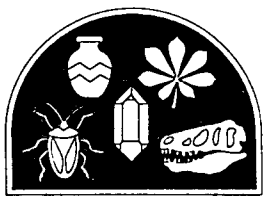
# Collection Forum



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# PLAGUE AT THE MUSEUM: DISEASE TRANSMISSION POTENTIAL AND BIOSAFETY PRECAUTIONS

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*Abstract.*—A case study involving the discovery of plague-killed woodrats (*Neotoma cinerea*) is described. Recommendations are made for the safe handling and preparation of animal specimens based on federal biosafety standards.

On February 27, 1989, David Nagorsen, a mammalogist at the Royal British Columbia Museum (RBCM), received an autopsy report from the Animal Health Centre of the British Columbia Ministry of Agriculture. The case of death in two specimens of bushy-tailed woodrat (*Neotoma cinerea*) was the microorganism *Yersinia pestis* which causes plague. The museum was placed in the position of dealing with a complex situation regarding the health and safety of staff and the public. Over the following month the museum reviewed the potential for transmission of plague and other disease to humans and developed a series of recommendations for dealing with potentially infectious specimens.

The purposes of this paper are:

1) To illustrate how this incident was managed to avoid undue alarm to the museum staff or the public.
2) To discuss the likelihood of the presence of pathogenic organisms in fresh or frozen bird and mammal specimens handled at museums.
3) To prescribe standard processing protocols to reduce the potential risk to staff of zoonotic disease transmission.

## THE HISTORY OF PLAGUE IN NORTH AMERICA

Plague in humans was first discovered in North America in San Francisco in 1900 (Olsen, 1981). In 1934, a case of plague in Oregon became the first human case of plague outside California. The disease is now documented from 57 wild rodent species or their ectoparasite vectors in at least 15 western states, Mexico, and the provinces of Alberta and Saskatchewan in Canada (Olsen, 1981).

In 1950, the first occurrence of plague in British Columbia was discovered when a flea removed from a marmot was found to be infected with plague (British Columbia Department of Health and Welfare, 1955). This prompted the start of annual surveys for plague in British Columbia, although in July 1954 the collecting of specimens was discontinued (British Columbia Department of Health and Welfare, 1955). In 1985, the British Columbia Ministry of Health developed a plan for the management of human plague and the Ministry of Environment and Parks began serology surveys of wildlife captured with the assistance of selected trappers in British Columbia. The 1986–87 plague wildlife serology survey in-

dicated that 3 of 163 samples collected from trappers by the British Columbia Ministry of Environment and Parks had titres indicating some past plague infection. It was concluded that British Columbia was well below having a level of plague that would cause concern for the public. No public education or awareness program was conducted and staff of the museum and some health officials remained unaware of the serology survey results. The discovery of *Neotoma cinerea* killed by plague was, therefore, surprising to staff at the RBCM and to the health officials that became involved.

There have been 119 cases of human plague in the United States from 1908 through 1967, 66 of which were fatal (Olsen, 1981). From 1956 to 1983, 231 persons in the United States were reported infected with plague. Zoonotic sources included rabbits, snowshoe hares, bobcat, coyote, domestic cat and Abert's squirrels (Morbidity and Mortality Weekly Report, 1984). Three human plague cases were reported to and confirmed by the U.S. Centers for Disease Control (CDC) in the 1983–84 winter season. All affected individuals were hunters who had recently skinned cottontail rabbits or coyotes and bobcats and had acquired their infection by direct contact with infected tissues (Morbidity and Mortality Weekly Report, 1984).

A literature search revealed no published accounts of plague infection during specimen preparation in museum laboratories. There was, however, a wealth of evidence linking zoonotic disease to workers such as veterinarians, zoo keepers, and game wardens (Hubbert *et al.*, 1975). The possibility of plague infection in the field or the laboratory remains.

## Plague at the Royal British Columbia Museum

Although not informed by Fish and Wildlife officials of the occurrence of plague in British Columbia, the mammalogist found that the pattern of death was consistent with plague outbreaks that occur in rodents in the western United States. He therefore arranged for testing by the British Columbia Ministry of Agriculture and Fisheries Animal Health Centre in Abbotsford, British Columbia prior to specimen processing by RBCM staff. The mammalogist had sent two specimens for autopsy and had kept the remaining 19 specimens in a chest freezer in the preparation laboratory. The diagnosis of plague prompted an immediate assessment of the potential health risks to staff and the public.

With the confirmation of the presence of *Y. pestis,* steps were immediately taken to ensure that the frozen unprepared specimens were not handled by staff for any reason. It was uncertain if freezing would kill *Y. pestis,* although it was believed that the fleas that transmit plague would have been killed by freezing. It was also uncertain if treatment would be needed for the staff who had participated in the field trip. The Government Employees' Health Service physician stated that the frozen specimens did not present a risk while in storage. In addition, it was mentioned by the Government Employees' Health Service physician that provincial health officials would have to be involved immediately to manage the release of information to the community in the area from which the specimens were collected. The physician also recommended that all other mammal collecting by museum and British Columbia Ministry of Environment staff at the collecting location be stopped until the situation had been reviewed.

All specimens collected were completely wrapped and frozen, to be opened only

with the permission of the mammalogist. The following day, the Government Employees' Health Services physician inspected the laboratory facilities and confirmed that no danger to the health of the staff or the visiting public existed. Arrangements were made to transport the remaining 19 specimens, associated pellets and plant material to the Animal Health Centre the following week. The mammalogist also contacted the CDC Plague Branch in Fort Collins, Colorado and was advised that there would be no risk of live fleas on the dead animals, and that the laboratory risk was restricted to transmission from infected blood or tissue.

Throughout the following week, plans were made to brief government officials and to make arrangements for a CDC official from the Plague Branch to come to Victoria to provide advice and assistance. On Friday of that week, it was reported that a Vancouver newspaper planned to write a story on the discovery of plague in British Columbia. Members of the RBCM senior management met with all staff to inform them of the situation.

The following week a meeting was arranged for museum biology staff, provincial and local health officials, the Local Occupational Health and Safety Committee and the representative of the CDC Plague Branch. At this meeting the Deputy Medical Health Officer of the Capital Regional District recommended that the RBCM review its specimen handling and laboratory procedures. The museum then agreed to create a review committee which included provincial and local medical health officers, museum officials, the biosafety officer from the University of Victoria and the union chairperson of the Local Occupational Health and Safety Committee. Throughout this period, the local newspapers interviewed officials from the British Columbia Centre for Disease Control, the RBCM, and spokespersons for the British Columbia Ministry of Health, the Capital Regional District Medical Health office, and the British Columbia Government Employees' Union. There was no suggestion in the press coverage that the officials involved were not taking every reasonable step to fully involve interested authorities in the situation. Press interviews resulted in the public being made aware that professionals were reviewing the procedures in the light of new information. Museum officials were also quoted as having appropriate basic laboratory procedures in place including the requirement for cleanliness, working with the appropriate disinfectants, using proper laboratory apparel, and sending frozen waste tissue to the Society for the Prevention of Cruelty to Animals (SPCA) for incineration. This last procedure eliminated the possible concern that tissues remaining from specimen preparation could find their way into local garbage disposal systems, to be later uncovered by animals frequenting the landfill.

## The Review Process

In 1988, prior to the discovery of the plague-killed specimens, the museum had obtained information from a consulting veterinarian regarding the types of zoonotic diseases which may occur in the animals handled by museum staff. This information led to the development of laboratory health and safety guidelines for all personnel working in the specimen preparation laboratory. The review committee examined the museum's laboratory procedures and incorporated additional biosafety practices which were outlined in Canadian (Medical Research Council of Canada, 1989) and American (Centers for Disease Control, 1988) federal bio-

safety guidelines. These guidelines are similar in their designation of four biosafety levels which describe laboratory safety practices, safety equipment and laboratory facilities appropriate for the operations performed and the hazards posed by infectious agents.

In Canada, biological agents (bacteria, parasites, fungi and viruses) are classified in four risk groups reflecting their ability to cause disease in humans:

Risk Group 1: low individual and community risk
Risk Group 2: moderate individual risk, limited community risk
Risk Group 3: high individual risk, low community risk
Risk Group 4: high individual risk, high community risk.

As the ability to cause disease increases, the design of the laboratory must change to accommodate safe handling of the biological agent. The type of laboratory required for handling the agent will, under normal conditions, correspond directly with a risk group level. Therefore, four levels of laboratory containment (1–4) appropriate to the four risk groups for infectious agents are defined. Higher levels of containment require increasingly sophisticated safety equipment, isolated laboratories, and restricted entry.

Before implementing additional biosafety standards at the RBCM, an assessment of the potential risk of laboratory-acquired infection was required to determine the appropriate level of containment. A unique aspect of biological collection laboratory work is the handling of animal specimens of unknown clinical history. Zoonotic diseases which could potentially be transmitted to museum staff are caused by biological agents which fall largely into Risk Groups 2 and 3. The review committee recommended the designation of Containment Level 2 for the museum laboratory. This decision was based on the knowledge that a Containment Level 2 designation is recommended for clinical laboratories handling human blood, tissues and fluid of unknown history and on the lack of documented cases of occupationally-acquired disease in museum laboratory staff. In addition, a Containment Level 3 laboratory requires sophisticated physical and operational procedures designed primarily for work with live cultures of biological agents. The committee determined that using Containment Level 2 physical and operational requirements would provide a workable standard of biosafety appropriate to the museum.

The results of the review process were finalized in late March of 1989. The recommendations were as follows:

1) Field collecting should be reviewed by an interministry task force, with active collecting of mammals to cease until protocols are established.
2) Specimen preparation steps involving evisceration should be conducted in a biological safety cabinet with Level 2 procedures being followed. Biological safety cabinets should be certified after installation, whenever moved, and on an annual basis. These cabinets must be approved by the Canadian Standards Association (CSA) or designated authority and, if possible, should have an external ventilation duct.
3) Gloves, masks and eye protection should be standardized to meet Workers' Compensation Board (WCB) requirements.
4) Daily disinfecting of the laboratory floor should be implemented.

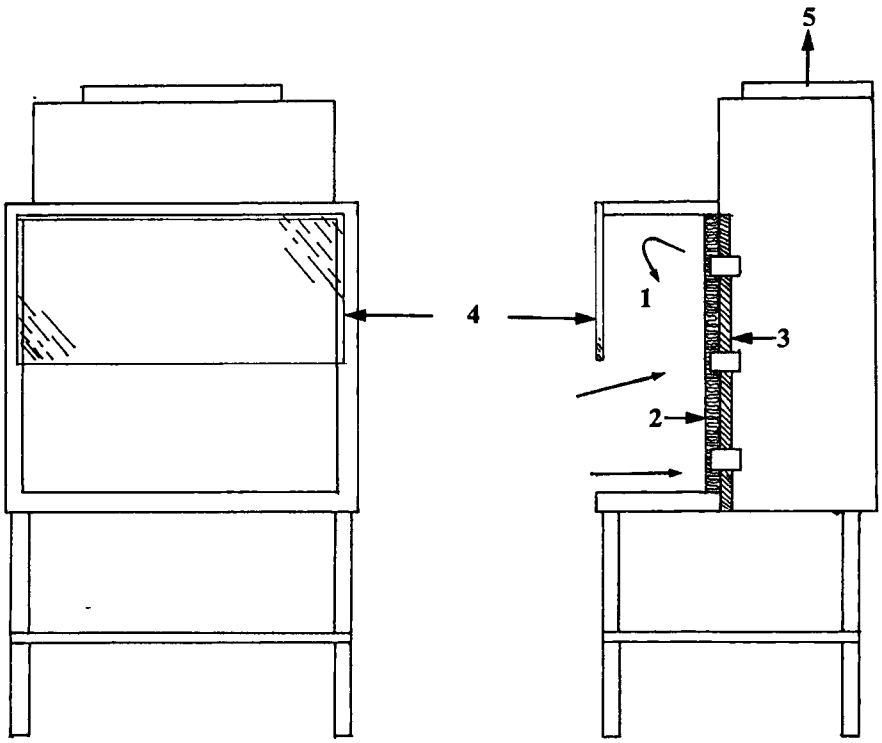


Figure 1. Drawing of R.B.C.M. biological safety cabinet. (1) Unrecirculating air flow; (2) prefilter; (3) HEPA filter; (4) hinged sash; (5) exhaust air. Drawing by A. Beltane.

5) Dry nesting material collected from field sites should be frozen before examination and handled with gloves.
6) Supernatant from the maceration of skeletal material should be diluted with bleach to 10% volume per volume prior to being discarded.

