Conservation of Archaeological Osseous Materials

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Statement of the problem

The archaeological record is a finite resource; there exist only a limited number of sites yet to be discovered or excavated. As one reaches farther back into time, this condition is exacerbated: Paleolithic sites, those dating between 140 and 12 thousand years ago (kya) are few and the vast majority were excavated before the development of modern excavation methods and the implementation of modern techniques for the recovery and post-excavation care of artifacts. There now exists a vast wealth of unstudied artifacts unearthed during these earlier excavations to which researchers are beginning to turn their attention, in an attempt to conserve those unexcavated sites that remain until we have further refined our information capturing techniques (e.g.: Kehoe 1990, Soffer 2004). One problem for archaeologists who wish to study this material is understanding the potential treatments that have been applied to the artifacts. The majority of analyses that are done in archaeology today, aside from basic site reports, involve either artifact examination under low or high-power microscopes, chemical analysis, or other highly detailed analyses. Techniques regularly used to analyse archaeological material include fine-scale surface analysis with a high-power light microscope or a scanning electron microscope (SEM) (Lemoine 1997, Semenov 1964), microspectroscopy (Bitossi et al 2005), stable isotope analysis (Hedges et al 2005, Katzenburg and Weber 1999), residue analysis (Babot and Apella 2003, Sobolik 1996), nuclear magnetic resonance (NMR) (Lambert et al 2000), and others.

Archaeologists have noted the problem of analyzing consolidated material, but it appears that the lack of communication between the fields of conservation and archaeology has limited the effect of these concerns and little research has been done into the analysis of conserved materials. Here, when I use the term "conservation" or "conservation treatments," this includes both the work of trained conservators and those treatments done by field and lab archaeologists with the goal of conservation, either with or without the advice and assistance of a trained conservator. Although the presence of a conservator would be ideal in any excavation, constraints of time, space and economics often make this an impossibility. Thus, conventional wisdom and occasional consultation with a conservator often inform archaeologists' treatment of excavated material, both in the field and when examining older collections. This lack of knowledge of conservation methods among archaeologists is problematic. Training in basic conservation is not standard in archaeological study programs, so many archaeologists know neither how to conserve the materials they excavate nor how to recognize and manage the study of conserved collections. Many archaeologists exclude conserved material from their analyses, which is due both to problems resulting from conservation techniques and a lack of thorough knowledge on the part of archaeologists of the chemistry, mechanics, and reversibility of common consolidants. Patricia McComb (1989), when selecting material for her dissertation on Upper Paleolithic osseous tools found that she had to omit from microscopic analysis those specimens that had been treated with consolidants. Olga Soffer (2004) likewise found prior treatment of an object by a conservator to be grounds for omission from her study of Upper Paleolithic bone implements. Douglas Campana had a similar experience: "Unfortunately, these implements had been conserved by consolidation with a plastic binding agent and were not suitable for wear-pattern analysis" (Campana 1989:21). Both McComb and Soffer were attempting to analyse material with low-powered light microscopes; the problem is amplified at the level of magnification achievable with an SEM (e.g.: Campana 1989, LeMoine 1997, Runnings et al 1989).

Because these analyses rely on examination of the microscopic structure of the surface or makeup of the artifact, any alteration of the object can be detrimental to the analysis. Many of these analyses also aim to separate the raw material of the artifact from other foreign materials that may provide information on use, taphonomy, or production sequences. In light of the importance of understanding the physical and chemical makeup of the object and the origins of the various components, an analyst looking at objects that have been held in a museum setting must understand the potential treatments that have been applied to archaeological materials.

Another factor in the lack of communication between the two disciplines is that some conservators seem to have the correct, yet vague, idea that archaeologists are doing "experimental" or "scientific" analysis without having a more concrete understanding of what that might entail. Stephen Koob (1984:98), for example, states that "the bone specialist is primarily concerned with the morphology of bone, which fortunately is little affected by burial", displaying a lack of working knowledge of the range of analyses that can be done on archaeological osseous material, even though he later notes that archaeologists may be interested in details of surface morphology such as cutmarks or polishes. Koob does state that while conservation should be done "with permanence in mind" (Koob 1984:100), all treatments should be reversible so that bare surfaces can be studied at some later point in time.

However, there is has long been an awareness among members of the conservation community of the incompatibility of standard conservation techniques with new analysis techniques that are fast becoming standard in archaeological research, as evidenced by the conclusions made over a decade ago by Noreen Tuross and Marilyn Fogel at a 1992 Getty Conservation Institute conference:

> It may be that optimal treatments for morphological preservation are incompatible with many types of molecular analysis. Historically, both

> excavation and conservation techniques have emphasized maintaining the shape of excavated materials. The development of fields such as isotopic paleodietary analysis and ancient DNA studies suggests a future in which the principle excavator, the archaeologist, will be required to balance the need for morphological integrity with the information accessible at atomic and molecular levels.
>
> Once in the museum environment, excavated materials remain at risk to conservation treatments that could render a collection useless for comparative molecular analysis…(T)he applications of established experimental paradigms and new developments are most likely to derive from unconsolidated remains whose molecular potential is recognized at the point of excavation.
>
> Tuross and Fogel 1994:375-376

Tuross and Fogel had done experimentation with the so-called "exceptional fossils" (i.e. very well-preserved organic material – not really fossils at all) at the prehistoric sites of Monte Verde, Chile and Windover, Florida and reported significant difficulties in either removing "reversible" consolidants or testing bones treated with consolidant, concluding that chemical and isotopic analyses are compromised by standard conservation treatments. R.E.M. Hedges (1987) also outlined several areas where conservation practices may compromise archaeological analyses. The analyses highlighted by Hedges are trace element, isotopic, thermoluminescence (TL), electronic spin resonance (ESR), ^{14}C dating, uranium-series (U-series) dating, amino acid racemization (AAR), and genetic (DNA) analysis. Conservation practices that may compromise archaeological research include exposure to a variety of treatments and conditions. Inorganic solutions can alter the trace element make-up of the specimen, affecting several types of analysis. Organic reagents can be used in conservation, but Hedges recommends that their use be superficial only, in order to avoid damage to the artifact. Exposure to ^{14}C sources is essential if a sample is to be used for ^{14}C dating, and may be avoided if all organics used are amino acid free. Radical shifts in pH from the burial environment to the post-excavation and storage environments can result in exposure to chemicals that harm unstable bio-molecules. Exposure to heat, light, or radiation can also be detrimental, but is virtually unavoidable. However, heat and light should be kept to the bare minimum possible and no artifact should ever be raised above room temperature. Exposure to fungicides or bactericides could also have detrimental effects; if absolutely necessary, such treatment should be very carefully documented (Hedges 1987).

It is clear that both archaeologists and conservators are, and have been for some time, aware of the potential problems that can arise from misunderstanding or a lack of communication between conservators and archaeologists. However, a precise and in depth knowledge of how to avoid or circumvent such problems is generally lacking among many professional archaeologists. Archaeologists and conservators must gain a working knowledge of the goals and limitations of each other's disciplines and work together to adapt conservation techniques to changing research goals, technological capacities, and innovations in archaeological analysis.

