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Fossils, heritage and conservation: Managing demands on a precious resource

Kevin N. Page

Plymouth University, United Kingdom, Drakes Circus, Plymouth, PL4 8AA, UK (kpage@plymouth.ac.uk)

Abstract: Managing palaeontological heritage is one of the greatest challenges for nature conservation, as a balance needs to be struck between use of the resource for science and education, as a component of raw materials for industry and the intrinsic natural heritage value of the resource – whilst all the time maintaining a basic human right to its use and enjoyment (where no greater societal aims are genuinely prejudiced). Although many national systems have developed procedures and legal frameworks for palaeontological heritage conservation akin to those applied to archaeology – by definition a finite resource – many palaeontological resources are much better being considered as being analogous to biological resources, where the aim is a responsible 'husbandry' and some level of managed, responsible, *sustainable* use is acceptable (e.g. analogous to gathering wild plants and game) which will not prejudice the safeguard of the rarest or most exception expressions of the resource.

Key words: Heritage; palaeontological heritage; fossils; collecting; conservation; management

Introduction

If there is one subject in geoconservation that is guaranteed to cause controversy and generate misunderstanding, it is the issue of geological specimen collecting, especially of fossils. To understand why, one has to examine the cultural traditions associated with such materials, their potential economic value, their scientific significance and the developing awareness of the significance of geological heritage amongst site managers and governments. Each group implicated has its own philosophies and prejudices and all too commonly conflict can arise.

Fossils in folklore and culture

From the earliest millennia of a developing ‘human’ awareness of the natural world, people have had a fascination for fossils and minerals. Beyond the simple utilitarian use of flint and other hard stones to make tools, there are records of collections of fossil shells in caves up to around 80,000 years ago (e.g. Burgundy, France), decorating burials from at least 35,000 years ago (e.g. Grimaldi, Italy) and from the early Bronze age (Dunstable Downs, southern England; Gayrard-Valy, 1994; Smith, 1894). This association implies a belief that fossils possess magical powers or a religious significance, and this mystical association with human cultures continues to the present day. For instance in the Himalayas, the coiled shells of Upper Jurassic ammonites are sold to passing pilgrims as good luck charms, known as *shaligramma* (Page, 2008). A contrasting interpretation from northern Europe, however, is that such fossils represent some ancient evil, now turned to stone – for instance by the Christian missionary St. Hilda (614-680) at Whitby, North Yorkshire, England. Nevertheless, in a parallel display of human enterprise, a similar trade developed, with local entrepreneurs, ‘re’-carving snake heads onto ammonites found on the area’s beaches, to sell to pilgrims and tourists (Fig. 1).

Figure 1: Toarcian (Lower Jurassic) ammonites on the beach near Whitby, North Yorkshire, England – and a snake-stone’, a carved souvenir for visiting pilgrims

This misunderstanding of the origins of fossils is not always so explicitly religiously linked, with other folkloric explanations being common – for instance bullet-like belemnite fossils considered to be thunderbolts, sharks teeth petrified tongues and the bones of giant extinct animals giving rise to stories of giants and dragons.

The use of geological materials for decoration is also very old and certainly blurs with their mystical associations. Fossil shell necklaces are known from 35,000 years ago (Cro-Magnon, France) and fossils set in metals are known from Dynastic Egypt (c.3200-343BC) and Etruscan civilisations (c.800-400 BC (Gayrard-Valy 1994; Shackley 1977) – and the latter style of use continues today. Minerals, however, have long been considered attractive as ornaments and the concept of 'precious' stones is still as culturally relevant as it has been for thousands of years. Although strictly speaking fossil resin, amber seems to be one of the first 'minerals' to have been widely used for jewellery and is a common 'luxury item' in Bronze age burials across Europe (Shackley, 1977).

Today, 'symbolic fossils' (*sensu* Henriques and Pena dos Reis, 2015) are still culturally very relevant, although their origins perhaps now owe more to scientific discoveries than legend. Most notable amongst such fossils are those stars of screen and literature, the dinosaurs, whose public fame is not matched by an appropriate understanding of the science of palaeontology (Stewart and Nield, 2013).

Fossils and science

Ancient Greek natural philosophers of the 6th century BC were some of the first to appreciate that fossils were the remains of creatures that once lived in the sea, even if found far from the coast (Gayrard-Valy, 1994). Folkloric interpretations dominated, however, and religious dogma suppressed scientific study until the European 'Renaissance' of the 16th and 17th centuries, when 'natural sciences' began to generate a more fashionable interest amongst certain nobility. By the late 18th century and into the early 19th century, as members of this elite themselves, early palaeontologists such as George Cuvier in France and William Buckland in England, relied on others to supply the fossils they were studying, and a trade with quarry workers, and other collectors developed to supply new specimens.

Inevitably, commercial trading of fossil and mineral specimens emerged, with some traders acting as intermediaries between impoverished workers and the fashionable intelligentsia and nobility (for instance during the 19th mining boom in SW England; Embrey and Symes, 1987). Some such collectors and traders became closely intertwined with the early history of geology, in England famously including the much misrepresented Mary Anning of Lyme Regis, Dorset (now part of the 'Jurassic Coast' World Heritage site). From her correspondence with her customers, however, it is clear that she had a great understanding of the materials she traded – but as a woman from a poor background she was blocked from making any direct scientific contribution herself.

