Symposium Volume

2nd INTERNATIONAL CONSERVATION SYMPOSIUM-WORKSHOP
Natural History Collections
6 - 9 May 2015    BARCELONA - SPAIN

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www.jpaleontologicaltechniques.org

ISSN: 1646-5806
FOSSIL TRACKS AND TRACKWAYS: THE DILEMMAS OF PRESERVATION

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ABSTRACT

Important fossil bones are generally excavated and removed from a site. There are exceptions as when in situ displays are possible or preferred because of the extent of the fossil field or the large number of the same species does not justify removal. Fossil bones typically have a three-dimensional physicality that allows their excavation and transportation, whereas fossil tracks are mere impressions in the substrate, and most trackways are not removed. Tracks are vulnerable to damage and loss, generally more so than bones, so that removal may place them at risk and at the same time it destroys the context of the tracks in their landscape setting, which in some instances affects the significance, even though recording has been done, as at the Laetoli hominid trackway site in Tanzania. Other options for preservation in situ, are sheltering and reburial. This paper discusses the options and a number of examples of in situ preservation efforts for track sites and fossil bone sites to illustrate the issues. The examples reveal that there is no panacea and the conundrum of how best to preserve yet make accessible the evidence of fossil sites is difficult to solve. When non-scientific intangible values such as symbolic significance, exemplified by the fragile Laetoli tracks, are taken into account preservation requirements for the site in its setting preclude removal and preservation options are limited to reburial or sheltering. Each of these has drawbacks. Only a rigorous assessment of the sites condition, threats and management context will result in a solution that has the greatest likelihood of success.

Keywords: preservation; conservation; tracks; trackways; hominids

RESUMO [in Portuguese]

Ossos fósseis importantes são geralmente escavados ou removidos de uma jazida. Há algumas exceções, como quando exposições in situ são possíveis ou preferíveis porque a extensão da jazida ou o elevado número da mesma espécie não justifica a sua remoção. Ossos fósseis tipicamente possuem uma tridimensionalidade que permite a sua escavação e transporte, enquanto pegadas fósseis são meras impressões no substrato, e a maioria dos trilhos não é removida. As pegadas são susceptíveis de dano ou perda, geralmente ainda mais do que ossos, tornando a sua remoção arriscada e ao mesmo tempo destruindo o contexto das pegadas no seu enquadramento, o que, em alguns casos, afecta a sua significância, mesmo que haja um registo feito, como por exemplo no trilho de hominídeos de Laetoli, na Tanzânia. Outras opções para preservação in situ são abrigar a jazida ou o enterramento. Este artigo discute as opções e alguns exemplos de esforços de preservação in situ de jazidas de pegadas e ossos fósseis de forma a ilustrar os problemas. Os exemplos revelam que não existe uma panaceia e que o enigma de como melhor preservar, mas mantendo acessíveis as jazidas fósseis, é difícil de resolver. Quando valores intangíveis não científicos, como significado simbólico, exemplificado pelas frágeis pegadas de Laetoli, são tidos em conta, os requisitos de preservação para a jazida no seu enquadramento impedem a remoção e as opções de preservação são limitadas a enterramento ou à construção de abrigos. Cada um destes tem desvantagens. Apenas uma avaliação rigorosa das condições das jazidas, ameaças e gestão resultarão numa solução com a maior probabilidade de sucesso.


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www.jpaleontologicaltechniques.org ISSN: 1646-5806
INTRODUCTION

Fossils, whether tracks, traces or bones, are the subject of scientific enquiry by paleontologists and are also of enduring interest to the public. The wealth of information, as it were a window into the deepest past of the origin and evolution of life on the planet, is what the fossil record offers. This is the usual perception of the value of fossil material – a way in which the methods of science can elucidate, date and understand evolutionary trees and extinctions over time. Fossils, however, may also touch a deeper chord in society. Discoveries about the origin of the human species, for example, are almost guaranteed to make headline news and catapult the discoverer into the realm of the famous. The subject is an abiding interest of society today and as such fossil material relating to our origin has cultural as well as scientific value. Human origins is one of the few areas where science and the humanities truly merge and where the methods of science evoke wonder and reflection and allow us to view the place of our species in a humbler context among the spectrum of life, particularly vertebrate life, and specifically as a member of the primate family. Vying for, or often exceeding, interest in human origins are the dinosaurs, whose fossil bones and tracks share issues of conservation with those of hominin footprints.

