Consolidation of Archaeological Bone: A Conservation Perspective

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Various organic polymers have been used in the field for preserving the morphological structure of bone. Archaeologists and conservators have separately devised techniques and materials using these polymers to give structural support to deteriorating, fragile bone. Historical examination of the methods and materials used by archaeologists helps to identify materials found on collections stored in museums that may be needed for analysis, identifies types of materials used successfully in the past, and points out differences in the approaches of conservation and archaeology towards the preservation of archaeological materials. The decision to apply a polymer to bone should be carefully considered, based on an understanding of the physical and chemical interactions between the bone and consolidation system, and the effects one's choice may have on long-term preservation and future research needs.

Introduction

Archaeological bone has often been preserved in the field and laboratory by using organic polymers. These materials are generally called consolidants or preservatives. Polymers are very long molecules made up of hundreds to millions of groups of smaller molecules called monomers (Crafts Council 1983: 25–44). Application of an organic polymer works to preserve deteriorated bone by consolidating the morphological structure within a network of polymer molecules. Consolidation can add structural strength to fragile, deteriorated material (FIG. 1). It may also have profound physical and chemical effects, some of which may be unknown, as many aspects of consolidation have never been critically examined. Understanding the physical and chemical interactions between the bone, the environment, and the consolidation system, including their effects on future preservation and research, is the most effective method of preserving bone for current and future research interests.

This paper presents a history of polymer use in archaeological research and evaluates the issue of bone preservation from the contrasting perspectives of American archaeologists and conservators. It also discusses consolidant materials that are being used now and recommends several consolidants, while pointing out some problems with the use of each. Included is a brief summary of some analytical techniques that may be made more difficult, or impossible, through the use of consolidants.

Understanding the theory (Allen 1984) and techniques of consolidation, the effects of organic consolidants on analytical techniques, and the basic premises of archaeological methodology and how bones are used in archaeological research, are all necessary for an informed decision on whether or not to apply an organic polymer to preserve bone. Identifying the concerns of archaeology, conservation, and archaeometry should also assist in the collection and maintenance of excavated bone for present and future research. The intent of this article is to make information that is well known in conservation more available to archaeologists, and to point out gaps in the knowledge of both fields.

This paper is not intended to be a how-to manual for the treatment of bone, though the best available alternatives are noted. There are several new manuals written by conservators that the archaeologist can refer to for field conservation techniques (Cronyn 1990; Cross, Hett, and Bertulli 1989; Pearson 1988; Sease 1992; Watkinson 1981). This summary is intended to be an examination of the history of bone preservation and an identification of some of the trade-offs conservation decisions involve as well as a call for much more research into the materials and techniques used for the preservation of archaeological materials. Some of what might be termed "post-excavation formation processes" may have as much influence on the data that can be obtained from archaeological materials as the pre- and post-depositional processes (Schiffer 1987: 359–361). To date, there has been little critical examination of this aspect of recovery.

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Figure 1. An organic polymer being applied in the field to consolidate fragile bone. (Photo taken at the Cattle Guard site in Colorado.)

Archaeology and Conservation

While there have always been contacts between archaeology and conservation (and some of these interactions are noted below with respect to bone preservation), there are few long-term relationships between archaeology and professional conservation in the United States. This is especially apparent when the history of anthropological archaeology is examined separately from that of classical archaeology (Johnson 1990). Archaeologists in the United States have developed their own techniques and materials for preservation of excavated remains in the field and laboratory, with little long-term interaction with formally-trained archaeological conservators. In contrast, conservators have long been a part of excavation crews in other parts of the world (e.g., in England and around the Mediterranean) as well as working in museums.

Preservation of Bone in the Field

Field treatment of newly excavated remains requires using materials and techniques in often difficult and sometimes uncontrolled environmental conditions. Factors in the field environment that can affect the successful recovery of bone include: 1) condition of the bone upon removal of the overlying soil, which in turn depends upon the taphonomic processes that have already acted on the bone; 2) soil environment, including pH, amount of moisture, and presence of soluble and insoluble salts; 3) the size of the bone (relative ease or difficulty of lifting); 4) the amount of time required for the bone to remain in situ for maximum visibility (e.g., for purposes of recording through photography, mapping, and drawing), which could range from a few hours to a few days; and 5) the external environment, including temperature and relative humidity.

Three other factors that should be considered in developing a recovery technique are: 1) the purpose for which the bone will be used (e.g., biometric analysis, chemical and physical analyses, exhibit); 2) the place where the specimen(s) will ultimately be housed (with or without environmental controls); and 3) cost of recovery (in both materials and manpower).

All of the above factors must be evaluated when choosing a method for preservation. Every conservation decision requires a compromise between ideals and practicalities. Where archaeologists and conservators have differed most when evaluating techniques, however, is in their approach to choosing the type of polymer to add physical strength to the object.

Generally, archaeologists have focused on the working properties of the preservatives they have chosen, selecting materials that are easy to apply and that do the job in a particular setting, generally depending on trial and error. In many cases, they also have settled on a material that is readily available (like Elmer's Glue-all, a poly[vinyl] acetate/poly[vinyl] alcohol emulsion). This allows for the recovery of the morphological structure of the specimens with preservation sufficient for collection and research. The effects of treatments on long-term preservation of collections that may be the subjects of future research are often overlooked, however.

