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ORIGINAL ARTICLE

Linking geological heritage and geoethics with a particular emphasis on palaeontological heritage: the new concept of 'palaeontoethics'

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Abstract

Geoconservation and geoethics are two emergent domains in geosciences. During the last decade, both topics have increasingly gained the attention of geoscientists and the society, but the main geoethical dilemmas related to the conservation and management of geoheritage are not clearly identified yet. This work aims at providing an overview on the meaning and scope of geoethics and how it intersects geoheritage and the practice of geoconservation. Some case studies—many of which are under current debate and have a high potential as geoeducational resources—are presented for addressing ethical, social and cultural settings as well as dilemmas affecting geoheritage. We find that there are particular cases (mostly concerning the trade of fossils, and in particular the growing concern about activities that rely on amber from Myanmar) for which a clear dichotomy of views makes them much more problematic and complex. These cases deserve more suitable legal frameworks that help implement more balanced ethical standards and practice guidelines for geoconservation, guarantee human rights and needs in relation to that heritage and contribute to the advancement of geosciences. Particular attention is given to palaeontological heritage, as fossils are among the most threatened elements of the Earth's diversity and are in need of more effective and statutory protection measures. In the context of geoethics applied to palaeontological heritage, and given the need of a clear understanding of what ethics in palaeontology means, a new concept—*palaeontoethics*—is proposed and formally defined.

Keywords Geoheritage · Geoconservation · Geosites · Fossils · Myanmar · Geoethics · Palaeontoethics

Introduction

Geoethics is a young, multidisciplinary field that studies and reflects upon the values that underpin appropriate human practices, whenever anthropogenic activities interact with the Earth System (see Di Capua and Peppoloni 2019 for a comprehensive definition of geoethics). It emerges from the idea that human actions (positive and negative) have an impact on the natural processes and on the environment and that ethical criteria are needed to guide such interactions, especially if considering that global population has increased rapidly particularly over the past few decades and global warming (Ripple et al. 2020; Tortell 2020; Wiedmann et al. 2020).

The foundation of geoethics is primarily traced back to the following three main elements: (i) the importance of geological culture as an essential part of the geoscientist's background; (ii) the concept of responsibility (both individual and social); and (iii) the definition of an ethical criterion

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on which to guide behaviour and practices in geosciences (Peppoloni et al. 2019).

Despite the fact that more and more geoscientists have (to some extent) integrated and considered ethical and social issues in their professional research and practice during the past decades (Matteucci et al. 2014; Mayer 2015; Peppoloni and Di Capua 2015, 2016; Bobrowsky et al. 2017; Foss 2019; Peppoloni et al. 2019; Antić et al. 2020), geoethics is still an emerging, relatively complex, and little known field of geosciences (Bobrowsky et al. 2017). In the case of geological heritage, it is still a major challenge to demonstrate geoethical values involved in the adequate management of in situ occurrences (geosites) and ex situ elements (fossils, minerals, rocks) in order to ensure their sustainability in the long term (Peppoloni and Di Capua 2020; Manni 2012).

The goal of this paper is to examine and discuss different aspects of geoconservation through different examples and case studies, many of which are under current debate and constitute serious ethical issues. A particular attention is given to palaeontological heritage, as fossils are among the most threatened elements of the Earth's diversity and are in need of more effective protection measures and statutory support.

Geodiversity, geoheritage and geoconservation

Background and main concepts

Before identifying dilemmas and problems related to the cultural, economical and social value of geoheritage, it is important to briefly consider some relevant concepts. Geodiversity or geological diversity, defined as the 'natural range (diversity) of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features. It includes their assemblages, structures, systems and contributions to landscapes' (Gray 2013), is crucial for understanding the variability of the natural substrates, which is indeed fundamental for the development of life and its diversity, as well as for supporting cultural and social diversity (Peppoloni and Di Capua 2016). Although this term was introduced at the beginning of the 1990s, three decades later it is still generally unknown by the majority of the society. Brilha et al. (2018) reviewed the concept of geodiversity and showed how it connects with other natural systems, highlighting its essential role to ensure human sustainability based on the use of renewable and non-renewable natural resources.

A responsible use of geodiversity elements by society demands a solid understanding of how Earth systems work. To gain scientific knowledge, it is essential to guarantee access to natural elements that hold a particular scientific value. The definition of geoheritage refers to the set of natural geological resources (including minerals, rocks, fossils, soils, landforms, geological formations and tectonic structures and other geological manifestations) with scientific, educational, cultural and/or aesthetic value. In many domains of geosciences, some of the scientific data are obtained directly in the field, whereas in others samples are collected for further analysis in the laboratory. In both cases, however, these geological sites that are object of study must be preserved as evidence of the history of the planet, thus allowing the advance of geosciences. These places are known as geosites and the set of geosites in a given territory constitutes its geological heritage (in situ) (Brilha 2021).

The geological samples that are organised in scientific collections and available for scientific research are also part of the geological heritage (ex situ). These valuable in situ and ex situ geological features must be preserved in the best possible conservation status, and they must hold some characteristics that differentiate them from other similar geological features. The scientific relevance of a geosite is also attested by national and international publications directly related to its geological value. In addition to their use for scientific purposes, geological sites may offer other opportunities of sustainable use, e.g. in education. The value of some geodiversity elements can indeed be easily understood by students, and this is particularly applicable to sites with good accessibility and safety conditions for both students and teachers. In other cases, geodiversity elements are natural attractions that can be used for leisure purposes and tourist activities. For a recreational and tourist use, the aesthetic and cultural values of these elements are particularly relevant.

