Symposium Volume

1st INTERNATIONAL CONSERVATION SYMPOSIUM-WORKSHOP
Natural History Collections
18 - 21 September 2013
BARCELONA - SPAIN

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www.jpaleontologicaltechniques.org
ISSN: 1646-5806
ABSTRACT

Conservation juggles between fieldwork, work at the lab and the requirements of a frequently-visited research collection. Conservators have little control over field conditions, which are mostly directed by the physical conditions, time limitations and budget restraints. In the field, the actual challenge is to understand the physical conditions, to be aware of the nature of the sediments, their permeability, the effects of hydrological systems, and form an idea of their effect on the condition of the skeletal remains. The conservator has to function in an almost unknown terrain, at least during the first excavation season in a given site. Ideally, research and conservation goals follow the same direction and tempo. In the actual situation, accumulation of taphonomical data of a locality/site is not necessarily in accordance with the process of conservation. Such dichotomy impedes the synergy between research and conservation. Old excavations, revisited several years later, one-day expeditions dealing with incidentally-exposed fossils, long-term excavations: each of these cases poses different challenges. How do these different environments affect the condition of skeletal finds? Can knowledge gained from studies on collagen loss and mineral growth in bone give us insight into taphonomic, as well as diagenetic, processes? Environmental conditions are possibly the main deciding factor for preservation of skeletal material in situ, and therefore also affect working methods on-site. The complex interaction between the environment and the methods we choose for bone conservation merits discussion.

RESUMO [in Portuguese]

A conservação tem de conciliar o trabalho de campo, trabalho de laboratório e os requisitos de uma coleção científica frequentemente visitada. Os conservadores têm pouco controlo sobre as condições no campo, que são maioritariamente ditadas pelas condições físicas, limitações de tempo e constrangimentos orçamentais. No campo, o desafio verdadeiro é compreender essas condições físicas, reconhecer a natureza dos sedimentos, a sua permeabilidade, os efeitos do sistema hidrológico e formar uma ideia dos seus efeitos na condição dos restos esqueléticos. O conservador tem de funcionar num terreno quase desconhecido, pelo menos durante a primeira época de escavação numa dada jazida. Idealmente, os objetivos de pesquisa e conservação seguem a mesma direção e tempo. Na realidade, a acumulação de dados tafonómicos de uma localidade/jazida não está necessariamente em concordância com o processo de conservação. Esta dicotomia impede a sinergia entre investigação e conservação. Antigas escavações, revisitadas vários anos depois, expedições de um dia que resultam em exposição de fósseis por acaso, escavações a longo prazo: cada um destes casos coloca diferentes desafios. Como é que estes ambientes diferentes afetam a condição dos achados esqueléticos? Como pode o conhecimento ganho de estudos de perdas de colagénio e crescimento mineral no osso dar-nos pistas sobre os processos tafonómicos e diagenéticos? As condições ambientais são possivelmente o fator decisivo principal para a preservação de material osteológico in situ, e, consequentemente, afetam também os métodos de trabalho na jazida. A interação complexa entre o ambiente e os métodos arqueológicos que escolhemos para a conservação de osso merece discussão.

INTRODUCTION

Efforts at standardizing the assessment of archeological bone have been made (Chavagnac et al., 2007), but they are complicated by the great variety of factors governing taphonomic processes. Current approaches generally tackle geological research and bone preservation as separate entities. This paper aims at considering the possibility of a practical working relationship between these two aspects. Such relationships may be found by looking into the information gained from archeological sites, seeking to understand how they affect bone condition, and in turn considering the implications for bone conservation. Four sites in Israel are presented as examples for this kind of approach, representing different cases of excavation and conservation: long-term excavation, seasonal excavation, renewed excavation and one-day exposure. We will discuss their context and its effect on the condition of the finds. Though spanning a very large time scheme – Miocene to Upper Pleistocene – we will concentrate on the special conditions prevalent in these sites, coupled with modes of conservation and exposure. Most of the material from these sites is under study and the actual identification is incomplete. We will take into account the ongoing nature of the work, and will try to pinpoint possible issues of conflict and suggest ways of reconciliation.