Conservators generally choose a consolidant from a small group of polymers that are known or expected to have good long-term aging properties (Horie 1987: 6–8). Chemical and physical stability are considered important, as damage can be caused by changes such as polymer shrinkage or acidic by-products of deterioration. Long-term reversibility of the consolidant is also an ideal; however, this may be a moot point and is discussed in more detail below. Knowing the chemical and physical properties of various polymers allows one to consider the advantages and disadvantages of each before using a consolidant on bones or other artifacts. Other characteristics that conservators consider when choosing a consolidant are viscosity, particle size, solvent system, glass transition temperature (Tg), pH, and toxicity (Koob 1984)—all of which affect the working properties (see the glossary for definitions of these and other technical terms). Taking all these factors into account, a conservator selects a particular polymer for a specific project.

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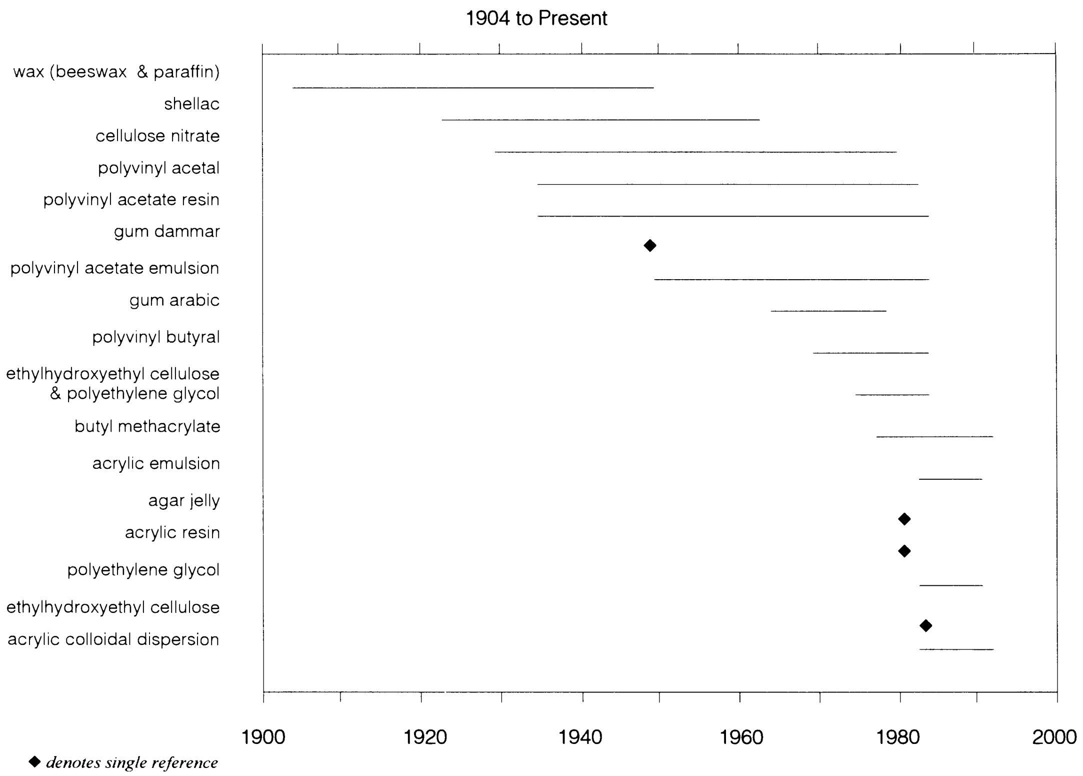

Figure 2. Bone preservatives described and recommended in the archaeological literature, 1904 to the present. This timeline reflects only published use by archaeologists; many of these preservatives probably were in actual use for longer periods.

Polymers Used for Consolidation of Bone

A search of the archaeological literature was conducted to compile a list of references on techniques of bone preservation (the materials employed are generally termed "preservatives" in the archaeological literature). The major source for these references was a bibliography compiled for the Smithsonian Institutions's Conservation Analytical Laboratory (Garbin 1983). These references were used to develop a timeline illustrating the use of preservative materials and to show how different materials became popular through time (FIG. 2). Different brands were recommended in different references; Figure 2 lumps different brands under their chemical name. It is assumed that publication reflects, at least to some extent, the general use of these materials. Of course, this timeline reflects only published use by archaeologists; many of these preservatives probably were in actual use for longer periods.

Considering the wide range of polymers available, relatively few materials have been employed, with new preservatives (or simply new brands) typically replacing previously popular ones. This is true except in the case of two easily available and often-used materials: cellulose nitrate resins (Duco Cement is popular now) and emulsions like Elmer's Glue-all. These two materials and especially these particular brands both have significant problems with respect to stability but have been employed by many archaeologists for a long time, and continue to be used, because they are so easy to acquire.

Knowing when particular consolidants were popular for archaeological purposes may help in identifying consolidants used on materials found in collections when one is considering them for analysis. This type of search, however, does not identify less common materials that may have been used when no plans had been made for the preservation of bone. The oral history of bone preservation includes stories about the use of materials such as plastic tent windows dissolved in acetone and acrylic floor finish, techniques not often described in published accounts.

