07°13′46″, W039°24′32″), at the State of Ceará, occupying a total area of 3441 km^2 (Fig. 3). It was designated as a member of the Global Geopark Network in 2006 and as UGGp by UNESCO in 2015, based on the exceptional preservation of its fossils (UNESCO 2021b). Besides its geological and paleontological record of the Gondwana Lower Cretaceous, in a geodiversity hotspot context (Bétard et al. 2018), it also presents important biomes of the Brazilian semi-arid regions.

Despite the importance of its geological heritage, the main regional economic activity is the extraction of rocks for cement production and construction, which leads to the exposure of new outcrops that show a great number of fossils. However, besides mineral exploration, the Araripe UGGp uses its geodiversity in the design and implementation of resources for scientific, educational, and tourism purposes (Boas et al. 2013; Carvalho et al. 2021; Henriques et al. 2020).

The area of the Araripe UGGp covers the Araripe Basin, where one can find two fossil conservation and concentration (the Crato and Romualdo Lagerstätten), which can be considered the best-known Mesozoic Lagerstätten of Gondwana

Fig. 3 Geographic location of the Araripe UGGp (Brazil) and the Arouca UGGp (Portugal)

(Martill 1997; Maldanis et al. 2016; Dias and Carvalho 2020; Carvalho et al. 2015a,b, 2019).

The discovery of fossils in the Araripe Basin dates to 1799 in the locality of Engenho Gameleira, in Jamacaru, by João da Silva Feijó (Nobre 1997). The locality provides large amount of fossil fishes included in carbonate concretions, called ichthyoliths (ichthy, fish; lithos, rock). Since then, the repository of these fossils has been carried out in different national and international institutions (Carvalho et al. 2021). The Crato Lagerstätte was discovered as the result of mineral exploitation of laminated limestones in Nova Olinda County (mainly in the Mina Três Irmãos and Mina Pedra Branca) to its use as ornamental rock. Until the 1980s, there were only a few small quarries to supply the surrounding small cities, but during the 1990s, the stone became popular and new markets were open (Andrade 2007). This ornamental rock is composed of laminated limestone and is commercially known as "Pedra Cariri." Extraction is relatively simple, with the cutting of large blocks or even small surfaces ready for industrial use. In these laminated limestones, the discovery of fossiliferous outcrops only became possible due to the existence of mining fronts, which advance in various directions and locations in the municipality of Nova Olinda. The thousands of fossils discovered since then, and the description of new species, are essentially restricted to the mining district (Fig. 4). But this arouses a new problem to the geological heritage — the improvement of knowledge is conditioned by the environmental damage generated by the mineral extraction, besides the complex legal frame that regulates the extraction and management of fossils in the territory (Figs. 5, 6A and B).

The Arouca UNESCO Global Geopark

The Arouca UGGp is located in northern Portugal and coincides with the area of the Arouca Municipality (N40°55′56″, W008°14′42″), occupying a total area of 327 km^2 (Fig. 7). It was designated as a member of the Global Geopark Network in 2009 and as UGGp by UNESCO in 2015. This was based on the relevance of its geological record representing ancient seas that bordered the supercontinent Gondwana and the formation of Pangea that occurred during Paleozoic times (UNESCO 2021c). The high fossil content of large Ordovician trilobites is one of the most distinctive characters of the geopark — the giant trilobite fossils of Canelas, some reaching 70 cm like *Hunginoides bohemicus* (in Gutierréz-Marco et al. 2009). The first specimens were discovered as a result of artisanal quarrying of roofing slate ("Lousas de Canelas") which started in 1820 by the Valério family and then became mechanized in the last decade of the twentieth century leading to the increasing appearance of fossils which were carefully collected by its last owner, Manuel Valério de Figueiredo (Figueiredo 2011). Besides scientific activities, the Arouca UGGp also uses its geodiversity in the design and implementation of resources for educational and tourism purposes (Henriques et al. 2012).

The Valério´s quarry located in Canelas village is one of the 40 geosites inventoried at the geopark operating accordingly with the Portuguese legislation. The discovery of the large Ordovician trilobites at this quarry only became possible due to the existence of mining fronts exposing large surfaces of dark grey slate, commercially known as "Lousas de Canelas." In addition to trilobites, other fossils were found (bivalves, rostroconchs, gastropods, cephalopods, brachiopods, crinoids, cystoids, hyoliths, conulariids, ostracodes, graptolites, and ichnofossils; Sá et al. 2021 and references therein). For almost 30 years, the owner, on his own initiative, collected all the relevant fossil occurrences found as a result of the quarry operations and during the industrial processing of slates in order to reach the appropriate dimensions and thicknesses for commerce. In partnership with paleontologists, Manuel Valério de Figueiredo contributed decisively to increasing knowledge about the paleontological heritage of the Arouca UGGp. All the material is properly stored and the more relevant specimens are exhibited at the Museum of Trilobites of the Geological Interpretation Centre of Canelas (CIIGC 2021a, b), held by Ardósias Valério & Figueiredo, Lda., the quarry owner (Figueiredo 2011; Fig. 8). Although the ownership of this paleontological heritage remains in private hands, the formal partnership with the Arouca Geopark Association, the management structure of the Arouca UGGp, ensures its availability for exhibitions, educational programs, and collaboration with scientific research (Henriques et al. 2012; Sá et al. 2021). Valério's quarry geosite represents a best-practice example showing that it is possible to make quarrying of fossiliferous sites and private ownership of fossil collections compatible with geoconservation with benefits for the local communities and the scientific world (Brilha 2020).