Present day Israel enjoys a relatively high diversity of animal and plant species per square meter. Israel has a small land area, although the country is only about 470 kilometers long, biotopes, topography and climatic elements in it are exceptionally diverse (e.g., Tchernov, 1999:390). Israel is the meeting place of four out of the six phyto-geographical zones existing on our planet: Mediterranean, Irano-Turanian (Steppe), Saharo-Arabian (Desert), and Sudanian (Extreme desert). As such, important landmarks of the hominin species dispersal and exploitation of the environment (hunting, gathering, domestication), are evident in the local archeological sites and form an integral part in discussions on issues such as how and when hominins started hunting, fishing, burying their dead, and when domestication of plants and animals became part of human society.

The following sections will present finds from four prehistoric sites in Israel (Figure 1): Ein Yahav, Revadim Quarry, Erq el Ahmar (EEA) and Nahal Mahanayeem Outlet (NMO). The sites we will discuss are all open-air sites. Under the current climatic system, with short cool winters and long hot summers, the result is difficult conditions for bone survival. Very little organic matter, if any, survives under such conditions. The state of the finds from these sites varied according to the environment, the soil type and the action of water, as well as the type of excavation. The latter factor is the main difference in terms of conservation work.

CASE I: LONG TERM EXCAVATION - REVADIM QUARRY (CA. 300-500 KYA)

Although this was a salvage excavation, the last season had been planned in advance and lasted for several months (Marder et al., 2011). Seasonal changes are complex due to rainfall and the location near a confluence of rivers, with the ongoing work in an active stone quarry adding to the mix. Even the type of sediment from which the bone finds were salvaged, a quartzitic sandy grey loam, is representative of change. This layer was deposited in two stages, the first more humid and the second much drier (Gvirtzman et al., 1999; Marder et al., 2011). Thus, environmental changes were characteristic of this site from the very beginning, and affected the condition of the finds.

Some of the most remarkable finds in Revadim included elephant remains. No conservator was
present on site, but the archeozoologist received a kit including fine medical gauze and Paraloid B72 preparations in acetone, along with work guidelines. Since the descriptions from the site gave a picture of entire, but very cracked and weak bones – instructions were to coat the finds with gauze strips impregnated with Paraloid B72. The point was to keep the cracked parts together until they reached the lab. The gauze system proved very effective in this case and the National Natural History Collections at the Hebrew University, Jerusalem, now include some nearly entire scapulae and pelvises from Revadim. Some finds were salvaged with one side (the down-facing side) very badly fragmented. An elephant scapula (Figure 2A) was especially fascinating, because cleaning revealed the presence of cut marks (Rabinovich et al., 2012). However, before the cut marks could be seen, there was plenty of grey-brown quartzitic sandy paleosol deposit to be removed. In this case, the matrix had to be removed from in between the fragments. Due to post-depositional processes, some of the matrix accumulation in join areas was not new, and a discussion with the archeologist on morphological traits and the presence of cut marks made it clear that joining the fragments was too important, so post-depositional accumulations were removed from join areas as much as possible. Cleaning involved cotton swabs dipped in acetone plus mechanical cleaning with soft bristle brushes and porcupine quills. The loss of major parts of bone required some creative gap-filling to support the weight of the entire structure. In this case, Japanese tissue dipped in Paraloid B72 and built up in layers proved to be a very efficient, lightweight and cheap filler (as described in Beiner and Rabinovich, 2013). The final result (Figure 2b) was sent out from our lab for photography and 3-D imaging, and was successfully turned over and around by the photographer.

Figure 2: The site of Revadim Quarry, elephant scapula: A) before treatment in the lab; B) after treatment in the lab.