As geological sciences matured, however, the need to collect and record more systematically than the traders was realised and gradually it became the norm for scientists to collect their own research materials (Fig. 2), including with the aid of junior 'field assistants'. This process was aided by funding from newly established museums and national geological surveys as well as from philanthropists and ultimately through the provision of governmental or private research grants. Crucially, for scientific studies, the accurate documentation of all significant finds is necessary and any ‘competition’ from commercial or recreational specimen collectors can become a serious issue. Not surprisingly, therefore, many modern palaeontologists see geological conservation as a process through which the sites and specimens which they study can remain available for research (although some, regrettably, still see conservation as an ‘in-convenience’).

In some cases, however, especially at very rapidly changing sites such as active quarries and eroding coastlines there is a real risk that key specimens of scientific importance could be ‘lost’, for instance into an aggregate crusher or simple eroded away by the sea. Under such circumstances, a more ‘reactionary’ approach to collecting important specimens for research may be necessary and as few geoscientists have time to regularly inspect such sites, some have promoted the role of amateur or commercial collectors as ‘salvagers’ of specimens. Where appropriate mechanisms are in place to ensure that any recovered specimens find their way into national institutions for study and safeguard for future generations, this approach can be very successful. Elsewhere, however, as discussed below, the only consequence is that the majority of specimens are still ‘lost’, but now to a global market place, rather than to the sea or the crusher…

Figure 2: Scientific collecting in action – members of the Oxfordian Working Group of the International Subcommission for Jurassic Startigraphy sampling the Callovian-Oxfordian boundary level at Osgodby Nab, near Scarborough, North Yorkshire, England.

The rise of the ‘Rock Hound’ – and fossils become a commodity

There is no doubt about it, fossils can be very attractive and many people become sufficiently fascinated that they start to build up their own private collections. Some will purchase specimens from commercial dealers, whilst others collect the specimens themselves, independently or as part of the activities of clubs and societies. Some will ultimately develop an interest in the geological sciences and make a 'transition' from 'collector' to amateur, or even professional, scientist – indeed this is how many of the latter first became interested in the subject.

Others, however, retain a more acquisitive approach, where the expansion and 'improvement' of the collection takes precedent over the scientific significance of the materials being accumulated – the trans-Atlantic expression '*Rock Hound'* perhaps best summing up this type of collector. Such an approach can inevitably have conservation consequences, as obtaining new and 'better' specimens becomes the priority and the resultant and cumulative effects on the source geological sites becomes irrelevant. Commonly, such collectors also become 'dealers', selling 'surplus' specimens to others, and as a result remove even more of the natural geological resource than they might 'need' for their own purposes.

Figure 3: Illegal strip-mining of Hettangian (Lower Jurassic) mudrocks on the West Somerset coast, SW England by commercial fossil collectors in the search for vertebrates and ammonites (see Webber 2001).

Fossil and mineral collectors are also supplied by networks of full time commercial traders, some with shop-front facilities, although many now supply specimens mainly through international internet trading. This trade is worth millions of dollars annually and not only supplies fossil and mineral collectors, but provides tourist souvenirs and '*Objets d'art'* to decorate designer living spaces. Most of the materials traded, however, are not only of intrinsic heritage importance in themselves, they may also have been obtained from scientifically important geological sites, often with conservation designations or with applicable national conservation laws (very few legally approved commercial quarries and mines for fossil specimens exist). The effects of this trade, especially as it is virtually unregulated in many countries, are a major issue for the global conservation of palaeontological heritage.

Unfortunately, some scientists and institutions have continued to support this activity, by purchasing specimens for research and display, without ascertaining whether the material has been legally obtained. Examples include the purchase of illegally collected early vertebrate material from a protected site in Scotland by the Humboldt Museum in Berlin (Macfadyen 2006), crystalline palladium-gold from Torquay, SW England by the Natural History Museum (NHM) in London in the 1980s (as illustrated by Embrey and Symes, 1987) and the majority, if not all, of the articulated ichthyosaur and plesiosaur skeletons from the Lower Jurassic of the West Somerset coast, England (Fig. 3) now held by institutions in the UK, Germany, Canada, USA and elsewhere. Some institutions, however, such as the NHM, now have safeguards in place to ensure that such issues do not arise again.

The rise of the 'conservation manager'

Through much of the early history of geology and palaeontology, the conservation of geological sites and materials was rarely an issue for the developing science, as new localities with 'new' fossil assemblages were continually being discovered. By the later 19th century, however, urbanisation and industrialisation was beginning to damage well-known localities and by the mid 20th century, a general awareness of the need for some form of site protection had developed (Page and Wimbledon, 2009). Nevertheless, in most countries it took until the late 20th century for this awareness to evolve into conservation systems and networks of protected sites (Page et al., 1999).

Initially, geological sites had been the territory of the scientist and amateur enthusiasts, with commercial specimen collectors only locally being significantly active. As geology and palaeontology have developed in popularity, however – not least due to the success of major motion pictures such as '*Jurassic Park'* – the latter have become more and more active and locally have a highly damaging effect on the scientific integrity of fossiliferous sites. To address such problems, a whole new profession of heritage managers has developed, to implement new conservation laws and 'police' the protected sites. Unfortunately, however, there is a common misunderstanding of the nature of geological heritage amongst this group, especially confusion with the more restrictive requirements of archaeological and rare species protection. As a result, there are many cases where geoscientists have been marginalised in the site management process, even virtually prevented from re-sampling the localities that they themselves first brought to the attention of society (Page et al., 1999). As commented by Wimbledon (1988): "*Who should judge what is best for a site? Those who understand the site – the specialist, the more generalized researcher, and the knowledgeable user – must have the most to contribute*."