Discussion

The Brazilian Federal Constitution (Brasil 1988) includes the fossil record of the country as part of its National Heritage (Art. 216, V) based on the concept that paleontological heritage is a key part of the heritage of the Union. This legal instrument is reinforced by several laws and decrees (e.g., protection of areas with important geological heritage falls under Law 9985/2000) that aims to regulate the extraction and management of fossils in the territory (Carmo et al. 2010; Piranha et al. 2011; Haag and Henriques 2016). Since 1942, fossiliferous deposits are owned by the nation and the extraction of fossils depends on prior authorization by the state.

In theory, restrictive rules on fossil collection ensure the conservation of the paleontological heritage. However, when

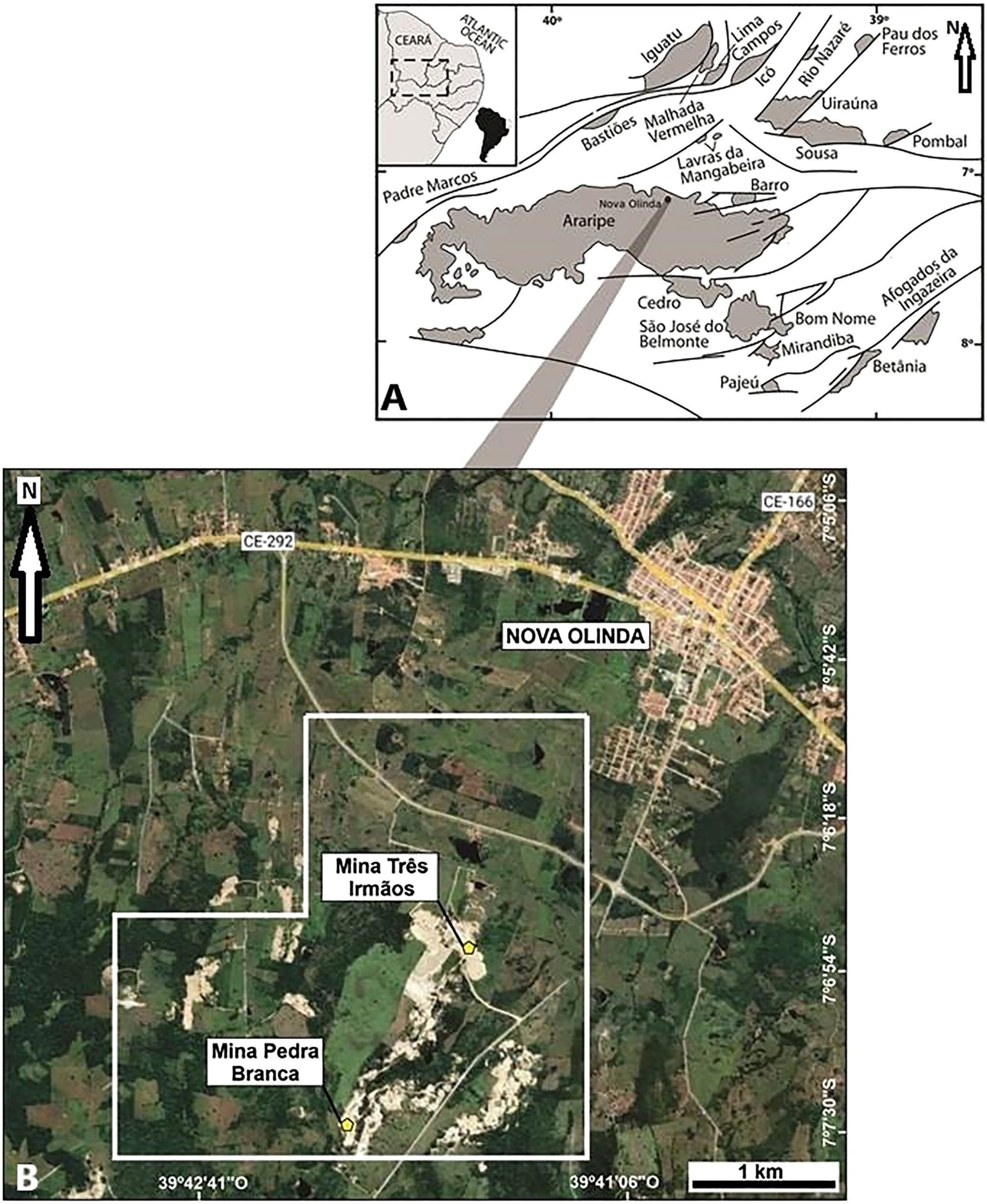


Fig. 4 Location of the Araripe UNESCO Global Geopark (**A**) and the quarries where the "Pedra Cariri" has been exploited at Nova Olinda county (Ceará State, Brazil) and where most of the new species from the Crato Lagerstätte were found (**B**)