The basic chemical types and manufacturers were identified for popular brands of polymers used by archaeologists and are listed in Table 1. Many archaeological references list a material only by its brand name, for example

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Table 1. Some products used by archaeologists for bone consolidation, their manufacturer and chemical name (specific type listed in parentheses when known).

Brand name	*Manufacturer*	*Chemical name*
Acryloid B-72	Rohm and Haas Co.	Methylmethacrylate/ethylacrylate resin
Acrysol WS-24	Rohm and Haas Co.	Acrylic colloidal dispersion
Ambroid	Ambroid Company	Cellulose nitrate resin
Alvar	Shawinigan Products Corp.	Poly(vinyl) acetal resin
AYAA, AYAF	Union Carbide	Poly(vinyl) acetate resin
Butvar	Shawinigan Ltd. and Monsanto	Poly(vinyl) butyral resin
Celluloid	–	Cellulose nitrate resin
Duco Cement	DuPont Co. and Devcon Corp.	Cellulose nitrate resin
Elmer's Carpenter's Glue	Borden	Poly(vinyl) acetate emulsion
Elmer's Glue-All	Borden	Poly(vinyl) acetate/poly(vinyl) alcohol emulsion
Gelva	Monsanto	Poly(vinyl) acetate resin or emulsion
Modocoll	–	Ethylhydroxyethyl cellulose and polyethylene glycol
Rhoplex (AC-33)	Rohm and Haas Co.	Acrylic emulsion
Vinamul (6815)	Vinyl Products	Poly(vinyl) acetate emulsion
Vinylite (A)	Carbide and Carbon Chemical Corp.	Poly(vinyl) acetate resin

"Ambroid," without describing its chemical makeup. Names such as Alvar or Duco, specify proprietary brands of consolidant of a more specific chemical type. Duco Cement is one brand of cellulose nitrate resin; Ambroid is another. Each brand has specific properties and additives that make it different from the others. Knowing the working properties and long-term aging properties of one brand cannot be used to predict these properties in another brand. Conservators often mix their own adhesives and consolidants so that all the ingredients and their properties are known.

The major materials used by archaeologists for preservation of bone include the following: natural resins, cellulose nitrate, poly(vinyl) acetal resins, poly(vinyl) butyral resin, poly(vinyl) acetate resins, poly(vinyl) acetate emulsions, acrylic emulsions, acrylic colloidal dispersions, and acrylic resins. Some advantages and disadvantages of each material are discussed below.

A brief explanation of the types of consolidants is included here, in order to make the following discussion of the history of polymer use easier to follow. Most polymers used for consolidation of archaeological bone are applied in a liquid carrier that subsequently evaporates, leaving a network of polymer molecules supporting the fragile bone. Three basic types of consolidants are used. They can be defined as resins in solution, emulsions, and colloidal dispersions. Resins are basically plastics dissolved in a solvent, for example, celluloid in acetone, or poly(vinyl) acetate in ethanol. The solvent molecules and the resin (a solid polymer) molecule are completely mixed together. Emulsions and dispersions have spherical particles of high molecular-weight polymers dispersed in water. The particle size in emulsions is approximately 0.1–1 micron. Emulsions usually contain additives such as emulsifiers, stabilizers, and plasticizers which help to keep the polymer molecules from settling. Colloidal dispersions have a much smaller particle size (0.03 microns) as well as chemical characteristics that result in some molecular solubility. They can be considered hybrids between solutions and emulsions (Koob 1980). A more complete discussion of the effects that properties of different polymer formulations have on consolidation can be found elsewhere (Horie 1987; Koob 1980, 1981, 1984; Rosenquist 1961).

Below is a brief discussion of the advantages and disadvantages of the materials that have been commonly used to consolidate bone. Much more information on all these materials can be found through a review of literature in conservation, paleontology, and the polymer industry.

Materials Used to Preserve the Morphology of Bone

Natural Resins

There has been a gradual change in the types of consolidants that archaeologists have used (FIG. 2). Early archaeologists such as Flinders Petrie (1904) commonly used wax, and this material was also recommended by the British Museum (1929). Other natural consolidants such as gum dammar, gelatin, agar jelly, or glue solutions like isinglass and animal glue were certainly also employed (Rathgen 1905). Individual references to the use of these materials can be found in the archaeological literature (Hrdlička 1923; Woolley 1949; Cummings 1953). Shellac was commonly used as late as 1963 (Keel 1963: 15). Most of these natural materials will only poorly penetrate the bone structure and also obscure surface detail. In addition,

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some of these natural polymers can shrink quite dramatically with age, pulling away the surface of the bone (FIG. 3).