Definition of the Scope of this Paper

In order to define a manageable, yet still informative, subject area for this study, historic and modern practices of archaeological conservation of osseous materials will be examined. Osseous materials are the hard body parts from animals (i.e., bone, antler, teeth and ivory), primarily mammals, and artifacts made from those parts. Some researchers also include mollusk shell, tortoise and turtle shell, hooves, and horn in this category. However, since the properties of these materials are quite distinct from those of bone and antler, they will not be included in this survey. Additionally, with the exception of marine shells, these materials are also rarely recovered from archaeological contexts and their recovery warrants special attention far different from that given to the overwhelming quantity of bone and antler that are yielded by many archaeological excavations. This paper will focus in particular on bone and antler for several reasons. Bone and antler, as will be discussed in depth below, are virtually the same material, so their conservation and preservation can be examined together. Tooth and ivory are physically quite distinct from each other and from bone and antler, although some characteristics are shared among all the osseous materials. Tooth and ivory will be discussed only minimally. Waterlogged sites present an entirely different set of challenges in terms of excavation, conservation and study and will not be addressed.

Second, the focus of this paper is on the conservation of osseous artifacts, that is, worked portions of bone, antler, tooth, and ivory, in particular, formal tools. Formal tools are artifacts about which there is no ambiguity about whether human actions intentionally created the product and which are interpreted as implements to aid work, rather than being artifacts of a primarily symbolic nature. As with any reductive technology, the production of bone and antler tools may result in a number of ambiguous types that may have been expedient tools, production debris, errors and rejects, tool blanks, or accidents of taphonomy (e.g: Choyke 1997). However, with tools such as sagaies, needles, pierced batons, discs, and a wide variety of other examples, there is no ambiguity as to the cultural nature of the modification of the raw material. While there may be great debate over the function of such items, their attribution as artificial seems fairly secure. Analysis done on tools and utilized bone fragments varies from that done on unmodified, unused faunal material or human remains, especially in terms of the technological and functional analyses that can be done on implements. However, much of the archaeological and conservation practices used effectively on unmodified faunal material have been transferred to osseous artifacts, without in-depth consideration of the differences between the two material classes. Osseous artifacts present different challenges to both the archaeologist and the conservator because of the differences between worked and unworked bone. This is further complicated by the fact that artifacts of bone are more likely to be displayed in the museum context than unmodified bone, so the demands on the conservation requirements for such materials are also heightened.

Archaeological Osseous Materials

Nature and Composition of Bone and Antler as Raw Materials

The following discussion of the physical properties of bone is drawn from Child (1993), Cronyn (1990), Hedges (1987), and T. O'Conner (1987), unless otherwise noted. Different osseous materials have very different properties and must be conserved appropriately. On drying ivory is apt to split into layers while bone regains stability. In alkaline conditions, antler can be rewet during treatment, but this is likely to cause bone to split longitudinally; the converse may be true at other sites (S. O'Conner 1987). Plenderleith (1962) notes that worked, well-preserved bone and ivory may be indistinguishable at the macroscopic level, although they have very different structures at the microscopic level, which may be visible with a handlens. Bone and antler are difficult to distinguish because antler is actually a form of rapidly growing bone. The cancellous portion of antler, or the medulla, has a honeycomb structure that expands in size toward the edges of the antler while cancellous bone is more angular. In larger artifacts some diagnostic features may be retained, but on artifacts made from the compact section of bone or antler it may be impossible to identify raw material. Other more subjective factors include antler having a more "woody" surface appearance and bone being able to be more highly polished. Bone matures over time, resulting in a more ordered structure but antler is shed before this process can take place. The reordering of bone can be identified by the presence of concentric arcs and long, straight lines on the surface of the bone running parallel to the long axis. Mature bone will break along distinct lines revealing the laminar character of bone growth as layers of compact bone. Additionally, secondary osteones, while not unknown in antler, are generally present and regularly spaced in mature bone, so their presence in relatively great numbers suggests that the raw material is bone rather than antler.

Antler differs from other bones in that it grows quite rapidly and does not usually develop osteotones, which are tubes of highly mineralized bone that form along blood vessels running lengthwise on the bone. Antler also contains more collagen and less mineral than bone. T. O'Conner does not, however, suggest that either of these factors can be used to differentiate the two materials; he considers them essentially the same material: "The distinction of small pieces of compact bone from compact antler by non-destructive methods can be very difficult, as they are, after all, virtually the same material and each varies considerably in structure" (T. O'Conner 1987:7). Subjectively, one can argues that the microstructure of holes and spaces on the surface of an artifact is more regular and uniform on bone than on antler. T. O'Conner also suggests that the best differentiating measure may be artifact function, as antler is tougher and more resilient than bone and was selected preferentially for shock-absorbing artifacts. Antlers have tapering tines and the beam to which they are attached. Beams are used to produce flat or artifacts while the shape of the tines restricts the types of artifact blanks that can be removed from them. However, because of antler's high collagen content, it can be soaked and the shape altered somewhat; this is less successful with bone.

Bone has two structural forms, which are indistinguishable microscopically, but can be easily differentiated macroscopically. The outer portion of the bone or antler is known as the cortical, compact, or laminar section and is hard and dense. The inner portion is known as the spongy or cancellous bone and is characterized by a porous structure, which in the living state, is filled with marrow. The cortical portion of long bones or antler is commonly used for artifact production, although small areas of cancellous bones are sometimes present. Osseous materials in the living state are composed of both organic and inorganic materials. About half the weight of fresh bone is mineral while 95% of the other half is collagen. Living bone contains 75-90% inorganic material, providing a framework in which organic material is embedded. The portion of living bone which is inorganic is primarily composed of the mineral calcium hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$). The remaining organic portion contains 19-25% collagen, a complex protein structure with the remaining portion being made up of protein, lipids and carbohydrates. Type I collagen, the most common organic component, is well understood chemically. It has a triple-helical structure with an amino acid sequence in which every third location on the structure is glycine, a very small molecule that allows compact folding and twisting of the chain. On a macroscale, bone is anisotropic. Collagen is arranged in long, aligned fibrils, which gives bone anisotropic properties, meaning that its reaction to outside force varies along different planes or axes.

Preservation of Osseous Materials in the Archaeological Record

Understanding the different processes that have affected an artifact is an essential facet of all archaeological analysis. Bones deposited in the archaeological record are subject to a wide range of taphonomic processes that can drastically impact our understanding of human use of animals in the past. While many factors work to shape the types of bones that will be deposited, diagenesis, the transformation and deterioration of buried organic material, works to alter the actual content of the bone. By depleting the mineral or organic component of bone deposits, these processes degrade the archaeological record and drastically impact the ways in which human behavior is interpreted and reconstructed.

However, along with taphonomic processes that act on the object between its use and recovery, there is also a suite of processes that affect the artifact during and after recovery, but before analysis. Conservation is one of these factors. Johnson (1994) argues that any researcher attempting to analyze museum collections must understand the conservation history of the material in order to properly interpret the artifact's characteristics. Otherwise, modern additives may be interpreted as residue, polishes or other traces of wear or manufacture. In his discussion of the nature of archaeological data, O'Connor (1996) draws a parallel between diagenesis or decomposition and recovery techniques as the two factors affecting the integrity of a faunal assemblage.