Fig. 5 Changes in the terrain topography in the mine fronts are daily, resulting in a change in geomorphology, generation of millions of cubic meters of mined rock and associated tailings. The opening of the mining front and the rupture process in the bedding planes lead to the appearance of fossils. This is not an intentional search for this constituent element of the rock, as it is part of the rock itself. Mining front in Nova Olinda, 30 July 2014

fossils are found in raw materials, the situation becomes more complicated. The paleontological heritage becomes more vulnerable if the communities, where the deposits are located, rely on the extraction of fossiliferous raw material for their livelihood. At the Araripe UGGp, the limestone extraction contributes significantly to the local economy, apart for being the host material where the exceptionally well-preserved fossils from Romualdo and Crato formations occur. During the extraction of the rock, the workers perform different actions such as cutting (square) the rock, removing the rock, and cutting the rock slabs (Henriques et al. 2020).

Fossils appear throughout this process; since they are part of the Brazilian Heritage, workers who legally exploit a quarry are alleged criminals because they are handling fossils. Furthermore, this illicit behavior persists whether the fossil is commercialized or stored to be analyzed later by a specialist. Faced with the prospect of imprisonment by the Brazilian police, it is safer to destroy the region's abundant quarry mining waste, which is generally rich in fossils, reducing the chances of discovering outstanding fossil occurrences. In order to avoid problems, relevant paleontological information is being lost, in an attack on the integrity and conservation of paleontological heritage. Moreover, the quarry mining waste can be useful to stimulate locals to perpetuate the tradition of using the Cariri Stone for the construction of their houses instead of paint-coated cement (Carvalho et al. 2020). This has evident positive impacts, by promoting a circular economy, reducing natural resource use and depletion, and recovering traditional construction techniques (Henriques et al. 2020).

So, in the absence of legal instruments that make it possible to distinguish between the different contents present in each fossil, as well as their potential heritage value determined from them, in practice, this allows for the indiscriminate criminalization of fossil collection and sampling, as well as the emergence of a parallel economy that feeds big merchants at the expense of low-income local mining workers. As pointed out by Martill (2001), although the commercial traffic of Brazilian fossils is prohibited, it thrives, namely involving the exceptionally well-preserved fossils from Romualdo and Crato formations of the Araripe Basin.

In Portugal, collecting fossils for scientific studies has no legal constraint, while amateur collecting is prohibited only in places with recognized paleontological heritage included in protected areas (Regional or National Natural Monuments) or geoparks. However, this situation does not necessarily cause a greater loss of fossil record or damage to geoconservation, and it is often the case that gains made through private initiatives largely cover putative losses. In fact, this legal status allows the establishment of local private museums that promote the teaching of paleontology and the popularization of fossils, as it is the case of the Geological Interpretation Centre of Canelas at the Arouca UGGp (Figueiredo 2011).

The two geoparks display different relationships between geological resource exploration and geoconservation.

To face the challenges of implementing nature conservation, land-use planning, and sustainable development within geoparks requires overcoming the dissociation between

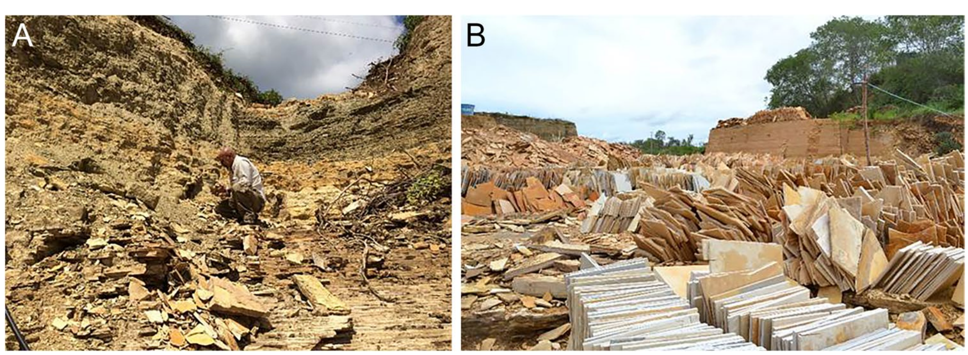


Fig. 6 Field monitoring at collection sites previously carried out, as in the case of fragments of birds and feathers in 2011 (**A**). The advance of mining led to the destruction of the outcrop, and the disappearance of all surfaces of fossiliferous layers. Photograph on February 9, 2014 (**B**)