A Class I biological safety cabinet is a ventilated cabinet for personnel protection with an unrecirculating inward air flow away from the operator (Fig. 1). The biological safety cabinet is fitted with a high efficiency particulate air (HEPA) filter to protect the environment from discharged biological agents. The cabinets may recirculate filtered air into the laboratory but exhausting to the outside is preferable.

After the adoption of these recommendations, the review committee was disbanded. Implementation of the recommendations followed.

## IMPLEMENTATION

*A. Field procedures.*—Field collecting was reviewed by an interministry task force and resulted in the increased awareness of the potential for disease transmission from animals. The recommendation resulted in the adoption of the protocol to wear rubber gloves when handling mammals in the field. A representative of the CDC Plague Branch noted that a plague preventative vaccine was available but was considered ineffective.

*B. Laboratory procedures.*—The RBCM's experience with *Y. pestis*-infected *Neotoma cinerea* revealed the potential for the transmission of zoonotic disease in a biological laboratory.

The procedures and practices unique to the biological collections laboratories required special considerations in implementing the committee's recommendations. Class I biological safety cabinets with larger than normal dimensions were custom-made, and prefilters were installed to protect the expensive HEPA filter from excess fur and feathers. A hinged sash was incorporated into the design of the cabinet to allow for the movement of larger specimens into the work space. Plastic aprons were provided in addition to laboratory coats, for protection from fluids that may be generated during the specimen preparation process.

As the dermestid colony may be exposed to infected material and some infections can be maintained the colony (Rehacek, 1979; Prokopic and Minar, 1980; Rustin and Munroe, 1984) the use of personal protective equipment was incorporated into the normal handling procedures for the colony. In addition, the waste generated from boiling skeletons or from trypsin treatments is now effectively disinfected with bleach prior to release, and sharps (glassware, needles and scalpel blades) are now considered potentially contaminated, hazardous and are disposed of accordingly.

## Zoonotic Disease Potential in British Columbia

In light of the information about plague in British Columbia, a project was conducted by the museum and the Wildlife Branch of the British Columbia Ministry of the Environment in 1989.

RBCM mammalogist David Nagorsen surveyed nine sites in the same area where the dead *Neotoma cinerea* were found the previous year. No new cases of plague were discovered. A total of 176 small mammals comprising 17 species were collected and analyzed serologically for plague antibodies. All specimens tested negative. It appears that the plague epizootic in 1988 did not affect the mammals collected in 1989.

A list of known or suspected zoonotic diseases that occur in British Columbia or its surroundings was created to assist museum staff in recognizing the risk that may occur in specimens they prepare (Appendix).

## Conclusion

The knowledge that collected *Neotoma cinerea* were infected with *Yersinia pestis* necessitated an immediate assessment of the health risk to all museum staff and the public. It was determined that a potential risk existed for collectors and preparators. Experts reviewed the museum's specimen collection, handling and preparation procedures. Containment Level 2 facilities and procedures were recommended and implemented.

An extensive literature search found no citations linking zoonotic disease to museum workers but clearly, health risks to museum preparators do exist. Museum professionals should assess local zoonotic risks and implement suitable procedures that ensure the health and safety of museum employees and the community.

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## Appendix: Known or Suspected Zoonotic Diseases in British Columbia and Surrounding Area

Anthrax—*Bison* (bison), *Alces* (moose) (Davis et al., 1981; Tessaro, 1986).

Aspergillosis—water fowl and sea birds (A. Hoey, R. West, personal communication).

Brucellosis—*Alopex lagopus* (Arctic fox), *Bison* (bison), *Rangifer arcticus* (caribou), *Cervus canadensis* (elk), *Ursus arctos* (grizzly bear), *Citellus undulatus* (ground squirrel), *Alces alces* (moose), *Vulpes fulva* (red fox), *Rangifer tarandus* (reindeer), *Canis lupus* (wolf) (Tessaro, 1986).

Chlamydiosis (avian)—imported parrots, *Columbia* sp. (pigeon) (R. Lewis, personal communication).

Chlamydiosis (mammalian)—domestic mammals (R. Lewis, personal communication).

Dermatophytosis—all mammals (R. Lewis, personal communication).

Echinococciasis—*Canis latrans* (coyote) (Davis and Anderson, 1971), *Vulpes* sp. (fox) (L. Friis, personal communication), *Canis lupus* (wolf) (Davis and Anderson, 1971).

Larva Migrans—cat and dog families, *Procyon lotor* (raccoon) (R. Lewis, personal communication).

Leptospirosis—a variety of land and marine mammals (R. Lewis, personal communication).

Lyme Disease—from tick (*Ixodes pacificus*) found on ground-living birds and mammals (Farley *et al.*, 1990).

Plague—*Neotoma cinerea* (bushy-tailed woodrat) (D. Nagorsen, personal communication), *Marmota* sp. (marmot) (British Columbia Department of Health and Welfare, 1955).

Q Fever—*Cervus canadensis* (elk) (R. Lewis, personal communication).

Rabies—*Eptesicus fuscus* (brown bat), *Castor canadensis* (beaver), *Canis latrans* (coyote), *Vulpes fulva* (fox), *Equus* sp. (horse), skunk, *Canis lupus* (wolf) (Prins and Yates, 1986).

Seal Finger (Blubber Finger)—marine mammals (M. Bigg, personal communication).

Seal Pox—*Phoca vitulina* (Harbour seal), *Zalophus californianus* (California sea lion) (Smith and Skillings, 1979).

Tetanus—nearly all mammals (R. Lewis, personal communication).

Tuberculosis (avian)—*Gallus* sp. (chicken), *Pavo* sp. (peafowl), *Phasianus* sp. (pheasant), *Columbia* sp. (pigeon), *Cygnus* sp. (swan) (D. Onderka, personal communication).

Tuberculosis (mammalian)—*Bison* (bison), *Cervus canadensis* (elk), *Cervus dama* (fallow deer), *Alces alces* (moose), *Odocoileus hemionus* (mule deer) (Tessaro, 1986).

Tularaemia—*Castor canadensis* (beaver), *Odocoileus hemionus* (mule deer), *Ondatra zibethicus* (muskrat), *Citellus* spp. (ground squirrels), *Lepus* spp. (rabbit and hares), *Sylvilagus idahoensis* (rabbit), *Sorex vagrans* (shrew), *Microtus* spp. (voles) (Davis *et al.*, 1981).

# MINIMIZATION OF POTENTIAL PROBLEMS ASSOCIATED WITH THE MORPHOMETRY OF SPIRIT-PRESERVED BAT WINGS

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*Abstract.*—An important but largely ignored problem in using museum specimens of bats in morphometric studies is that changes are induced in the specimens during the preservation process. Values obtained from preserved specimens may thus differ markedly from those obtained from the living animal. A brief diagnosis of this problem in dealing with chiropteran specimens is presented, as is a summary of the current knowledge dealing with potential changes during preservation of study skins and alcoholic chiropteran specimens. Finally, it is suggested that a standardized procedure for obtaining wing tracings be used by specimen collectors, museums, and chiropteran researchers to alleviate or at least minimize these problems for bat specimens.

An assessment of the lifting surface area (Fig. 1), usually simply referred to by the misleading term "wing area," of bat species forms a vital component of many chiropteran studies. With a knowledge of the value of lifting surface area (LSA), it is possible to predict a large portion of the flight performance of a particular bat species by examining its flight efficiency (derived from aspect ratio) and minimum flight, minimum power, and maximum range speeds, turning radius, and general manoeuverability (derived from wing loading) (Pennycuick, 1975; Aldridge, 1987; Norberg, 1987). The accuracy of such predictions, however, depends upon the degree to which the measurement of LSA from the specimen reflects the actual value possessed by the living animal.

Heretofore, discussion involving LSA determination has centered primarily on which portions of the bat's anatomy should be included in the LSA, or what technique of determining the LSA yields the most accurate results. However, underscoring this discussion is a very basic problem; do changes occur to the LSA as a result of the various preservation techniques used to produce permanent specimens from which such measurements can be taken? The seriousness of this problem is thrown into sharp focus when it is realized just how many chiropteran studies have used preserved museum specimens to obtain raw data for subsequent analysis (e.g., Vaughan, 1959, 1966; Struhsaker, 1961; Jones, 1967; Farney and Fleharty, 1969; Findley *et al.*, 1972; Myers, 1978; Smith and Starrett, 1979; Norberg, 1981; Baagøe, 1987; Norberg and Rayner, 1987). This list is by no means exhaustive.

Common preservation modes for bat specimens are the preparation of study or flat skins and fluid-preserved specimens (DeBlase and Martin, 1981). Thus far, no studies have specifically examined changes induced (if any) in LSA as a result of preservation. There are, however, indications that changes might occur.

It has been noted that forearm lengths decrease in dried and skinned bat specimens due to desiccation and compaction of the wrist elements (Arata, 1968). Such drying out and compaction probably occur elsewhere in bat study skins, especially in the wing membrane. The magnitude of this potential decrease in

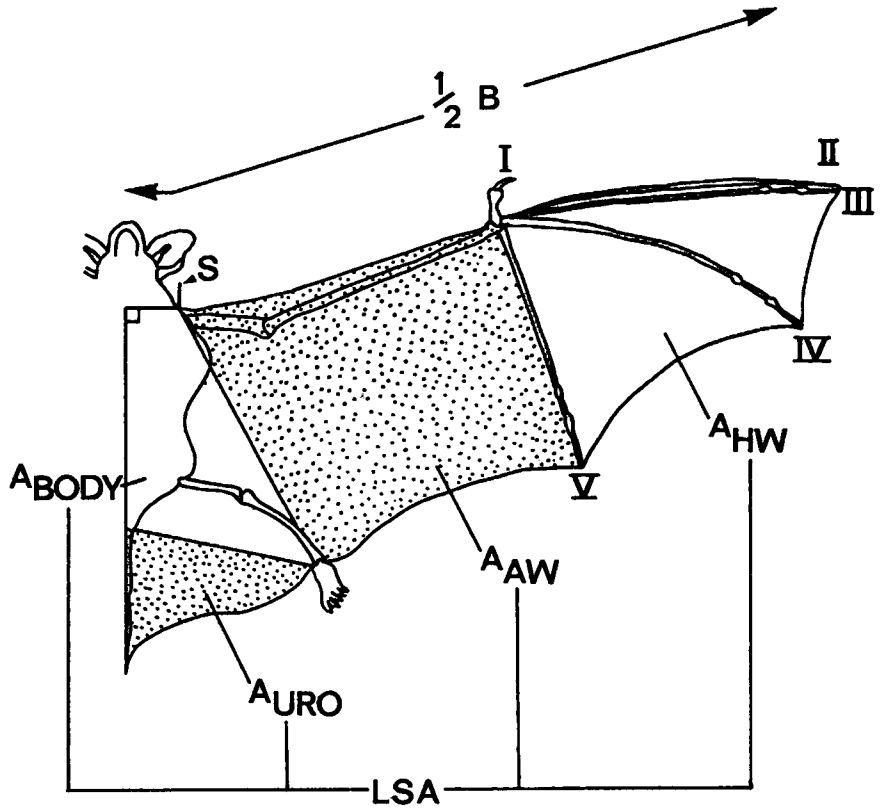


Figure 1. Diagrammatic representation of *M. lucifugus* showing definition of one-half of the wingspan (½ B), and boundaries of one-half of the lifting surface area (LSA) and its subunits: handwing area ($A_{HW}$), armwing area ($A_{AW}$), body area ($A_{BODY}$), and uropatagial area ($A_{URO}$). LSA does not include the area of the head. Digits are indicated by Roman numerals. S marks the position of the left shoulder. (Adapted from Saunders, 1989).

wing membrane area has not been investigated to date. Furthermore, it is difficult to carry out morphometric work on bat study skins because of the risk of damaging the wings. Ideally, one should only make wing tracings from bat study skins where at least one wing has been preserved in an "extended" position, i.e., spread out (Hangay and Dingley, 1985; Blood and McFarland, 1988). This extended position is not generally recommended, however, as it requires considerable space for storage and the specimens are also more susceptible to breakage (Wagstaffe and Fidler, 1968). Such factors limit the amount of usable bat study skin material available to researchers interested in wing morphometry and its role in the understanding of bat flight. Flat skins present the additional problem of converting a three-dimensional animal to essentially two dimensions. Thus, the body area calculated from such specimens will be larger than that recorded from equivalent (three-dimensional) study skins—an unwanted and undetermined source of variation.