The majority of geodiversity elements that lack significant scientific value but hold another type of use (educational, tourist, leisure, etc.) are designated as geodiversity sites, and they must also be protected following specific geoconservation strategies (Prosser et al. 2013; Brilha 2018; Gordon 2019).

The need for geoconservation and its feature as an applied geoscience

Geoconservation aims at the protection and management of geosites and geodiversity sites, including the management of the geological collections. Inventorying and quantitative assessment, statutory protection, conservation, promotion and interpretation and monitoring of sites are some specific methods used to promote geoconservation (Page 2004; Page and Wimbledon 2008; Brilha 2018; Meléndez 2018).

All these measures are needed because many geological sites today are under a real threat (and run the risk of disappearing) due to several types of anthropic degradation:

- *Cultural and scientific illiteracy* — Decision-makers and the society in general have a very low awareness of geology and the importance of geodiversity components for the natural capital, ecosystems services and human well-being. Consequently, public decisions about geoconservation tend to be slow or completely overlooked.
- *Unsustainable mining* — Although mining and energy resources are absolutely pivotal for the human development, their irresponsible use may put many relevant geological sites at risk.
- *Urban development* — The rapid expansion of cities towards rural areas (due to population growth and the migration from the countryside to urban areas) is responsible for the destruction of many geological sites worldwide.
- *Deficient statutory protection* — Without a solid statutory protection at the international, national, regional or local levels, the preservation of the geological sites is fragile and frequently useless.
- *Inefficient administration* — Public administrations without sufficiently trained staff, solid geoconservation strategies and proper funding can lead to an increase of the vulnerability of geoheritage.
- *Smuggling and illegal collecting* — Fossils, minerals and rocks are vulnerable to be stolen from many countries, hereby feeding international smuggling networks and being of huge benefit to speculators.
- *(Some) scientific research* — There are geosites strongly affected by deficient scientific sampling procedures that do undervalue the different types of information that the outcrops can provide.
- *Unsustainable tourism and leisure activities* — Mass tourism in areas with fragile geological features (e.g. caves, soft and unconsolidated substrates, rare fossils) can negatively affect many geological sites.

It is necessary to acquire knowledge about all these factors in order to contribute towards more effective preservation measures of the geological sites and their different types of components. Fortunately, a growing number of scientific activities have significantly sharpened our knowledge for this purpose over the last two decades. Some of these initiatives include research schools and teaching activities that have produced master and doctoral theses on this subject, scientific discussions in international forums and publication of peer-reviewed papers in dedicated indexed scientific journals. All these lines of reasoning claim that geoconservation may be also considered as an applied geoscience (Henriques et al. 2011).

Palaeontological heritage

Among the different components of Earth's geodiversity, fossils are particularly affected by many of the threats mentioned above (Page et al. 1999). Due to its fragile nature and because it is the only source of information about past biodiversity, palaeontological heritage demands strategic and more effective protection measures.

Fossils and palaeontological heritage

Fossils are any evidence (remains, impressions, moulds, casts, traces, biochemical molecules, etc.) of once-living organisms from the geological past that are preserved in the materials of the Earth's lithosphere (i.e. they are typically found in rocks of sedimentary nature). They represent a relevant component of geodiversity with the unusual capacity to connect people with our natural environment and, importantly, with our origins and past. Fossils inform about the environment where past organisms lived, and along with their accompanying contextual data (usually, the environment of accumulation of the sediments corresponding to the rock in which fossils are found), they are a unique resource for palaeontologists to understand the history of life.

Given the exceptional nature of the process of fossilisation, a fossil is, by definition, 'a unique or rare and non-renewable natural object and, as such, a highly valuable asset' (Henriques and Pena dos Reis 2015). Fossils are therefore the result of three types of convergent histories (Fig. 1) which make them very useful as scientific and educational resources:

- *History of life* — Since a fossil is the evidence of a once-living organism, it is the result of an evolutionary history, and, as such, it informs about past life on Earth and the relationships with biodiversity.
- *History of humanity* — Considering that the humankind forms part of this evolutionary history, fossils inform about our own history as living beings (hence, evolutionary anthropology or the study of humankind from a palaeontological perspective is particularly important), and consequently about our changing role in nature and our relationships with Earth.
- *History of Earth* — As a fossil is the result of a fossilisation process, it informs about its own geological history, which in some cases may be different from the history of the rock that contains the fossil. For instance, there are particular processes (such as pyritization or carbonisation) that may affect the fossil but not the outcropping rock. Fossils are also informative about the