CASE II: SEASONAL EXCAVATION – NAHAL MAHANAYEEM OUTLET (CA. 50 KYA)

The site of Nahal Mahanayeem Outlet (NMO) was exposed during a drainage operation in 1999. NMO is a Middle Paleolithic open air site with faunal, botanical and lithic remains (Sharon et al., 2010; Kalbe, et al., 2013:2). NMO is not under water, at least not during
summer, but it is on the eastern bank of the Jordan River and water wells up from the ground. Every morning, the excavation team bailed out water and continued doing so in intervals throughout the day. Besides the difficulty of distinguishing between the dark brown bone finds and the surrounding dark brown mud (Figure 3A), a main problem was that all exposed material began deteriorating immediately. The condition of the bones seemed pristine, but they tended to fall apart easily when exposed. Valuable morphological and taphonomical data was lost. After several seasons, it became clear that on site constant conservation was required. Paraloid B72 does not work under such conditions, and other more water-friendly products such as Primal WS24 also have a problem if they do not have the time to set before more water enters the system. Communication with underwater marine archeologists in effort to search for solutions yielded that apparently, other than using freshly prepared Plaster of Paris mixture inside plastic bags as a kind of cushion, there are not many possibilities for supporting and consolidation in active waterlogging conditions. Some of the ideas tested included making a temporary jacket (over a barrier layer) out of plumber’s putty, or reinforcing weak areas with cyclododecane (CDD) before they became waterlogged. The putty proved too weak and friable as a supportive jacket for lifting bone. Experiments with CDD actually worked, but between the hazards of using a portable burner in such conditions and the difficulty of creating an adequate CDD support for actively cracking bone forced rejection of the method as a working option for this site, especially since the conservator (GGB) could only be there for consultation visits. The requirement was for something that could work in the hands of a non-conservator. After discussing issues such as which bones will need to undergo analysis, an agreement with the archeologist involved a trial use of gauze combined with Primal WS24. This did work, as long as the coated objects were not left overnight to become completely covered by water. Therefore the final procedure consisted of keeping all exposed bone damp along with immediate consolidation of bones with diluted Primal WS24 in water and then coating with gauze (Figure 3b). By these means, bones were salvaged in their entire form.

In this case, slow-drying and padded packing proved to be of utmost importance. Care was taken to slow down the drying of the bones by putting salvaged finds in containers covered with polyethylene. The polythene layer was slit to prevent mold growth, and no paper bags were used in direct contact with the wet finds. Each find was padded with a good amount of bubble wrap, in an open packaging which made the padded product open enough to allow for air circulation.

Salvaged material is currently being treated in the lab, with damp and semi-dried mud being removed into plastic bags and surfaces cleaned with acetone and saliva on swabs. It appears that the protection offered by the cover of the matrix and the slow-drying in the field lab helped preserve many more features of the bones (Figure 3c).

CASE III: RENEWED EXCAVATION – ERQ EL AHMAR (LOWER PLEISTOCENE)

The Erq el Ahmar (EEA) site was excavated by the late Prof. Eitan Tchernov, following parts of an elephant tusk found during survey. The elephant skeleton parts exposed by the Tchernov expedition had been preserved on a floodplain with active soil formation (pedogenesis) with small fluvial channels nearby, during a regressive phase of the lake (Feibel, 2004:24). Parts were extracted by the Tchernov expedition after coating, or partial coating, in a heavy plaster of Paris jacketing (Figure 4). The jacketed finds were kept in a store until very recently, but had deteriorated very badly within the jackets, presumably due to a process of dehydration connected with the presence of the plaster. Most of the skeleton was left in situ, with an unidentified applied to part of the bones and a cover of newspapers. Some of the bones had been plastered over and marked with metal stakes. At the end of that expedition, the site was covered over with nearby sediments, and further covering occurred as the area eroded out. The previously exposed bones and new parts of the skeleton were uncovered by our team in 2013. It was noticed that although the metal stakes correctly marked out the location of the bones, the plaster had apparently caused serious dehydration and powdering. A conservator (GGB) was part of the 2013 excavation team, so there was an opportunity to try different methods on site. Since the exposed bones were dry and very fragmented, with tendency to powdering, the material of choice was Paraloid B72 (with acetone as a solvent due to safety limitations). The team members were asked to drip or inject Paraloid B72 on exposed bone finds. Our first procedure of choice involved coating large finds with gauze, as in the Revadim Quarry, in effort to
Figure 3: The site of Nahal Mahanayeem Outlet, waterlogged scapula: A In situ, waterlogged; B: Coated with gauze soaked with Primal WS24; C: Scapula from NMO after treatment in the lab.