Bats are also routinely stored as fluid-preserved specimens to avoid the desiccation of the wings (Rosevear, 1965). Although such specimens provide in-

valuable data for research on bats, our investigations (Bininda-Emonds and Russell, in press) indicate that care must be exercised when using them for inferring aspects of flight morphology or performance. Preparation of such specimens involves a two-step procedure: fixation, typically in 10% neutral buffered formalin, and preservation, in 65–70% ethanol, 45–60% isopropyl alcohol, or 10% neutral buffered formalin (Nagorsen and Peterson, 1980; DeBlase and Martin, 1981). We were able to standardize preparation and preservation conditions for a series of bats of known provenance and living dimensions, and to conduct a protracted series of observations on them throughout the preservation process. This has revealed potentially serious problems resulting from changing specimen dimensions in employing such specimens for morphometric studies of the flight performance of bats (Bininda-Emonds and Russell, in press).

Both LSA and wingspan of little brown bat (*Myotis lucifugus*) specimens were found to be dependent upon the specimen type examined during the fluid-preservation process. Bininda-Emonds and Russell (in press) documents measurement and assessment procedures, and preservation effects. Complicating this basic difference between specimens were differences between the preserved specimens depending upon the fixation position of the wings ("compressed," "intermediate," or "extended"). Although originally suggested for study skins and not fluid-preserved specimens (Wagstaffe and Fidler, 1968; Hangay and Dingley, 1985), the intermediate and extended wing positions were demonstrably better than the conventional compressed position. These results were primarily evident when LSA was determined by tracing the preserved bat specimens onto paper and digitizing the outlines to determine their areas.

These "tracing procedures" are of generally limited use for preserved specimens due to the potential effects of formalin fixation on the collagen network of the wing membranes (Holbrook and Odland, 1978; Viidik 1980). Some procedures that estimate LSA based on idealizing the wing as a combination of simple geometric figures were initially proposed with the hope that they would be immune to the effects of formalin as they rely on measurements of the forearm and various digits of the wing. Unfortunately, this generally has not proved to be the case. These "estimation procedures" are similarly affected by the fixation and preservation procedure, i.e., results are dependent on the specimen type examined and, for preserved specimens, on the fixation position of the wing. The procedures of Pirlot (1977) and Blood and McFarland (1988) significantly underestimated LSA for all specimen types. Only Smith and Starrett's (1979) procedure yielded accurate estimates of LSA for live specimens and for preserved specimens with the wings fixed in the extended position (Bininda-Emonds and Russell, in press).

Due to their nocturnal and secretive nature, it is difficult to directly observe most bats in the wild. Thus, bat researchers rely on predicting the flight behaviour of a bat species (a key factor determining the ecology of these animals) from its morphology. However, we have shown that we may be seriously misrepresenting what a given bat species is capable of in the field based on measurements obtained from fluid-preserved specimens (Bininda-Emonds and Russell, in press). It is vital, then, to find a procedure that will let us accurately assess LSA and the other morphometric characters used to predict flight behaviour.

One simple solution for minimizing the potential errors outlined above when using fluid-preserved specimens is to use only specimens where one of the wings

has been fixed in the extended position. This is the only wing position that will yield accurate LSA values for fluid-preserved specimens (with respect to the live animal) whether through tracing procedures or Smith and Starrett's (1979) estimation procedure. This suggestion is not likely to be followed, however, because of the impracticality of the extended wing position (Wagstaffe and Fidler, 1968). Fixing bats in the extended position in the field would be problematic for many collectors, and the extended specimens require more storage space, a valuable commodity in most museums.

An even better solution would be to use the estimation procedure provided by Aldridge (1988) which uses mass to estimate LSA. No significant differences were found between LSA estimated from live mass and the actual traced live LSA (Bininda-Emonds and Russell, in press). Thus, as long as the preserved specimen has had its live mass recorded, an accurate assessment of LSA can be made. However, a drawback of this and any other estimation procedure is that they accurately estimate only one definition of LSA and, more importantly, they do not provide any estimates of the areas of the various subunits comprising the LSA. A solution that yields more general output is thus required.

Museums already compile a number of characteristic measurements for bat specimens: forearm length, tragus length, and occasionally wingspan (Nagorsen and Peterson, 1980). We suggest the compromise solution that a wing tracing of the live or freshly-killed specimen also be taken. Many museums already retain catalogues, field notes, photographs, and maps of collecting sites pertaining to individual specimens (Nagorsen and Peterson, 1980), so the addition of a wing tracing should not be an unreasonable demand. As demonstrated by Saunders (1989), wing tracings can be performed in the field and so should not present a serious problem to collectors who begin preparation procedures in such situations.

An accurate value for the LSA is certainly as important to chiropteran studies today as are the other measurements noted above. The advantages to be gained from having such information available more than compensate for the inconvenience incurred in making the tracing. The area of the wing tracing need not be calculated by the collector or museum either, but merely stored for future reference. Access to the wing tracing would allow researchers with different definitions of the LSA and its subunits to follow their own procedures and to minimize variability in their samples, while avoiding the inaccuracy that comes with recording wing dimensions from preserved specimens. All that need be done is to follow a specific set of instructions for making the tracing and to ensure that demarcation points are marked on the tracing to enable the areas of appropriate subunits of the LSA to be measured (Fig. 1).

The exact procedure for obtaining this wing tracing should be standardized and formalized to minimize error between collectors. We suggest the following simple method. The live or freshly-killed bat should be placed on a sheet of paper on its back to minimize rolling and to keep the wing as flat to the paper as possible. The left wing should then be stretched to its fullest extent without damaging it, pulling the leading edge of the wing to lie as nearly perpendicular as possible to the long axis of the body. The left hind limb and the uropatagium should also be stretched out and held flat. Small weights may be employed to aid in keeping the wing membranes flush with the paper. The position of the shoulders (the points at which the wings insert into the body) should then be marked (to demarcate the

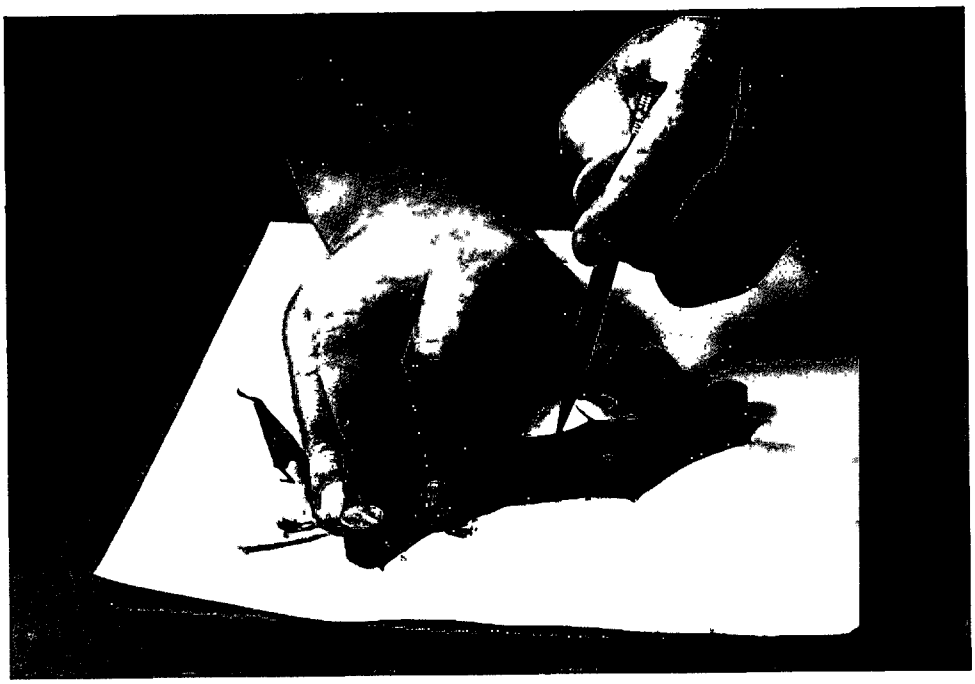

Figure 2. Photograph illustrating our suggested technique for tracing the left wing of a bat specimen. Note the small brass weights holding down parts of the patagium.

boundary between the wing and the body), followed by an outline extending around the left wing and uropatagium to the tail tip (Fig. 2). Such raw data, if cross-referenced to voucher specimens, can then be maintained in a file until such time that they are required for analysis.

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# METHODS OF PROCESSING OSTEOLOGICAL MATERIAL FOR RESEARCH VALUE AND LONG-TERM STABILITY

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*Abstract.*—Investigations were conducted on alternative treatments for cleaning osteological material that would be superior to other methods by enhancing specimen research potential, as well as specimen stability for long-term preservation. The procedures developed relied heavily on the management of a dermestid colony to produce completely cleaned skeletal material. Following the removal of non-osseous tissues, the remaining dermestids and debris were removed by a vacuum process using an aspirator hooked to a forced-air supply. Tissue remnants were removed in a similar manner with the aid of probes, forceps, and brushes, when necessary. To ensure against the survival of insects that might remain inside specimens, the skeletal material of smaller specimens was stored in closed vials for at least three weeks. Results show the effectiveness of this quarantine procedure. Discussion is given to possible methods for controlling pests in the skeletal material of larger specimens.

Methods of processing osteological material in vertebrate research collections have evolved with time. Techniques such as maceration and boiling have been regarded as destructive. They have been replaced with methods that involve scavenging organisms, followed by washing procedures (Hall and Russell, 1933; Tiemeier, 1940). Even with improvements to these methods, in terms of quality and efficiency, there are concerns associated with long-term stability, specimen integrity for research purposes, and inefficient operations. These factors establish a need to develop better methods for processing osteological materials.

Current techniques often involve cleaning bones with organisms, followed by one or more treatments. For instance, the skeletal material may be treated with toxic chemicals for pest control. Further treatment often involves soaking the bones in detergents, enzymes, or alkaline solutions (Chapman and Chapman, 1969; Gross and Gross, 1966; Hall and Russell, 1933; Hildebrand, 1968; Hoffmeister and Lee, 1963; Williams *et al.*, 1977). The entire effort of placing skeletal material in containers, mixing and adding solutions, soaking, washing, drying, and finally placing the specimens in storage containers, is labor-intensive and time-consuming. These procedures require diligent planning and scheduling; absenteeism or sudden changes in daily job priorities can raise havoc with efforts to process osteological materials before visible damage occurs.

Studies have demonstrated that the soaking and washing of osteological material with any kind of aqueous solution is destructive because of the hygroscopic and anisotropic nature of bone (Lafontaine and Wood, 1982; Williams, 1991). The solutions that are often used for cleaning bones are also potentially deleterious to proteinaceous materials (Balfe, 1948; Gustavson, 1956; Rose and Von Endt, 1984; Shelton and Buckley, 1990). With regard to the incorporation of toxic chemicals for pest control, it is known that at least some fumigants degrade collagen and lipids (unpublished data; Williams *et al.*, 1989). Although it is recognized that various treatments may compromise long-term stability of bone, it must be re-

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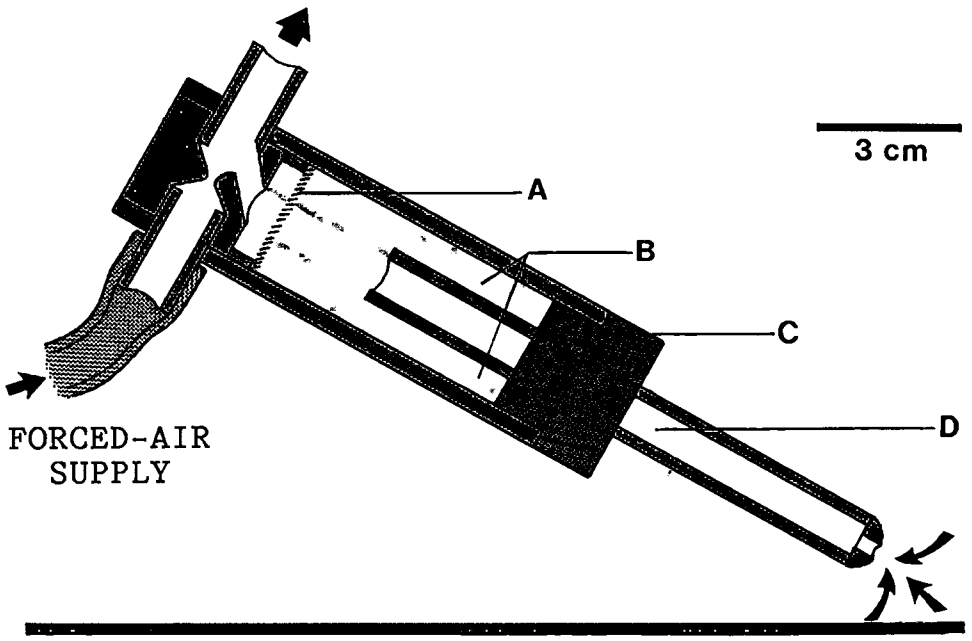


Figure 1. Schematic of aspirator. Debris is filtered out of the air-flow by a fine-mesh screen (A) and accumulated within the aspirator chamber (B). The debris is cleaned out by removing the stopper (C) that supports the suction-tube (D).

alized that these treatments also may compromise research potential, particularly for biochemical and genetic investigations (unpublished data).