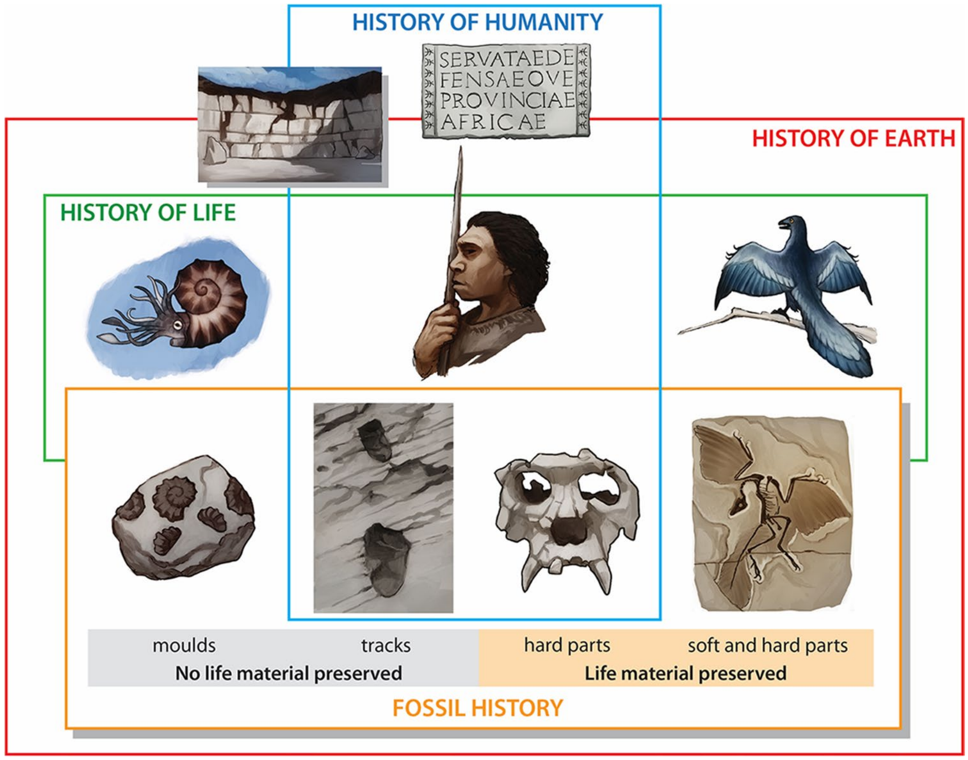

Fig. 1 Schematic diagram illustrating different types of information provided by fossils. Although fossils are preserved in the strata, they also have their own natural history (in yellow) that results from a taphonomical cycle. They incorporate information and material from the biosphere to the lithosphere, contributing to reconstruct the *history of the Earth* (in red). Even in those (many) cases when no direct life remains (fossilised skeletons, shells, etc.) are preserved, fossils inform about the original organisms that directly or indirectly produced them, e.g. as in footprints. Consequently, fossils also offer a way to learn about the *history of life* (in green) on Earth. Since humans are part of this history, fossils also contribute to know the *history of humanity* (in blue). As nature is used and modified by humans, we fossils also contribute to the history of the Earth

history of a changing Earth in space and time, so they are a valuable archive that has been used to reconstruct past environments and palaeogeography.

Palaeontology, or the study of fossils, is then placed at the intersection among geological, biological and archaeological/anthropological disciplines. Hence, palaeontological heritage shares common characteristics with both our natural and social/cultural/historical heritage (despite being natural objects) and cannot be interpreted or studied without this synergetic perspective. In common with the natural heritage, fossils are formed in and by nature, while the obvious link with the social/cultural/historical component is the popular fascination of fossils that lead to collection of these elements as a hobby (Alcalá and Morales 1994) or to the popular passion for ancient life (including our own clade). It is also important to stress that fossils present compelling evidence of evolution and are real evidence of past life and extinctions, thus have traditionally caused conflict with religion and beliefs (i.e. science vs. religion).

Because fossils are the unique geodiversity elements which allow for the reconstruction of the history of life, palaeontological heritage is understood by some authors (Meléndez and Soria-Llop 2000a) as a particular type of geoheritage. In view of such particularity, and despite the fact that fossils are geodiversity elements, it has been argued that palaeontological heritage can be considered as a separate entity from geoheritage, hereby acquiring its own status.

The scientific value of fossils is related to the fossil itself and to the rock in which it is contained; therefore, the term palaeontological heritage refers to both a set of rocks containing fossils, the palaeontological site itself, and all the fossils extracted from the site. In this sense, fossils are comparable to other geoheritage elements such as the mineralogical ones and also the archaeological heritage.

Palaeontological heritage management

Fossils are valuable objects offering different types of benefit or interest to society (Meléndez and Soria-Llop 2000b; Page 2004, 2018; Henriques and Pena dos Reis 2019). There is a plethora of reasons for which fossils attract the attention of people, which is particularly evident for certain groups (such as dinosaurs and anthropoid primates). On the one hand, this positively contributes to promote learning for students and the general public, while, on the other hand, it may result in a direct, serious impact and a hazard for the integrity of the fossil record. There is a long and complex process from the discovery of a fossil in the field (which requires active searching for rocks that are more likely to contain fossils and careful excavation of valuable fossils) to its scientific study and incorporation into a collection or exhibition and dissemination.

Most museums and exhibits show macrofossils as they can be observed by visitors with a naked eye and also because of their aesthetic appeal. Microfossils are equally relevant to science but are commonly underrepresented in museums and exhibits because magnifying lenses and microscopes are required for their observation. Fortunately, this idea is gradually changing in modern exhibitions, which display enlarged pictures of microscopic fossils as well as microfossil bearing rocks, usually associated with a relevant story (importance of microfossils in oil exploration, high-resolution studies to reconstruct past events, etc.).

A palaeontological site is a ‘particular location (or group of nearby occurrences) in which fossils (of any type and concentration) are present’ (Alcalá and Morales 1994). It is evident that not all fossil occurrences can be considered as palaeontological heritage, such as not all paintings can be recognised as cultural heritage. This is clear for microfossils, as they are a common feature of the geological record (Fig. 2). Microfossils have been traditionally neglected in geoconservation, but there are many type-localities and stratotypes which are formally defined and named on the basis of microfossils and must be considered as palaeontological heritage as well.

Consequently, palaeontologists have to decide (1) which fossils and sites have the sufficient importance to be considered as palaeontological heritage and (2) how to manage them in the best possible way. Three groups of criteria may help resolve this task (Alcalá and Morales 1994):

- *Scientific criteria* — Nature of fossils (fossils of exceptional importance); geological age of the rocks; type localities (i.e. those from which species have been first recognised and formally defined); degree of preservation; association with archaeological remains; diversity of fossils (for instance, association of plant and animal remains); taphonomic (i.e. the process leading up to preservation or fossilisation) information; bio/chronostratigraphical relevance (sites which date important geological formations at international level); wider geological interest; and level of knowledge (i.e. sites that have provided new knowledge about a particular topic).
- *Socio-cultural criteria* — Geographic location; vulnerability to damage; historic value; educational interest (a criterion of special relevance to this chapter as it informs about the potential of a site for use in education); touristic interest (similar to the previous); and additional value (i.e. sites in places already protected for other reasons).
- *Socioeconomic criteria* — Urban value (sites in urban areas potentially available for development); mineral value (sites associated with mineral exploitation); agriculture value of arable lands on soft fossiliferous rocks; public works (sites linked with works); and economic value.