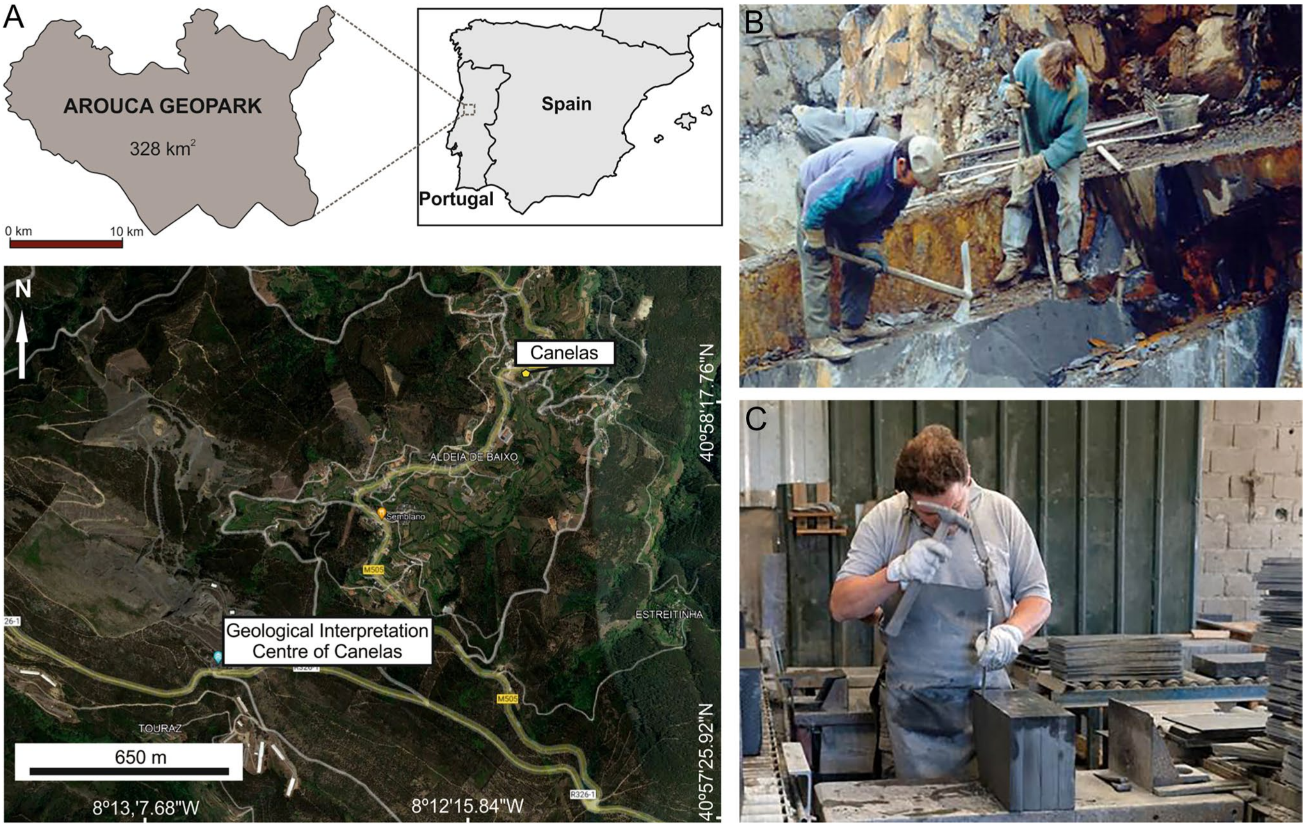


Fig. 7 Location of the Arouca UNESCO Global Geopark and the Ardósias Valério & Figueiredo, Lda. quarry at Canelas village (**A**). The extraction of slates in this quarry allows the discovery of many trilobites which are one of the main interests of visitors in the geopark (taken from 2021b (**B**); taken from andarilho.pt with permission (**C**))

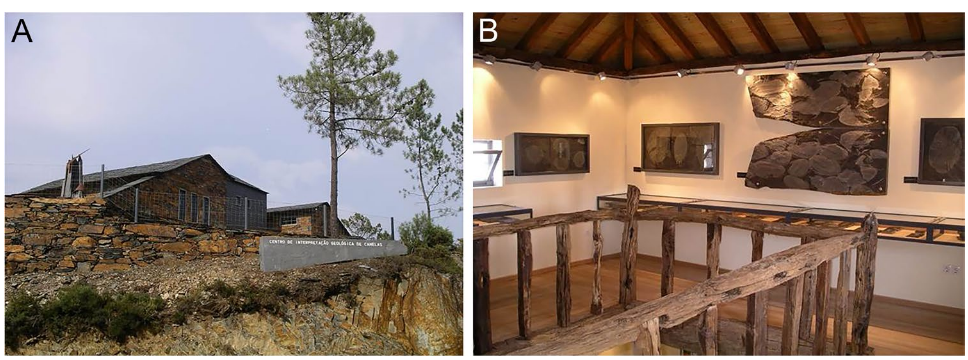


Fig. 8 The private Museum of Trilobites, property of the Ardósias Valério & Figueiredo, Lda. quarry: views from outside (**A**) and inside (**B**) of the Museum of Trilobites at the Geological Interpretation Centre of Canelas

community, science, and politics and capitalizes on geological heritage and its relationship with local communities. In the Arouca UGGp, the mineral exploration was the motor to the fossil discoveries and to the establishment of the geopark. The existence of mineral activity is organically related to the local community and brings clear benefits for knowledge and heritage conservation. Despite some good examples of partnerships between the government, universities, businesses, and non-governmental organizations for the development of education at the Araripe UGGp (Carvalho et al. 2020; Henriques et al. 2020; Fig. 9), the institutional conflicts, legal uncertainty, lack of community interest in preserving heritage, and economic damage to activities already established in the region harm the paleontological heritage.