In the current study, methods were tested that did not involve either fumigants or aqueous solutions. The elimination of these treatments should promote long-term stability and research potential of specimens, as well as provide healthier work environments. In addition to these benefits, the methods tested resulted in increased productivity, and procedural risks were virtually eliminated.

## Methods and Materials

Osteological material was initially cleaned with dermestids (*Dermestes*). Individual specimens were isolated from one another with the use of separate containers or partitioned containers, such as egg cartons. Containers were stacked in an aquarium where dermestids were introduced to clean the osteological material. Any specimens that were not thoroughly cleaned were simply placed in new containers and the procedure was repeated.

After specimens were thoroughly cleaned, they were individually placed in glass jars so that hidden dermestids would be contained. Each specimen was vacuumed with an aspirator (Fig. 1) connected to a forced-air supply to remove debris and possibly insects. Although the aspirator provides low levels of suction, sufficient to safely remove debris, the forced-air supply can be turned down to provide even lower levels of suction, if necessary. It was convenient to support the aspirator with a laboratory stand so that both hands would be free to safely handle the specimen. Occasionally probes, forceps, or soft brushes were used to dislodge non-osseous materials missed by the dermestids.

Although the aspirator was capable of capturing insects, there was concern about dermestids remaining in inaccessible parts of the specimen. Pest control methods varied according to the size of the specimen. Procedures for specimens too large to fit in glass vials are still being investigated. For specimens small enough to fit in glass vials, the bones were simply placed in a vial and sealed with a polyethylene cap. The vial and its contents were quarantined for at least three weeks. The effectiveness

of this method was tested by observing the survivorship of dermestids stored in open vials, closed vials, closed vials containing cleaned skeletal material, and closed vials containing uncleaned skeletal material. The vials measured 65(H) × 29(D) mm. The skeletal material involved skulls from mice (*Peromyscus*) collected within the previous six months and not exposed to any chemicals that might be used for preservation, pest control, or processing. For each storage condition, fifteen dermestids for each of five age-groups were observed. Age-groups, determined by relative sizes, included small-sized larvae (3–6 mm), medium-sized larvae (7–10 mm), large-sized larvae (12–15 mm), pupae, and adults. For purposes of observation and preventing cannibalism between individuals, each dermestid was placed in its own vial. Survivorship was documented till all 300 dermestids had died. The test was conducted in a room maintained at about 22–24°C and 25–35% RH. Except for examination periods, the vials were kept in the dark during the test.

## Results

The elimination of aqueous solutions from osteological preparations provided greater productivity and flexibility of operations without risking damage to specimens. The vacuuming procedure was used for over a year on a variety of specimens. It was consistently possible to process about 100 small skulls (mouse size) within a four-hour period; the cleaning of 20 larger skulls (coyote size) took about two and a half hours. As would be expected, the processing of post-cranial material required more time. Except for an occasional greasy specimen, the quality of cleaning appeared to be as good as standard procedures involving soaking and washing. With the described system, work could be started and stopped as needed, so that even a 15–30 minute time-period could be effectively used.

The quarantine of specimens in sealed glass vials proved to be an effective method of pest control. Results of the tests involving dermestid survivorship in vials are summarized in Figure 2. Although there were significant differences ($P \leq 0.05$) between storage methods within each age group, the greatest variation was observed with the larger larvae (>12 mm) and pupae. Situations involving these age groups typically showed prolonged survivorship because of dormant periods encountered as large larvae pupated and/or as pupae changed to adults. Almost all of the small- to medium-sized larvae and adults died within three weeks. For all age groups, except the small-sized larvae, the sealed vials with cleaned skulls had the shortest average period of survivorship. It was noted that the presence of cleaned or uncleaned skeletal material with large larvae, pupae, and adults consistently resulted in lower survivorship averages.

## Discussion

In biological research collections there is a need to use methods of preservation that do not compromise the scientific integrity of specimens. It is essential that all parts of specimens remain as natural as possible so that reliable and repeatable results can be obtained for technical research, such as biochemistry, genetics, and detection of environmental chemicals. The introduction of reactive substances undoubtedly affects specimens by removing or altering natural components, as well as possibly leaving chemical residues or reaction by-products on the specimen. These factors, combined with the uncertainty of previous treatments, greatly reduce the desirability of using existing specimens for some types of research. This situation causes collections as a whole to have reduced value for technical research, resulting in a continual need to collect more specimens to accommodate new research initiatives.

The introduction of osteological materials to adverse environments, such as

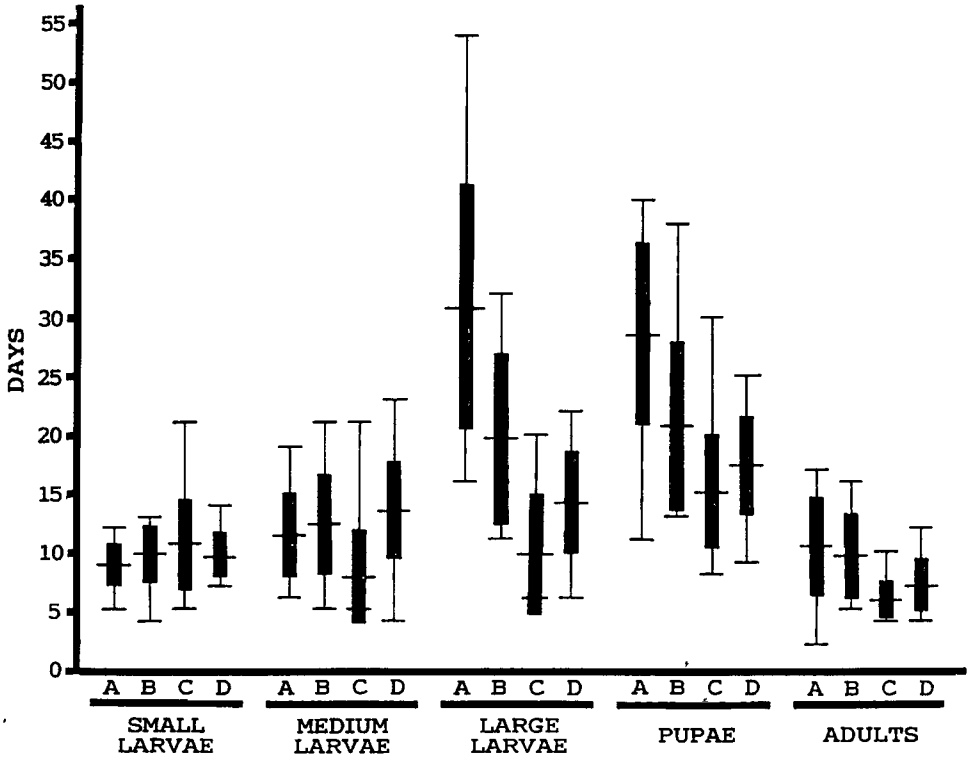


Figure 2. Survivorship of dermestid (*Dermestes*) age-groups in glass vials used for storing specimens. A = empty vial with no cap; B = empty vial sealed with polyethylene cap; C = capped vial containing cleaned skull; D = capped vial containing uncleaned skull. Vertical bars show mean, standard deviation, and range for conditions labeled on the horizontal axis. There were significant differences ($P \leq 0.05$) between all groups of vials in each age group of dermestids.

those created with solutions or fumigants, compromises material stability and is in direct conflict with current museum conservation philosophies. These philosophies support non-intrusive methods that promote long-term preservation and often involve optimizing "specimen environments" with the use of desirable climatic conditions and inert materials.

The rationale for soaking and washing osteological materials has been discussed by Williams (1991). The objective of cleaning is to expose the skeletal material for purposes of detailed examination and measuring. The methods described above, using dermestids and vacuum cleaning, were effective in removing extraneous materials from the bone. Because the described methods do not require the use of harsh environments or chemicals, they serve the research and preservation interests of specimens.

The need for further treatment of osteological material beyond cleaning is based solely on the threat of introducing insect pests to the collection. The concept of quarantining small specimens in glass vials accomplishes pest control objectives without compromising specimen integrity or stability.

Data for small-sized larvae and some medium-sized larvae indicated that survival in an open vial was generally less likely than in a closed vial, regardless of

the vial's contents. Comparing the survivorship of the small larvae under different situations and with that of other age-groups of dermestids, it seems that desiccation may be a major threat to smaller larvae. With regard to other age groups, the lowest survival rates were found with dermestids enclosed in vials with cleaned skeletal material. Defining the contributing factors of this trend would require further research, as well as sophisticated equipment. Gilberg (1991) noted the effectiveness of low oxygen atmospheres in controlling developmental stages of several types of museum pests. Although it may be possible that low-oxygen atmospheres may affect survivorship, results of this study also suggest that metabolic rates influence survivorship. Dermestids in empty vials (capped or uncapped) may have survived longer because the metabolic rate was low as a result of reduced activity and nourishment. Metabolic rates of dermestids in vials containing skulls (cleaned or uncleaned) may have been higher because chemicoreceptors of the insects activated feeding responses. The only difference is that uncleaned skulls provided an adequate food source, whereas cleaned skulls did not. The increased metabolic rate, combined with the lack of resources to maintain metabolic activities, resulted in reduced survivorship of dermestids with cleaned skulls. Fortunately, conditions that reduce survivorship in dermestids are also conditions that are typical in research collections.

The rationale for selecting a three-week quarantine is based on several factors. The range of survivorship for all individuals in closed vials with cleaned specimens of all age groups (except pupae) generally did not exceed three weeks; the means and standard deviations easily fell within this time frame. Under normal situations, the large-sized larvae, pupae, and adults would be removed because they would be easily noticed. The possibility of eggs occurring on skeletal materials may cause concern. However, if ambient temperatures are maintained between 25°C and 30°C, the incubation time for *Dermestes* (*maculatus* and *lardarius*) should be two to five days (Hinton, 1945). As long as appropriate temperatures are maintained, the larvae should hatch during the first few days of the quarantine and should die of desiccation before the end of the quarantine period. Although *Dermestes* is commonly used for cleaning osteological material, other dermestids are used at some institutions and should also be tested for survivorship. For example, *Attagenus piceus* (Tiemeier, 1940) has an incubation period up to nine days for temperatures between 25°C and 30°C (Hinton, 1945).

Although it may be possible to incorporate quarantine methods with larger specimens, it becomes increasingly difficult because there may be a greater risk of dermestids finding conditions that would sustain life. Furthermore, there is a greater risk of dermestids escaping from storage containers typically used for larger specimens (for example, pasteboard boxes) because they are not well-sealed and they are often composed of materials that can be penetrated by insect pests.

At this time it seems that the least intrusive methods for controlling pests in larger skeletal material would be either 1) quarantine and observation, 2) using temperature extremes, or 3) dipping the skeletal material in alcohol. There are questions about which is the best solution. The rationale for quarantine and observation is supported with the current study. Although this method may be preferred over others, it would require more time and the risk of infestation would still be questioned. It may be possible to incorporate other detection systems to reduce the risk (Wojcik, 1968). The use of freezing temperatures may have po-

tential (Florian, 1986, 1990a), but situations that risk desiccation and lipid and protein degradation must be considered (Florian, 1990b; Williams, 1991). Temperatures high enough to eradicate insects may cause similar problems. Brief immersion in alcohol also may be a solution for pest control. Alcohol is often used with fluid-preserved specimens (de la Torre, 1951) and to protect specimens from adverse field conditions (Williams and Rogers, 1989). Furthermore, Matienzo and Snow (1986) reported ethanol to be a less intrusive solvent than acetone or toluene. However, alcohol is a desiccant and a solvent that may cause mobilization of lipids (Williams, 1991) and possibly cause material reactions with the ultrastructure of bone. Until these issues can be properly addressed, it is inappropriate at this time to make recommendations about suitable procedures for the processing of skeletal material of larger specimens.