> In a sense, these two things are parts of the same process, even though one can be controlled (to some degree) by the bone specialist, while the other cannot. Both, however, are stages of data attenuation, a reduction of the information inherent in the assemblage at the point and time of deposition.
>
> O'Conner 1996:8

Archaeologists and conservators working on archaeological bone must understand the biological integrity of the sample before making decisions about how to analyse or treat the material. All materials must come into equilibrium with their environment. Artifacts go through several such stages. The raw material is in equilibrium with its environment in the living state and is then extracted by humans to be made into artifacts. At this point the material undergoes changes so that it can come into equilibrium with the new, changed environment. In the case of bone, this includes the shift from the living to the non-living state, during which process water is lost, the proportion of organic to inorganic components shifts, and the physical and mechanical properties of bone are changed. After the artifact is discarded and enters the archaeological context, it must once again come to equilibrium with the new environment. The changes that take place during this period are more difficult to predict, being based on local soil chemistry, but may include the loss or uptake of minerals, the loss of organic material to microorganisms, the loss of material due to mechanical abrasion by both water and sediment, and chemical exchanges with the environment that may affect the overall makeup of the object. Upon excavation the object is once again required to come into equilibrium, with a new environment. It is the goal of conservation to make this process as rapid as possible and to decrease the changes necessary for the artifact to reach equilibrium, as every shift of equilibrium state results in the further deterioration of the original object (Bolker et al 1998, Child 1993, Dowman 1970, O'Conner 1996, O'Conner 2000, Sease 1994).

Archaeological sites often produce vast amounts of bone that may be in a considerably weakened state. Bone may be fossilized, mineralized, or partially mineralized. Polished objects often have better preservation than those that are not polished, which may be related to microscopic changes in the bone surface, although these changes are not fully understood (LeMoine 1997).

Partially mineralized bone is particularly vulnerable to damage from changing water content because not all parts of the bone will expand and contract so the organic matrix cannot accept and lose water easily. Polyvinyl acetate is often used as an in-field consolidants for weakened bone, but there are problems with its long-term stability. Bone reacts quickly to changes in relative humidity. In the 1970s and 1980s acrylic polymers and copolymers, especially Paraloid B72, have been used on fragile osseous material and have been shown to be stable and removable. Paraloid B72 can be used *in situ* with organic solvents or as an aqueous solution. Polyethylene glycol (PEG) grades 6000 and 12000 have also been used, but the large molecular size of this consolidant can be problematic (Bunn 1987, Cronyn 1990).

Because burial environments are extraordinarily complex, estimating preservation from the composition of the matrix is reliable only on an extremely gross scale. Bone is in chemical equilibrium with its living environment, but loses this equilibrium at burial, which is a primary cause of decay. The triple-helical structure of glycine allows compact folding and twisting of the chain is primarily responsible for the resilient properties of fresh bone against collagen breakdown. Collagen must be demineralized before microbial collagenases can cleave the collagen molecule. Thus both collengenase and acidic byproducts are required for the breakdown of bone. Calcium hydroxyapatite can be altered by both dissolution and recrystallization; vivianite, brushite, and calcite are all byproducts of these processes. Both brushite and calcite are larger crystals than hydroxyapatite and this replacement can lead to structural weakness. Brushite is water-soluble and the conversion of hydroxyapatite to brushite in drained soils will eventually lead to the complete deterioration and disappearance of the bone. While both brushite and vivianite are formed in acidic environments, in calcium-rich soils, the presence of acid acts primarily as a deterrent to microbes and thus can aid preservation (Child 1993, Hedges 1987).

One component of the assessment of preservation made on bone is the estimation of the preservation of both the organic and inorganic components. Bone preservation varies with the biological properties of the bone and with the physical and chemical agents that impact specimens before and during burial. Major influences on preservation include soil pH, presence of water or air, and climate changes. Organic material decays quickly if bacteria are encouraged; that is, in well-aerated soils. Mineral salts are leeched out in acidic soils, especially if water can percolate through the deposit, removing minerals and preventing the saturation and balancing of the outer environment with the bone. Collagen and 'ground substance' are well-preserved in alkaline soils, although extreme alkalinity causes brittleness by removing nearly all organic content. Alternating temperatures cause fracturing, especially of long bones; soluble salts exacerbate this process and amplify the effects of variable humidity as well. Waterlogged sites will yield bones that appear to be very well preserved but are prone to shrinking, warping and fracturing once dried (Koob 1984). The preservation of bone varies from that of many other materials because the two components of bone preserve at different pH levels; alkaline environments preserve the inorganic portion while acidic environments preserve the organic portion. Hydroxyapatite is quite stable except in highly acidic environments, especially if groundwater leaching removes protective phosphate-rich zones that accumulate around decaying bone and inhibit further decay. Collagen, on the other hand, degrades at high pH, probably due to the action of microorganisms, unless there are significant ferrous or heavy metal ions present to inhibit microorganism action. Thus osseous material from an alkaline site will be brittle, but generally the overall form is well-preserved. Acidic matrixes will yield bone and antler that have lost their mineral structure and are warped or shrunken (Cronyn 1990). In environments that are damp, oxygenated and alkaline, collagen tends to decay while hydroxypatite tends to survive. Fungi and microorganisms complicate this generalization as they are often found in damp, alkaline environments and may contribute to the loss of the both the protein and mineral components of skeletal material. Calcium hydroxypatite is soluble in wet, acidic environments. Bone deposited in a middens or other location with a large skeletal deposit may survive despite damp, acid surroundings due to the saturation of the sediment of phosphate ions that would normally be removed from the bone into solution. In certain highly saturated sediments, ions may fall out of solution and recrystallize within the bone's structure, creating a highly complex taphonomic history (O'Conner 2000). The deposition of minerals into the natural cavities in bone ill cause color changes in well-preserved bone but significant damage to the artifact's form in cases of significant collagen loss.

Child (1993) devised a test of the taphonomic agents working on archaeological bone. In order to test the role of collagenase and organic acid producing microorganisms in the breakdown of mineralized collagen, Child tested a range of microbes. She chose to test them at 10ºC, which is typical of burial environments, rather than 37ºC, which is the temperature at which earlier studies have often been conducted. Lowered temperatures inhibit some microbes while encouraging others, so a temperature closer to that of the archaeological record *in situ* is more appropriate. The soil microbe *Pseudomonas flourescens* was introduced onto sterile bone and left until, after about seven months, population numbers fell, indicating that the microbe culture was dying. In 53 days, however, significant weight loss had already occurred. Thus, Child showed that microorganisms alone can contribute significantly to the breakdown of bone. However, in a true burial environment various bacteria and fungi are in competition for food sources (archaeological material in this case) and both put out various products to discourage other organisms. It is this competition between microorganisms that is sometimes to blame for the preservation of osseous material. The greater the variety of microorganisms, the longer bone may be expected to survive.