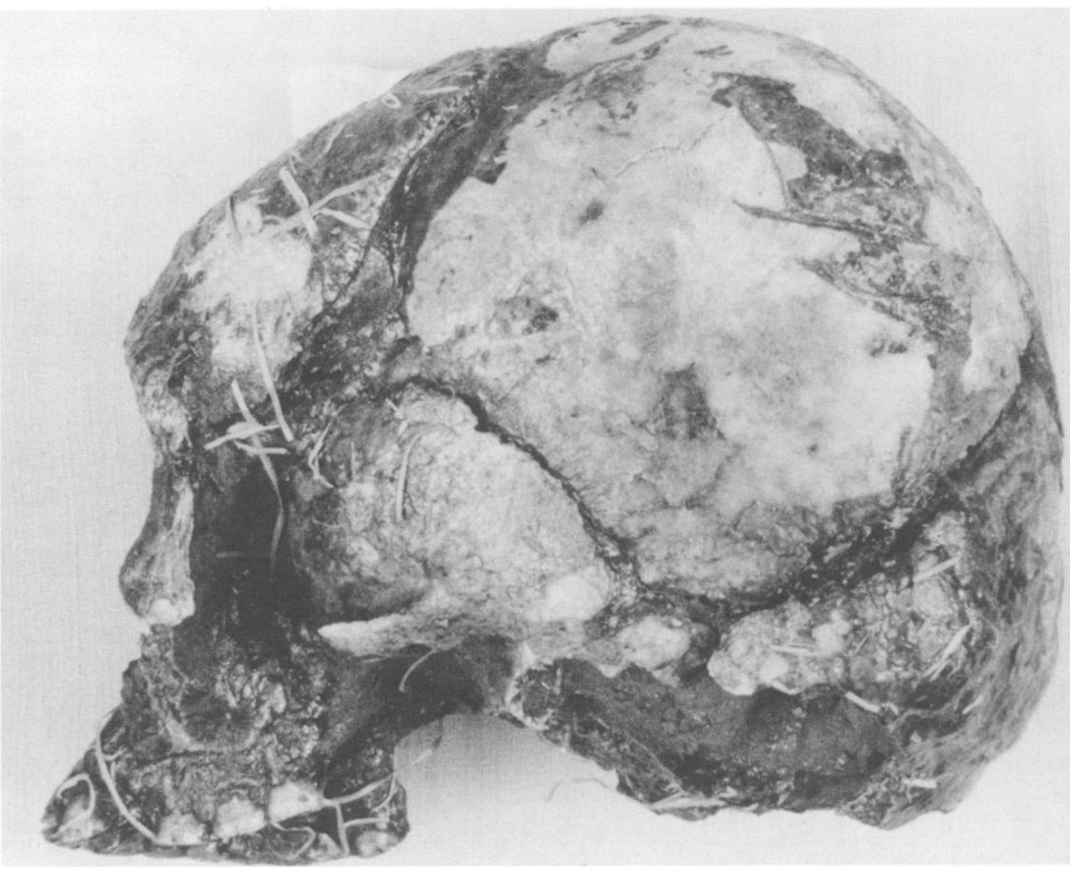
Cellulose Nitrate Resins

One example of a common consolidant is cellulose nitrate resin. Leechman (1931), in his classic publication, "Technical Methods in the Preservation of Anthropological Museum Specimens," states that the preparation of celluloid in acetone "was first brought to the attention of the museum world by Mr. A. Lucas," a chemist in the Egyptian Department of Antiquities in 1924 (Leechman 1931: 131). Solid celluloid is a cellulose nitrate resin plasticized with camphor and was recommended by the British Museum by 1929. Ambroid, a cellulose nitrate resin supplied in solution accompanied by a thinner of alcohol and chloroform, was commonly used from at least 1939 (Byers 1939; Emil Haury, personal communication, 1991). More recently, Duco Cement has become ubiquitous for use as an adhesive for bone and ceramics (Keel 1963: 11), and has also been suggested as a bone consolidant when diluted with acetone (Gehlert 1980: 8).

The instability of cellulose nitrate adhesives was recognized in archaeology as early as 1936. Woodbury (1936: 449) noted that celluloid compounds "become brittle and flake away." Problems with instability were also noted by industry soon after the development of cellulose nitrate, and for most uses it has been replaced by other, more stable synthetics. Because of its easy availability and workability, and its familiarity, cellulose nitrate (especially Duco Cement) continues to be commonly used as an adhesive; and these characteristics probably also recommend it for continued use as a consolidant by archaeologists, when other materials are not available.

Breakdown of the polymer results in brittleness and shrinkage, as well as severe yellowing (Koob 1982; Selwitz 1988). Damage caused by the adhesive breakdown can be seen on many museum specimens, where the ad-

Figure 3. Shrinkage of aged polymers can pull apart the structure of bone. The bone surface in the center of the photo has been pulled away by the dark adhesive (probably shellac). (Photo taken in the Physical Anthropology Collections, National Museum of Natural History, Washington, D.C.)



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hesive has pulled the paste of a ceramic away on the edges where it was applied.

Poly(vinyl) Acetal, and Poly(vinyl) Butyral Resins

Poly(vinyl) acetal resin (Alvar) was introduced to archaeology by George Woodbury in 1936. This material was recommended to him by Rutherford Gettens, at that time a conservator at the Fogg Art Museum at Harvard. (Gettens was one of the first professional, scientifically trained conservators in the United States.) Woodbury conducted some unpublished experiments with Alvar solutions and developed a technique of immersing specimens in a 20% solution in acetone after a preliminary saturation with acetone. He noted that the long-term stability of Alvar and other vinyl acetate polymers was unknown. Alvar was available until the late 1960s, at which time it was replaced by the poly(vinyl) butyral product known as Butvar (Horie 1987: 102). Butvar is commonly used in archaeology and paleontology today and appears to have good aging characteristics (it is the adhesive used in safety glass), though no testing has been reported. One should note that the initials PVA have been used to refer to several different materials: poly(vinyl) acetal (Alvar), poly(vinyl) acetate, and poly(vinyl) alcohol. To avoid confusion, the entire chemical name should be written out when describing these materials for reports and publications.