One problem encountered with the procedures described above was the presence of minute amounts of connective tissue remaining on the bone surface. Although this is often not evident without the aid of magnification, it can contribute to bleeding of ink during labelling procedures. This problem and the problem of ink penetrating porous bone can be alleviated by following standard conservation procedures for labelling museum materials (Wolf and Denton, 1985). This involves coating the area to be labelled with a thin layer of polyvinyl acetate (Dowman, 1970:153), Acryloid B-72 (Dudley and Wilkinson, 1979:52), or acrylic varnish (Wolf and Denton, 1985) and labelling the coated area of the bone; these materials are reversible and recognized to be relatively stable. If Acryloid B-72 is used, it should be dissolved in ethanol instead of toluene or acetone for purposes of health and safety (C. Rose, personal communication).

## Conclusions

This study presents a new rationale in selecting methods for processing osteological materials, based on objectives of enhancing research value and specimen stability for long-term preservation. It is believed that this philosophy must prevail in all management operations if collections are to continue serving the needs of advancing scientific technology, as well as provide research material for future generations. It is noteworthy that such methods also can serve the interests of health and safety, as well as the efficiency and economics of collection management operations.

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# IMPROVING THE SELECTIVITY OF A SELECTIVE DISSOLUTION PROCESS: A SOLUTION FOR REMOVING CALCITE FROM FLUORAPATITE

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*Abstract.*—A solution has been formulated which is capable of dissolving calcite from fluorapatite without causing damage to fluorapatite surfaces. This solution has a pH of 3.7 which is the point of maximum difference in the molar solubilities of calcite and fluorapatite. It was formulated to be just saturated with fluorapatite. The solution contains 0.100 $mol L^{-1}$ of the disodium salt of ethylenediamine tetra-acetic acid, 0.050 $mol L^{-1}$ of calcium chloride, $1.5 \times 10^{-5}$ $mol L^{-1}$ of sodium dihydrogen phosphate, $5 \times 10^{-6}$ $mol L^{-1}$ of sodium fluoride, and a buffer mixture, 0.100 $mol L^{-1}$ of sodium formate with enough free formic acid to achieve the pH required. Experimental determinations of dissolution rate and scanning electron micrographs of treated surfaces confirm that the solution is capable of dissolving calcite at a reasonable rate without damaging fluorapatite crystal surfaces.

The value of a mineral specimen for display and, in some instances, for research, is often dependent on how well the mineral species of interest are exposed to view. If, when the specimen is collected, the species of interest is encased in or covered by a mineral of less interest, then removal of the less interesting species can greatly enhance the utility and value of the specimen. Removal of one mineral species from another can often be accomplished by mechanical or chemical means or both.

As a rule, mechanical methods are preferred since they present little risk of introducing deleterious contaminants into specimens. Often, however, the species of interest will be mechanically less robust than the species to be removed so that the risk of damage to the species of interest may preclude the use of mechanical methods. In these cases, a chemical approach is preferred. The chemical removal of one mineral species from another requires a chemical or a solution that will dissolve or decompose the species to be removed while not significantly removing or altering the species to be retained.

Traditionally, most selective chemical dissolution treatments have depended on a sufficiently large difference in the solubilities of the species to be removed and the species to be retained. It is the resultant difference in the rate of attack rather than complete impunity of the species to be retained that both leads to, and restricts, the partial success of these methods. This work was undertaken to determine if a solution could be designed which would be completely non-aggressive toward one moderately soluble species while retaining a reasonable rate of dissolution of another soluble species.

The species combination that was selected for study was fluorapatite [$Ca_5(PO_4)_3F$] and calcite [$CaCO_3$], fluorapatite being the species to be preserved. This combination was selected because the removal of calcite from fluorapatite in mineral specimens is a not infrequent problem and can be difficult to perform mechanically. In addition, it was anticipated that the results of this study may have

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application in other fields where the safe dissolution of calcareous material from apatitic specimens is a problem. Such fields include vertebrate palaeontology (Rixon, 1976; Lindsay, 1987), invertebrate palaeontology (Cooper and Whittington, 1965) and archeology (Ewing, 1950).

Previous work on improving the selectivity of calcite dissolution from apatite group minerals included the replacement of mineral acids, such as hydrochloric acid, with carboxylic acids, such as acetic acid, during the nineteen forties (Whybrow, 1985). Braillon (1973) proved that the addition of tribasic calcium phosphate to acid solutions reduced the extent of dissolution of fossil rodent teeth in such solutions. Jeppsson *et al.* (1985) showed that the addition of a quantity of partially neutralized acetic acid solution (from previous limestone dissolution treatments) to newly prepared acetic acid solution reduced damage to conodonts extracted by selective dissolution from limestone. In the work presented here, knowledge of the particular apatite species of concern is used to permit the formulation of a solution that will be just saturated with fluorapatite, thereby eliminating its dissolution.

In this paper, first, we report the calculation of the solubilities of fluorapatite and calcite in a solution likely to attack both substances but in which the fluorapatite is likely to be much less soluble than the calcite. This is done to find the pH at which the difference in their solubilities is maximized. Second, we report the preparation and testing of a solution calculated to be saturated with respect to fluorapatite but undersaturated with respect to calcite. We report the comparison of dissolution rates in the proposed solution and five and ten volume percent solutions of acetic acid and demonstrate the relative immunity of fluorapatite surfaces to the proposed solution as compared to acetic acid solutions. Finally, we report the results of scanning electron microscopic examination of treated fluorapatite surfaces.

## Calculation of the Solubilities of Calcite and Fluorapatite

The calculation of the solubility of a salt of a weak acid, in a medium containing a pH buffer and a complexing agent that is itself a weak acid, involves the balancing of several effects. Solubility tends to be increased by the action of acid on the anions of the solid and by the action of the complexing agent on the cations of the solid, but may be decreased by the effect of the acid on the complexing agent. Similarly the general effect of increasing the concentration of miscellaneous ions, that is increasing the ionic strength, working through the various competing equilibria may be to increase or to decrease the solubility.

Details of the calculation of the solubilities of calcite and fluorapatite are given in the Appendix. The results of one set of calculations for each substance are presented in Figure 1. In both calculations the solvent mixture was water containing 0.100 $mol L^{-1}$ of the disodium salt of ethylenediamine tetra-acetic acid (EDTA), 0.050 $mol L^{-1}$ of calcium chloride, and a buffer mixture, 0.100 $mol L^{-1}$ of sodium formate with enough free formic acid to achieve the pH required. The ionic strength calculated for this solution is 0.55 $mol L^{-1}$. Because of compensating effects, the total effect of this rather large ionic strength is of the order of the estimated uncertainties of the calculation which may be as large as a factor of

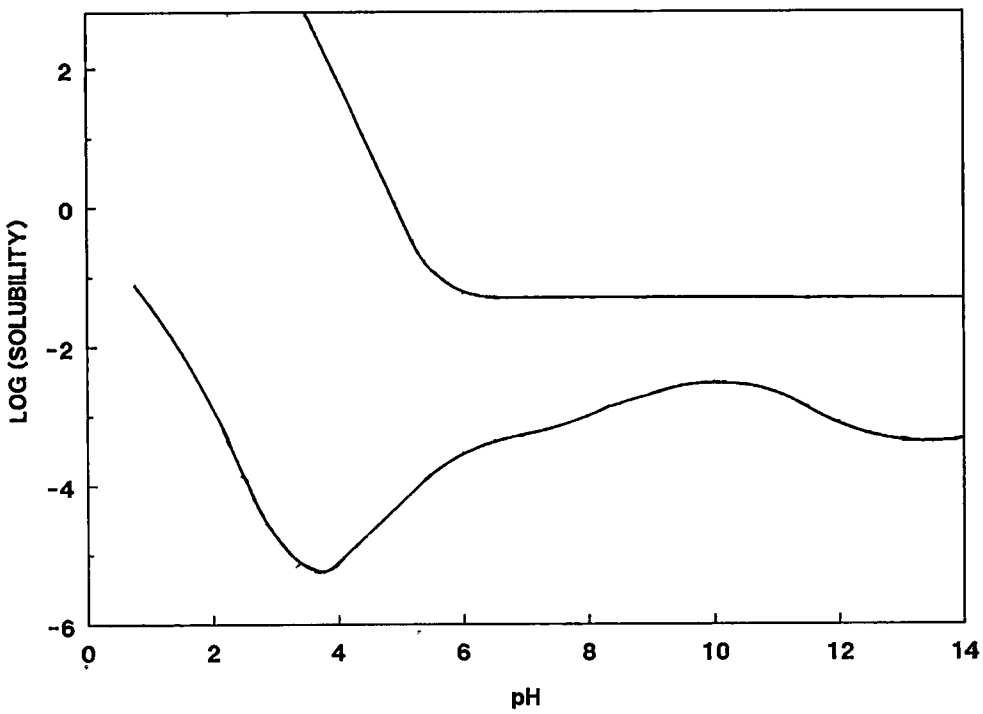


Figure 1. Calculated molar solubilities of calcite (upper curve) and fluorapatite (lower curve) as a function of pH in the test solution (see text for solution composition).

two. Consequently, only the results for zero ionic strength are presented and used to establish the formulation of the test solution.

The plot of solubility versus pH for calcite is rather simple in form. At high pH it is determined almost entirely by the amount of the complexing agent, EDTA, present. At lower pH values it begins to be increased, first by the formation of bicarbonate and dissolved carbon dioxide and finally by the evolution of gaseous carbon dioxide.

The more complex behavior of fluorapatite is dominated at low pH by the reactions of the phosphate and fluoride ions with acid. In the alkaline extreme (pH > 13) the competition between the solid and the EDTA for the free calcium ions is dominant. In the intermediate pH range, the balance between the effects of acidity on the various equilibria causes several inflections and undulations. The most striking feature of the curve is the strong minimum at pH = 3.7. Since the least uncertainty in solubility would result from a given amount of uncertainty in pH at a minimum (or maximum) in the curve, the pH at the minimum was designated as the most likely optimum.

The molar solubilities of fluorapatite and of calcite in this solution at pH = 3.7 were calculated to be $10^{-5.25}$ and $10^{2.45}$ respectively. This represents a difference of nearly eight orders of magnitude in molar solubility. Based on this predicted solubility data, a solution with close to this composition but with sufficient added calcium, phosphate and fluoride to be just saturated with respect to fluorapatite was chosen to be the test solution.

Table 1. Preparation and composition of the test solution.

| Substance: Name | Formula | Stock solution *mol*L$^{-1}$ (gL$^{-1}$) | Volume taken (mL) | Formal concentration *mol*L$^{-1}$ |
|---|---|---|---|---|
| Calcium chloride (anh.) | $CaCl_2$ | 0.20 (22.2) | 250 | 0.050 |
| Formic acid (88%) | HCOOH | 1.00 (43.8) | 100 | 0.100 |
| Sodium formate (anh.) | HCOONa | 1.00 (68.0) | 100 | 0.100 |
| Sodium dihydrogen phosphate dihydrate | $NaH_2PO_4 \cdot 2H_2O$ | $1.0 \times 10^{-3}$ (0.156) | 15 | $1.5 \times 10^{-5}$ |
| Sodium fluoride (anh.) | NaF | $1.0 \times 10^{-3}$ (0.042) | 5.0 | $5.0 \times 10^{-6}$ |
| EDTA disodium salt dihydrate | $C_2H_4N_2(COO)_4H_2Na \cdot 2H_2O$ | 0.20 (74.45) | 500 | 0.100 |
| Water | | | 30 | |
| | | | To make: 1,000 | |

## Experimental Application

### *Rates of Solution*

*Materials.*—Mineral samples fluorapatite, Wilberforce, Ontario, and calcite, Pine Point Mines, Pine Point, North West Territories were obtained from the Canadian Museum of Nature for the study of dissolution rates. Dunn (1977) established that the green apatite from Wilberforce and similar localities is fluorapatite. All chemicals used were of ACS Reagent quality or better.

The following solutions were prepared:

1) Acetic acid, 5% v/v, by measuring 50.0 mL of glacial acetic acid and making up with deionized water to 1.00 L in a volumetric flask.
2) Acetic acid, 10% v/v, similarly prepared.
3) Test solution, by diluting in deionized water appropriate volumes of stock solutions of reagents as listed in Table 1.

The concentrations of reagents in the test solution mixed as described above conform approximately to the calculated composition of the solution at the minimum of the lower curve in Figure 1. Formic acid (pKa = 3.75) rather than acetic acid (pKa = 4.73) was used as the value of its dissociation constant is such that the required concentrations of the acid and the conjugate base are similar. With acetic acid the concentration of acetate needed is inconveniently small. Final adjustment of the pH to 3.7 was done by small additions of HCl or NaOH solutions.