The evaluation of the various management models that already exist for geoparks in areas where mineral activity occurs is thus of great importance. In these cases, the new governance models must envisage actions postulated within the scope of environmental, social, and governance, i.e. taking into account non-financial factors as part of the analytical process to identify material risks and growth opportunities within any organization (Senadheeraa et al. 2021). Fossils must be recognized, above all, as part of the geological heritage and mining as an activity relevant to the discovery of the Earth's history, when envisaged as products and services that can contribute to promote sustainable development. However, this does not imply that they should only be considered with an immaterial heritage value, since there are specific economic elements involved in their prospecting or casual discovery.

Conclusions and Final Remarks

The fossil record, whether it forms part of geosites or museum collections, must be seen as an important component of the diversity of the Earth. When fossils display heritage value — therefore composing the paleontological heritage — they require geoconservation awareness in accordance with its polysemic and multifunctional nature.

Conventional approaches to geoconservation of the fossil record mainly emerge from the academic world and follow a top–bottom methodology of inventorying, assessment, conservation, valuing, and monitoring procedures to fossils and fossil sites. While experts are likely to actively participate in the first step of the process, local communities are expected to accomplish its final part by ensuring the physical integrity of the fossils and/or fossil sites. Education is considered the main key to increase the public awareness and involvement in geoconservation.

However, fossils attract other groups of people besides paleontologists who assign to fossils different meanings and heritage contents and who may provide the safeguard of their integrity. In this sense, they represent polysemic entities and this propriety may endanger its geoconservation. This simplistic reasoning leads to the appearance of prejudices relatively to non-experts like fossil amateurs, dealers, or mining owners. They may have great responsibilities on the disappearance of specimens included in private collections, or on their destruction due to mining activity. But among them, there are many exceptions that should be disclosed as they represent inspiring examples of good practices of cooperation between the academic and the non-academic worlds. In fact, quarry owners and workers, as well as amateur collectors, can be important suppliers of paleontological heritage when specialists can achieve an effective communication around the different heritage contents that fossil may display.

A semiotic vision of the fossil record can help to perceive the different meanings that anyone can assign to fossils and fossil sites. Heritage contents of great social attractiveness, i.e., with scenic contents, are more likely to promote public awareness on geoconservation, representing a culturally differentiated path towards the conservation of the paleontological heritage. This is a starting point for increasing community engagement in valuing the paleontological heritage in general, supported by bottom-up approaches to geoconservation.

Acknowledgements The authors are grateful to Sofia Pereira for the detailed revision of the manuscript, and to José Artur Ferreira Gomes de Andrade and Francisco Idalécio de Freitas for their helpful assistance during the fieldwork. This work pays tribute to Manuel Valério de Figueiredo (1962-2021) and to his trilobite collection of Canelas that he preserved and valued throughout his life.

Funding This study was supported by Portuguese funds by Fundação para a Ciência e a Tecnologia, I.P. (Portugal) in the frame of the UIDB/00073/2020 and UIDP/00073/2020 projects of I & D unit Geosciences Centre (CGEO), by Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro (Proc. E-26/200.828/2021, Brazil) and by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq 303596/2016–3, Brasil) and is a contribution for the Portuguese National Committee for the International Geosciences Program of UNESCO (IGCP).

Declarations

Conflict of Interest The authors declare no competing interests.

References

Andrade JAFG (2007) Commercial exploitation of the Crato Formation. In: Martill DM, Bechly G, Loveridge RF (eds) The Crato Fossil Beds of Brazil. Window into an Ancient World. Cambridge University Press, Cambridge, pp 63–69

Antunes MT (1976) Dinossáurios Eocretácicos de Lagosteiros. Ciências da Terra 1:1–35

Besterman TP (2001) Frontiers to science: free trade and museum ethics. Geol Curator 7(6):199–209

Bétard F, Peulvast J-P, Magalhães AO, Carvalho Neta ML, Freitas FI (2018) Araripe Basin: a major geodiversity hotspot in Brazil. Geoheritage 10(4):543–558. https://doi.org/10.1007/s12371-017-0232-5

Boas MV, Brilha JBR, De Lima FF (2013) Conservação do patrimônio paleontológico do Geopark Araripe (Brasil): enquadramento, estratégias e condicionantes. Bol Paranaen Geociências 70:156–165. https://doi.org/10.20396/td.v15i0.8653660

Brasil (1988) Constituição da República Federativa do Brasil de 1988. http://www.planalto.gov.br/ccivil_03/constituicao/constituicao.htm. Accessed 21 set. 2021

Brilha J (2015) Mining and Geoconservation. In: Tiess G, Majumder T, Cameron P (eds) Encyclopedia of mineral and energy policy. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-40871-7_9-1