Poly(vinyl) Acetate Resins

In the same article recommending Alvar, Woodbury (1936) noted that he had tested the poly(vinyl) acetate resin Vinylite A, but did not feel it was as useful as poly(vinyl) acetal. Poly(vinyl) acetate resins have been employed by archaeologists (Keel 1963: 17; Walker 1978; Sanford 1975), and recommendations for their use can often be traced to a conservator (Dowman 1970: 65; Storch 1983). They are generally used in solutions of acetone or ethanol.

Poly(vinyl) acetate resins are commonly used in the conservation field, and have been tested and found to have good long-term stability (Feller 1978). Resins AYAA and AYAF, commonly used for consolidation, are made by Union Carbide; the letters denote polymers with different molecular weights. The molecular weight of a polymer affects solubility, hardness, strength, and glass transition temperature (see glossary). These resins can become soft and sticky in warm temperatures. Rapid evaporation of the solvent in a field situation may prevent good penetration. In addition, concerns with the toxicity of long-term use of solvents are becoming important to individuals who have used solvent-based preparations for years.

Poly(vinyl) Acetate Emulsions

The most common poly(vinyl) acetate emulsion used recently by archaeologists is probably Elmer's Carpenter's Glue (George Frison, personal communication, 1991). Elmer's Glue-All is also commonly employed; it is a poly(vinyl) acetate/poly(vinyl) alcohol copolymer emulsion. These emulsions are also known as white glues. They were first introduced to archaeology in about 1950 by paleontologists who had used them successfully in the treatment of fossil bone (Toombs and Rixon 1950: 141). These water-based emulsions were considered especially useful for field consolidation of damp or waterlogged material (Kenyon 1953: 150).

Several references appear to recommend poly(vinyl) acetate emulsions without understanding their solubility properties (Fladmark 1978: section M; Ubelaker 1978: 36; Wing 1983: 11). Emulsions are not polymers dissolved in water, but are finely dispersed particles suspended in water with additives to give good working properties (Crafts Council 1983: 51–52). After they set completely, they are no longer dissolvable in water, but will dissolve in an organic solvent, just like poly(vinyl) acetate resins (Feller 1966: 27). Poly(vinyl) acetate/poly(vinyl) alcohol copolymers, however, maintain some water solubility, at least for a time, due to the poly(vinyl) alcohol component.

Many of these emulsions may become insoluble due to crosslinking (see glossary) of the polymer. Additives such as copolymers, emulsifiers, and stabilizers, used to give the material better application properties, may catalyze the crosslinking (Horie 1975). Any insoluble polymer that has penetrated into the pores of the bone is probably not removable, if at all, without complete destruction of morphology. Briefly, other problems with poly(vinyl) acetate emulsions include: large particle size, acid pH (3.0–6.0), high viscosity, low glass transition temperature, and high moisture absorption properties (Koob 1981). All of these can cause problems with respect to application or long-term effectiveness for consolidation.

Acrylic Emulsions

Acrylic emulsions were first recommended to archaeology by Gayle Wever (1967: 3), a conservator at the University Museum in Philadelphia, who used a material called Bedacryl 277 on damp material from a site in Alaska. Most recently, an acrylic emulsion (Rhoplex AC-33) was chosen by archaeologists, using practical tests, over polyethylene glycol (PEG) on the waterlogged Win-

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dover site in Florida (Stone, Dickel, and Doran 1990). Preliminary testing indicated that Rhoplex AC-33 was stable over time (Feller 1963), though little additional testing has been done. The pH of acrylic emulsions ranges from 7 to 9.6. The effects of soaking in the higher pH emulsions are not known, but have been considered to be minimal if the bone is not left in solution for a long time (Stone, Dickel, and Doran 1990: 183). This is an assumption that needs careful testing.

Acrylic Colloidal Dispersions

Recently, Stephen Koob has suggested the use of acrylic colloidal dispersions for the consolidation of archaeological bone in the field (1984). These materials are water-based and have a very small particle size, about 0.03 microns, which should allow for better penetration into fragile bone (Koob 1981). The pH of colloidal dispersions is closer to neutral than the larger particle acrylic emulsions such as Rhoplex AC-33. Most workers have settled on Acrysol WS-24 as an effective brand for field consolidation of bone.

The British Museum has conducted limited accelerated-aging tests (see glossary) on Primal WS-24, the Rohm and Haas UK equivalent of the American brand, Acrysol WS-24 (Shashoua 1989). Its tests showed that after accelerated aging using light and heat, thin films of Primal WS-24 remained about 90% soluble in acetone. Before aging, the Primal WS-24 was about 94% soluble. The pH of this material was about 7.5 before and after testing. Results of tests showing reversibility of thin films of resin may not be applicable to the removability of a polymer from porous materials such as bone, however. This problem will be discussed in more detail below.