It will be noted that the formal concentration of calcium chloride is not measurably different from that originally taken to be present in the calculations of calcite and fluorapatite solubility in the test solution. The concentration of fluoride is equal to, and the concentration of phosphate is three times, the solubility.

*Procedure.*—Each mineral was crushed, using a porcelain pestle and mortar, and hand picked for purity. The −10 to +20 mesh fraction of the calcite sample

was used. The fluorapatite sample was ground further and the −80 to +120 mesh fraction was used. The sieve fractions employed were selected for convenience in anticipation of different dissolution rates. Surface areas for the two fractions were not measured since our interest was only in the relative dissolution rates of each sample in the three solutions tested. The ratio of the specific surface areas can be roughly estimated, however, assuming that the fragments are similarly shaped, as equal to the ratio of the nominal mesh sizes here about 6:1.

Sintered-glass filter crucibles, medium porosity, were washed with distilled water, dried for 1 hr at 110°C, cooled in a desiccator and weighed to ±0.2 mg. A sample of the crushed mineral weighing approximately 0.25 g was placed in a crucible, and the crucible and contents were similarly washed, dried, cooled and weighed.

The selected solution was then allowed to trickle through the bed of solid, while suction was maintained below the filter, in such a way that the liquid level was always above the level of the solid. After a suitable interval (2–10 minutes, depending upon the expected dissolution rate), the flow of solution was stopped, the bed of solid allowed to be sucked dry, and two successive small portions of distilled water were passed through the sample to remove residual solution. The crucible and the contents were then again dried and weighed. The sequence of percolating, washing, drying and weighing was repeated four to six times.

The data, originally recorded as weights of crucible plus contents and time intervals were converted to percentages of original sample apparently dissolved and the corresponding total contact times. The whole procedure was performed in duplicate with each combination of mineral (fluorapatite or calcite) and solution (5% acetic acid, 10% acetic acid or the test solution).

*Results.*—The data, expressed as percentage dissolution versus contact time, for each of the two solids in each of the three solutions are presented in Figure 2 together with the straight lines fit to the data by linear regression. Table 2 contains a summary of the results of the linear regression analysis performed on the data.

In comparing the three solvents in their effects on calcite, it is apparent that it makes little difference to the rate of dissolution whether 5% or 10% acetic acid is used, but that the dissolution rate is considerably slower in the test solution than in either of the acetic acid solutions.

A similar comparison among the rates of dissolution of fluorapatite shows that the aim of reducing the rate by the use of the presaturated test solution appears to be substantially achieved. The slope of the curve fit to the data for fluorapatite dissolution in the test solution is, within experimental error, zero. There is a considerable difference between the rates of dissolution of fluorapatite in the two acetic acid solutions, the rate in 10% acid being about 50% greater than the rate in 5% acid.

Most to the point for the present study is the ratio of the rates of dissolution of the two minerals in each of the three solutions. These are given in the right-hand column of Table 2. These ratios can be considered as indicators of the selectivity of the dissolution process. A ratio equal to one would indicate that both species are dissolved at equal rates when expressed as weight percent dissolved. In contrast, a ratio equal to zero would indicate that the solution is perfectly selective, since the species to be retained is not dissolved to any measurable extent. The ratio for the test solution is 0.0074 ± 0.0085 and is, within experimental

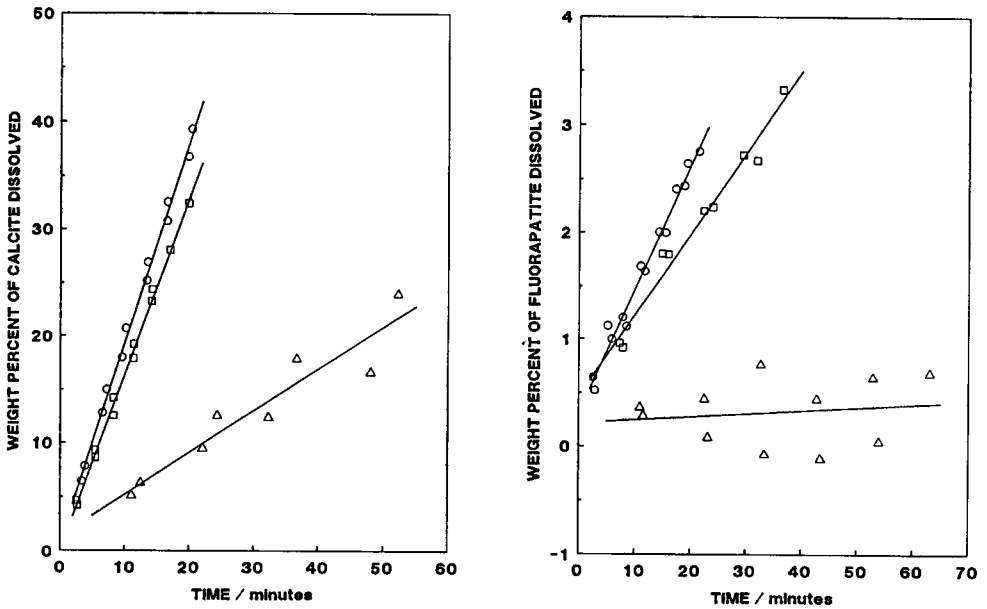


Figure 2. Experimental dissolution rates for calcite and fluorapatite in 10% acetic acid (circles), 5% acetic acid (squares), and the test solution (triangles).

error, equal to zero. Considering the estimated ratio of surface areas of fluorapatite to calcite samples the actual ratio is estimated as 0.001 ± 0.001 which appears even more favorable and is again, within experimental error, equal to zero.

### *Surface Topography of Treated Fluorapatite*

Because a solution saturated with respect to a mineral is in a state of dynamic equilibrium with any of the solid mineral present, it is not necessarily certain that the mineral can be exposed to the solution without undergoing surface alteration. Specifically, it is possible that the mineral might be dissolved from certain areas and reprecipitated in others. Although it was considered unlikely that this would happen to any detectable extent with a mineral having so low a solubility as fluorapatite in the proposed test solution, the following experiment was conducted to determine whether or not this does happen. To account for the different rates of dissolution of calcite and hence the different probable durations of exposure

Table 2. Experimental dissolution rates for calcite and fluorapatite in the three solutions investigated.

| Solvent | Solid | Slope/ % $min^{-1}$ | 90% Confidence interval | Ratio of slopes fluorapatite/calcite |
|---|---|---|---|---|
| 5% acetic acid | calcite | 1.652 | ±0.017 | 0.046 ± 0.002 |
| 5% acetic acid | fluorapatite | 0.076 | ±0.003 | |
| 10% acetic acid | calcite | 1.871 | ±0.021 | 0.062 ± 0.001 |
| 10% acetic acid | fluorapatite | 0.116 | ±0.002 | |
| Test solution | calcite | 0.391 | ±0.037 | 0.0074 ± 0.0085 |
| Test solution | fluorapatite | 0.0029 | ±0.0032 | |

of a fluorapatite crystal to a solution, the experiment was designed such that fluorapatite samples were exposed to each solution for the time required for that solution to dissolve a fixed thickness of calcite.

*Materials.*—Fluorapatite from the same sample described above was used for this experiment. On a carbon planchet four fragments about five millimeters across were mounted such that portions of prismatic $\{10\bar{1}0\}$ crystal faces were the uppermost surfaces. On a second carbon planchet four fragments were positioned such that portions of a fracture surface common to all fragments were the uppermost surfaces. The carbon planchets were then cut in quarters to allow each fragment to be used separately.

Cleavage rhombs of calcite, Madawaska Mines, Faraday Township, Hastings County, Ontario were prepared to have a thickness of $3.4 \pm 0.1$ mm and an area perpendicular to the thickness of $2.6 \pm 0.4$ cm$^2$. These rhombs were coated with paraffin on five sides leaving only one of the large sides available for dissolution.

*Procedure.*—A rhomb of calcite, a fragment of fluorapatite showing a crystal face and a fragment of fluorapatite showing a fracture surface were placed into each of three one liter beakers. One of each of the types of fluorapatite samples was kept as a control. Each beaker received 500 mL of one of the solutions: 5% acetic acid, 10% acetic acid, or the test solution. Each beaker was stirred by a magnetic stirrer at an equal, moderate rate. Dissolution of the calcite was uneven with material near the center of the exposed surface dissolving much more rapidly than material near a paraffin coated surface. Consequently, samples were allowed to remain in the solutions until calcite was dissolved through the 3.4 mm thickness over an estimated 50% of the exposed area.

Both the 10% acetic acid and 5% acetic acid solutions required 24 hours to effect this extent of dissolution while the test solution required 72 hours. Consequently, the fluorapatite samples exposed to each of the two concentrations of acetic acid received 24 hours of exposure to solution while the sample from the test solution received 72 hours of exposure. In all cases the exposure was approximately that required for the respective solution to dissolve 3.4 mm of calcite.

*Results.*—Optical and scanning electron microscopic (SEM) examination of the crystal faces and fracture surfaces of the fluorapatite samples revealed extensive alteration to the fluorapatite surfaces exposed to acetic acid solutions. Similar examination, at magnifications up to 50,000 times, of fluorapatite exposed to the test solution revealed no difference in the surfaces of the test and control samples. Figure 3 shows fluorapatite fracture surfaces that are representative of the type and extent of surface alteration observed.

## Discussion

This investigation established that it is possible to exploit differences in equilibrium solubility to dissolve one moderately soluble mineral species without appreciably damaging the surface of another.

Although this work specifically addressed the case of calcite dissolution from fluorapatite it is interesting to speculate on the possible behavior of other forms of apatite in the test solution. If, for example, a specimen which was thought to be a fluorapatite but was a hydroxylapatite were to be immersed in this solution, what would the consequences be? It is certain that the hydroxylapatite would suffer less damage than it would immersed in a simple acetic acid solution of the same

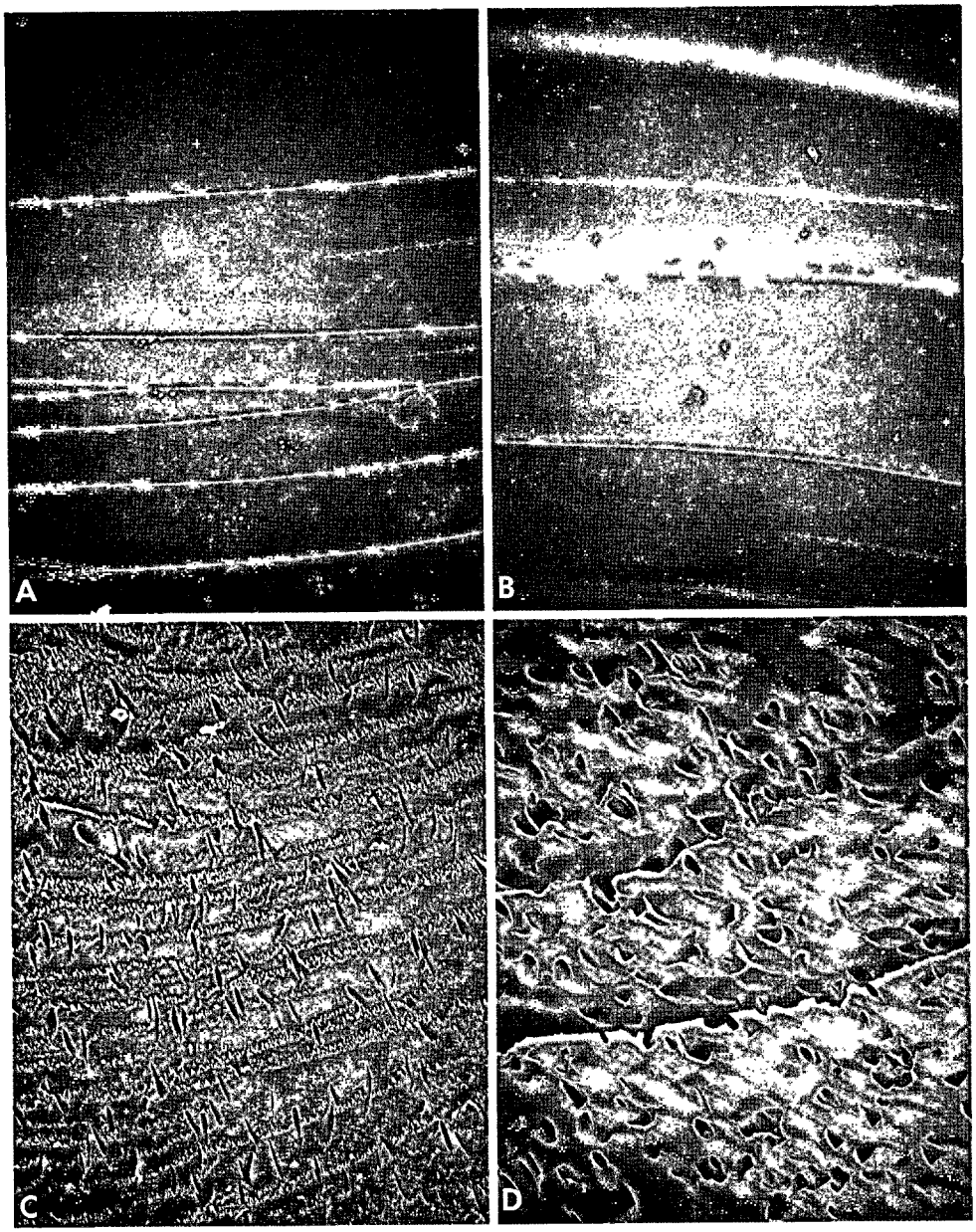


Figure 3. Scanning electron micrographs of portions of a fluorapatite fracture surface. A. Control; B. Exposed to test solution for 72 hours; C. Exposed to 5% v/v acetic acid for 24 hours; and D. Exposed to 10% v/v acetic acid for 24 hours. Area shown in each micrograph is 0.19 mm × 0.14 mm.