In such cases, the geoscience community – and especially palaeontologists – clearly need to reassert their requirements and re-educate both national and local administrators about the true nature of geological heritage, as a resource to be *used* by both scientists and educators and not something to 'freeze' in time.

Why conserve fossils?

Within the communities of geoscientists and conservation managers, the answers to this question should be obvious – however, as administrative decision-makers do not always have such an awareness, it is useful to review the question (based on Page, 1998):

Science: As discussed by the majority of authors (including most recently Endere and Prado, 2015; Henriques and Pena dos Reis, 2015; Thomas, 2012), first and foremost amongst justifications for conserving palaeontological sites and materials is their significance for scientific studies. This includes as evidence of past Earth processes and ecosystems, as well as the origins of the natural biodiversity we see today. Indeed, some recorded processes, for instance, 'mass extinctions', are highly relevant to our own future. In addition, fossils are crucial to the relative dating of rocks, and hence understanding Earth history, and their use underpins the standard geological framework for most of the Phanerozoic (see www.stratigraphy.org, accessed 01.05.2017; see also Page and Meléndez, 1995). Maintaining access to such materials, in both institutions and in their original rock-outcrop context should, therefore, be a priority for geological conservation and is essential for ongoing scientific studies.

Natural Heritage: Fossils are by definition part of a natural heritage and should, therefore, be an integral part of any philosophy or practice that promotes the management of other aspects of the natural environment, such as wildlife and landscapes. Crucially, at least 99% of all living species that have lived on our planet are extinct (Benton and Harper, 1993) and hence only now exist as part of the natural heritage of the fossil record. The concept of 'natural heritage' also forms a key part of the concept of World Heritage and hence justifies the inclusion of some of the most important palaeontological heritage sites in UNESCO's World Heritage list.

Education: Geological materials such as fossils and minerals are the raw materials through which geological, as well as chemical, biological and ecological principles, are taught at all levels from primary school to university, and beyond. Access to such materials in both their original context (i.e. within a geological site) and as a classroom resource is, therefore, essential and conservation practice should permit, where appropriate, the collection of specimens for teaching purposes or, indeed, as an educational exercise in its own right – as in 'Fossil Parks' in the USA (Clary and Wandersee, 2014).

Recreation: Many people enjoy either looking at or collecting geological materials and will devote recreational time to visiting geological sites and attractions. The more passive observers are the easiest to accommodate within the context of a conserved geological site, although appropriate presentation and interpretation will still be essential. Recreational collectors, even including 'rockhounds', can also be accommodated where the palaeontological resource is sufficiently abundant or robust that some level of removal will not prejudice its long-term conservation. Indeed, providing managed sites for amateur enthusiasts to collect at, can help the process of raising awareness of scientific and heritage values, and hence help create a respect for sites where conservation prescriptions are necessarily more restrictive. In addition, the chance discovery of a new or rare species by such amateurs can benefit the scientific and heritage documentation process and the potential for developing positive collaborations should not be under estimated.

Economic: Access to fossils, and especially minerals, *in situ* is crucial for guiding or refining exploration techniques for new mineral deposits of economic value. In addition, recreational or educational groups attracted to fossils have the potential to bring money into an area, either as passive observers or as active users of the geological resource. Some touristic providers offer 'collecting holidays' for recreational collectors (although the sites being visited are not necessarily those most suitable for such activities). Much more rarely, however, the commercial value of the specimens themselves has been promoted as a justification for certain approaches to site management – as in the 'Jurassic Coast' World Heritage site in Dorset, SW England (Page and Wimbledon, 2009). As with other cases of economically-justified fossil collecting, however, such practices can raise serious ethical questions when considered in the context of the philosophy and practice of geological heritage conservation elsewhere.

Figure 4: A Geotouristic attraction in La Rioja, Spain, based on a palaeontological heritage of Lower Cretaceous dinosaur footprint trackways.

Ecological: The study of fossils can bring important insights into the nature and origin of modern ecosystems and their evolution through time to the present day – including the effects of climate change and 'mass extinctions'. Crucially, as modern biodiversity is a reflection of past biodiversity, linking studies should be fundamental as they can help inform decisions about the management of contemporary biodiversity (see Henriques and Pena dos Reis, 2015; Matthews, 2014), including in the context of international agreements such as the 'Rio Convention' on Biological Diversity of 1992.

Cultural: As museum collections are a cultural resource and science is a cultural activity, key historical associations for both – including links with famous pioneers such as Charles Darwin – are strong arguments for conservation (beyond any intrinsic scientific or natural heritage value that the same materials may be considered to possess). Some sites are also important to archaeological studies, especially those yielding traces of early hominids, including both bones and tools. In some assessments of palaeontological heritage, 'socio-cultural and 'socio-economic' criteria are explicitly used (e.g. Endere and Prado, 2015).

Managing sites of palaeontological importance

The nature of the geological resource

Every palaeontological site is different, but in order to make informed management decisions, it is useful to be able to classify both the nature of the natural resource and the significance of any specimens collected. The former UK-wide Nature Conservancy Council (NCC) established one of the most useful – and crucially 'tried-and-tested' schemes for classifying sites in 1990 in its ground breaking national strategy (NCC, 1990). The NCC's classification of geological and geomorphological sites as a guide to their conservation requirements recognised two basic categories of site-type, exposure and integrity.