Figure 4: The site of Erq el Ahmar: finds from the Tchernov expedition, 1989.
keep the fragments together. When a very large tusk was exposed, with at least 4 break areas and some very weak parts, concerns about the weight led to the preparation of a light partial jacket for the more fragmented part out of plaster bandages. As expected, the difficult part involved moving the tusk. We only had ten days of work on this excavation so we could not slow down work to coat the underside and consolidate the tusk completely before moving it. It was moved in three sections, and the underside was damaged in the move. A fourth, but failed, method involved using polyurethane. Barrier layers were created out of aluminum foil and clingfilm, and coated a large tibia bone with polyurethane, but had not succeeded in moving the block out cleanly because the polyurethane cover did not hold the block tightly enough and earth on the underside fragmented when we tried to move the block and turn it over. Finds from this excavation are currently being treated in the Paleontology Lab in Jerusalem.

**CASE IV: ONE DAY EXPOSURE - EIN YAHAV (MIOCENE)**

Two teeth from a proboscidean jaw from the site of Ein Yahav, ca. 17-18 myr, were found by an 8-year old walking about looking for hornets' nests with his father. One of us (RR) surveyed the find location and salvaged further parts of the mandible (Figure 5). In this case, no conservator was present on site, but the bone was brought directly to the conservation lab, still covered with the sandy eolian deposit matrix. The teeth sitting in the jaw were coated with a hard sandstone sediment layer, and the bone material was cracked due to post-depositional processes, but the pieces mostly stayed in their correct positions in relation to each other. Despite the damage caused by water percolation in post-depositional activity, this find was relatively stable because its current environment was also relatively stable: arid desert. The result was that both the bone and tooth material were easy to clean mechanically in the lab, using a bristle brush and tools such as porcupine quills and wooden cocktail sticks. The sediment on the teeth was a bit harder, and required a micro-jack tool using air pressure. Several gaps existed in the bone, and these were filled with layers made of strips of fine lens tissue dipped in 30% Paraloid B72 (methyl acrylate/ethyl methacrylate co-polymer) in acetone. Since bits of the mandible were still missing, the three existing fragments were kept apart.

![Figure 5: The site of Ein Yahav: find from the one-day expedition, in situ.](image-url)
DISCUSSION

Because of the potential complex interaction between bone and sediment inherited in their chemical components, humidity, temperature and so on, no simple model can predict how exactly bones are preserved in the sediment. Theories on this subject relate to the action of water, moving organic constituents out from the bone and depositing soluble minerals from the surrounding soil matrix within bone pores (Trueman, 2004:732; Schweitzer et al., 2008:160). As a result, ancient bones end up as bio-apatites with abundant authigenic mineral phases both in larger pore spaces in cancellous bone and in smaller vascular pores (Chavagnac et al., 2007:178). Chemical change begins immediately once bones are removed from their in vivo context (Trueman et al., 2008:160), and organic "leaching" appears to occur very quickly once the bone is deposited, as shown by bone exposure experiments. Samples collected five years or more after death already exhibited low organic content, and bones exposed for 26 years or less already undergo considerable physical and chemical changes (Trueman et al., 2004:726, 729).