Brilha J (2020) Good practices in the promotion of geoethical values in a UNESCO Global Geopark. In: Vasconcelos C, Schneider- Voß S, Peppoloni S (ed) Teaching Geoethics. Resources for Higher Education. Erasmus Plus GOAL – Geoethics Outcomes and Awareness Learning, Porto, pp.173–176. https://doi.org/10.24840/978-989-746-254-2; ISBN 978–989–746–254–2

Brito PM, Martill DM, Eaves I, Smith RE, Cooper SLA (2021) A marine Late Cretaceous (Maastrichtian) coelacanth from North Africa. Cretac Res 122:104768. https://doi.org/10.1016/j.cretres.2021.104768

Carmo DA, Carvalho IS, Santucci RM, Silva MA (2010) Jazigos fossilíferos do Brasil: legislação e cooperação científica

internacional. In: Carvalho IS (ed) Paleontologia: conceitos e métodos. Editora Interciência Ltda, Rio de Janeiro, pp 561–584
Carvalho IS, Novas FE, Agnolín FL, Isasi MP, Freitas FI, Andrade JA (2015a) A Mesozoic bird from Gondwana preserving feathers. Nat Commun 6:714–715. https://doi.org/10.1038/ncomms8141
Carvalho IS, Novas FE, Agnolín FL, Isasi MP, Freitas FI, Andrade JA (2015b) A new genus and species of enantiornithine bird from the Early Cretaceous of Brazil. Braz J Geol 45(2):161–171. https://doi.org/10.1590/23174889201500020001
Carvalho IS, Agnolin F, Aranciaga RMA, Novas FE, Xavier-Neto J, Freitas FI, Andrade JAFG (2019) A new genus of pipimorph frog (anura) from the early Cretaceous Crato Formation (Aptian) and the evolution of South American tongueless frogs. J S Am Earth Sci 92:222–233. https://doi.org/10.1016/j.jsames.2019.03.005
Carvalho IS, Henriques MH, Castro ARSF, Félix YR (2020) Promotion of the Geological Heritage of Araripe Unesco Global Geopark, Brazil: the Casa da Pedra Reference Center. Geoheritage 12:17. https://doi.org/10.1007/s12371-020-00452-9
Carvalho IS, Raminelli R, Henriques MHP, Soares RC, Andrade JAFG, Freitas FI (2021) The Araripe Geopark (NE Brazil): discovering the earth's past as a driver of economic and social transformation. Geoheritage 13:60. https://doi.org/10.1007/s12371-021-00586-4
CIIGC (2021a) Centro de Interpretação e Investigação Geológica de Canelas. http://aroucageopark.pt/pt/explorar/o-que-visitar/museus-e-unidades-interpretativas/museu-das-trilobites-centro-de-interpretacao-geologica-de-canelas/. Accessed 29 September 2021
CIIGC (2021b) Geological interpretation Centre of Canelas. Museum of Trilobites. https://museudastrilobites.pt/en/museum/. Accessed 29 September 2021
Demnard F, Neraudeau D (2001) L'utilisation des oursins fossils de la Préhistoire à l'époque gallo-romaine. Bull Soc Préhistorique Fr 98(4):693–715
De Miguel D, Brilha J, Meléndez G, Azanza B (2020) Geoethics and geoheritage. In: Vasconcelos C, Schneider-Voß S, Peppoloni S (eds) Teaching geoethics. Resources for Higher Education, Erasmus Plus GOAL – Geoethics Outcomes and Awareness Learning, Porto, pp 57–71. https://doi.org/10.24840/978-989-746-254-2
De Miguel D, Brilha J, Alegret L, Arenillas I, Arz JÁ, Gilabert V, Strani F, Valenciano A, Villas E, Aranza B (2021) Linking geological heritage and geoethics with a particular emphasis on palaeontological heritage: the new concept of 'palaeontoethics.' Geoheritage 13:69. https://doi.org/10.1007/s12371-021-00595-3
Dias JJ, Carvalho IS (2020) Remarkable fossil crickets' preservation from Crato Formation (Aptian, Araripe Basin), a Lagerstätten from Brazil. J S Am Earth Sci 98:102443. https://doi.org/10.1016/j.jsames.2019.102443
Drąsutė V, Drąsutis S, Corradi S, Kelpšaitė N (2000) Social responsibility and ethical attitude on the media. In: Vasconcelos C, Schneider-Voß S, Peppoloni S (eds) Teaching Geoethics. Resources for Higher Education, Erasmus Plus GOAL – Geoethics Outcomes and Awareness Learning, Porto, pp 30–40. https://doi.org/10.24840/978-989-746-254-2; ISBN 978–989–746–254–2
Druguet E, Passchier CW, Pennacchioni G, Jordi Carreras J (2013) Geoethical education: a critical issue for geoconservation. Episodes 36(1):11–18. https://doi.org/10.18814/epiiugs/2013/v36i1/003
Duffin C (2008) Fossils and folklore. Ethical Record 13(3):17–21
Duque J, Mateos MA (2006) "Serendipia" en geología: el Messiniense y el Cráter Chicxulub. Enseñanza de las Ciencias de la Tierra 14(2):131–141