Exposure sites facilitate access to extensive deposits of scientific and educational value, for instance by providing a window through a cover of soil and vegetation into the geology below. Conservation of such sites, therefore, focuses on the maintenance of representative natural or artificial exposures, rather than the potential of other areas to reveal similar features (should future excavation take place). In the case of fossils, it will be the size of the accessible exposure – and related erosion rates – combined with the relative abundance of the key fauna and flora – which will determine what management measures may be appropriate. For instance, extensive and actively eroding (e.g. 'refreshing') natural exposures with abundant fossils may require less restriction than smaller (including most artificial) exposures, yielding rare and scientifically important taxa, which may require ‘stronger’ conservation measures.

In contrast, *integrity sites* have deposits, features or processes, which are very limited in extent and hence irreplaceable, if removed or damaged. Conservation management consequently becomes a more exacting process, as the aim is typically to maintain the deposit or features intact and prevent any significant and potentially damaging intervention. Nevertheless, with very few exceptions, it is essential that scientific study can continue, hence, conservation ‘off-site’ of sampled materials, for instance within an institutional collection, becomes essential.

A key omission from the original scheme, however, was the concept of ‘*Moveable geological heritage*’ (sometimes known as ‘Movable Natural Values’ or ‘Ex situ’ palaeontological heritage), which is crucial to effective conservation of fossils (Fig. 5). Indeed, as Henriques and Pena dos Reis (2015) strongly argue, the conservation of palaeontological heritage requires the expansion of the concept of geological heritage to formally include such *ex situ* geological objects. With few exceptions – primarily dinosaur footprints – fossils must first be removed from their original bedrock context, before they can be studied (or sold). They will, therefore, always be potential or actual items of ‘Moveable geological heritage’ and any geological conservation system that fails to recognise this factor, and omits consideration of the fate of removed materials, will inevitably fail in its ambitions to safeguard a national and international heritage.

In most institutions, ‘Moveable geological heritage’ is protected by the curatorial systems in place and the codes of conduct and guidelines established by national museum associations and national laws. In some countries, such as the UK, however, such collections usually have no specific legal protection and the same applies to all other specimens once they have been removed from their original site context.

Figure 5: A collected fossil – now corrected considered to be ‘moveable’, despite still resting on the rocks within which it was only a short time previously, embedded; Middle Jurassic, Aragón,

Spain.

Inevitably, such collections will also have an explicit cultural heritage value, for instance linked to famous scientists – or even, exceptionally, may have other associations, such as the famous Upper Cretaceous mosasaur skull from Maastricht in the Netherlands, plundered by Napoleon's troops in 1794 and still residing in the Muséum national d'Histoire naturelle in Paris (https://en.wikipedia.org/wiki/Mosasaurus, accessed 01.05.2017). The latter specimen also raises some important philosophical issues, as although it is fully safeguarded in a national institution, it is no longer in its source country. This is a very common scenario for palaeontological heritage, and not just where export has been technically 'illegal'. Percival (2014) discusses this problem in the context of Australian palaeontological heritage, but there are countless other examples (and archaeological parallels are obvious, including the marble friezes notoriously removed from the Parthenon in Athens, Greece, and now held in foreign museums). As with the Parthenon marbles, however, claims for re-patriation are rarely successful (cf. Macfadyen, 2006), although in one notable example, an US museum has agreed to return a key collection of Devonian fossils to Brazil (Lima and Ponciano, 2017).

This link between site and institutional conservation, for instance deposition in a university or public museum where it can be safeguarded for future generations to enjoy and learn from is fundamental (i.e. conserved in a museological sense, as discussed by Schemm-Gregory and Henriques, 2013). Indeed, the only 'safe' place for the specimen to reside may be an institution, as on site, it will be vulnerable to both natural and human threats. But do all fossils really need this level of protection, as some may be so abundant as to be rock forming? Clearly some selection process which assesses relative scientific and cultural value is required, and this is discussed further below.

The nature of the scientific resource

Although a range of factors, including social and economic, can be used to categorise palaeontological heritage resources (e.g. Alcala and Morales 1994, Endere and Prado, 2015; Henriques and Pena dos Reis, 2015), it can be argued that only scientific criteria provide an objective and internationally applicable assessment framework. In 2002, a series of such guidelines were produced as part of the activities of a Geoconservation Working Group of the International Subcommission on Jurassic Stratigraphy, part of an International Union of Geological Sciences (IUGS) project. The Guidelines were developed to help establish some common principles to guide both conservation administrations and site owners and managers, as to the needs of geological science and, hopefully, create a more balanced and informed approach to site and specimen management (Page, 2004).

The Guidelines recognised four categories of palaeontological heritage – as summarised below – with categories 1 to 3 requiring different levels of protection but including a Category 4 for common fossil types, which do not need any special protection.

Category 1: *Type (a), figured (b) and cited (c) specimens: The first (Category 1a) are fundamental to the definition of fossil species as regulated by the International Commission on Zoological Nomenclature (a UNESCO project); the latter two categories (1b and 1c respectively) underpin all palaeontological studies as supporting material or evidence of scientific observations or conclusions.*

Every type specimen is a global reference for the species it defines and hence is irreplaceable – scientific method, therefore, dictates that all Category 1 fossils must be deposited and protected in nationally recognised institutions, and legal systems should help achieve such ends. Similarly, figured and cited specimens provide the evidence base for palaeontological science, and their security within recognised institutions should also be of paramount concern as part of a general approach to palaeontological heritage conservation which supports scientific methodology. Specimens only become types, or are figured or cited, however, after scientific study, which can only be facilitated by free and open access to palaeontological localities for *bona fide* geological study. Legal systems should on the one hand ensure that such access can take place and on the other hand seek to guarantee that institutional deposition and full protection of the relevant *described* specimens is achieved once study is completed.