Generally speaking, modern bone is composed of (soluble) carbonated hydroxyl apatite (Berna et al., 2004), whereas ancient bones typically contain fluorinated apatite (Chavagnac et al., 2007:178), also known as francolite (Berna et al., 2004:868). However, it is recognized that regions of a single bone can vary greatly in preservation (Schweitzer et al., 2008:160). For example, loss of organic content in the same bone can differ considerably, with bone surface losing double the organic content as subsurface regions of the same bone (Trueman et al., 2004:726). Preservation in different parts of the skeleton may be affected by various factors, ranging from anatomical characteristics such as tooth, tusk or skull morphology versus long bone composition (Rabinovich et al., 2012:2) to microbial action, biogeochemical reactions, cell or tissue breakdown, acid formation, and molecular breakdown processes (Schweitzer et al., 2008:161). The latter taphonomic pathways combine to degrade all organic remains completely. When bone is well preserved, it may be assumed either that the diagenetic processes were halted at an early stage, or that mineralization proceeded faster, preserving the shape of the bone (Schweitzer et al., 2008:161).

Current methods for assessing bone preservation tend to heavily emphasize collagen preservation (e.g., Weiner and Bar-Yosef, 1990; Weiner et al., 1993). Another approach relies on measuring bone crystallinity, which is also considered to be connected with degradation of bone protein (e.g., Trueman et al., 2004) and is even rate-limited by collagen decomposition in the early stages of diagenesis (Trueman et al., 2008:165). However, it has been stated that although loss of collagen weakens the bone structure, destruction is mainly a factor of physical weathering (Trueman et al., 2004:729). Another statement is that long-term preservation, again mainly of organic constituents, depends on the rate at which bone becomes a closed system (Trueman et al., 2008:165).

Studies on the relationship between bone diagenesis and depositional environment often aim at paleoenvironmental, paleoclimatic and paleoecological reconstructions. However, in some cases it may be possible to reverse the relationship and gain some information on the effect of depositional environments on bone preservation. For example, different minerals identified on and within archeological bone may be indicative of the type of taphonomic process, e.g., the mineral Trona \((\text{Na}_2\text{(CO}_3\text{)}\text{(HCO}_3\text{)}\cdot2\text{H}_2\text{O})\) is formed on bone surfaces via evaporation of water containing dissolved calcium and sodium (Trueman et al., 2004:732), indicating that the bone was exposed to air, resting on the soil surface. Following this line of thought, it is interesting to note the finds from the chemical analysis of bones from Revadim. Chemical analysis indicated the presence of the mineral dahllite, and that no collagen was left (Rabinovich et al., 2012:7). Bone crystallinity was assessed according to parameters set by Weiner and Bar-Yosef (1990), and the results indicated severe bone diagenesis, with varying degrees of manganese oxide accumulation (Rabinovich et al., 2012:7). Dahllite tends to accumulate mainly on exterior surfaces and its presence may possibly indicate exposure and weathering processes, as shown by experiments on freshly exposed bone (Trueman et al., 2004:725).

In the EEA locality, previous excavations revealed information on the geology of the site. Generally speaking, sediment accumulation processes by lake margins create good burial and preservation potential (Feibel, 2004: 22). Lake margins exhibit complex sedimentary components, deposited either by water or by air, and modified by the fluctuating lakeshore (Feibel, 2004:22). Although EEA is within a formation characterized by a lacustrine environment, this particular site exhibits sediments with well-developed paleosols (Feibel, 2004:23). Out of 20m of sediments
exposed in the excavation site, the base and top exhibit fully lacustrine character, with a full cycle of transgressive-regressive oscillation in between (Feibel, 2004:24). A good portion of the finds from EEA had a powdery character, flaking easily and requiring considerable consolidation before being touched and lifted. Chemical analysis will be needed to gain better understanding of the situation, but it seems likely that the cyclic nature of the sedimentation may prove to be one of the main causes of this condition.