The preservation of fossil material can be challenging, especially when left in situ. Bones are typically excavated and removed from the site for preservation in laboratory and storage or display in museums. There are, however, instances when in situ display is possible without apparent deterioration - the exception rather than the rule – as when the extent of the fossil field or the sheer number of the same species makes removal of all but a few both too costly and unnecessary. Such is the case of Dinosaur National Monument in Utah that has a famous display in a protective shelter, the “Wall of Bones” with approximately 1500 fossils embedded in the cliff face (http://www.nps.gov/dino/planyourvisit/quarry-exhibit-hall.htm). A very different example is Wadi el Hitan World Heritage Site in the Fayoum area, south of Cairo, where fossil remains of the earliest, and now extinct, suborder of whales, Archaeoceti, are exposed at the surface over a large area. Some of the fossils are casts reproduced as originally found, others are authentic fossils. All are part of a national park with creative interpretive shelters and panels and may be visited on foot in a beautiful desert environment (Figure 1). While the management of the site appeared exemplary during early years of opening in the mid-2000s, this type of open display is extremely vulnerable to erosion from wind and physical damage or pilfering if management...
systems break down (Figure 2). In other instances, although unusual ones, removal of fossil specimens has resulted in later loss, as in the famous Peking Man specimens from China that disappeared during World War II (Boaz and Ciochon, 2004; China Heritage Project, 2005). Nonetheless, fossil bones have a three-dimensional physicality that allows their excavation and transportation, whereas tracks are mere impressions in the substrate and their conservation in situ is more complex.

Tracks and trackways

Fossil tracks and trackway sites are common around the world. This is not surprising because a vertebrate animal moves while living and leaves many traces but once it dies it leaves only one set of remains. Tracks record a moment in time, recent or many millions of years ago, and evoke speculation about the track maker and the circumstances under which the tracks were made. Furthermore, tracks and trackways often provide information that bones cannot: behavior, stride, soft tissue morphology, and claw marks, for example. Invariably imprinted in sediments, tracks however can be highly susceptible to loss. From a preservation point of view it is not relevant to distinguish between categories of track maker. What is important is scientific and cultural value assigned to a particular site; its physical condition and threats; and the management context in which it will be preserved.

The impression of animal tissue in the substrate carries the information and it is the impression that is the objective of preservation. Tracks are found in many sedimentary substrate types from mud to sandstone to volcanic ash fall. At the time of impression all were soft and had enough cohesion to take and retain the impression. Usually the substrate was damp enough for this to happen. Later through natural burial, or protection from weathering as in caves, the impression survived or was transformed through lithification into more durable rock types such as sandstone, shale, or tuff in the case of volcanic deposits. Unquestionably a great many more tracks and trackway sites were lost to natural erosional processes than have survived, and the continuing frequency of discovery of new sites
indicates that there are many yet to be discovered when we train our eyes to see them.

**PRESERVATION OPTIONS**

The conundrum of how best to preserve these vulnerable traces, yet make accessible the evidence of fossil tracks, is difficult to solve and in many instances there are no good options, just less bad ones. Any search for the best preservation solution, however, must begin with a rigorous assessment of in situ versus ex situ options and a clear recognition of the obstacles to sustainability. Three principal preservation options have long been practiced:

**Ex situ preservation: Museum storage**

Because of their unique characteristics, when tracks or trackways are found scientists may argue for their removal to a museum. Intrinsically, there is no doubt that museum storage of removed fossils, whether tracks or bones, away from the hazards of the outdoor environment offers better protection, but not necessarily always, especially in developing country contexts. Humid conditions in museums, for example, may in fact accelerate decay as with framboidal pyritic fossils that oxidize, liberating sulfur oxides and sulfuric acid to the detriment of other museum objects stored in proximity to the affected fossils (Howie, 1979). Egyptian material in the British Museum containing both hygroscopic salts and smectite clays have been documented to undergo quite drastic deterioration in comparatively short time periods in unsuitable humid storage (Bradley and Middleton, 1988; Rodriguez-Navarro et al., 1998). More to the point in terms of removal of tracks for their protection is the example of the Cretaceous tracks from Dinosaur Valley State park along the Paluxy River near Glen Rose, Texas, which were lifted out in parts and moved to the Texas Memorial Museum, where they have survived well, and to a purpose built display structure, where the in situ tracks suffered severe deterioration (Shelton et al., 1993), and the example of the Langebaan Holocene footprints from South Africa, which suffered loss when being removed to a museum (Roberts, 2008). Thus, removal to museum storage is by no means the panacea it may seem to be. Moreover, museum storage facilities are often overcrowded and poorly maintained in regions where inadequate resources are available for good curation of collections, and objects may be forgotten, inaccessible, in effect lost. Last, but sometimes most importantly, removal of tracks destroys the context and thereby diminishes both cultural and scientific value. Thus in situations where removal is the only option, the necessity of comprehensive documentation becomes paramount.

**In situ preservation: protection by sheltering**

The option of in situ conservation without the protection of a shelter cannot be considered a preservation option, although many track sites that are extensively excavated or exposed through natural erosion may be so treated. Such is the case of the 120,000 years old human footprints in volcanic ash from the very remote site of Engaro Sera near Lake Natron in northern Tanzania. These were exposed mainly through erosion of the thin top soil and have remained exposed (Figure 3), ensuring their demise if nothing is done to protect them. Keeping a site in situ under the protective cover of a shelter is a commonly espoused and implemented response to the problem of conserving archaeological sites, in which category we include track sites. There are thousands of shelters over archaeological sites worldwide and this option is especially favored for visited sites or on sites that hope to attract visitors. Unfortunately it is one that frequently results in little or no benefit to the site and sometimes leads to further deterioration. The reasons are many, but there are two principal ones: 1) the difficulty of understanding and then re-creating through design of a shelter an environment that will provide long-term stability for the archaeological remains being covered; and 2) lack of sufficient or proper maintenance of the shelter and/or site over time. A common approach to sheltering – ‘build it and they will come’ – assumes a naïve understanding of tourism, its costs and its impact on sites and local communities. In fact, while ostensibly shelters are built to protect sites, they are primarily erected when there is the expectation that the site will be visited. When few visitors come, in due course the funds for maintenance, staffing and operations dry up. In the long run neglect and deterioration are often the result: hence, the importance of a realistic assessment of the management context in which the site must survive. For a comprehensive review of the issues and an annotated bibliography on shelters over archaeological sites see Stanley-Price and Matero (2001) and Demas (2013).
In situ preservation: reburial

Reburial is a proven preservation strategy and a reversible one, but it is a reluctant preservation option for most stakeholders. For, however beneficial reburial may be from a conservation perspective, it is generally viewed with skepticism or disfavor by those with legal authority over a site, and by those stakeholders, especially scientists and researchers, who want access to a site for study and education, or those who desire to exploit the site’s economic value. Although the authors are strong advocates of reburial as a preservation strategy, they know well the difficulties attendant on its use. Aside from stakeholder reluctance, reburials are too often neglected or forgotten – an unfortunate consequence of being out of sight, and therefore out of mind. Thus the conditions for long-term preservation, especially the management context of the site, need to be carefully thought through. For discussion of a decision-making process and other aspects of reburial see Demas (2004) and other articles in that special issue of the journal devoted to reburial of archaeological sites.