Category 2: *Unique, rare or exceptionally complete or well-preserved taxa or specimens or assemblages of specimens of fundamental importance to actual or future scientific studies.*

Category 2 specimens are crucial to the science of palaeontology, as the raw material for ongoing or future studies. Conservation and legal systems or practice should, therefore, ensure (including through the use of expert advisors or assessors), that such specimens are deposited and protected within nationally recognised institutions, where they will remain accessible for future study and appreciation.

Category 3: *Key specimens of stratigraphical or palaeobiological significance, material complementary to ongoing scientific studies, specimens of especial suitability for museum display or educational use, by virtue of completeness or other features of instructive value*.

Category 3 specimens are not only important for ongoing scientific research, they are also important for scientific education. They include rare records of important taxa better known at other localities and assemblages of ecological or stratigraphical importance in place in natural outcrops. Conservation and legal systems or practice should aim, therefore, to promote the wise management of

Category 3 fossils by preventing over-exploitation and ensuring that the needs of educational and research are not prejudiced by activities such as commercial or unregulated, recreational collecting. Wherever possible, these procedures should encourage the deposition of Category 3 fossils in national or regional institutions, to maximise availability for future scientific study or educational use.

Category 4: *Common and representative species and specimens, well represented in national museums and other institutions, or sufficiently abundant that any non-scientific collecting or removal will not prejudice future scientific work; also includes specimens collected loose, for instance from scree, rubble or beach material, where the lack of stratigraphical information significantly reduces scientific use.*

Such specimens can be very abundant, even rock-forming and some may form part of a commercial resource, such as ornamental limestone. The use of such specimens for teaching, public education and personal enjoyment provides opportunities to promote a respect and understanding for geological heritage, without prejudicing its long-term conservation. Category 4 fossils do not normally require legal protection, especially if they occur outside of protected areas, and legal systems can, therefore, adopt a degree of flexibility to allow more public interaction and use (whilst at the same time providing guarantees, guidelines and statutes to ensure that any new finds assignable to categories 2 and 3, or potentially 1, can be fully protected).

In the context of this guidance, Categories 1-3 can be considered to be of "significant scientific importance", whereas Category 4 specimens would be considered to be as "not of significant scientific importance".

Threats to the resource and management solutions

As with most other classes of geological and geomorphological heritage, threats can be classified according to a 'standard scheme', such as that established by the UK, NCC in its 1990 strategy. The original scheme recognised eight basic categories of threat, but reclassification into five main themes provides a more useful way of looking at the various threats posed to sites of palaeontological heritage importance:

1. *Natural degradation and vegetation growth* – including chemical and physical weathering and erosion.

2. Agricultural, forestry and other land management practices – including physical damage, infill or contamination of sites and concealment by tree cover.

3. *Engineering works, including infrastructure, industrial and domestic building works and coastal protection / flood defence works* – including physical damage,

infill and contamination, concealment and burial.

4. *Mineral / aggregate extraction and restoration of working sites (including waste disposal)* – including physical damage, infill, concealment and burial or removal of deposits.

5. *Overuse or misuse* – including physical damage, removal of deposits and/or loss of key specimens to a global market place and private collections.

The exposure of palaeontological materials to natural surface processes can have a serious degradation effect (Threat 1). Depending on local climatic controls, these processes will include oxidation, hydration, desiccation and dissolution, leading to the physical break-up of, as well as removal by erosion (e.g. coastal, fluvial, rain, etc.). Typically, however, the effects of weathering are limited to a surface zone, perhaps no more than a few decimetres thick, and a mantle of weathered material can protect un-weathered deposits below – providing that the damaging effects of plant roots can be prevented by controlling vegetation growth. Nevertheless, the removal of vulnerable material to an institution where appropriate curatorial conservation work can be carried out, for instance using consolidants, may be the only pragmatic conservation solution.

In areas where physical erosion, for instance coastal or fluvial, is very active, recovery to a safe location, such as a museum, may also be the only practical solution. Nevertheless, as erosion may continue to reveal new specimens, some form of control, for instance using engineering works, might not be a sensible site conservation measure, as there are opportunities for new materials to appear in the future. In reality, some level of loss is inevitable, but is balanced by this potential for future discoveries.

Although threats such as 2, 3 and 4 can potentially be managed through national spatial planning systems, the commercial or economic value or strategic importance of the operation can often override such conservation systems (and not just for geological heritage features…). However, some mitigation may be possible, and the establishment of regular site inspections or 'rescue digs' may be the only solution, with the deposition of collected materials in an appropriate institute. Examples of such schemes include the recovery of rich Lower Jurassic faunas from road construction works near Charmouth, Dorset, England (Page and Wimbledon, 2009; Fig. 6), Middle and Upper Jurassic faunas from high-speed rail works near Ricla, Aragón, Spain (Melendez and Soria, 1994) and an important Lower Permian faunas from a working quarry at Cabarz, Thuringia, Germany (Fohlert and Brauner, 2010).

Figure 6: ‘Rescue collecting’ of Lower Jurassic insects on the Charmouth bypass road construction works, Dorset, England.

Crucially, such works can also create exposures where previously there were none, with very positive results for the geosciences. A notable example is the creation of fossil-rich cuttings during forestry works in Mortimer’s Forest near Ludlow (W central England) which became fundamental to international definitions of the Silurian, Ludlow Series (Holland et al., 1959). Planning and heritage management process should embrace such opportunities, but also facilitate the protection and conservation of such exposures for ongoing study and educational use.