Since many of these criteria might lead to various ethical conflicts, they directly relate to geoethics. In particular, public works (especially for transport, water and power infrastructures), mining and agriculture activities or engineering projects, among others, can destroy sites of relevant importance to palaeontology, but they have also a decisive role in the discovery of new heritage. Conservation is needed to protect fossils and sites from loss and destruction through illegal sampling and to regulate the selling and exportation of fossils.

In terms of regulations, and because palaeontological heritage is considered as a type of heritage in many countries,

Fig. 2 Example of foraminiferal assemblages in ornamental limestones. Alveolinids (left) and *Nummulites* (right)

there are legal measures for a correct protection and management of sites and fossils. These laws vary widely among countries, with some governments being less strict than others (Meléndez 2018; Meléndez and Soria-Llop 2000b; Wimbledon and Smith-Meyers 2012; Liston and You 2015). A relevant difference among countries concerning fossil collecting is the private or public ownership of the surface and the underground.

Ethical issues and challenges associated with geoheritage: with a particular emphasis on palaeontological heritage

As previously discussed, geoheritage offers great opportunities to promote geoscience education for the benefit of the society. In addition, the research and management of geoheritage raises among geoscientists a reflection on a plethora of aspects (still poorly addressed in the literature) concerning ethical principles. Some of these issues are briefly presented in the following paragraphs, with the purpose to trigger reflective learning and considerations on individual roles and responsibilities when working on geoheritage.

Collecting of geological specimens (fossils, minerals and meteorites)

There is no doubt that the popularity of some geological elements as collectible and commercial items has significantly increased in recent years. Among these elements, interest in collecting fossils (probably the most common geological object to be collected; Gutiérrez-Marco 2020) is booming. At least in part, this is likely attributable to the prominence of dinosaurs in movies and cartoons, and as a result some big-spending collectors have amassed private fossil collections over the past decades.

The collecting of geological specimens is done for five primary reasons:

- *Scientific research* — The sampling of fossils, minerals and rocks in geosites and its study in laboratories is an essential step of the research process in geosciences.
- *Commercial reasons* — Geological specimens are collected to supply the international and national markets. In a recent auction, the cost of a 67 million year-old *Tyrannosaurus rex* skeleton reached 31.8 million USD (https://edition.cnn.com/style/article/stan-t-rex-skeleton-auction-scli-intl-scn/index.html).
- *Education* — The description and study of geological specimens in laboratory classes is an important strategy for school and university students. In informal educational contexts (such as museums and interpretive centres), minerals, fossils and rocks samples are part of permanent and temporary exhibitions.
- *Conservation* — When the integrity of geological materials with high geoheritage value are at risk due to natural or man-made threats, its removal from the outcrop and transfer to local facilities (museums, universities, etc.) is the only possibility to ensure their preservation.
- *Private collections* — The collecting of objects is a very common hobby in many societies, including fossils, minerals and meteorites. Private collectors can obtain their specimens in the commercial market or may collect them directly in the field. Sometimes, these private collectors have no academic training, but due to their interest in the topic, they gain knowledge about the collected objects. In some countries, these amateur scientists are responsible for very important findings that have been subsequently studied and described by certified scientists (Robinson 2001). On the other side, there are cases of research misconduct and even fraud by people without scientific knowledge.

Regardless the reasons for collection of geological specimens, this practice can be considered:

- *Legal* — When it follows local and/or national collection regulations
- *Illegal* — When it does not follow local and/or national collection regulations
- *Uncontrolled* — When it is done in areas without specific or appropriate collection regulations

The existence of regulations contributes to a sustainable use of these geological objects, but it does not suffice. The collectors of geological specimens must know the regulations and follow them. Authorities and the administration must have resources to guarantee that these regulations are really implemented and accepted by collectors. Illegal collecting is certainly reprehensible and should be subject to sanctions through legal action. Unfortunately, the most common situation for most countries is the uncontrolled collecting. Without statutory regulations, only geoethical and collecting codes may contribute to promote a responsible action of collectors.

In 2016, the International Union for Conservation of Nature approved the "Resolution 083 Conservation of moveable geological heritage" with three main aims (https://portals.iucn.org/library/sites/library/files/resrecfiles/WCC_2016_RES_083_EN.pdf):

- To promote and support national and international initiatives oriented towards the conservation and sustainable use of moveable geoheritage

- To prepare guidelines on the protection, conservation and management of moveable geoheritage
- To promote and support the discussion on the conservation and management of moveable geoheritage, in compliance with national and international regulations of its commerce

In spite of the efforts made by many countries to develop procedures and laws against unregulated economy of geological specimens, the increasing interest in fossils has raised the competition (and opportunity) for commercial and pseudo-scientific collectors. Collecting for commercial purposes raises many ethical issues (Triebold 2007; Jones 2020) and has a detrimental effect on education and science, as geological specimens are irreplaceable objects. For instance, the increase of the economic value of fossils has limited the possibility of public museums and educational centres with small budgets to acquire fossils for their collections. The sampling of fossils without following a scientific protocol contributes to a permanent loss of information of the depositional environment and geological context, which holds precious scientific information for palaeontologists, occasionally even more valuable than the fossil itself.