If reburial or removal to a museum is chosen, compensating stakeholders for ‘hiding’ or removing the resource is critically important; this will certainly involve documentation and publication of the resource. The importance of excellent documentation (e.g. mapping, digital recording, photography) and publication cannot be overemphasized, since it may be the only form of preservation to survive, no matter what solution is chosen. Bennett et al. (2013) work though a decision-making process similar to that applied to the Laetoli trackway for the younger (1.5 My) footprint sites discovered at the site of Ileret in Kenya. Concluding that ‘record and rescue’ was the only viable choice,
they make an especially strong argument for using the various methods of 3-D digital capture as a preservation strategy for track sites, especially those formed in soft sediments. But additional forms of compensation should be considered, such as creating replicas or exhibitions, which may be especially important to community stakeholders, and also taking molds of the tracks, if this can be done without damaging them, which can be used for scientific study as well as exhibition. A caveat is warranted about replication by taking a mold: while this can provide the most accurate representation of a track, it may cause damage to the impression and stain the surface, so needs to be undertaken by preparators with experience and tested on the substrate beforehand. As example, while the molds produced during the 1978-9 Leakey expedition at the Laetoli trackway resulted in superb casts of the footprints, problems resulted from the use of Bedacryl to consolidate the prints prior to molding (see Getty Conservation Institute, 1996: pp. 31-33).

A BRIEF REVIEW OF TRACKWAY CASE STUDIES

Examples of the many approaches that have been taken for preservation of fossil tracks and trackways, both human/hominin and dinosaur, are reviewed for a number of significant sites. It should be noted that while there are many publications about hominin and faunal track sites (see Kim et al., 2004; Lucas et al., 2007; and references therein), very few of these publications have anything to say about the state of preservation, conservation interventions that have been undertaken, and follow-up regarding current status. The sites reviewed here include the Laetoli hominin trackway in Tanzania, the human footprints found at the Willandra Lakes Region site, and the Dinosaur Stampede National Monument at Lark Quarry, both in Australia, all of which the authors have had professional involvement with, as well as other sites that demonstrate the complexity of issues and the uncertainties of being able to assure preservation over the long term. They provide useful lessons for anyone contemplating the options for preserving a fossil track site. While some of the scientific literature is cited, the intention of this paper is not to discuss the scientific, paleontological issues of the sites; rather, the intention is to elucidate the problems, options and decision-making considerations related to their long-term preservation.

Willandra Lakes Trackways, Australia

The human tracks in the Willandra Lakes Region, a UNESCO World Heritage Site in far western New South Wales, dated to some 20,000 years BP, are of great cultural significance to Aboriginal communities in the region and are of scientific importance with respect to the antiquity of human presence in Australia and as the largest collection of Pleistocene footprints in the world (Webb et al., 2006). Discovered in 2003, the site has revealed over 700 footprints and 23 trackways of men, women, and children on the shore of an ancient lake (Figure 4). The decision about how to protect the site and whether to open it to visitors involved long discussion between professionals and community members. Fortunately, decisions were not made hastily and wise council prevailed. Thus, the site is buried and protected against wind ablation and freeze-thaw cycles that undoubtedly would have destroyed the fragile surface within a short time (Figure 5), leaving open the option in the future to display the footprints to the public if an adequate solution for their preservation can be found. Instead the footprints are interpreted elsewhere within the World Heritage area and three tribal groups, the traditional owners, are responsible for the site, assisted by the New South Wales National Park Service (Johnson and Mintern, 2013). As with so many track sites, documentation has been central to trying to find patterns and interpret the complex trails.

Lark Quarry Dinosaur Trackway, Australia

In 1976-77, the Lark Quarry dinosaur trackway site, as of 2004 officially the Dinosaur Stampede National Monument, Lark Quarry, was discovered in central Queensland. This too is a site of exceptional importance as it records the only known stampede of dinosaurs (Thulborn and Wade, 1984). It was one of the first three places to be nominated to Australia’s National Heritage List in July 2004. Some 4000 tracks in an area of 210 square meters feature unique evidence of small to medium size running bipedal dinosaurs, perhaps 150 in number, apparently stamped by a large theropod, though interpretations differ, whose presence is known from eleven tracks. The site, dated to the Early Cretaceous Epoch some 95 million years ago, records individual animals as they ran swerving and crossing each other’s path during a few seconds of time (Thulborn and Wade, 1984).
Figure 4 - The ancient lakebed and stark landscape setting in which the human footprints were discovered in the Willandra Lakes Region, as seen in 2007 with elders of the community assembled nearby.