When all the spatial planning, developmental and natural process issues for conservation are resolved or accommodated, there remains one category of threat which affects important palaeontological sites more than almost any other type of geological and geomorphological site– that of overuse or misuse – especially by specimen collectors. Effects vary from a simple cumulative attrition, where ‘collectable’ specimens become rare or when the rock outcrop gradually disappears under a scree of broken rock fragments, or, in extreme cases, where targeted collecting activity, often commercially driven, can virtually remove entire deposit for sale (e.g. Late Triassic dinosaur footprints from Bendrick Rocks, South Wales; Page and Wimbledon, 2009). This type of activity is unfortunately becoming more and more common as the internet provides not only a global marketplace for fossils and minerals, it also often provides comprehensive information about where to find them. Worrying, as noted previously, some institutions and researchers, have promoted such activities by purchasing specimens for research or display without adequately enquiring as to the circumstances of their removal from their source locality.

Where collecting is clearly illegal, only enforcement action against the perpetrators is adequate – however, only the resultant damage is often observed, once the collectors are long gone. The use of the internet by traders, however, can allow stolen materials to be traced and recovered, as the Late Triassic dinosaur footprints noted above, seized by Welsh police after a raid on a fossil shop in west Dorset (England). The recovered material, is now housed in the National Museum of Wales in Cardiff (Page and Wimbledon, 2009).

Where damage is due more to a lack of awareness of conservation issues by site users, rather than simply illegal, the establishment of ‘Codes of Conduct’ can be very useful. Such ‘Codes’ define what types of activity can be considered acceptable, and those that can be damaging, including in the context of the sustainable management of the resource. One of the earliest and most widely distributed of these fieldwork codes in the UK was established by the national Geologist’s Association in 1977, and still forms the basis for most other codes of geological conduct used in Britain today (Geologist’s Association, 1977). A later statement by the then state conservation agency, English Nature, subsequently defined what can constitute ‘responsible’ or ‘irresponsible’ fossil collecting (English Nature, 1996), but the most comprehensive guidance is that in Scottish Natural Heritage’s fossil collecting policy statement, which has the added benefit of being backed by the Scottish legal system (Scottish Natural Heritage, 1996; Fig. 7).

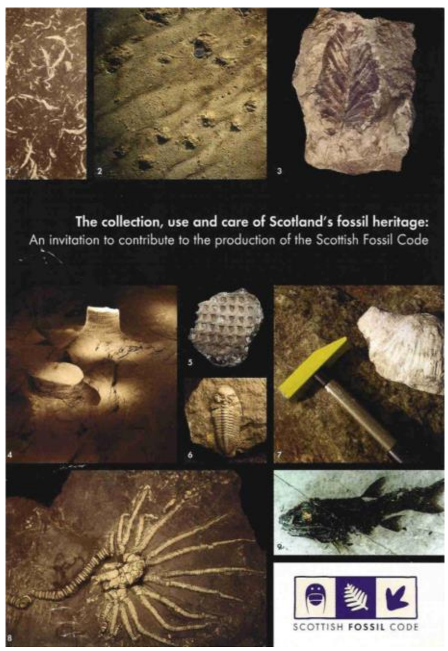

Figure 7: The ‘Scottish Fossil Code’, an exemplary guide to responsible and scientifically informed fossil collecting backed by national legislation.

A benefit of ‘raising awareness’ – or increasing ‘Earth Science literacy *sensu* Henriques and Pena dos Reis (2015) – through these non-statutory approaches is that fossil and mineral collectors can be encouraged to inform scientists and museums of their finds and hence contribute to the advancement of science itself. Some may even be encouraged to make the transition from ‘Rock Hound’ to amateur geoscientist.

An effective approach to providing such opportunities is through the provision of specific resources for recreational and educational fossil collecting, in particular sites managed for this purpose. The idea is not a new one and early examples include the UK nature Conservancy Council's 'New sites for old' programme in the 1980s (Duff et al.,1985) and the extremely successful supervised collecting days for school children at Writhlington Geological Reserve near Bath, UK (Fig. 8). At the latter site, community activity has led to the recovery of one of the richest late Carboniferous arthropod faunas known in Europe (Selden, 2010), whilst providing opportunities for visitors to collect and study a rich 'Coal measures' Flora (Fig. 8). In the USA, an informal 'network' of 'Fossil Parks', managed for sustainable, educational fossil collecting is now developing and provides a marvellous opportunity for communities and visitors alike to learn about their palaeontological heritage (Clary and Wandersee, 2014).

Figure 8: Educational fossil-collecting at the Writhlington Geological Reserve, Avon, SW England (Upper Carboniferous).

In some countries such as Spain and Croatia, however, many of these considerations become meaningless, as all palaeontological heritage is protected and all collecting of fossil specimens is illegal without official permits. This all-encompassing approach becomes problematic, however, when one considers that fossils may still be legally destroyed by quarrying activities, but as no recovery as fossil specimens is permitted without research permits, the inevitable result is a massive and avoidable loss of important specimens from active sites and coastlines. In addition, a potentially important group of amateur supporters of science and conservation is alienated. As discussed by many authors (e.g. Henriques and Pena dos Reis, 2015; Percival, 2014; Wimbledon, 1988), such restrictions are, therefore, likely to be counterproductive, and simply curtailing all independent collecting activity, or driving it 'underground', prevents it from significantly contributing to science and heritage studies.