Acrysol WS-24 has begun to be used as an on-site preservative among North American archaeologists working on Paleoindian bison kill sites, based on the recommendation of conservators (Dennis Stanford, personal communication, 1991). Acrysol WS-24 is popular because it is a water-based material and does not have the toxicity of organic solvent-based consolidants. It is effective in consolidating slightly damp to dry material and dries quickly in field situations. The consolidant is effective in preventing cracking and spalling during excavation, transport, and storage, so that artifacts can be used for biometric analysis.

Acrylic Resins

Acryloid B-72 (in Britain, Paraloid B-72), a methyl methacrylate/ethyl acrylate copolymer, has found some use in archaeology, mostly by the British (Brothwell 1981: 10), who have probably become acquainted with this product through interaction with conservators. It was originally used in conservation as a varnish for paintings. It is usually dissolved in toluene or acetone for use. In conservation, this material is widely used as a consolidant, adhesive, and coating material because it is one of the most stable polymers available (Koob 1986). Acryloid B-72 is probably considered the best choice for bone consolidation by conservators if moisture in the excavated material is not a problem.[1]

Other Materials

Two other materials, epoxies and cyanoacrylate resins (super glues), have not been discussed because they have not yet been published as preservation techniques in archaeology. Little or no testing has been done on their stability or their effectiveness over time. It is known that some epoxies discolor and cannot be removed with solvents (Snow and Weisser 1984: 142). Cyanoacrylate resins can be difficult to remove, may stain, and have unknown aging characteristics (Horie 1984: 94). Polyethylene glycol waxes have been used on waterlogged sites and are commonly used for wood. Stone, Dickel, and Doran (1990) found in practical tests that an acrylic emulsion worked more effectively to consolidate waterlogged bone.

Most of the consolidant materials discussed above can be traced back to developments in conservation and subsequent recommendation to field archaeologists. In many cases, however, materials recommended by conservators have not fallen out of favor as quickly among archaeologists as among the former, because they remain effective in the short term as a preservative; emulsions like Elmer's being the most obvious example. Table 2 shows which of the consolidants discussed above are used by conservators, as well as giving field conditions where the more stable consolidants have been used successfully.

For more specific information on application techniques and materials, see the manuals cited and Koob (1984) for acrylic colloidal dispersions; Stone, Dickel, and Doran (1990) for acrylic emulsions; Storch (1983) for poly(vinyl) acetate resins; and Sease (1992) for Acryloid B-72. Table 3 lists working strengths and solvents that have been used successfully with these polymers. Individual conservators and archaeologists have different preferences in their choices of consolidant materials. The information contained here represents the personal experience

1. Poly(vinyl) acetate resin (AYAA and AYAF) (solid pellets), Rhoplex AC-33 (liquid), Acrysol WS-24 (liquid), and Acryloid B-72 can be obtained from Conservation Materials Ltd., 240 Freeport Blvd., P.O. Box 2884, Sparks, NV 89432.

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Table 2. Polymers currently used by conservators for the consolidation of bone (compiled from Sease 1992; Koob 1980; Storch 1983; and personal communication with numerous individuals).

Polymer name	*Used by conservators?*	*Field conditions*	*Problems*
Natural resins	No	Not used	Poor penetration, poor consolidation
Cellulose nitrate resins	No	Not used	Not stable
Poly(vinyl) acetal resins	No	Not used	No longer available
Poly(vinyl) butyral resin	Yes	Dry, solvents available	Mostly used in paleontology, no testing on long-term stability, solvent toxicity
Poly(vinyl) acetate resins	Yes	Dry, solvents available	Need proper molecular wt., can soften in heat, solvent toxicity
Poly(vinyl) acetate emulsions	No	Not used	Often unstable
Acrylic emulsions (Rhoplex AC-33)	Yes	Wet, damp	Questions about long-term stability and effects of high pH
Acrylic colloidal dispersion (Acrysol WS-24)	Yes	Wet, damp	Questions about long-term stability
Acrylic resin (Acryloid B-72)	Yes	Dry, solvents available	Solvent toxicity, may soften in high temperatures
Epoxies	No	Not used	Staining, not reversible
Cyanoacrylate resins	No	Not used	May stain, not stable

of the author. It must also be repeated that many of the polymers (except for some poly(vinyl) acetate resins and Acryloid B-72) have not been subjected to rigorous testing protocols and may prove to be less stable than expected.

The oral history of field conservation of bone includes many stories of preservation gone wrong. Sometimes the wrong technique was used, other times soil conditions caused an unexpected reaction, or companies had supplied the wrong grade of polymer that had different and unexpected properties. Variables like soil pH, level of water soluble and insoluble salts, temperature, and humidity, as well as the experience of the excavators may affect the usefulness and effectiveness of a particular polymer formulation, even if it looks good in theory. Practical testing in the laboratory and field is needed to evaluate the parameters for successful use of various polymer formulations.

The Effects of Organic Polymers on Analytical Techniques

In general, archaeologists have not been concerned about the long-term stability of the preservatives they use and the effects of polymer deterioration on bone. In contrast, considerations of reversibility and stability are major concerns in conservation (Applebaum 1987). As the focus in North American archaeology shifts increasingly toward the use of museum collections, however, these older collections are becoming more important (Ford 1977). The historical information presented here (e.g., in FIG. 2) can be used as a database when attempting to identify undocumented materials used on artifacts now housed in museum collections.