Public administrations that manage geoheritage should be assisted by geoscientists, particularly when they lack staff with specific training (Alcalá and Morales 1994). Some regional administrations in Spain are examples of good management as they have recently included professional palaeontologists in their permanent staff and promote the deposit of collected materials in an appropriate institution (Meléndez and Soria 1994).

Smuggling of geological specimens versus economic revenue of deprived communities

The potential economic value of geological specimens in many local communities constitutes another serious issue concerning illegal collecting. This issue may be source of controversy (of particular importance when specimens come from conflict zones; see Barret and Johanson 2020; Haug et al. 2020; Rayfield et al. 2020), as the collection of fossils, minerals and meteorites becomes a source of income for poor families in rural areas of some countries. Without other alternatives, this activity is the only resource available for non-educated people, and it guarantees a regular income.

In many places, like in the Tafilalet region (Morocco, North Africa), there is a real risk that search for fossils for commercial purposes and associated massive digs may lead to the rapid destruction of sites and loss of key specimens of scientific importance (Gutiérrez-Marco and García-Bellido 2018; Gutiérrez-Marco 2020). However, the same uncontrolled trade of fossils can also bring a benefit for science, as the massive exploitation of fossiliferous layers leads to thousands of new findings (especially marine invertebrates such as trilobites and cephalopods), which allow for a better understanding of taxonomic, taphonomical and palaeoecological aspects of past organisms, if professional palaeontologists can have access to these fossils.

Fossil replicas for sale: fakery or handcraft?

Specimens of some fossil groups are scarce, and museum collections all over the world cannot display real fossils of these groups. In this case, the production of replicas is an excellent solution. In several natural history museums, fossil exhibitions are almost entirely based on replicas. Hollow plastic casts are particularly useful when displaying large dinosaurs or mammals, whose skeletons are often incomplete or too heavy. The production of precise casts can be seen under three different perspectives:

- As an *educational and scientific resource* — When the availability of real fossils is limited and expensive or in order to prevent the original specimens from damage
- As a *handcraft* — When artistic fossil recreations are produced and sold as any other economic activity (Fig. 3)
- To *simulate true fossils* with a clear purpose to deceive (particularly non-expert) buyers.

Countries where fossil fakery is common include the USA, Colombia, Peru, Russia, Germany, France, and especially Morocco (with marine trilobites) and China (with *Archaeoraptor*—a chimera of bird and dinosaur features—and the cheetah *Acinonyx kurteni* being two of the most conspicuous fossil fakes, Zhou et al. 2002; Mazák 2012; Wang 2013). The impact of this practice on science and society is negative, as many fake fossils are difficult to identify as such (sometimes even by experts) and are sold at higher prices to museums and educational institutions, which ultimately include them in their exhibits as real fossils (Budik and Turek 2003).

The production of fossil replicas with a licit aim may decrease the pressure on limited outcrops and can constitute an economic alternative for local communities.

Mineral and fossil shows: an educational occasion or an incentive for smuggling of geological specimens?

Mineral and fossil fairs/festivals/shows are organised all over the world. Some of them have already a worldwide recognition, such as the Bourse Internationale aux Minéraux et Fossiles de Millau (France) or the Tucson Gem and Mineral Show of Arizona (USA), this latter gathering around 4000 trade companies each year. Smaller events are frequently organised by universities and museums, with the

Fig. 3 Traditional selling of minerals and fossils. The "giant ammonite" can be considered as an example of traditional local handcraft in Morocco (North Africa)

participation of for-profit professional sellers who display and sell beautifully preserved specimens (Fig. 4).

While these events may have an educational character, raising awareness of the public for a usually less known natural world and eventually stimulating young people to follow a geoscientific career, everyone watching these specimens should ask themselves about their provenance (see, for example, https://preview.springer.com/us/editorial-policies/research-involving-palaeontological-and-geological-material, for Springer policies involving provenance information of palaeontological and geological specimens). In other words, the fact that there are commercial mineral and fossil fairs does not mean that we should not raise the questions about legal and ethical implications of this activity. Under the geoethical perspective, these events may raise some pertinent questions that should be seriously considered by their organisers: Were the specimens collected following the national legislation in each country? Were local collectors in remote areas and commonly from poor countries properly paid for their work? Are there fossil and mineral sites with high scientific relevance being lost due to over-collecting to feed the international market? Are the administrations aware of the fact that that their natural heritage is going out of the country? Do these countries collect taxes as they do for any other commercial activities? Geoscientific and academic organisations that sometimes co-sponsor these events should be engaged in promoting the exhibition and selling of geological specimens with a geoethical certificate.

Commercial collecting and the market in fossils (and other geological specimens) is one of the most complex aspects affecting geological heritage (Page 2018) and raise many interesting observations. Indeed, there is a dichotomy of views in the professional or academic community on this matter which should not be ignored. On the one hand, a benefit of the increasing global market for fossils is that many critically important specimens, especially vertebrates