Legal approaches to conserving palaeontological heritage, i.e. protected sites versus protected heritage

Legal measures

Legal measures for the protection and management of palaeontological heritage vary widely from country to country, with some systems emphasising protected sites, rather than heritage, and others protected heritage rather than sites. The former approach is exemplified by legislation and policies in England, where site selection, designation and protection systems are well developed, but palaeontological heritage has no specific legal status. Such legislation has been most successful in defending site boundaries against development, but has often failed to prevent the removal of geological specimens from within those boundaries, even where a legal restriction on collecting has been applied through the designating legislation (Page and Wimbledon, 2009). In an attempt to redress this problem, a reliance on voluntary 'codes of conduct' has developed, in part as an attempt not to alienate a strong tradition of amateur geologists and palaeontologists, who have been a major contributor to geosciences (see Burek, 2008; Robinson, 1988). Very little or typically no legislative framework supports these codes, however, and the most destructive site users remain undeterred from their activities.

This problem is most extreme within the protected sites that comprise the fossil-rich Dorset and East Devon 'Jurassic Coast' World Heritage site in southern England, where such a code has been used as a substitute for direct intervention by national conservation authorities. In addition, as the implemented Code emphasises fossil collecting rather than conservation, it has created a mechanism through which historical commercial activity can continue to flourish in the area (Page and Wimbledon, 2009; Page 2011;). Analysis of a published register of recorded finds provides confirmation of the failure of this Code as a conservation mechanism, with only 265 specimens being reported in the first 12 years of its operation (to 2011) – an average of only around 20 specimens a year from, in theory, one of the richest fossiliferous sites in the world (Page, 2011). The remaining thousands of specimens, which will have been collected over the same period of, by definition, World Heritage value, are now effectively 'lost' – many into a global market place (Page, 2011; Page and Wimbledon, 2009; Fig. 9).

Figure 9: Mixed messages on the Jurassic Coast 'World Heritage' site at Charmouth – Heritage centre above, fossil shop below…

Elsewhere in the UK, the effects of this inability to adequately control the fate of palaeontological heritage is equally concerning, although conservation agencies in Wales and Scotland have made more concerted attempts to recover stolen material and guard vulnerable protected sites than in England (Page and Wimbledon, 2009). There are, however, more positive stories from across the UK, where amateur enthusiasts have contributed to the advancement of palaeontological science through both new discoveries and actual collaboration with geoscientists (Page 2010; Fig. 10).

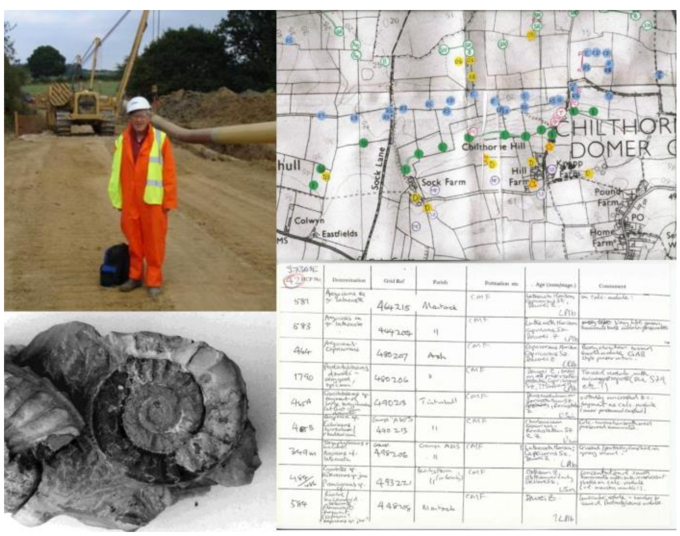

Figure 10: The contribution of the amateur to the geosciences in Somerset, England: Site survey and documentation by the late H.C. Prudden (illustrated) and Mr M Harvey. Key stratigraphical results have been published in Page (2010).

The other extreme in the approach to protecting sites and palaeontological heritage is demonstrated by the Autonomous Community of Aragón in Spain, where the emphasis has been on protecting specimens, rather than sites, as they are considered to be cultural heritage (Andrés-Moreno, 2006; Soria et al. 1996. In Aragón, the regional government controls palaeontological studies and there is a legal requirement for an official permission from its General Directorate of Heritage, before any palaeontological field sampling can take place. The same laws also effectively prohibit the establishment of independent collections of fossils from Aragón within Aragón (but ironically not from any other region or country…) by dictating that all collected materials are deposited either in the Palaeontological Museum of the University of Zaragoza, or the *Dinopolis* dinosaur-focussed attraction in Teruel city. In practice, however, obtaining permission to carry out palaeontological research can be difficult, even for researchers in the community's only university in Zaragoza.

Elsewhere, however, palaeontological heritage is destroyed on a daily basis due to quarrying, infrastructure works (including the development of ski stations) and palaeontological materials are commonly seen in building and decorative stones. The irony of the Aragonese scenario is that aspects of the community's palaeontological heritage are being destroyed or abused every day, but it is technically illegal for anyone, including most geoscientists, to attempt to save it, unless, of course, they have a specific permit.

If the English and Spanish examples demonstrate extremes in approaches to the conservation of palaeontological heritage, then most other national examples lie somewhere between, often with a mixture of site protection and moveable heritage protection (although not necessarily specific to fossils). In Germany, as in the UK, there is a strong tradition of amateur fossil collecting, not uncommonly linked to commercial activity (Germany is an important market for UK fossils) which has its consequences for site protection. Nevertheless, with increased federalisation and the establishment of state conservation laws and protected site networks, increasing restrictions are being put on this activity. Nevertheless, the contribution of committed amateurs can continue as fossil-collecting is not prohibited at many sites. A notable and innovative 'catch-all' legal framework to safeguard the most important parts of this heritage, which quite obviously cannot be expected to locate itself only within the boundaries of a protected site, has been developed in Württemberg. Invoking an ancient, feudal law of 'treasure trove' it requires that all fossil specimens of particular geological importance are deposited in a state museum, specifically the Staatliche Museum fur Naturkunde, Stuttgart, Germany (Bloos, 2004). In return, compensation is paid to cover the time commitment in collecting the specimen. Crucially this is NOT the international market place price accepted in the UK and hence the system can work well within available publically available financial resources. The analogous Museum Act law of 1989 in Denmark – with subsequently emendations – however, applied market values and hence its implementation had the potential to become problematic (https://www.retsinformation.dk/Forms/R0710.aspx?id=12017, accessed 01.05.2017).