pH. Either it will dissolve at a reduced rate or it will undergo a surface transformation to fluorapatite similar to the well known effect of fluoridated water on human teeth. The work of Chen *et al.* (1975) on the transformation of phosphate rock to fluorapatite suggests that the latter effect may not occur within normal treatment time periods.

Generalizing the procedure to other pairs of mineral species to be dissolved and preserved is possible as long as solubility data for both species are available. It is not necessary that the mineral to be preserved is congruently soluble so long as a solution can be prepared in which the mineral is in equilibrium at the temperature of the treatment.

## Acknowledgments

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## Appendix

### *Calculation of the Solubilities of Calcite and Fluorapatite (R.A.S.)*

This appendix is included to show the calculations required for formulating the test solution. It could serve as a model for calculating solubilities of other mineral pairs. The complexity of the calculations demonstrates the benefit of collaboration with a professional chemist.

The calculation of the solubility of a salt of a weak acid, in a medium containing a pH buffer and a complexing agent that is itself a salt of a weak acid, involves the balancing of several effects. At high pH, in the absence of the complexing agent, the solubility is essentially that calculated from the solubility product constant alone. At lower pH, reaction of the anions to form protonated species increases the solubility, but at low pH the protonation of the active ion (ligand) of the complexing agent reduces its effectiveness, so the solubility may be expected to decrease. The effect of increased acidity of the medium on the solubility of the salt may thus be in either direction.

The last effect to be considered is the effect of the ionic strength of the solution which is accounted for by activity coefficients of the various ionic participants in the equilibrium. Owing to some compensatory effects in the present system, the overall effect of ionic strength is not large, but it is, nevertheless, considered.

There are four weak acids in the system considered here, which by chance are characterized by one, two, three and four dissociable protons. Hence, it is convenient to number them: 1) HF; 2) $H_2CO_3$ (as customary, this is not distinguished from dissolved $CO_2$); 3) $H_3PO_4$; and 4) ethylenediamine tetraacetic acid (EDTA) which is herein symbolized $H_4Y$. The successive dissociation constants of these

acids will be designated $K_{mn}$ for the $n^{th}$ constant of the $m^{th}$ acid. In the expressions below, square brackets [ ] represent the concentration of the species within the brackets, in $mol L^{-1}$. See below, however, for the effect of non-zero ionic strength.

## Common Considerations

In both calculations, i.e., for the solubilities of calcite ($CaCO_3$) and fluorapatite ($Ca_5(PO_4)_3F$), the following equilibria, with the corresponding equilibrium constant expressions, occur:

$$Ca^{2+} + Y^{4-} \leftrightarrow CaY^{2-} \quad : \quad K_f = \frac{[CaY^{2-}]}{[Ca^{2+}][Y^{4-}]} \tag{1}$$

$$H_4Y \leftrightarrow H^+ + H_3Y^- \quad : \quad K_{41} = \frac{[H^+][H_3Y^-]}{[H_4Y]} \tag{2}$$

$$H_3Y^- \leftrightarrow H^+ + H_2Y^{2-} \quad : \quad K_{42} = \frac{[H^+][H_2Y^{2-}]}{[H_3Y^-]} \tag{3}$$

$$H_2Y^{2-} \leftrightarrow H^+ + HY^{3-} \quad : \quad K_{43} = \frac{[H^+][HY^{3-}]}{[H_2Y^{2-}]} \tag{4}$$

$$HY^{3-} \leftrightarrow H^+ + Y^{4-} \quad : \quad K_{44} = \frac{[H^+][Y^{4-}]}{[HY^{3-}]} \tag{5}$$

in addition, the conservation of the radical Y provides that:

$$[H_4Y] + [H_3Y^-] + [H_2Y^{2-}] + [HY^{3-}] + [Y^{4-}] = y_0 - [CaY^{2-}] = y \tag{6}$$

where $y_0$ is the total concentration of the radical Y in the solution as first prepared, and $y$ is the equilibrium value of this total.

## Calcite

For the calculation of calcite solubility we must add the following equilibria:

$$CaCO_3 \leftrightarrow Ca^{2+} + CO_3^{2-} \quad : \quad K_{cal} = [Ca^{2+}][CO_3^{2-}] \tag{7}$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^- \quad : \quad K_{21} = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} \tag{8}$$

$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-} \quad : \quad K_{22} = \frac{[H^+][CO_3^{2-}]}{[HCO_3^-]} \tag{9}$$

and the statements of conservation of calcium and of the carbonate radical:

$$[Ca^{2+}] + [CaY^{2-}] = c_0 + t \tag{10}$$

$$[H_2CO_3] + [HCO_3^-] + [CO_3^{2-}] = t \tag{11}$$

where $c_0$ is the concentration of calcium ions originally present, as added $CaCl_2$, and $t$ is the solubility of $CaCO_3$ in the medium considered.

These eleven equations can be solved simultaneously for $t$. It is convenient to define the quantity $\beta_m$ such that:

$$\beta_m = \sum_{n=0}^{m} \frac{[H_{m-n}A^{m-}]}{[A^{n-}]} \tag{12}$$

for each of the four weak acids, HF, $H_2CO_3$, $H_3(PO_4)$ and $H_4Y$, represented generically as $H_mA$.

In each case $\beta_m^{-1}$ is equal to the fraction of the radical A present as the fully ionized species $A^{m-}$. For carbonate, for example, it can be shown that:

$$\beta_2 = 1 + \frac{[H^+]}{K_{22}} + \frac{[H^+]^2}{K_{22}K_{21}} \tag{13}$$

Similar expressions are derived for fluoride, phosphate and EDTA having two, four and five terms respectively. In this way, equations (1) to (11) can be reduced to:

$$t = \frac{K_{cal}\beta_2}{[Ca^{2+}]} \tag{14}$$

and

$$t + c_0 = [Ca^{2+}] + y_0\left(1 + \frac{\beta_4}{[Ca^{2+}]K_f}\right)^{-1} \tag{15}$$

Simultaneous solution of equations (14) and (15) at various pH values yields the solubility $t$ as a function of pH as shown in Figure 1 of the main body of this paper.

At low pH, below about pH = 5, the equilibrium concentration of $H_2CO_3$ is sufficiently high that the equilibrium pressure of $CO_2$ exceeds normal atmospheric pressure. Therefore, in an open vessel, evolution of $CO_2$ may take place. This is, of course, the effervescence normally associated with carbonates dissolving in acids. Equation (14), which was derived in part from equation (11) and hence assumed conservation of $CO_2$ containing species, is not valid at these lower pH levels. Equation (14) must be replaced by:

$$K_{cal} = \frac{[Ca^{2-}]s_{CO_2}K_{21}K_{22}}{[H^+]^2} \tag{16}$$

where $s_{CO_2}$ is the solubility of $CO_2$ in water at normal atmospheric pressure and room temperature. It is taken to be 0.033 $mol L^{-1}$.

## Fluorapatite

In the calculation with respect to fluorapatite equations (1) to (6) remain valid. Equations (7) to (11), which pertained to calcite, are replaced by equations (17) to (24):

$$Ca_5(PO_4)_3F \leftrightarrow 5Ca^{2+} + 3PO_4^{3+} + F^- \quad : \quad K_{fap} = [Ca^{2+}]^5[PO_4^{3+}]^3[F^-] \tag{17}$$

$$HF \leftrightarrow H^+ + F^- \quad : \quad K_{11} = \frac{[H^+][F^-]}{[HF]} \tag{18}$$

$$H_3PO_4 \leftrightarrow H^+ + H_2PO_4^- \quad : \quad K_{31} = \frac{[H^+][H_2PO_4^-]}{[H_3PO_4]} \tag{19}$$

$$H_2PO_4^- \leftrightarrow H^+ + HPO_4^{2-} \quad : \quad K_{32} = \frac{[H^+][HPO_4^{2-}]}{[H_2PO_4^-]} \tag{20}$$

$$HPO_4^{2-} \leftrightarrow H^+ + PO_4^{3-} \quad : \quad K_{33} = \frac{[H^+][PO_4^{3-}]}{[HPO_4^{2-}]} \tag{21}$$

$$5s + c_0 = [Ca^{2+}] + [CaY^{2-}] \tag{22}$$

(conservation of calcium)

$$3s = [H_3PO_4] + [H_2PO_4^-] + [HPO_4^{2-}] + [PO_4^{3-}] \tag{23}$$

(conservation of phosphate)

$$s = [HF] + [F^-] \tag{24}$$

(conservation of fluoride)

where $s$ is the solubility of fluorapatite in $mol L^{-1}$.

Equations (1) to (6) and (17) to (24) form a system of fourteen equations to be solved simultaneously. This is possible since here, as above, $[H^+]$ is not an unknown. Rather, it is fixed by the pH buffering property of the solution and by initial adjustment as described in the main body of the paper. Proceeding as before, by the use of $\beta$ functions for fluoride, phosphate and Y, we obtain equations (25) and (26) to be solved for $s$.

$$s^4 = \frac{K_{fap}\beta_3^3\beta_1}{27[Ca^{2+}]^5} \tag{25}$$

$$5s + c_0 = [Ca^{2+}] + \frac{y_0}{1 + \dfrac{\beta_4}{[Ca^{2+}]K_f}} \tag{26}$$

## Effect of Ionic Strength

The equilibrium constants above have been written in terms of molar concentrations. These expressions can be corrected to be in terms of activities of ionic species through the use of activity coefficients. Activity coefficients are dependent on the ionic strength, $\mu$, of the solution which is given by:

$$\mu = \frac{1}{2}\sum_i z_i^2[i] \tag{27}$$

where $[i]$ is the molar concentration of the ionic species $i$ and $z$ is its charge in atomic units. A convenient approximation to the Debye-Hückel activity coefficient, $y_z$, is provided by the Davies equation (Davies, 1962):

$$\log_{10} y_z = -0.5z^2\frac{\mu^{1/2}}{(1 + \mu^{1/2}) - 0.3\mu} = z^2\log_{10} y_1 \tag{28}$$

This equation neglects complexities arising from differing ionic radius and other factors and, hence, is only considered a good approximation in dilute solution having a molar concentration below about 0.1 molar. The equation was used beyond this range as an approximation of the magnitude of the correction. Using $Q_{mn}$ to represent the "practical equilibrium constant," written in terms of molar concentrations (for all species except H) and $\alpha[i]$ for the activity of the species $i$, we obtain:

$$\begin{aligned} K_{mn} &= \frac{\alpha[H^+]\alpha[H_{m-n}A^{n-}]}{\alpha[H_{m-n+1}A^{(n-1)-}]} \\ &= \frac{\alpha[H^+][H_{m-n}A^{n-}]y_n}{[H_{m-n+1}A^{(n-1)-}]y_{n-1}} \\ &= Q_{mn}y_1^{2n-1} \end{aligned} \tag{29}$$

The activity of $H^+$ has been retained in $Q_{mn}$, rather than a molar concentration and activity coefficient, as it is the former that is measured by a pH electrode and, hence, established in the solution. Similarly, the two solubility constants can be expressed:

$$K_{cal} = Q_{cal}y_1^8 \tag{30}$$

$$K_{fap} = Q_{fap}y_1^{48} \tag{31}$$

Equations (14) to (16) for calcite and equations (25) and (26) for fluorapatite can now be used in the calculation as before, with $Q$s in place of all $K$s.