History of Conservation of Archaeological Osseous Materials

Handbooks of Archaeological Conservation

Once the archaeologist has made the decision to concentrate on museum collections rather than on objects freshly removed from the ground, assessing the nature of the collection becomes a critical first step of the analysis. Archaeologists and conservators tend to have different priorities when selecting a consolidating treatment. Conservators tend to focus primarily on long-term stability; ease of application and economy of both time and money are often more salient factors for field archaeologists. Additionally, different treatments have come in and out of use over time, so knowing the date of excavation can help identify the treatments likely to have been applied to an artifact from a museum collection. Most consolidants used on bone are resins in solution (beeswax, Duco Cement, Ambroid), emulsions (Elmer's glue, Vinamul) or colloidal dispersions (WS-24). Many of these consolidants are organic polymers that create a network around the structure of the osseous material. The interactions between bone, consolidants and the environment determine the effects of treatment on both research and long term stability of the artifact (Johnson 1994).

For the non-specialist in bone conservation, standard handbooks of archaeological conservation provide guidelines on typical treatments for archaeological bone encountered in the excavation context. A survey of such handbooks shows shifts in both consolidation chemicals and treatments and attitudes toward conservation through time. Plenderleith wrote the first comprehensive manual on conservation of archaeological material in 1956; a revised version from 1962 is also widely available and has been a staple resource for museum conservators. Plenderleith suggests that dry osseous materials can be consolidated with polyvinyl acetate or polymethacrylates. Ployvinyl acetate in the form of a lacquer or an aqueous emulsion was recommended as both a consolidant and an adhesive for archaeological bone as early as 1934. Antler that is treated with polyvinyl acetate lacquer must be dried in toluene vapor, otherwise the surface will acquire a high sheen that is undesirable from both an analytic and aesthetic perspective. Polymethacrylate emulsions such as Bedacryl L can be used to consolidate both bone and ivory in the field. Plenderleith states that emulsions are stable unless exposed to frost. Nitrocellulose lacquers and adhesives "suffer from certain minor defects" but are seen as appropriate for osseous material because they are easy to both apply and remove and are reliable adhesives (Plenderleith 1962).

In 1970, Dowman wrote an updated manual of archaeological conservation, which was aimed at the archaeologist, rather than the museum professional. She included an overview of soil chemistry and the mechanics of decomposition. After a comprehensive summary of chemicals and techniques available for the treatment of artifacts both during and immediately after excavation, she included recommendations on the treatment of specific materials commonly found in archaeological excavations. Dowman argues that the treatment of archaeological materials should always err toward less, rather than more, active treatment. Artifacts that appear stable should be left as is, rather than risk compromising later analyses through unnecessary conservation treatments. Dowman suggests cleaning bones by gentle scrubbing in water, or if in a more fragile state, with a wooden or plastic tool. Glacial acetic acid in a 15% solution in water or formic acid in a 10% solution with water can be used to clean bones with accretions from deposition in a calcareous matrix. PVA, Bedacryl 277 emulsion, and Butvar B98 are recommended consolidants and polyvinyl alcohol is also suggested, with the caviat that over time polyvinyl alcohol will become insoluble. Dowman notes that bones that are to be sampled for chemical analysis or 14C analysis must not be treated with any chemicals and can only be washed with distilled water, wet washing is determined to be absolutely necessary.

Twenty years later, Cronyn (1990) wrote a new volume on archaeological conservation, including detailed discussions of the chemical composition of various archaeological materials and conservation treatments and explaining the chemical reactions between different materials. According to Cronyn, of primary concern in the stabilization and conservation of osseous materials is the maintenance of proper RH. First, the material must be brought into equilibrium with the storage RH and then the RH must be controlled so that sudden or great fluctuations are avoided. For active stabilization, Cronyn suggests polyvinyledene chloride emulsion.

Sease's 1994 volume is closely modeled after Dowman's manual and provides an updated set of recommendations in the same format used effectively by Dowman. Like Dowman, Sease notes that conservation treatment of archaeological material should be kept to a minimum. She also suggests that samples of all materials be retained without conservation for use in later, unforeseen analyses. Sease recommends Acryloid B72 or PVA in a 3-5% solution for *in situ* consolidation of friable but dry bone. If the bone is damp, PVA emulsion diluted with water 1:4 or 2-4% Acrysol WS24 can be used. Acryloid B72 can make bone brittle, but PVA may not be strong enough to protect fragile bones. Additionally, PVA will soften in heat, so it cannot be used on artifacts that will not be stored immediately in a climate-controlled environment. Sease notes that all emulsions will cross-link over time, so resins should be used in place of emulsions whenever possible. Whichever consolidant is selected, it should be applied in several coats, until the consolidant no longer penetrates the bone's surface. Sease suggests that bones can usually be cleaned effectively with a dry brush, or with water if dirt is adhering to the surface, but no detergent should be used in the washing of osseous material. Glacial acetic acid is recommended for dissolving calcareous matrixes which are cemented to bone. Whichever technique is used, care should be taken not to scratch the bone. Sease notes that worked bone should not be washed, it at all possible. Bone should be stored at a relative humidity of 45-55% and at a temperature of 5-30°C, away from both heat and light (Sease 1994).

Rodgers' (2004) treatment of the conservation of osseous materials is brief. He suggests a 50% PVA solution in distilled water as an appropriate consolidant for fragile specimens and suggests minimal intervention when possible.

Specialized Research into the Conservation of Archaeological Osseous Material

In addition to handbooks, some researchers in conservation have specialized in osseous material and provide more detailed information on techniques and treatments specifically tailored to the nature of archaeological bone and antler. In the early 1970s Lawrence Majewski wrote on conservation techniques specific to osseous materials. He suggests that many fragile objects should be removed with the surrounding matrix after consolidating the whole area with resin. Organic materials that are found damp must be dried as slowly as possible. Osseous artifacts have often lost a majority of their organic content, which leads to their brittleness and fragility. Majewski (1973a) points out that samples for ^{14}C dating must be removed before any consolidation action is done. It is important to note, and ideally identify, archaeological stains or accretions. Black light may be used to identify old repairs from previous conservation and to distinguish accretions of various sorts (Majewski 1973b). Majewski (1973b) states that broken objects should be repaired with an adhesive such as polyvinyl acetate or internally plasticized polyvinyl acetate emulsions such as Jade #403. These are both removable with acetone. He writes that epoxy resins should be generally avoided but may sometimes be useful for artifacts that will be subjected to stress. Dilute polyvinyl acetate solution can be used to consolidate flaking or friable pieces by impregnating the object with the solution. Dull surfaces can be shined with microcrystalline wax mixed with petroleum benzine. All osseous materials can be stored at 65-70F and 45-60% humidity (Majewski 1973b).