Figueiredo MV (2011) The trilobites of Canelas. Two decades living with slate and giant trilobites. CIGC, Canelas
Gambim Jr A, Scheffler SM, Fernandes ACS, Carvalho CRF (2017) Crinoides fósseis associados a urnas funerárias na foz do Rio Amazonas. In: Max Cardoso Langer MC, Adel AW, Ferreira GS, Hermanson G, Marsola JCA, Onary-Alves SY (eds) Paleontologia em Destaque, Boletim de Resumos XXV Congresso Brasileiro de Paleontologia 2017, Ribeirão Preto, Ed. Esp. 32, pp 121–121.
Geer AVD, Dermitzakis M (2008) Fossils in pharmacy: from "snake eggs" to "Saint's bones. Hell J Geosci 45:323–332
Geer AVD, Dermitzakis M, de Vos J (2008) Fossil folklore from India: the Siwalik Hills and the Mahabharata. Folklore 119:71–92. https://doi.org/10.1080/00155870701806225
Gutierréz-Marco J, Sá AA, García-Bellido DC, Rábano I, Valério M (2009) Giant trilobites and trilobite clusters from the Ordovician of Portugal. Geology 37(5):443–446. https://doi.org/10.1130/G25513A.1
Haag N, Henriques MH (2016) The paleontological heritage of the Acre (Amazonia, Brazil): contribution towards a national paleontological database. Geoheritage 8:381–391. https://doi.org/10.1007/s12371-015-0163-y
Henriques MH (2010) Paleontologia e Educação para a Sustentabilidade. In: Carvalho IS (ed) Paleontologia, 3rd edn. Editora Interciência, Rio de Janeiro, 1, pp 577–588
Henriques MH, Pena dos Reis R (2015) Framing the palaeontological heritage within the geological heritage: an integrative vision. Geoheritage 7:249–259. https://doi.org/10.1007/s12371-014-0141-9
Henriques MH, Pena dos Reis R, Brilha J, Mota TS (2011) Geoconservation as an emerging geoscience. Geoheritage 3(2):117–128. https://doi.org/10.1007/s12371-011-0039-8
Henriques MH, Tomaz C, Sá AA (2012) The Arouca Geopark (Portugal) as an educational resource: a case study. Episodes 35(4):481–488. https://doi.org/10.18814/epiiugs/2012/v35i4/004
Henriques MH, Pena dos Reis R (2019a) A contemporary vision of nature through Geoheritage. In: Oosterbeek L, Caron L (eds) Resilience and transformation in the territories of low demographic density, Arkeos, Instituto Terra e Memória, Mação, 8(1), 131–147
Henriques MH, Pena dos Reis R (2019b) Improving geoconservation of the palaeontological heritage through a semiotic vision. Span J Palaeontol 34(1):95–102. https://doi.org/10.7203/sjp.34.1.15248
Henriques MH, Castro ARSF, Félix YR, Carvalho IS (2020) Promoting sustainability in a low-density territory through geoheritage: Casa da Pedra case-study (Araripe Geopark, NE Brazil). Resour Policy 67:101684. https://doi.org/10.1016/j.resourpol.2020.101684
Larson NL (2001) Fossils for sale: is it good for science? Geol Curator 7(6):219–222
Larwood JG (2001) Commercial fossil trade: good or bad for sites of special scientific interest? Geol Curator 7(6):223–226
Lima JTM, Carvalho IS (2020) Geological or cultural heritage? The ex situ scientific collections as a remnant of nature and culture. Geoheritage 12:3. https://doi.org/10.1007/s12371-020-00448-5
Maldanis L, Carvalho M, Almeida MR, Freitas FI, Andrade JAFG, Nunes RS, Rochitte CE, Poppi RJ, Freitas RO, Rodrigues F, Siljeström S, Lima FA, Galante D, Carvalho IS, Perez CA, Carvalho MR, Bettini J, Fernandez V, Xavier-Neto J (2016) Heart fossilization is possible and informs the evolution of cardiac outflow tract in vertebrates. eLife 5:e14698. https://doi.org/10.7554/eLife.14698
Martill DM (1997) Fish oblique to bedding in early diagenetic concretions from the Cretaceous Santana Formation of Brazil e implications for substrate consistency. Palaeontology 41:1011–1026
Martill D (2001) The trade in Brazilian fossils: one palaeontologist's perspective. Geol Curator 7(6):211–218
Martins B, Pereira A (2018) Residents' perception and assessment of geomorphosites of the Alvão-Chaves region. Geosciences 8:381. https://doi.org/10.3390/geosciences8100381

Moncel M-H, Chiotti L, Gaillard C, Onoratini G, Pleurdeau D (2012) On-utilitarian lithic objects from the European Paleolithic. Archaeol Ethnol Anthropol Eurasia 40(1):24–40. https://doi.org/10.1016/j.aeae.2012.05.004

Moura GJB, Albuquerque UP (2012) The first report on the medicinal use of fossils in Latin America. Evid Based Complement Alternat Med:691717.https://doi.org/10.1155/2012/691717