## Computation of Equations

The equations obtained by eliminating [$Ca^{2+}$] from the relevant pairs of equations are cubic for calcite and of higher order for fluorapatite. Consequently, they were solved by searching for values of [$Ca^{2+}$] that make the values of $t$ or $s$ self-consistent using a programmable calculator. Solubility and stability constants employed in the calculations were taken from Martell and Smith (1974).

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# BOOK REVIEWS

**IVORY AND RELATED MATERIALS: AN ILLUSTRATED GUIDE, 1990, OLGA KRZYSZKOWSKA.** (The Institute of Classical Studies, Classical Handbook 3, Bulletin Supplement 59, London, England, 109 pp. £12.) Although the ivory and related materials discussed in this book are only those found on archaeological sites in the ancient Mediterranean, a surprisingly wide range of materials is covered: elephant and hippopotamus ivory, boar's tusk, bone, and antler. What broadens the scope of the book even further and makes it of great interest to a wide audience is the discussion of criteria and procedures that can be used to identify these materials once they have been modified into objects. Anyone who has been called upon to determine whether an object is made from bone or ivory knows how difficult this task can be. This book is a valuable new tool to help make these identifications with some degree of certainty. It is not just archaeologists or conservators in the field who will benefit from this book.

The first two chapters are introductory. The first deals with methods and equipment and sets out the basic problems of identifiying ivory and related materials. The second chapter discusses the potential sources of these materials for the people of the ancient Mediterranean.

Chapters three and four form the heart of this book. The premise of the book is that in order to distinguish between ivory and related materials once they have been modified into artifacts, it is "important to have a clear understanding of the principal features and properties of these materials in their unworked state." These features and properties are clearly set forth in chapter three for ivory and boar's tusk and in chapter four for bone and antler. The morphological and surface features and structures are discussed for each material. These discussions are not, and were not intended to be, comprehensive expositions on these topics. Rather they are limited to those aspects of these materials most relevant for identification purposes. They were also purposely kept non-technical for the non-expert reader for whom the book is intended.

In chapter five, the author sets out a method for approaching the identification of these materials. The diagnostic criteria presented in chapters three and four have been worked into a methodology that the reader can use to distinguish between elephant and hippopotamus ivory, bone, antler, and boar's tusk. As well as providing a logical step-by-step procedure, the author also carefully discusses the pitfalls that may confuse identification.

The text is augmented with short appendices covering 1) other animal products, 2) inorganic substitutes for ivory, 3) the care and storage of ivory and related materials, and 4) reference collections. Each of these topics is very cursorily dealt with; each could easily be the subject of a book in and of itself.

This book pulls together a wealth of information from a variety of different sources and presents it in a clear and very readable form. Each section is copiously illustrated with excellent line drawing, diagrams, and photographs. While the detail on some of the photographs could be clearer and sharper, they are still extremely valuable.

Considering how much the book will be used as a reference, it is a pity that it was not bound better. After reading my book once and leafing through in writing this review, the back signature is already pulling away from the spine. In spite of

this, this book will be a valuable addition to the library of anyone who handles artifacts made of ivory and related materials. It should be a must for every archaeological excavation's library.—*Catherine Sease, Field Museum of Natural History, Roosevelt Road at Lake Shore Drive, Chicago, Illinois 60605.*

**NATURAL HISTORY MUSEUMS: DIRECTIONS FOR GROWTH, 1991, Paisley S. Cato and Clyde Jones, eds.** (Texas Tech University Press, Lubbock, Texas, 252 pp.) This book grew out of a joint meeting of the Mountain-Plains Museum Association and the Midwest Museums Conference in Kansas City in 1988. Twenty two speakers addressed critical museum issues in a symposium entitled "New Directions and Professional Standards for Natural History Museums." Editors Paisley Cato and Clyde Jones compiled eighteen of these presentations into the present volume.

The book's four sections (Roles and Functions, Collections, Exhibits and Education, and The Future) include something for everyone. In the Roles and Functions section for example, Catherine and Thomas Shropshire describe the relationship between Mississippi's Museum of Natural Science and its Department of Wildlife, Fisheries and Parks. A comprehensive planned management system instituted in 1985 revealed that the Museum plays a key role in helping the Department meet educational goals related to its mission. One wonders why more wildlife management and conservation organizations don't have museum components to help with the public education functions so critical to their missions.

The Collections section contains nuts and bolts information about everything from archaeology and paleontology collections to frozen semen specimens and sets of karyotype slides. John E. Simmons, for instance, presents a thorough review of "Conservation Problems of Fluid-preserved Collections" with 61 literature citations. This description of the state of the art of fluid preservation proved quite helpful during a recent conservation assesment of our own collections, saving a considerable amount of literature review time.

The Exhibits and Education section contains five selections. Louise DeMars' is a look back at a distinguished 25 year career in exhibition design and construction at Yale's Peabody Museum. She chronicles the evolution of the design process; then looks to the future, suggesting trends and initiatives she feels will lead to better exhibits for visitors. This refreshingly honest reflection is a welcome contrast to some recent analyses suggesting, self servingly, that an individual or an institution is singlehandedly bringing about a revolution in exhibit planning and design. In fact, the roots for revolution run deep, and a large number of thoughtful, hardworking professionals have struggled for some years now to bring about change.

In the same section, Jeffry Gottfried, Rebecca Smith and Judy Dacus present a meticulous dissection of the $356,859, NSF-funded rural science education project of the New Mexico Museum of Natural History. They detail what was done and why, what worked, what didn't work, and what they would do differently next time. The New Mexico model can be modified to work in many different regions and institutions dealing with a wide variety of subject matter.

The final section, entitled The Future, contains four thought provoking articles.

Charlotte Porter's contribution, "Natural History in the 20th Century: An Oxymoron?", looks ahead by looking back. She reviews the development of natural history museums, providing fascinating tidbits about the origins of our profession. From the first use of the term natural history by Pliny the Elder, her account outlines the contributions of artists, presidents, ring masters, moguls, and scientists. She concludes that if museums can live up to the dreams and expectations of the profession's founders, we will have accomplished great things.

The book is well designed and well made. Set in 10 point Baskerville type, the text is attractive and easy to read. Abstracts at the beginning of each chapter help the reader navigate through the wealth of information, but unfortunately there is no index. In the computer age, that omission is hard to justify, and it would have made what is already a very useful work even more readily accessible. The binding is strong, and the book should be able to take the wear and tear of frequent use for many years. The dust jacket is more fun than the cover itself. It includes a subdued image of an antique compass. The arrow for north doesn't point straight up but tilts slightly right, suggesting magnetic declination. Does that mean that in setting a course we must remember that "north" doesn't necessarily lie in the direction the compass points to? Life in the museum world is tricky, things aren't always what they seem and we must remain alert to many different sources of information to make our way in it. This book is one such.—*Walter R. Davis II, Dallas Museum of Natural History, P.O. Box 150433, Dallas, Texas 75315.*

**NATURAL HISTORY COLLECTIONS: THEIR MANAGEMENT AND VALUE, 1990, E. M. Herholdt, ed.** (Special Publication #1, Transvaal Museum, Pretoria, 172 pp.) This collection contains 17 of the papers presented at a recent symposium on the Management of Natural History Collections in South Africa held at the Transvaal Museum in Pretoria. The purpose of the symposium, the first to be held in South Africa on this topic, was to encourage the participants to "reflect on and reconsider our attitudes towards natural history collections, defining the role and importance of collections managers in natural history, giving collections managers a boost as far as their attitudes towards themselves and that of other museologists towards them are concerned, and defining common problems with a view towards doing something about them." It sounds like a very useful initiative to improve the state of collections care in South Africa and to provide a forum for the exchange of collections management information.

As might be expected from a symposium with such a broad goal, the result is a very eclectic collection of papers in the fields of herpetology, mineralogy, entomology, and botany, as well as general museum and collections management issues. Six of the papers are general overviews of conservation or management issues, four deal with specific management or preparation techniques, three (including one of the general review papers) are on computerization, and five address the role of museum collections. Here lies a weakness of the book, for there really is no coherent theme holding the papers together. Although it is a logical step to wish to perpetuate the contributions to a symposium, it is worth evaluating whether the papers would better reach their respective audiences if published in established, specialized venues.

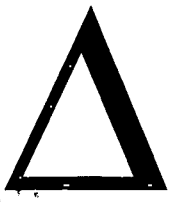
E. M. Herholdt starts out the volume with a quick overview of the scope of collections management in the very broadest sense of the term. C. A. Hawks reviews the state of conservation in natural science collections. The remaining four general review articles cover herpetological collections management (A. J. L. Lambiris), geological conservation (G. Balkwill), conservation of library materials (D. van Driel) and computerization and consortium development (R. D. Owen). These reviews are brief introductions to their topics and were indubitably valuable contributions to the symposium. However, as published resources they suffer from competition with generally available and comprehensive resources dealing with the same topics, many of which are cited frequently in these papers.

The four technical papers are principally of interest to specialists in the fields addressed. E. de Wet, P. Robertson and I. Plug's paper on degreasing bones describes work in progress to evaluate different mammalian skeletal preparation techniques. Given the sample size and the number of variables in treatment allowed for in their checksheets, it is unlikely to yield definitive answers, but it represents an encouraging step towards documenting preparation techniques with an eye to evaluation. Other technical papers include the preparation of Curculionidae (Coleoptera) larvae for SEM photography (S. Louw), record keeping for a Coleoptera collection (S. Endrödy-Younga) and containers for wet collections (F. C. de Moor).

Two of the papers present examples of computerization in South African Museums: the National Herbarium's PRECIS (T. H. Arnold); and a dBase system used for the mammal collection at the Kaffrarian Museum (L. R. Wingate). For those interested in comparing strategies, they add to the body of literature describing specific systems for computerizing collections records.

Five papers discuss the role of collections and deal with the need for scientists to deposit voucher specimens in museums (J. Meester), the role collections can play in conservation (J. A. Cambray, and I. L. Rautenbach and E. M. Herholdt), and the broad usefulness of reptile wet collections to a variety of ecological, physiological, biochemical, and other studies (M. F. Bates). The most appropriate audience for these articles would seem to be the scientists that need to be convinced of the utility of museums in these contexts, rather than museum workers themselves.

The volume concludes with an interesting essay by M. A. Raath that touches upon the question of the worth of maintaining university collections versus divestment of collections to independent museums. Mr. Raath describes the formation at the University of Witwatersrand of a Museum Users Group to establish and propagate professional collections management within the University's 15 diverse collections that could serve as a model of cooperation in other university settings.—*Elizabeth Merritt, Cincinnati Museum of Natural History, 1720 Gilbert Avenue, Cincinnati, Ohio 45202.*



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Each page of the manuscript should be numbered. Do not hyphenate words at the right-hand margin. Each table and figure should be on a separate page. The ratio of tables plus figures to text pages should generally not exceed 1:2.

The first page includes the title of the article, names of authors, affiliations and addresses of authors, and the abstract if present. In the top left-hand corner of the first page, indicate the name and mailing address for the author to whom correspondence and proofs should be addressed. All subsequent pages should have the last names of the authors in the upper left-hand corner.

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Jones, E. M., and R. D. Owen. 1987. Fluid preservation of specimens. Pp. 51–64 in *Mammal Collection Management* (H. H. Genoways, C. Jones, and O. L. Rossolimo, eds.). Texas Tech University Press, Lubbock, 219 pp.

Sarasan, L. 1987. What to look for in an automated collections management system. Museum Studies Journal, 3:82–93.

Thomson, G. 1986. *The Museum Environment*, 2nd ed. Butterworths, London, 293 pp.

*Tables and illustrations.*—Tables and illustrations should not repeat data contained in the text. Each table should be numbered with arabic numerals, include a short legend, and be referred to in the text. Column headings and descriptive matter in tables should be brief. Vertical rules should not be used. Tables should be placed one to a page, after the references.

All figures must be of professional quality as they will not be redrawn by the editorial staff. They may include line drawings, graphs or black and white photographs. All figures should be of sufficient size and clarity to permit reduction to an appropriate size; ordinarily they should be no more than twice the size of intended reductions and whenever possible should be no greater than a manuscript page size for ease of handling.

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