As mentioned above, it is likely to be impossible to remove a consolidant from bone without destruction of the morphology. Horie (1982) conducted an experiment showing that about 50% of a polymethyl methacrylate resin remained in glazed earthenware after eight hours in a Soxhlet extractor (which continually introduces clean solvent into the system), though this resin was considered 100% reversible. Hatchfield and Koestler (1987) showed, with SEM examination, that wax consolidation could not be completely removed from wood. Similar experiments with bone could provide similar results. Any consolidation treatment should be carefully examined and research questions and future use of the material carefully evaluated. Also, use of any consolidant should be carefully documented.

There are increasing concerns about how the addition of a polymer might affect future analysis. In addition to the better known difficulties of radiocarbon dating consolidated material, some analytical techniques that could be affected by consolidation include: stable isotope analysis, trace element analysis, scanning electron microscope surface analysis, DNA retrieval, and measurement of specific gravity, among others. Additionally, there is evidence that acrylics and poly(vinyl) acetate polymers may invalidate many biochemical laboratory analyses (Noreen Tuross, personal communication, 1991). At the least, removal of the preservative/consolidant can increase costs of the analysis.

Below are several different types of analyses that would be affected by consolidation.

Radiocarbon Dating

Addition of carbon to a sample through preservation would falsify any date obtained through radiocarbon dat-

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Table 3. Working strength and solvents used with bone consolidants currently in common use by archaeological conservators.

Working strength	*Solvent*
Acryloid B-72	3–10% in acetone or toluene
Poly(vinyl) acetate resin (Union Carbide AYAA or AYAF)	3–10% in acetone or ethanol
Acrysol WS-24	Diluted to 2–10% with water (distilled water best)
Rhoplex AC-33	Diluted to 2–15% with water (distilled water best)

ing. Petroleum based materials such as paraffin wax would give a date much too old, while natural and synthetic resins would do the reverse. Some polymers can be removed through solvent treatment (Protsch 1986: 5), but some polymers become very insoluble and cannot be removed that way. Consolidants can penetrate quite deeply into the structure of the bone and will not be eliminated by simple physical removal of the periosteal surface. Therefore, as a general rule, consolidants should not be applied to bone that may be used for radiocarbon dating (Salvatore Valastro, personal communication, 1992).

Isotope Analysis

Moore, Murray, and Schoeninger (1989) have shown that one common consolidant, Alvar, appears to have no effect on determination of stable isotope ratio (C and N) when a bone powder preparation of collagen is used. This technique, however, is not used on poorly preserved bone, the bone most likely to be treated with consolidants in the field. Other consolidants that are insoluble, or become insoluble over time, will also have an effect on these analyses.

Scanning Electron Microscopy

Scanning electron microscopy has been used to identify butchering and tooth marks on the surface of archaeological bone. Some researchers have had success with SEM surface analysis when using consolidated bone, by simply dissolving the consolidant at the surface through the application of solvent with a brush (Potts and Shipman 1981). As polymers age, however, some such as poly(vinyl) acetate emulsions or epoxies become insoluble. Any surface coating of a preservative could obscure minute surface features that the researcher is looking for (FIG. 4). If the polymer has become insoluble, this sort of analysis could become impossible.

Some recent articles on bone consolidation recommend that at least a sample of bone be left unconsolidated for later analysis (Koob 1981; Ubelaker 1978; Moore, Murray, and Schoeninger 1989). Other authors appear to assume that the materials they are recommending are completely reversible (Stone, Dickel, and Doran 1990; Wing 1983). Many archaeologists do not consolidate a sample of material, choosing to separate bone that is not useful for biometric analysis, either because there is little identifiable morphology left or it is an element such as a rib bone that is not identifiable at least to subfamily. Rapid advances in chemical analyses make it impossible to predict which skeletal elements will be of interest in the future (Moore, Murray, and Schoeninger 1989: 444). Careful consideration of the effects of consolidants on these and unknown future analytical questions must be considered when making the choice of whether or not to apply a preservative.

Conclusion

This discussion has attempted to show how complicated the decision to consolidate or preserve fragile archaeological bone in the field can be. By understanding the problems caused by polymers used in the past, a more informed decision can be made when choosing a new consolidant. The decision to consolidate bone should be based on an understanding of the properties of the organic polymer, the possible chemical and physical reactions between bone and the consolidation system, effects of the field and storage environment on success of the treatment, long-term effects of the consolidation on the physical stability of the artifact, and possible research interests in the future. At this point, many of these factors are unknown and there is a need for critical evaluation beyond simple visual examination.