Fig. 4 Example of international fair displaying a variety of mineral and fossil specimens to sell. Bourse aux Minéraux et Fossiles de Millau (France) 2016. Photo by F. A. Ferratges

but also relevant invertebrates (as in the case of Palaeozoic material from Morocco; see Gutiérrez-Marco and García-Bellido 2018), are purchased by major museums from collectors and traders—so this market ultimately constitutes the main source of income of many local people (including miners and diggers, artisans that prepare and restore fossils). In parallel, the development of this fossil industry contributes to a massive exploration (involving many commercial collectors and dealers, some of them with astonishing skills in discovering fossils) and exploitation of outcrops, which constantly brings to light hundreds of new discoveries that otherwise would not have been found, especially if considering the shortage of professional palaeontologists (Gutiérrez-Marco and García-Bellido 2018). Many commercial collectors and dealers have an amazing ability to prepare specimens out of the rock, whereas most museums have significantly cut down their lab staff—which has the added benefit of making palaeontological research quicker and easier. On the other hand, as in other cases of commercial activity, such practises raise serious ethical questions when considered in the context of geoconservation and legislation/regulation. As an example, governmental regulations of some countries (e.g. Brazil) prohibit selling fossils, and consequently museums should not be allowed to buy specimens from these countries. The sale of Brazilian fossils in fairs, shops and museum shops is clearly illegal, though it does take place. Another negative impact is that, while moving the natural heritage from its original country to another country (e.g. to be part of a permanent collection of a museum) can be legal, it may be unfair and unethical as it leads to the situation that museums from first world countries have access to the best specimens while museums from less wealthy countries only keep the low-value specimens. Finally, while intensive exploitation contributes to the advance of palaeontological science through new discoveries, this activity is carried out without excavation permits, and it inevitably leads to the massive loss of fossil-bearing sites and rocks, which in many cases contain more valuable information than the fossil itself.

The trade of Burmese (South East Asia) amber deserves special attention, since fossils preserved in amber are not only scientifically priceless but also an extremely contentious issue. As an overview, fossils preserved in amber have provided palaeontologists with an extraordinary glimpse into the Cretaceous period. These consist of exquisitely well-preserved fossils (e.g. insects and plants, vertebrates such as birds, lizards, snakes and frogs, or even the feathered tail of a dinosaur) (Fig. 5) that have resulted in hundreds of scientific publications. The Burmese fossil-rich collection involves, however, legal problems and ethical issues. First, the Myanmar national legislation regarding fossil protection is potentially misleading since exporting fossils without permission is technically illegal, but amber is considered as a gemstone and hence allowed to export—so it is unclear which law has priority. Second, the actual situation in Myanmar in terms of human welfare is complex, since rival political factions have engaged in armed conflict for the control of some mines, resulting in civilian casualties and human right abuses (since amber sometimes is mined in hazardous conditions). This is a serious ethical issue because commercial trading of amber in some zones may fuel and finance armed conflict. The troubling situation surrounding Burmese amber is complex, and a wave of reactions with pros and cons of dealing with these fossils have circulated recently (see the US Society of Vertebrate Paleontology *SVP* article by Rayfield et al. 2020 and the rebuttal by Haug et al. 2020). Although there have not been any substantial developments on this issue yet, and confronted opinions exist, the Burmese amber is a genuinely outstanding case from which some sort of ethical standards should be implemented. These should include recommendations to deal with this type of fossils and promote fruitful discussion towards an understanding of the reality on the ground in Myanmar, involving the broader palaeontological community as well as local stakeholders.

Mining industry and development works: a threat or an opportunity?

Mining and urban development can have a significant impact on geosites. In many cases, these in situ occurrences must be subject to geoconservation strategies or, at least, to reasoned discussion (from the geoethical viewpoint) between geoscience professionals, government agencies and local administrations.

In Spain, the planning of a new dam in the Santaliestra-Campo area (province of Huesca) put at risk many natural features, including physical (water and soil), biotic (fauna and flora) and palaeontological (fossils) values. The planned reservoir would have flooded 250 hectares of the Ésera River valley, thereby affecting the parastratotypes of two geological stages (the Ilerdian [Schaub 1969] and the Cuisian [Schaub 1992]) of extreme importance for the Eocene epoch (Fig. 6). In spite of intense pressure from politicians, stakeholders and the construction industry to build the dam, the perception of the negative impacts by geoscientists, the local administration and residents of the village of Santaliestra led to question the building of the reservoir and to take legal action. Eventually, the social and geoscientific opposition promoted the suspension of all development works. Considering various technical, geological and palaeontological reports (Gayubar et al. 2001), the Spanish National Court declared the construction project of the Santaliestra reservoir as illegal and the project was stopped.

However, mining activities and development works may also give access to rocky massifs where new geological occurrences with geoheritage relevance are identified (Brilha

Fig. 5 Example of Mid-Cretaceous Burmese amber and fossils. Extraordinarily preserved angiosperm flowers (**a**), lacewings, wasps and ants (**b**–**d**), snails (**e**), and vertebrate remains (f, lizard/gecko; and g, feathered dinosaurs) from Myanmar amber mines (**h**, **i**). Pictures courtesy of the Myanmar Amber Museum

2015). Mining of fossiliferous formations often leads to the discovery of new species. The same applies to mineralogical heritage, as many mineral samples with scientific value are only available because mining exploitation brought those samples to the surface. Without mining, many of these relevant specimens would have remained undiscovered and completely unknown to science.

The palaeontological site of Lo Hueco (in Central-East Spain) is a good example of potential conflict between infrastructure development and preservation of palaeontological heritage, with an eventual mutual benefit. In 2007, this site yielded an enormous and unusual concentration of Late Cretaceous (ca. 70–80 Ma) dinosaur fossils thanks to the works carried out for the construction of new high-speed railway (Ortega et al 2008; Barroso-Barcenilla et al. 2009). There were no signs of any fossils in the surroundings, but a new palaeontological heritage site came to light. Fortunately, the railway works stopped to facilitate the identification, documentation and protection of fossils. After this research, it was possible to introduce a change in the railway planning in order to protect the site. This was an exceptional example of cooperation between the company ADIF (Administrador de Infraestructuras

Fig. 6 Example of mining industry and development works. Panoramic view of two Eocene (Ilerdian and Cuisian) paratratotypes (outcrops in the middle of the picture) near the Ésera River valley (North East Spain) that were planned to be flooded and affected by development works and the building of a dam

Ferroviarias) and palaeontologists, with mutual benefit for the government, the society and the conservation of heritage.