Majewski (1973b) notes that osseous materials are extremely sensitive to changes in humidity; they may even absorb enough moisture from being handled directly that they can warp or crack. Swabs dampened in a cup of water with a few drops of liquid detergent may be used to clean dirt away, although fragile objects should only be cleaned with a dry brush. Cotton swabs must be only slightly damp due to the tendency of these materials to absorb moisture. Acetone with a few drops of ammonia can also be used on cotton swabs to clean osseous surfaces. Although Majewski was engaging a debate focused on balancing the issues of reversibility, science and aesthetics, the late 1960s and early 1970s were a time of rapid innovation in archaeological method and theory (Johnson 1999, Trigger 1989). Although some of his suggestions are still useful, he emphasizes the importance of the maintenance of form as a primary guide to decision-making, without attention to the minute surface details that are the focus of many modern archaeological studies. Shining the surface of an artifact with petroleum benzine, for example, may obscure detailed morphology on the microscopic level. Although he cautions against scratching artifacts, he suggests the use of detergent or acetone to clean osseous material which may also compromise chemical analyses of objects.

An example of the more specific research done within the field of conservation of archaeological bone is Bunn's paper (1987) on rapid conservation of friable bone with Saran. Bunn prefaces her discussion by listing the suggestions outlined by Rosenqvist of the necessary properties of consolidants for any material. Adherence to material is a primary requirement for any consolidant or adhesive. Maximum surface penetration is also a critical property. Consolidants must set without shrinking. The consolidated surface must be clear and provide a barrier against the environment. In addition, aging must not affect these properties and no harmful reactions between the consolidants and material are permissible. Finally, all treatments should be removable or reversible. For the treatment of bone, Bunn adds the requirement of low viscosity and surface foaming for better penetration of the porous surface. The structure of the polymer must be closely packed with minimal free volume (Bunn 1987).

Bunn discusses experiments done to assess the use of Saran as a protective coating on archaeological bone to prevent the uptake and loss of water. Polyvinyledene chloride has been used to treat ivory; this experiment tests the use of the polyvinyledene chloride Saran as a moisture buffer on archaeological bone. Bunn's experiment compared the water uptake of bones of three levels of apparent condition treated by "1) vacuum impregnated of 10% PVAc for 2 hours, 2) vacuum impregnation of 10% Paraloid B72 in acetone for 2 hours, 3) vacuum impregnation of Saran 143 (27% solids) for 2 hours, 4) surface application of Saran 143 (27% solids) in 3 coats following the grain of the bone to prevent accumulation of latex in the cracks" (Bunn 1987:31) along with control specimens. Although Bunn interprets her results as showing that Saran is the best water barrier, her actual data seems inconclusive and in fact indicates, if anything, that untreated bone gained and lost the least water in changing environments, especially in the case of more degraded specimens.

Saran latex 143 was chosen for the experiment; it is recommended by Bunn for porous surfaces because it leaves a coating that is "clear, continuous, flexible, tough, glossy, and non-tacky" (Bunn 1987:28). It is also non-toxic and inexpensive and removable with tetrahydrofuran. However, Saran deteriorates and yellows in 5-10 years and may lead to surface etching, although Bunn does not consider these shortcomings sufficiently serious to rule out Saran as a consolidant for osseous materials. She notes that the surface may be so glossy that a second matting agent may be necessary. Problems in terms of stability aside, glossy, continuous and tough are not desirable qualities to facilitate later analysis and the necessity of a second, different coating worsens the problems faced by archaeologists examining surface characteristics. Bunn is very thorough in describing her experiment and presenting data, but not appear to be familiar with the demands placed on conservation decisions by the necessities of various types of archaeological research.

Koob (1984) provides another treatment for *in situ* damp bone, which can be consolidated with an emulsion or colloidal dispersion diluted to 2-4%. Dry bone can be treated with Paraloid B72 diluted in acetone or toluene to 5-10%. After the material has been brought to the lab, cleaning can be done with a dry brush, water or consolidants, depending on the condition of the bone. Washing with water is fast but weak bones will split while drying and friable surfaces may disintegrate under water. Dry brushing is slow and less effective than wet cleaning, but is preferable in cases of poor preservation. Bones can also be washed in a water-based consolidant so that bones are strengthened at cleaned at the same time. If osseous material has been exposed to soluble salts, it can be soaked in de-ionized or distilled water for 24 hours to lower the salt content. Heavily concreted bone should not be consolidated. After being cleaned, bone should be kept somewhat damp and then soaked in 2-4% solids dilution of acrylic emulsion or colloidal dispersion and then cleaned with sponges or brushes to remove excess consolidant because scratching will ensue and could be misinterpreted as traces of manufacture or prehistoric use. Consolidant can also be brushed on, if necessary. Metal should never come into contact in any way with osseous materials. Consolidated material can then be left to dry in a cool, dark location. Some specimens may require two coatings of consolidant, especially if they are quite porous. Overall, Koob finds acrylic emulsions and acrylic colloidal dispersions to be best suited to the demands of archaeological bone conservation. This approach may yield better results for archaeologists interested in analyzing material after consolidation.

Overall, there has been relatively little research done into the conservation of osseous materials, which may be due to a number of reasons. Bone artifacts often preserve well and require less conservation treatment than metal or ceramic artifacts. Also, especially in the United States, osseous material receives less attention from archaeologists than do other material classes. Non-decorated bone tools are also less likely to be deemed "museum-quality" so their conservation has been a less salient issue than that of metals or ceramics. More research into the conservation of osseous materials is called for from both archaeologists and conservators so that the concerns of both disciplines can be adequately addressed (Tuck and Logan 1987).

Conclusions

Storage conditions at archaeological field labs are generally substandard to very poor and can contribute to the continued deterioration of materials (Koob 1984). Thus, it is important to know the history of the object since excavation, in both the field lab and through the process of conservation. Conservators' notes should be available from the museum and should contain information as to the treatments that have been applied to the material to be analysed. Knowing the date of conservation treatment and the consolidants commonly used at the time can also be of assistance in determining what techniques and chemicals may have been used (see Appendix B).

Recent studies by conservators have shown that many "reversible" treatments are difficult to remove after a period of several years, especially in the case of fragile and porous material such as bone. Concerns about the use of consolidants on osseous material have arisen due to the realization that conservators' treatments can prevent several types of common archaeological analyses. Obviously, as most consolidants contain an organic component, either petroleum based or natural or synthetic resins, treated bone cannot be radiocarbon dated or tested for stable isotope analysis. Microscopic analysis of surface morphology can also be rendered useless by consolidation treatment. Surface detail at the scale visible with an SEM is obliterated by many consolidants. Some archaeologists have circumvented this problem by sampling the artifact surface and selectively dissolving consolidants in sampled areas, however, this may not be possible with the treatments applied to older collections (Johnson 1994, Tuross and Fogel 1994).