In France, a very strong and well-established network of 'National Reserves' which provides many important palaeontological sites with a high level of protection, is being augmented by Department-selected inventories of key geological sites, which will attain a level of legal protection (De Wever et al., 2015). Although palaeontological heritage itself is not explicitly protected, as in the UK, this network provides a framework within which key sites, and the palaeontological heritage that they contain, can be safeguarded. Crucially, unlike in Spain, the contribution of *bona-fide* amateur groups and individuals to this process is often recognised.

Many other countries have mixed systems of site protection and moveable heritage protection (for instance see Wimbledon and Smith-Meyer, 2012), although the latter are often not sensitive to the 'needs' of geological science and the former are rarely systematically developed (although this is changing with the introduction of various inventory approaches).

International initiatives

Surprisingly, until recently, few attempts have been made to establish binding international agreements in an attempt to control or manage what is, after all, a global heritage. The only significant exception is the *UNESCO Convention on the Means of Prohibiting the Illicit import, export and transfer of ownership of Cultural Property* (1970), although it is rarely implemented by any country in the context of palaeontological heritage. The need to protect moveable geological heritage is, however recognised by the '*Recommendation on the Conservation of the Geological Heritage and areas of Special Geological Interest*' (Council of Europe, 2004) and the commercial exploitation of geological heritage is strictly prohibited by the principles under which UNESCO Global Geoparks Network was established (http://www.globalgeopark.org/uploadfiles/2012_9_6/ggn2010.pdf).

In 2008, however, such issues began to be developed on a more comprehensive global scale through Resolution 4.040 of the International Union for the Conservation of Nature (IUCN), which confirmed that geological heritage, including both sites and 'moveable items' (i.e. fossils), were part of natural heritage and geoconservation is, therefore, part of nature conservation (https://portals.iucn.org/library/efiles/documents/WCC-4th-003.pdf, accessed 01.05.2017). Crucially, unlike UNESCO, IUCN can establish global standards and guidelines for nature conservation without any implicit political context or conditions – hence they are more likely to be adopted where national recognition or support for UNESCO may be limited, even absent.

A further level of international agreement over the safeguard of geological specimens, most notably fossils and minerals, came with the adoption by IUCN of a second motion, specifically on the '*Conservation of moveable geological* *heritage*' (https://portals.iucn.org/congress/motion/091, accessed 01.05.2017) at its World Conservation Congress, held in Hawaii (USA) in September 2016. The Motion crucially included the a call to: "*Promote and support, in collaboration with UNESCO and the International Union of Geological Sciences (IUGS), the discussion towards a convention on the conservation and management of moveable geoheritage, in compliance with national and international regulations of its commerce..".*

Concluding remarks

The conservation of palaeontological sites and specimens is one of the most complex and emotive aspects of geological heritage protection, invoking as it does many aspects of cultural and scientific philosophy and prejudice. Many different solutions have been applied internationally and the above are no more than a few representative examples. In practice, every site is different and the fossils that each may yield will dictate its own unique management regime, if its qualities are to be adequately safeguarded for future generations. Nevertheless, scientifically-derived guidelines are crucial to this process and will help define the aims of any management regime, for instance is this a unique research site requiring a high level of protection and enforcement or, as in many other cases, a representative locality demonstrating some facet of geological heritage which can provide a valuable opportunity for education and inspiration? And the latter should include permitting responsible specimen collecting…

When it comes to making such decisions about the management of the resource, however, separating subjective cultural associations from more objective scientific justifications can be difficult, but is essential for the development of a coherent and credible justification for conservation. Crucially, as not every geological sample or specimen will meet any credible justification for protection – and there is simply not enough institutional space to store everything – it has to be accepted (including in the context of established human rights) that some level of private ownership is not fundamentally wrong, providing that the national and international safeguard of those sites and specimens which really do have a significant scientific and heritage value is not prejudiced.

Issues concerning the commercial exploitation of such a resource as 'collectable' geological specimens are much more problematic, however, especially as a global trade in fossils, in particular, often pays scant attention to national conservation laws and can promote damage to the most sensitive of sites. Nevertheless, what 'right' has an affluent 'developed' country to dictate to one in the process of developing that it cannot exploit its geological wealth, including fossils, for the economic and hence social benefit of its people? Indeed, it could even be argued that some exploitation of fossils, on a sustainable basis from non-protected sites (and with appropriate safeguards in place), is analogous to the sustainable exploitation of any other natural resource, such as wild game, fruit and wood.

Difficult decisions may need to be made, but it is crucial that these are informed and guided by scientifically-informed and internationally established principles and agreements, for instance developed through IUCN or IUGS (including through the Heritage Sites and Collections Subcommission of the latter's new International Commission on Geoheritage: http://geoheritage-iugs.mnhn.fr). This is global heritage and it requires a globally-informed framework for its sustainable management for the benefit of all peoples.

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