A similar case is the late Miocene (ca. 9 Ma) locality of Cerro de los Batallones (in Central Spain), which was discovered accidentally in 1991 thanks to mining works in a sepiolite quarry (Morales and Baquedano 2017), and the late Miocene–early Pliocene site of Langebaanweg 'E' Quarry (South Africa), found in a phosphate quarry (Hendey 1989). Both sites are considered today as some of the most renowned localities for their significant fossil remains.

Should all geological sites be available to geotourism?

There is increasing interest on geotourism, both by promoters and visitors (Dowling 2011; Štrba et al. 2018). The 161 UNESCO Global Geoparks are strongly supported on geotourism, as it promotes the visit to geological features, not only focused on geological interpretation but also on the links that can be established between these features and the biological and cultural character of communities. Geological sites with high aesthetic value, good accessibility and safe visiting conditions can be converted into touristic attractions with high potential to generate an economic activity.

However, the scenario here presented arises some questions and opens many interesting problems: What about if a geological site with high geotourism potential is vulnerable due to an intrinsic fragility of the geological element, or due to possible physical degradation caused, intentionally or not, by visitors? Should a manager open a certain geological site to visitors when it is not possible to guarantee its conservation? Fossil and mineral sites are a good example of this dilemma. Many sites have the potential to attract visitors but, without proper conservation measures, visitors may collect and vandalise fossils and minerals, contributing to the loss of the site value and consequently to a decrease of the number of visitors.

In geological sites, there is always a risk that tourists will collect fossils, rocks, minerals, etc. What if this activity is allowed in informal sites or 'fossil parks' where visitors appreciate the opportunity to work as a palaeontologist? Despite that fossil parks may have an educational character, one should question the ambiguous message they send concerning geoconservation.

Another example of potential geoethics issues focused on tourism refers to Global Boundary Stratotype Sections and Points (GSSPs), which are reference points on stratigraphic sections of rocks that define the lower boundaries of stages on the geologic time scale. The International Commission on Stratigraphy (ICS) is the scientific body that maintains the international GSSP register. Its primary objective is to define global units (systems, series and stages), which are the basis for the units (periods, epochs and age) of the International Geological Time Scale. The definition of these global geostandards is key to express the history of the Earth, and there are a number of ethical considerations on the GSSPs (see Page 2004, Page and Wimbledon 2008, and Page and Meléndez 1995 for particular cases of Jurassic GSSPs with palaeontological and stratigraphical importance).

A first obvious problem is the increasing cumulative impacts of researchers and visitors on stratigraphic sections and the surrounding geological environment (e.g. in the form of touching and climbing on landforms, congestion, access to restricted areas and the creation of informal trails, adding graffiti on rocks), a fact that is indeed promoted by the easy access and general connectivity to these areas of extraordinary scientific value. The Spanish Zumaia flysch section, in the Basque Coast UNESCO Global Geopark 'Geoparkea', is one of the best examples of well-managed GSSPs (Finney

Fig. 7 The Zumaia section in the Basque Coast UNESCO Global Geopark (North Spain). Example of cumulative impact of researchers and visitors on a reference section for the Cretaceous and the Paleogene. Photo by A. Hilario

and Hilario 2017) (Fig. 7). In addition to two formal GSSPs (for the bases of the Selandian and the Thanetian stages of the Paleogene; Schmitz et al. 2011) and an almost continuous record from the Cretaceous to the Eocene that allows unique, long-term palaeontological and palaeoclimate studies (Alegret and Ortiz 2010), two globally important boundaries are also exposed along this section: (1) the Cretaceous-Paleogene boundary (ca. 66 Ma), linked to a major mass extinction, has been extensively studied at Zumaia (Arz et al. 1999; Arenillas et al. 2004) and was designed as an auxiliary section of the GSSP for the base of the Danian (Molina et al. 2009), and (2) the Paleocene-Eocene boundary (ca. 56 Ma), linked to the largest warming event of the Caenozoic, has also been largely studied at Zumaia (Molina et al. 1999; Alegret et al. 2009; Dunkley Jones et al. 2018), and it was proposed as a candidate to host the GSSP for the base of the Ypressian (Canudo and Molina 1992). The Zumaia section is a clear example of international recognition of geological heritage, integral management and sustainable use. After an agreement signed by ICS and the local government, the local authorities are in charge of surveillance and maintenance of the outcrop (affected by continuous coastal erosion), of the marker plaques and golden spikes that mark the GSSPs, and of its accessibility. The geopark provides specific sampling permits for the > 100 scientists that work in the outcrop every year to ensure that highly valued geological features are not damaged, and the locals are so aware of the relevance of this section that they warn the authorities when scientists approach the outcrops. The local population is well aware of the scientific and economic importance of the section, as the geopark welcomes almost 20.000 visitors per year and offers geological tours, activities related to the local traditions, architecture and gastronomy; visits to the Algorri interpretation centre, the Nautilus museum and Arrietakua mansion (historical heritage); etc.

Other ethical issues involving the selection of stratigraphic reference sections include the falsification or omission of data by researchers, as well as sampling without permission of the landowner or the corresponding authorities. Decisions on the formal definition on GSSPs follow well-established voting procedures within ICS, whose voting members, officers, subcommissions and task groups are to maintain the integrity of the voting process when votes are taken. After a discussion period, any formal proposals for stratigraphic standards like GSSPs, formal stratigraphic stage names and units of other ranks are voted within a given ICS subcommission, ratified by ICS, and then by IUGS. In this regard, ICS has a role to play, carefully scrutinising proposals, checking that the principles and processes embedded in the commission are followed and finally making robust and testable decisions.