Archaeological concerns with preservation often focus on issues of transport and handling for morphological analysis. It may be more appropriate to consider modified data-recovery techniques that allow for excavation, transport, analysis, and storage instead of application of polymers that will have unforseen consequences on the research importance of excavated collections. These issues may be better served through non-chemical alternatives for preservation. In many cases, there are other possibilities for the safe structural removal of bone, including block lifting, plaster bandaging, and controlled drying (Sease 1992; Cronyn 1990). Use of these techniques can allow

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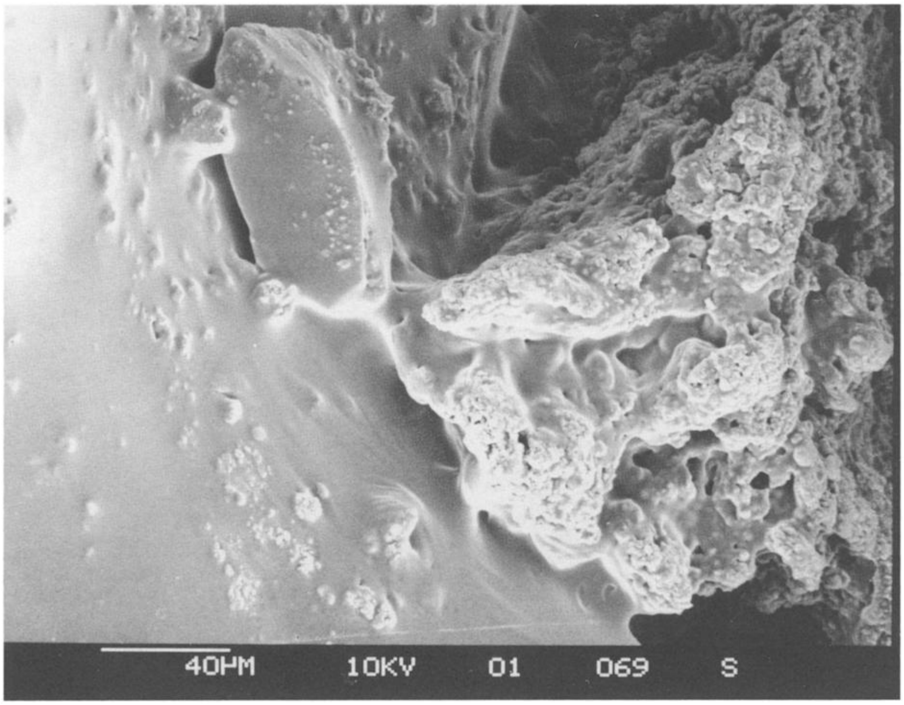

Figure 4. Application of a polymer can obscure surface features on bone when it is viewed at high magnification with a scanning electron microscope. This bone has been consolidated with 5% Acryloid B-72 in acetone. The polymer film covers up and smooths over surface features such as butchery marks.

the bone to be more carefully excavated in the more controlled conditions of the laboratory—controlled in terms of time available; outside humidity and temperature; and slower, more even drying. Testing, experience, and a knowledge of consolidation materials, site conditions, etc., will best determine the approach that should be taken at a specific excavation. As a rule, bone preservation techniques used during excavation should focus more on long-term preservation instead of short-term concerns.

Archaeologists have a responsibility to collect and record information about the consolidants they use, and also to document use on individual specimens as well as entire collections, so that future researchers will be able to choose appropriate material for analysis. This information should appear in the site report, daily logs, and other records, and should include consolidant name, chemical name, manufacturer, package number, and date purchased, as well as application technique and solvent.

Conservators recommending materials to archaeologists have a responsibility to make sure that the latter have technical information about the polymers that they recommend. This should be effected through individual interaction as well as publication in archaeological journals and attendance at archaeological conferences to reach the maximum audience. Conservators must also have a realistic understanding of what techniques can actually be applied effectively and economically by archaeologists working in the field.

Preservation of archaeological resources is a priority. While much attention has been focused on preservation of sites and general collections care, many conservation procedures used on artifacts by both archaeologists and conservators (consolidation of bone, acid-washing of sherds, reconstruction of ceramic vessels) have not been critically examined. Historical interaction between archaeologists and conservators has been stressed in this paper, not to imply that conservators have all the answers, but to illustrate that previous cooperation has been useful. This summary has attempted to examine one procedure, preservation of bone, and to point out some of the problems with the materials now in use. Collaboration in the field and laboratory, using the resources of both conservation and archaeology, is necessary to investigate the effectiveness of these materials as well as find other, perhaps better alternatives. It is easy for contention to develop between various professional groups working with a limited resource such as archaeological bone. Attempting to understand the interests and concerns of other groups will

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allow for better preservation of the data for current and future research interests.

Glossary

accelerated aging: a procedure in which polymers (and other materials) are subjected to more extreme conditions than usually experienced in order to raise the energy of the system and accelerate deterioration reactions.

crosslinking: the joining of polymer molecules by chemical bonds; this can occur during setting or as a product of deterioration processes.

emulsifier: (emulsifying agent), small quantities of various materials added to emulsions to help stabilize the product.

glass transition temperature (Tg): the temperature region where polymers change from a rubbery to a brittle state.

pH: a measure of the hydrogen ion concentration per cu decimeter of solution, used as a measure of acidity or alkalinity.

plasticizer: a liquid or solid added to resin to modify flow properties and prevent brittleness of the dried film.

polymer: the product of polymerization where monomers (small molecules) are joined together to produce a much longer molecule.

resin: synthetic plastic materials produced by polymerization as well as natural amorphous organic compounds secreted by some plants and insects.

solvent: a substance, usually liquid, that can dissolve other substances.

stability: for polymers, the property of not changing in physical or chemical state over time, not readily decomposed.

stabilizer: added to consolidant formulations to prevent chemical decomposition.

viscosity: the property of a fluid that enables it to resist flowing.

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