Figure 5 - The decision was made by the traditional owners to rebury the Willandra Lakes footprints for their protection, seen here with a covering of sand and a sandbagged border.
Many of the tracks are extraordinarily well preserved in the fine-grained mudstone that was buried by a coarser grained sediment shortly after the event. A small representative part of the trackway was lifted and moved to the Queensland Museum, and this is likely the best preserved section that exists today.

Various misfortunes befell the excavated site after the decision was made to keep it exposed for public visitation despite the remoteness from population centers and poor access on unpaved roads. These have been described in detail (Agnew et al., 1989). The decision was apparently based on the drama of predator with prey in desperate flight so perfectly preserved in the record of the rock across a great span of time, but no realistic evaluation of tourism potential or sustainability was undertaken. While plans were developed and funds being secured for sheltering, the site was left exposed, though covered with bales of straw which caught fire during unsupervised construction of the protective roof structure, resulting in extensive loss of the thin secondary deposit of limonite that defined the trackway surface and one track was lost when a support column for the roof was placed on it (personal communication from excavator of site, Mary Wade). Perhaps as few as ten visitors in a week came in the first years, though kangaroos seeking shade under the open shelter (Figure 6) came in far greater numbers and some died on the surface. A number of tracks were souvenired as the site had no guardian. Additional problems were flooding of the surface, the accumulation of dust in the prints rendering them difficult to see, and a general inability of the site to be understood by the visitor. In 2001 a new, environmentally “green” building was constructed to totally enclose the trackway site (Figure 7). Well-designed raking lighting allows the tracks to be viewed more clearly than in natural daylight, which was the situation under the first roof (Figure 8). The importance of good lighting is too often neglected; tracks, being by nature shallow depressions, are often very difficult to see without raking light, which can lead to frustration, and even vandalism, on the part of visitors. Despite the positive aspects of the new shelter, it too was not without problems. Soon after opening to the public in 2002 one of two large rammed earth walls, intended to provide thermal stability for the interior climate, collapsed onto the visitor walkway and the tracks, fortunately at night when no visitors were present; presumably failure of the material resulted in the collapse. Again in 2011 instability in a wall caused the track site to be closed to the public.

Figure 6 - The first shelter constructed over the dinosaur tracks at Lark Quarry in 1979 was open on the sides allowing dust, kangaroos, and acquisitive visitors to enter.
Figure 7 - A new shelter, utilizing green technologies, was constructed over the Lark Quarry trackway site in 2002, with further retrofitting undertaken in 2014.

Figure 8 - Interior of the new enclosed shelter at Lark Quarry, with raking lighting along the walkway that allows better viewing of the tracks; detail shows close-up of tracks.
The lessons to be learned in the Lark Quarry case study are many, but principally they can be summarized as follows: Outdoor sites are exposed to the full impacts of natural deteriorative forces: meteorological, physical, chemical and biological. A site of this significance should be assessed for visitation potential before deciding to keep it open; it must be thoroughly documented and adequately protected after excavation and while funds are being secured for permanent sheltering, staffing, access and interpretation; a risk analysis should be undertaken with many kinds of inputs from specialists in their own fields, as for example, environmental ones (animal habitation of the shelter, flood, petrological fragility of the rock); unsupervised construction should never be allowed; systematic monitoring of condition must be undertaken over the long term; and stable funding is needed for maintenance of the site and its infrastructure. While the shelter and the current management structure appear to be protecting and interpreting the site and the surrounding environment, and new roads and marketing are encouraging greater visitation, only time will tell whether the limited number of visitors will be sufficient to justify and sustain the interventions.