Replications of (show) caves: a way to promote tourist attraction or a loss of value?

Cave tourism (i.e. speleotourism) in karst sites is one of the most popular nature attractions worldwide, like the Postojna Cave in Slovenia and the Mammoth Cave in the USA (Tičar et al. 2018) or the Cacahuamilpa Cave in Mexico (Palacio-Prieto and Gómez-Aguado de Alba 2014). The underground environment raises a great curiosity among children and adults due to uncommon landforms such as stalactites and stalagmites and rock paintings. Because speleotourism brings significant economic profit, during the twentieth century, many caves were heavily adjusted to receive a high (and growing) number of tourists. These development works often introduced a great and sometimes irreversible degradation of the geological features and of the natural environment of the underground systems, particularly through changes in the accessibility and visiting conditions, like paved trails, artificial lightning, music and even artificial structures such as stairs and benches (Fig. 8).

Nowadays, this type of development can be considered unacceptable due to the level of fragility existing inside caves and the great ease to induce changes in their local biodiversity. From here, it emerges a major issue for the conservation of caves and the development of speleotourism: Should a cave be prepared to receive as much public

Fig. 8 Example of replication of cave. Cacahuamilpa Cave, the most visited cave in Guerrero (Mexico), discovered in 1883 and with about 350.000 visitors per year (Palacio-Prieto and Gómez-Aguado de Alba 2014), is part of the Grutas de Cacahuamilpa National Park, one of the largest cave systems in the world

(and types of public, e.g. students, children, adults, disabled people) as possible, allowing all the society to have an underground experience of high rarity? Or should it be kept instead in the most natural state possible, limiting its accessibility and use to a smaller group of visitors? While the former requires an artificialisation of the cave for its utilisation and development, the latter implies a more realistic experience to visitors and causes much less impact in geo- and biodiversity. As with most other classes of geological heritage, prior to the decision, it is necessary to put into practice geoethics values in order to achieve a balance between tourism development and protection of the caves.

An introduction and a formal definition of the new concept of *palaeontoethics*

As outlined above, there is increasing number of concerns about ethics in palaeontology that are particularly urgent to debate. For instance, what is legal and/or ethical to do, especially in terms of acquisition and curation of fossil specimens and subsequent publications.

The concept of ethics applied to palaeontology has recently gained much ground in scientific conferences and debates and is acquiring a wholly new significance, opening up new areas of research and discussion. Yet, surprisingly, our literature search indicates that a generally accepted and precise definition of ethics in palaeontology as a concept is missing. In recent months, the term ‘palaeoethics’ as alternative to palaeontology ethics has been invoked informally in online forums and workshops. However, this concept is inappropriate from an etymological viewpoint because the prefix *palaeo-* simply refers to something old or ancient, so ultimately palaeoethics would mean ‘old/ancient ethics’ and would encompass issues from various fields or disciplines not necessarily associated with palaeontology. This is why it is important to propose a clear, precise and unambiguous definition of what ethics in palaeontology means, in line and consistent with the definition of geoethics, which will ultimately benefit research, practice and education in palaeontology.

In response to this situation, we introduce and formally define for the first time the concept of ‘palaeontoethics’ (or *paleontoethics*). Palaeontoethics is the ‘branch of geoethics that consists of research and reflection on the values that underpin a correct behaviour and practice while collecting, handling, researching, and exhibiting fossils. Palaeontoethics promotes the analysis of ethical problems and dilemmas that arise in different geological, economical, social, and cultural contexts which affect the management, conservation, and popularization of fossils’. It is the union of the prefix *palaios* ‘old, ancient’, and the words *on* (gen. *ontos*) ‘being, creature’ and *ēthike* ‘moral principles’, thus meaning the reflection of what is morally right concerning fossils. This first proposal of the term palaeontoethics provides the framework needed to understand ethical standards to be applied in palaeontology.

Conclusion

During the last decade, the growing impact of humans on geoheritage has been specially recognised and documented, leading to a clear emergence of geoconservation and geoethics within the geosciences. Nevertheless, our community needs further discussion about which are the main geoethical dilemmas related with the conservation and management of in situ occurrences (geosites) and ex situ elements (fossils, minerals and rocks).

Common issues concerning the commercial exploitation of geological specimens, irresponsible/illegal collecting or the impact of mining and urban development, among others, are often subject of scant attention, while these contexts lead to conflict and promote damage to the most sensitive elements of the geological record. The cases here examined from diverse perspectives highlight that an ethical conscience and more adequate practices—including more statutory protection and management measures—in research and professional/amateur activities are necessary to ensure the conservation and transmission of geological heritage for future generations. We identify the trade of geological specimens as a particularly problematic case in the context of geoconservation and human rights and needs, given the clear dichotomy of views. However, there are ways of objectively and scientifically evaluating the effects of such activity.

The preservation of fossils and palaeontological sites emerges as one of the most problematic and complex aspects of geoconservation. Fossils are among the most threatened elements of geodiversity, as they can be very attractive as collectable and commercial objects, which cause inevitable conservation consequences. In recent years, the proliferation of concerns about ethics in palaeontology has changed our view about the protection and management of palaeontological heritage. This requires a formal definition and clear understanding of what ethics in palaeontology means, which ultimately can provide benefits for research, practice and education. With this aim in mind, we propose a new term: 'palaeontoethics'. The core concept is that human activity can lead to particular ethical dilemmas that affect fossils and, by extension, palaeontological heritage. Through the definition of palaeontoethics, we propose a word to be used and easily understood with the ultimate purpose of avoiding a confusing melee of uses and raising awareness of geoethics applied to palaeontological heritage.

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