As archaeological methods continue to develop and conservation studies progress, both disciplines have the opportunity to profit from increased familiarity with one another's work. Both archaeologists and conservators are involved in the study of the past through the record that exists in the present (Tuck and Logan 1987). Cronyn (1990), in fact, refers to conservation as "micro-archaeology." Although many collections that have been treated in the past may never be appropriate for today's analytical techniques, archaeologists must familiarize themselves with basic conservation chemistry so that, rather than dismissing consolidated collections out of hand, they understand fully the potential for reversibility of many treatments. Conservators have emphasized both stability and reversibility of consolidants for several decades, but few archaeologists are aware that many coatings can be removed for study purposes. Likewise, conservators who specialize in archaeological material must gain an awareness of the possible investigations of the material they are treating. Ideally, a conservator would work with a field crew or lab crew through an entire project, so that questions could be addressed during treatment by the appropriate archaeologist or analytical specialist. However, even when conserving a small portion of a collection, a conservator should be familiar with the research design of a site, along with the analyses that are planned for all materials, regardless if the archaeologist believes that conservation will affect any specific analysis. Overall, conservators have been sensitive to the issues surrounding the conservation of archaeological bone.

All conservators familiar with the demands of archaeological analyses have encouraged caution in cleaning and consolidating osseous material. However, more explicit, directed research into methods of stabilizing osseous material with minimal damage to archaeological data is necessary. These precautions and further communication between archaeologists and conservators will help preserve the archaeological record for study today and in the future.

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1962 *The Conservation of Antiquities and Works of Art: Treatment, Repair and Restoration*. Oxford, London.

Rodgers, Bradley A.
2004 *The Archaeologist's Manual for Conservation: A Guide to Non-Toxic, Minimal Intervention Artifact Stabilization*. Kluwer/Plenum, New York.

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1994 *A Conservation Manual for the Field Archaeologist*. Archaeological Research Tools 4. Institute of Archaeology, University of California, Los Angeles.

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1989 *A History of Archaeological Thought*. Cambridge University, Cambridge.

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Tuross, Noreen and Marilyn L. Fogel
1994 Exceptional Molecular Preservation in the Fossil Record: The Archaeological, Conservation, and Scientific Challenge. In *Archaeometry of Pre-Columbian Sites and Artifacts: Proceedings of a Symposium organized by the UCLA Institute of Archaeology and the Getty Conservation Institute, Los Angeles, California, March 23-27, 1992*, edited by David A. Scott and Pieter Meyers, pp. 367-380. Getty Conservation Institute, Los Angeles.

APPENDIX A: Annotation of References

Handbooks of Archaeological Conservation:

Cronyn, J.M. (with contributions on marine materials by W.S. Robinson)
1990 *The Elements of Archaeological Conservation.* Routledge, London.
Cronyn's manual is quite technical in terms of describing the nature of the archaeological record, but descriptions of conservation treatments are brief. This book is recommended for the conservator interested in archaeology.

Dowman, Elizabeth A.
1970 *Conservation in Field Archaeology.* Methuen and Co., London.
Dowman's volume is very well-organized and provides basic information for both the archaeologist and the conservator.

Plenderleith, H.J.
1962 *The Conservation of Antiquities and Works of Art: Treatment, Repair and Restoration.* Oxford, London.
Plenderleith's is the classic work on conservation and is thus an essential reference for the archaeologist seeking to understand the history of conservation of a collection. His recommendations for the conservation of osseous material are brief and more updated information is available for the conservator.

Rodgers, Bradley A.
2004 *The Archaeologist's Manual for Conservation: A Guide to Non-Toxic, Minimal Intervention Artifact Stabilization.* Kluwer/Plenum, New York.
Rodger's manual is extraordinarily well-organized with an extensive bibliography. Although his section on osseous materials is too brief, his bibliography is extremely comprehensive.

Sease, Catherine
1994 *A Conservation Manual for the Field Archaeologist.* Archaeological Research Tools 4. Institute of Archaeology, University of California, Los Angeles.
Sease's volume is an update of Dowman's manual and is likewise well-organized and easy to use. She presents specific, up-to-date recommendations for archaeologists who are in charge of the conservation of their own material without the aid of a full-time conservator. This volume is recommended as a field manual at any excavation.

Conservation of Archaeological Osseous Material:

Bunn, Maureen

1987 Saran as a Treatment for Bone. In *Archaeological Bone, Antler and Ivory*. Occasional Papers, Number 5, pp. 28-33. United Kingdom Institute for Conservation of Historic and Artistic Works, London.

Bunn's experiment concerns the efficacy of SARAN as a bone consolidant and focuses on the uptake and loss of water from osseous material.

Elder, Ann, Scott Madsen, Gregory Brown, Carrie Herbel, Chris Collins, Sarah Whelan, Cathy Wenz, Samantha Alderson, and Lisa Kronthal

1997 Adhesives and Consolidants in Geological and Paleontological Conservation: A Wall Chart. SPNHC Leaflets 1(2). Society for the Preservation of Natural History Collections, Washington, D.C.

This wall chart is a concise listing of consolidants used in geological and paleotological conservation, although with the advantages and disadvantages of various treatments.

Hedges, R.E.M.

1987 Potential Information from Archaeological Bone, its Recovery and Preservation. In *Archaeological Bone, Antler and Ivory*. Occasional Papers, Number 5, pp. 22-23. United Kingdom Institute for Conservation of Historic and Artistic Works, London.

Hedges describes common archaeological analyses done on bone; this paper is meant as an introduction for the conservator to archaeological methods.

Johnson, Jessica S.

1994 Conservation of Archaeological Bone: A Conservation Perspective. *Journal of Field Archaeology* 21:221-233.

Johnson summarizes the history of conservation treatments that have been applied to bone and assesses the success of different methods from the perspectives of stability and effect on archaeological analyses. This article is highly recommended for archaeologists who will be working with museum collections that have received conservation treatment.

Koob, Stephen P.

1984 The Consolidation of Archaeological Bone. In *Adhesives and Consolidants: preprints of the contributions to the Paris, 2-8 September 1984*, edited by N.S. Brommelle, pp. 98-102. International Institute for Conservation of Historic and Artistic Works, London.

Koob presents recommendations for the treatment of archaeological bone *in situ* and in the context of a field laboratory.

Majewski, Lawrence J.

1973a On conservation problems at an archaeological site. *Museum News* 51(3):11-12.

1973b On conservation: cleaning and care of ivory and bone objects. *Museum News* 51(7): 10-11.

In both articles, Majewski provides suggestions on the conservation of archaeological material.

O'Conner, Sonia
1987 The Identification of Osseous and Keratinaceous Materials at York. In *Archaeological Bone, Antler and Ivory*. Occasional Papers, Number 5, pp. 9-21. United Kingdom Institute for Conservation of Historic and Artistic Works, London.

O'Conner discusses the structural difference between different types of osseous materials and the implications of these differences for conservation treatment.

Storch, Paul S.
2003 Field and Laboratory Methods for Handling Osseous Materials. Minnesota Historical Society, St. Paul.

Storch provides instructions for the safe excavation and conservation of osseous artifacts. This article is recommended to the archaeologist as a basic introduction to the treatment of osseous materials from excavation through storage.

Tuck, James A. and Judith A. Logan
1987 Archaeology and Conservation: Working Together? In *In Situ Archaeological Conservation: Proceedings of meetings April 6-13, 1986, Mexico*, edited by Henry W.M. Hodges, pp. 56-63. Getty Conservation Institute, Los Angeles.

Tuck and Logan discuss the importance of conservation in archaeology, as well as some of the reasons for the lack of communication between the two disciplines. This article is highly recommended for both archaeologists and conservators.