**Formby Point, England**

These intertidal sites on the west coast of England, dating to about 5,500 years BP, are of high scientific value as they show the tracks of humans and animals such as deer, aurochs, and birds. Some 145 different trails at Formby alone have been noted. Accelerated beach erosion both exposes and destroys the tracks. Clearly in this instance the protection of sites is futile in the face of erosion by the sea. The sites are primarily research ones and photography of the footprints, recording their positions, and lifting and making casts of selected specimens has been an ongoing research activity and appropriate in the circumstances (Roberts et al., 1996).

**Liujiaxia Dinosaur National Geopark, China**

This site near the city of Lanzhou in Gansu Province was discovered in 1998. Paleontologically these Early Cretaceous tracks are noteworthy and the uplifted block on which the tracks are imprinted and the surrounding geology are dramatic, but visually and in terms of well-defined tracks the site is disappointing for the non-specialist visitor. As noted previously, however, the cachet of dinosaurs is such that a large protective structure was built over it in 2005 and nearby an interpretive center was under construction. Enquiry revealed that few visitors come and there was an air of neglect of the structure with evidence of roof leakage and deterioration (Figure 9). This example makes the point previously discussed, which is that without assessment of all factors that will affect the future of an exposed site, deterioration of the site and any infrastructure will inevitably occur. All too often the impulsive response, as with Lark Quarry, to an important find is to open it for visitors whereas a period of assessment and reflection may well bring forth more sustainable alternatives. As is also typical, continued excavation by the scientists have revealed more tracks, leading to more conservation dilemmas. These are being reburied and maintained by the authorities, but require frequent renewal of burial fill that is eroded out with each rain on the steep incline of the uplifted rock (Figure 10). The new interpretive museum at the bottom of the hill may bring better management of the site, but as of January 2016 it was still not completed.

**Laetoli Hominid Trackway, Tanzania**

The Laetoli trackway site, on the edge of the Serengeti in Tanzania and near the famous hominid site of Olduvai Gorge, is one in which the authors were involved over a six-year period, from 1993-1998. The site, discovered by Mary Leakey and team in 1977, was excavated, documented, molds and casts made, and reburied again for preservation against erosion and damage from large animals (Leakey and Harris, 1987). The reburial mound however, proved to be a fertile nursery for acacia tree growth and because the site was not monitored or maintained, within little more than five years trees had grown vigorously and root penetration, it was feared, would destroy the fragile prints if allowed to grow unchecked. A trial excavation in 1992 by the Department of Antiquities showed extensive root growth over and into the trackway (Figure 11).
Figure 9 - Interior of the Liujiaxia Dinosaur Trackway site shelter, which encloses the uplifted block with tracks, at lower left, and interpretive displays.

Figure 10 - Excavated dinosaur tracks outside the sheltered tracks at Liujiaxia, protected with a reburial and sandbags.
The trackway has been securely dated at 3.6 Mya by potassium-argon dating of biotite crystals in the tuff from volcanic ash fall (Hay, 1987). The trackways, which consist of 3 trails of hominids (Figure 12), likely Australopithecus afarensis, have high scientific significance: “The hominid footprints at Laetoli comprise one of the most unique and important discoveries in the history of human paleontology. It is most unlikely that any similar resource will be discovered and recovered in the foreseeable future, if ever again. This singular discovery plays a crucial role in our understanding of the evolution of our own species” (Lovejoy and Kelley, 1995: p.28). Its scientific value lies in the direct evidence of bipedalism and gait at 3.6 Mya; the cultural value is as a symbol of the rise of humanity to dominance on earth today and the fact that people respond powerfully to human traces such as the image of the first footprint on the Moon.

A systematic assessment of the options for conservation of the site was undertaken, premised on re-excavation and removal of the trees and careful extraction of roots as the initial step. The various options considered at the time and the decision-making process have been reported elsewhere (Demas and Agnew, 2006). Briefly, these were the three options, noted previously: reburial and maintenance to prevent revegetation by deep-rooted acacia trees; sheltering and presentation to the public; and lifting the tracks and removal to the regional museum in Arusha or to the National Museum in Dar es Salaam.