Nobre GS (1997) Prefácio de "Memória sobre a Capitania do Ceará e outros trabalhos. João da Silva Feijó". Biblioteca Básica Cearense. Fundação Waldemar Alcântara, Fortaleza

Nissen MD, Lau ETL, Cabot PJ, Steadman KJ (2019) Baltic amber teething necklaces: could succinic acid leaching from beads provide anti-inflammatory effects? BMC Complement Altern Med 19:162. https://doi.org/10.1186/s12906-019-2574-9

O'Brien K, Reams J, Caspari A, Dugmore A, Faghihimani M, Fazey I, Hackmann H, Manuel-Navarrete D, Marks J, Miller R, Raivio K, Romero-Lankao P, Virji H, Vogel C, Winiwarter V (2013) You say you want a revolution? Transforming education and capacity building in response to global change. Environ Sci Policy 28:48–59. https://doi.org/10.1016/j.envsci.2012.11.011

Page K (2003) The protection of Jurassic sites and fossils: challenges for global Jurassic science (including a proposed statement on the conservation of palaeontological heritage and stratotypes). Riv It Paleontol Strat 110:373–379. https://doi.org/10.13130/2039-4942/6313

Page K (2018) Fossils, heritage and conservation: managing demands on a precious resource. In: Reynard E, Brilha J (eds) Geoheritage. Assessment, Protection, and Management. Elsevier, Chennai, pp 107–128. https://doi.org/10.1016/B978-0-12-809531-7.00006-X

Peresani M, Vanhaeren M, Quaggiotto E, Queffelec A, d'Errico F (2013) An ochered fossil marine shell from the Mousterian of Fumane Cave, Italy. PLoS ONE 8(7):e68572. https://doi.org/10.1371/journal.pone.0068572

Peppoloni S, Di Capua G (2021) Current definition and vision of geoethics. In: Bohle M, Marone E (eds) Geo-societal narratives - contextualising geosciences. Palgrave Macmillan, Cham, pp 17–28. https://doi.org/10.1007/978-3-030-79028-8_2

Pena dos Reis R, Henriques MH (2009) Approaching an integrated qualification and evaluation system for geological heritage. Geoheritage 1(1):1–10. https://doi.org/10.1007/s12371-009-0002-0

Petrilli S (2009) Semiotics as semioethics in the era of global communication. Semiotica 173:343–367. https://doi.org/10.1515/SEMI.2009.015

Piranha JM, Lama EA, Bacci DC (2011) Geoparks in Brazil—strategy of geoconservation and development. Geoheritage 3:289–298. https://doi.org/10.1007/s12371-011-0043-z

Ribeiro LCB, Carvalho IS, Neto FM (2015) Geopark Uberaba: relevance of the geological heritage. Geoheritage 7(3):261–273. https://doi.org/10.1007/s12371-014-0131-y

Sá AA, Pereira S, Rábano I, Gutiérrez-Marco I (2021) Giant trilobites and other middle ordovician invertebrate fossils from the Arouca UNESCO Global Geopark, Portugal. Geoconserv Res 4(1):121–130. https://doi.org/10.30486/GCR.2021.1913689.1057

Schemm-Gregory M, Henriques MH (2013) The Devonian brachiopod collections of Portugal—a paleontological heritage. Geoheritage 5(2):107–122. https://doi.org/10.1007/s12371-013-0080-x

Senadheeraa SS, Withanaa PA, Dissanayakea PD, Sarkar B, Chopra SS, Rheed JH, Ok YS (2021) Scoring environment pillar in environmental, social, and governance (ESG) assessment. Sustain Environ 7(1):1–7. https://doi.org/10.1080/27658511.2021.1960097

Sonesson G (2011) Semiotics inside-out and/or outside-in. How to understand everything and (with luck) influence people. Signata 2:315–348. https://doi.org/10.4000/signata.742

Tavares AO, Henriques MH, Domingos A, Bala A (2015) Community involvement in geoconservation: a conceptual approach based on the geoheritage of south Angola. Sustainability 7:4893–4918. https://doi.org/10.3390/su7054893

UNESCO (2021a) UNESCO Global Geoparks (UGGp). UNESCO. https://en.unesco.org/global-geoparks. Accessed 28 September 2021

UNESCO (2021b) Araripe UNESCO Global Geopark (Brazil). UNESCO. https://en.unesco.org/global-geoparks/araripe. Accessed 28 September 2021

UNESCO (2021c) Arouca UNESCO Global Geopark (Portugal). UNESCO. https://en.unesco.org/global-geoparks/arouca. Accessed 28 September 2021

Vialou AV, Vialou D (2019) Manifestações simbólicas em Santa Elina, Mato Grosso, Brasil: representações rupestres, objetos e adornos desde o Pleistoceno ao Holoceno recente. Bol Mus Para Emílio Goeldi Cienc Hum 14(2):343–365. https://doi.org/10.1590/1981.81222019000200006

Werlen B, Osterbeek L, Henriques MH (2016) International year of global understanding: building bridges between global thinking and local actions. Episodes 39:604–611. https://doi.org/10.18814/epiiugs/2016/v39i4/103894