Tuross, Noreen and Marilyn L. Fogel
1994 Exceptional Molecular Preservation in the Fossil Record: The Archaeological, Conservation, and Scientific Challenge. In *Archaeometry of Pre-Columbian Sites and Artifacts: Proceedings of a Symposium organized by the UCLA Institute of Archaeology and the Getty Conservation Institute, Los Angeles, California, March 23-27, 1992*, edited by David A. Scott and Pieter Meyers, pp. 367-380. Getty Conservation Institute, Los Angeles.

Tuross and Fogel present a case study in the potentially detrimental effects of conservation on the integrity of archaeological bone for later investigations.

Taphonomic Studies:

Bolker, Benjamin M., Stephen W. Pacala and William J. Parton, Jr.
1998 Linear Analysis of Soil Decomposition: Insights from the Century Model. *Ecological Applications* 8(2): 425-4439.

Bolker et al discuss the process of soil composition and the use of modeling to predict decomposition patterns and rates. The paper is quite technical and is meant for the specialist in soils and taphonomic studies or systems modeling.

Child, Angela
1993 Microbial decomposition of archaeological bone. In *Conservation Science in the U.K.: preprints of the meeting held in Glasgow, May 1993*, edited by Norman H. Tennent, pp. 91-95. James and James Science, London.
Child's experiments into the role of microbes in decomposition are discussed in this paper. The description is non-technical and the paper is a good introduction to taphonomy for the conservator or other non-specialist.

O'Conner, T.P.
1987 On the Structure, Chemistry and Decay of Bone, Antler and Ivory. In *Archaeological Bone, Antler and Ivory*. Occasional Papers, Number 5, pp. 6-8. United Kingdom Institute for Conservation of Historic and Artistic Works, London.
O'Conner's short paper provides basic information on the nature and composition for the bone specialist in either archaeology or conservation.

1996 A Critical Overview of Archaeological Animal Bone. *World Archaeology* 28:5-19.
O'Connor's discussion of the state of faunal research in archaeology has two major focuses, the identification of archaeological bones and the taphonomic processes that intervene between the living context of the animal and their recovery from the archaeological record.

O'Connor, Terry.
2000 Taphonomy: From Life to Death and Beyond, pp.19-27. In *The Archaeology of Animal Bones*. Texas A&M, College Station.
This paper is a basic breakdown of the taphonomic process and is a good introduction to an archaeological understanding of taphonomy and its role in preservation and effect on archaeological research.

Archaeological Studies:

Babot, M. Del Pilar and María C. Apella
2003 Maize and Bone: Residues of Grinding in Northwestern Argentina. *Archaeometry* 45:121.
Babot and Apella analysed residues from grinding stones in order to establish the prehistoric use of *Zea mays* and the processing of burned bone.

Bitossi, Giovanna, Rodorico Giorgi, Marcello Mauro, Barbara Salvadori, and Luigi Dei
2005 Spectroscopic Techniques in Cultural Heritage Conservation: A Survey. *Applied Spectroscopy Reviews* 40:187-228.
Bitossi et al review applications of spectroscopy in a variety of conservation fields, including archaeology.

Campana, Douglas V.
1989 Natufian and Protoneolithic Bone Tools: The Manufacture and Use of Bone Implements in the Zagros and the Levant. BAR International Series 494, Oxford.
Campana describes his experiments and analysis of bone tools from Natufian and Protoneolithic contexts from both excavations and older museum collections, including detailed photos of both archaeological and experimental artifacts.

Choyke, Alice M.
1997 The Bone Tool Manufacturing Continuum. *Anthropozoologica* 25-26:65-72.
Choyke discusses the variation in bone tools, from heavily utilized but unmodified bone fragments, to minimally utilized but heavily worked formal tools.

Hedges, Robert E., Jonathon M.A. Thompson and Bradley D. Hull
2005 Stable isotope variation in wool as a means to establish Turkish carpet provenance. *Rapid Communications in Mass Spectrometry* 19:3187-3191.
Hedges et al describe initial attempts to develop a way to source wool based on stable isotope variation that should reflect geological and vegetal setting in which sheep were raised.

Johnson, Matthew
1999 *Archaeological Theory: An Introduction*. Blackwell, Oxford.
Johnson provides a history of the development of archaeological thought in the U.S and England.

Katzenberg, M. Anne and Andrzej Weber
1999 Stable Isotope Ecology and Palaeodiet in the Lake Baikal Region of Siberia. *Journal of Archaeological Science* 26:651–659.
Katzenburg and Weber used both human and faunal bone to determine the contribution of fish to the diet of lakeside Neolithic and Early Bronze Age communities.

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1990 Points and Lines. In *Powers of Observation: alternative views in archeology*, edited by Sarah M. Nelson and Alice B. Kehoe, pp. 23-37. Archeological Papers of the American Anthropological Association, Vol. 2. American Anthropological Association, Washington, D.C.
Kehoe reexamines bone and antler artifacts from the Upper Paleolithic that had been identified as hunting tools but may have been weaving implements.

Lambert, Joseph B, Catherine E. Shawl and Jaime A. Stearns
2000 Nuclear magnetic resonance in archaeology. *Chemical Society Review* 29:175-182.
Lambert et al describe various uses of NMR in modern archaeological research.

LeMoine, Genevieve
1997 *Use Wear Analysis on Bone and Antler Tools of the Mackenzie Inuit.* BAR International Series 679.
LeMoine uses high-power and SEM microscopes to examine use wear on osseous artifacts.

McComb, Patricia
1989 *Upper Paleolithic Osseous Artifacts from Britain and Belgium.* BAR International Series 481, Oxford.
McComb presents a detailed technological analysis of osseous assemblages from museum collections, along with some functional analysis of certain artifacts.

Runnings, Anna L, Carl E Gustafson and Dave Bentley
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Runnings et al discuss techniques for the study of use wear and manufacturing traces on bone tools.

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Semenov's book is the classic introduction to the study of archaeological use wear.

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1996 Lithic Organic Residue Analysis: An Example from the Southwestern Archaic. *Journal of Field Archaeology* 23:461-469.
Sobolik used organic residues on stone tools to determine their function.

Soffer, Olga
2004 Recovering Perishable Technology through Use Wear on Tools: Preliminary Evidence for Upper Paleolithic Weaving and Net Making. *Current Anthropology* 45:407-413.
Soffer describes her functional analysis of bone tools held in museum collections and previously interpreted as projectile points.

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1989 *A History of Archaeological Thought*. Cambridge University, Cambridge.
Trigger provides a history and analysis of changes in archaeological thought and theory.