The management context, specifically including the personnel and expertise to monitor and maintain the site, was paramount in decision-making. Sheltering was not considered viable for many reasons: lack of resources, trained personnel, roads, and difficulty of access; and the fragility of the tuff and the impact of continuous cleaning of the prints on that fragile surface. Removal to a museum was the option favored by many paleoanthropologists who often equate it with the universal practice of excavating rare fossil bones and displaying or storing them in a museum. There were many
Figure 12 - Southern portion of the Laetoli trackway, comprising trails of three hominids, two individuals walking in tandem in the right-hand trail, and hipparion tracks crossing hominid prints in lower right.
problems with this option: lack of proper and safe storage area in both the national and particularly the regional museum in Arusha, and the grave risks to the tracks posed by removal of the fragile prints in pieces (without complete consolidation of the tuff) and transportation from a remote location; moreover, to consider the Laetoli hominid tracks apart from the landscape in which they were created and the other animals that inhabited that landscape and left their tracks in far greater abundance than the hominids is to undermine their real significance. Scientific investigations of the tracks themselves and the trails they made are best done on the excellent set of casts made in 1978-79 when they were initially excavated.

Reburial, in conjunction with photogrammetry and photography of the individual prints and trackway, was therefore chosen as the most appropriate option at the time given the remoteness of the site and the lack of infrastructure and personnel to monitor and maintain a shelter. Furthermore, it is a reversible intervention should the circumstances change that make other options viable in the future. Thus, with concurrence and participation of the Antiquities Department of Tanzania, after excavation, conservation and detailed recording (see Getty Conservation Institute, 1996), the site was reburied (Figure 13).

Realizing the need for public exhibition and community outreach our project undertook a permanent display at the Olduvai Museum. This was centered on a replica of the cast of the trackway that Mary Leakey had made during the original excavation in 1979 (Figure 14). The exhibition, with information in English and Swahili, focused on the discovery of the trackway, its significance and conservation, and an explanation of the reasons for its reburial. Along with extensive re-casting of original casts and documentation of the trackway, the exhibit was considered an important strategy to compensate the scientific and local communities for not keeping the trackway open for study and visitation.

A political decision in recent years has led to new plans for re-excavation of the trackway and construction of a shelter and interpretive center at the site (Anonymous, 2014). With new management, now under the Ngorongoro Conservation Area Authority in which the track site is located, and a realistic risk assessment of sheltering and the visitation potential, this may be a solution, but a transparent demonstration of this is warranted. On-going field and research activity in the area can also be an important way to help protect a site, but is not always sustainable in the long term – researchers move on and research interests change. Protection is the necessary and avowed purpose of a shelter, but few shelters are ever built without visitors as a principal objective. Maintaining all these factors – good management, appropriate conservation and protection, visitation, and research in the right balance and for the long-term in a remote site is often simply not possible.

Courtedoux dinosaur track site, Switzerland

The Jurassic dinosaur tracks found in Canton Jura, Switzerland, during the course of investigations for a highway (A16) present an interesting example of working through an assessment process to determine the future of the site (Marty et al., 2004, 2007). The importance of the sites both nationally and internationally is well demonstrated and the potential values of the site (scientific, research, education and economic) are explored. The initial plans were to keep the sites open for public viewing, continue research and excavation, provide a protective roof and interpretive center, all of which will entail large expenditures to divert the highway over the track sites (a ‘highway bridge’). The tracks cover a very extensive area and those track sites that were not destroyed in the construction of the highway were reburied, pending a final decision about their future (Marty et al., 2011). In their interesting review of dinosaur sites in Portugal, Santos et al. (2008) note that the Carenque (Pego Longo) dinosaur track site, also in the line of a highway, was covered pending long-delayed implementation of a decision to save the site by tunneling below it. Although the authors suggest that the covering was unfortunate since the site remained inaccessible to researchers, it would seem a wise decision in both these cases, for their protection.