In contrast, NMO bone-containing sediments were deposited mainly in two levels of a wetland/floodplain to lake environment. The more recent unit 3 consists of a dark grey silt containing montmorillonite, quartz, pyrite and calcite, while the earlier unit 4 contains black argillaceous silt containing also dolomite (Kalbe et al., 2013:3). Bones retrieved from this site are characterized by a dark brown color, similar to the fluvial sediment of the excavation. They are not intensely mineralized, and exhibit good morphological preservation. In other freshwater environments, for example from the Rhine River Valley, bones also exhibited lower levels of change in isotopic phosphate oxygen levels, compared with marine settings (Tütken et al., 2008:266). This possibly indicates that fewer diagenetic processes occur in freshwater environments, at least compared with marine or marine-influenced environments. Apparently, the archaeological finds were directly deposited on the floodplain on the margins of a marshy lake, and covered rapidly by a closely packed, fine grained sediment when the lake rose between 70-65 kya (Kalbe et al., 2013:8). In a similar manner, NMO bones exhibit excellent preservation.

Berna et al. (2004) propose a process during which layers of insoluble mineral precipitates are built up within bone pores in repetitive manner, the cycles working along with the hydrological regime to create a process of "recrystallization". According to their research, more recent bone tends to be less stable, with more soluble mineral components than fossilized bone. They postulate that this is due to the much larger surface area to volume ratio in fresher bone and a much thinner layer of crystals (Berna et al., 2004:877). It is not yet clear how the presence of collagen or other proteins affects the recrystallization process, but pH conditions below seven tend to promote bone dissolution and acids are released when collagen deteriorates. In other words, deterioration slows down as diagenesis progresses. In addition, it has been stated that field observations in archeological sites show that preservation of bones is enhanced by the presence of calcite and authigenic carbonated apatite in the matrix sediments (Berna et al., 2004:867). If bones are deposited in calcite-containing layers, similar to the calcareous soils of Israel, they may possibly remain stable as long as calcite remains (Berna et al., 2004:879). In Ein Yahav, the depositional environment apparently involves eolian sand layering on sediments of fluvial and lacustrine origin with a limestone (calcite) content. This may explain the relatively good preservation of the finds from Ein Yahav.

Taking this information into account, the levels of mineralization not only affect the integrity of the bone, thus influencing preservation of the finds, but also give us better understanding of the effects of the matrix and the hydrological system on bone material. Such understanding will help to determine whether finds are suitable for dating analysis and/or paleoenvironmental studies. Current research on fossilization processes emphasizes three main processes: degradation of the organic component in the bone, mineral accumulation (dark interstitial oxides and oxyhydroxides), and intake of trace elements (Kohn, 2008:3759).

In spite of the high-resolution microscopic examinations currently available, on-site conservation must cope with the actual macro aspect of bone conservation. Perhaps an intermediate medium is required in order to negotiate between the high detail of microscopic information on bone degradation and the external appearance of the bone as exposed during excavations. Conservators need to be aware of the relationship between the matrix and the bone so as to be able to recommend appropriate conservation procedures. As collagen-extraction for early DNA studies and other analytical methods become more and more prevalent, conservation knowledge needs to include better understanding of organic decay in bone material.

ACKNOWLEDGMENTS

We would like to thank the participants of the excavations in case studies that we have described: Revidim Quarry, Nahal Mahanayeem Outlet, Erq el Ahmar and Ein Yahav. The Revidim excavations were directed by Ofer Marder, in collaboration with Ianir Milevski and Hamoudi Khalaily. Conservation
was partially funded by the Israel Antiquities Authority and by the Irene-Levi Sala CARE Foundation. Gonen Sharon directs the continued Nahal Mahanayeem Outlet excavations, and the Ein Yahav and Erq el Ahmar excavations were conducted by our team at the Paleontology lab and the National Natural History Collections of the Hebrew University. Special thanks are due to Rebecca Biton, who is part of our team. We also especially thank Alan Matthews, the director of the collections, for constant support on our projects. Both projects of Erq el Ahmar and Ein Yahav gained valuable support from the local inhabitants. Ein Yahav project is a collaboration with Hanan Ginat, Yoav Avni and Rani Calbo.

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