APPENDIX B: Common Consolidants Used On Archaeological Bone

Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
Natural consolidants	Water-soluble consolidants	Gelatin, glycerol, gum-arabic, agar	Pre1984	Poor	Unless climate is completely stable, deterioration will continue		Koob 1984
	Non-water-soluble consolidants	Beeswax	1924 +	Poor – can damage surface as resin deteriorates	Does not penetrate the bone surface and can mute or completely cover surface detail. Older collections may have been treated with such resins, possibly rendering them useless for microscopic analysis.		Johnson 1994
Synthetic polymers	Polyethylene glycol	Carbowax, PEG			Limited reversibility	Can be used on damp materials	Elder et al 1997
			Pre1984		Treatment takes a long time; hygroscopicity		Koob 1984
Polyvinyl resins	Polyvinyl alcohol	Gelvatol	At least 1968+	Cross-links in ~3 years; softens in heat or humidity		Can be used on dry or damp bone	Dowman 1970
Acrylic resins	Solution or emulsion form			Cross-link if exposed to light; soften in heat	Fewer solvents available than for polyvinyl resins	Good penetration, strong	Dowman 1970
	Methacrylic co-polymer emulsion	Bedacryl 277		Reversible		Can be used on damp bone	Dowman 1970

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Emulsions	General			Poor – all emulsions will cross-link		Can be used on damp materials	Sease 1994
	Polyvinyl acetate					Applied in to dry bone solution, as an emulsion to damp bone	Dowman 1970
			Replaced by B72	Reversible, but softens in heat	May not be strong enough to support bone	Flexible	Sease 1994
		VINAC B-25			Inhibits DNA extraction		Tuross and Fogel 1994
	Cellulose nitrate resins	Duco cement, Ambroid			Should be avoided – very poor penetration		Cronyn 1990
				Yellow, deteriorate, shrink	Not recommended		Elder et al 1997

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Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
			at least 1939, maybe as early as 1924; in use today	Poor – instable over time	can cause severe surface damage to the artifact due to shrinking, discoloration and deterioration of consolidant		Johnson 1994
			Pre1984	Poor if bone is not well impregnated	Bones must be 100% dry before treatment or water will be trapped under the surface; immersion in hot solutions is required; obscure surface detail		Koob 1984
	Cellulose nitrate resins Poly(vinyl)	Alvar, Butvar		Unacceptable; yellow over time, crosslink	Should be avoided; turn brittle and damage objects		Storch 2003

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Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
	acetal and butryal resins		Acetal introduced 1936, replaced by butryal in 1960s; in use today	Good	None documented		Johnson 1994
	Poly(vinyl) acetal and butryal resins Poly(vinyl) acetate resins	Mowilth; Vinac range B-15, B-25; Gelva; Vinylite AYAA, AYAF, AYAC, A		Good. Cross-linking is rare. Not affected by light exposure. Reversibility medium to good.		Different solvents can be used to adjust physical properties.	Elder et al 1997
			Pre1984		high rate of water permeability and absorption – the action of soluble salts and anisotropic stress are both exacerbated		Koob 1984
			1930s+	Good	When applied in warm conditions does not penetrate and can obscure surface detail; toxic.		Johnson 1994

APPENDIX B: Common Consolidants Used On Archaeological Bone

Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
	Poly(vinyl) acetate resins Acrylic resins	10% solution with ethyl alcohol or acetone recommended Acryloid B72, Paraloid B72	Pre1984		Cannot be used on damp bone – traps moisture; high rate of water permeability and absorption – the action of soluble salts and anisotropic stress are both exacerbated		Koob 1984
				Good	Cold flow in uncontrolled temperature environments resulting in misalignment and preventing accurate measurements	Dries clear, nontoxic, available in several grades	Storch 2003
					Soft in warm temperatures; collects dirt on surface		Cronyn 1990
			1981+	Good	May cause damage if applied to even slightly damp artifacts		Johnson 1994
	polyvinylede ne chloride			Storage RH must be stable		Can be used on damp material	Cronyn 1990
	Acrylic resins	Acryloid B72, Paraloid B72		Good		Soluble in many organic solvents	Cronyn 1990
		5% weight/vol. solution in		Good if used as a resin, not an emulsion		Colorless, durable, stable, all-purpose resin	Sease 1994

APPENDIX B: Common Consolidants Used On Archaeological Bone

Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
		acetone for consolidation; 1:1 for mending		Good, up to 100 years; no yellowing or crosslinking		"Most stable synthetic polymer available" (2); soluble in acetone, little cold flow	Storch 2003
	Epoxy resins			May yellow over time	Nonreversible	Good penetration	Cronyn 1990
Colloid dispersions	General			Chemicals used to set the colloid decay quickly	Small particle size; good penetration		Cronyn 1990
	Poly(vinyl) acetate emulsions	Elmer's glue, Elmer's wood glue, Elvace, Jade, Mowilth DM427		Poor once set	Poor solubility; future treatment is often impossible. Not recommended		Elder et al 1997
			1950+	Poor – rarely reversible	Often become insoluble over time due to crosslinking of polymers and are not removable or reversible without significant to complete surface damage.		Johnson 1994

APPENDIX B: Common Consolidants Used On Archaeological Bone

Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
	Poly(vinyl) acetate emulsions Acrylic emulsions	Rhoplex AC-33, WS-24, B-60A, Lascaux	1934+; current in 1984		May require vacuum impregnation; low glass transition temperature; large particle size, low pH, poor water-resistance; high percentage emulsifiers and plasticizers	Can be used on damp or wet bone; bones can be cleaned during consolidation	Koob 1984
					If of poor quality may give off destructive organic acids; soft when warm; collects dirt		Cronyn 1990
				Medium to good; can be nonreversible			Elder et al 1997
			1967+	Good – provisionally	Minimal, but bone must be immersed in high pH solution during treatment – effects are unknown		Johnson 1994
	Acrylic emulsions Acrylic colloid dispersions	Rhoplex, Acrysol WS-24	Current in 1984			Well suited to archaeological bone: good penetration, strength and water-resistance; small particle size, pH 7.0-9.5	Koob 1984

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Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
				Good	Lacks the tack of emulsions, so may be less suitable to some tasks	Durable, reversible, small particle size is preferable for porous materials such as bone	Sease 1994
				Poor	Nonreversible; removal destroys collagen; prevents some atomic and molecular analysis		Tuross and Fogel 1994
			1984+	Good – provisionally	Minimal due to very small particle size, which penetrates the bone surface, but may not be reversible due to this property.		Johnson 1994
			Current in 1984	two-phase systems in water; polar groups lend stability		Very small particle size; require few emulsifiers or stabilizers; pH of 7-7.5; high molecffcular weight and glass transition temperature	Koob 1984

APPENDIX B: Common Consolidants Used On Archaeological Bone

Type	*Subtype*	*Examples*	*Used*	*Stability*	*Potential Damage*	*Advantages*	*Reference*
					Not reversible	Useful for damp bone	Storch 2003
				Chemicals used to set the colloid decay quickly	Tend to collect dirt due to a soft outer surface	Small particle size; good penetration	Cronyn 1990
	Polystyrene					Used to coat bone removed from calcareous matrix	Sease 1994
Monomers (then polymerized by □ -ray irradiation)	General				Best penetration	Polymerization process may damage artifacts	Cronyn 1990
	Vinyl acetate		Pre1984		Requires vacuum impregnation; subject to the same problems as polyvinyl acetate		Koob 1984
	Methyl mathacrylate		Pre1984		Requires vacuum impregnation; subject to the same problems as polymethyl		Koob 1984