For the Highway A16 sites, it is not clear what explicitly was being proposed for protection and conservation other than “protection by a roof or other adequate structure.” The 2004 paper cites the publication on Lark Quarry dinosaur stampede by Agnew et al. (1989) as an example of a track site that
Figure 13 - After conservation, the Laetoli trackway was reburied under multiple layers of sand and geosynthetic materials, here showing several layers on the southern portion of trackway.
“has been protected from normal processes of erosion by a roof” (Marty et al., 2004: p.45). However, as described in the article, the roof actually resulted in more damage rather than protection (for subsequent developments at the site see Lark Quarry discussion above). The mere fact of a roof over a site is no guarantee of protection and natural processes of erosion are by no means the only threats to a track site.

CONCLUSIONS

It is clear that neither an in situ or ex situ approach to fossil preservation is without problems nor will one or the other be effective in all cases. In that sense the notion of ‘options’ is merely an artifice to draw lessons from case studies, thereby allowing the issues to be elucidated. Fossil bones and for that matter other three dimensional fossils do not in general present the long-term preservation dilemmas that track sites do – they almost always are excavated if important enough and taken to the laboratory for further preparation, conservation, storage or display. There are, however, exceptions to this, and two were noted earlier: Wadi el Hitan and Dinosaur National Monument. Rare or spectacular finds, such as a complete *Tyrannosaurus rex* skeleton, are certainly removed, as are early hominin remains because of their high scientific and social value. Track sites on the other hand present particular problems: the scale may be large, and storage facilities for removed track sites are usually inadequate, as previously mentioned; moreover, the cost of lifting and transporting an entire trackway, as was proposed for Laetoli, can be technically challenging if only from a geotechnical and engineering point-of-view, prohibitively expensive, and removes the site from its larger landscape context.

In situ conservation with high level documentation (molding and casting, photogrammetry, photography as appropriate) tends therefore to be the preferred option. The question of how best to do this then becomes of paramount importance. When the significance of the site is high or the tracks are those of the popular and charismatic dinosaurs, the temptation to display them to the public may blind decision makers to the need for sustainable measures of preservation and interpretation. Track sites in general require robust and creative interpretation to make them understandable and interesting to the average visitor. Seldom are all the potential threats, or the constraints of funding over the long term, staffing and other management...
considerations taken fully into account. In other words, what we see frequently is a pattern of excavation, research and study, followed by touristic development, with very limited assessment of conservation approaches and considerations of long-term preservation. The options of reburial, sheltering, ex situ preservation, and the need for expertise, testing of materials or additional studies, such as on weathering rates, should be considered from the outset since funding for preservation can be slow or difficult to secure with delays and consequent damage to the site. While paleontologists recognize that exposure to weathering and erosion are destructive and that these sites are fragile, it is in fact quite rare to find technical conservation studies undertaken for track sites. As example, the practice of painting tracks so they are more visible to public is symptomatic of the visual challenges presented by track site, but the intervention taken to address it may be harmful or obscure details of the tracks, and is not discussed. This is of particular interest and importance as fossil and track sites are increasingly placed under the umbrella of the emerging concepts of geoscience, geoconservation, geotopes, geo-parks, and geoheritage (e.g., Marty et al., 2004; Santos et al., 2008; Bennet et al., 2013).

Track sites, however, would benefit equally, if not more, from methods employed and lessons learned in the field of archaeological site conservation and management.

Fossils and fossil sites of all kinds will continue to be found. Those of lesser interest to paleontologists will be excavated and either buried again after having been recorded or sometimes abandoned to erode away. Scientifically and culturally valuable sites will receive special attention. It is these cases that require a careful and complex decision-making analysis based on thorough understanding of their significance for different constituent stakeholders, investigation of environmental conditions and threats, and long-term human and financial resources. If this process is not followed the weakest link in the chain of considerations will eventually come to the fore and lead to an inexorable decline of the site and degradation of its condition and loss of values as the integrity diminishes. And since even the most rigorous assessment, planning and conservation approaches can be upended through unanticipated political interventions or changes in managing authority and personnel, multifaceted recording and documentation of sites is a sine qua non of their preservation.

REFERENCES CITED


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