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*This article provides an overview of bone composition and the taphonomic processes that affect the representation of skeletal elements in archaeological deposits. Soil chemistry and composition, bone size, and other variables affect these processes.*

## Introduction

The two main components of bone are minerals and protein (Von Endt and Ortner 1984). Once bone has been discarded and entered the archaeological record, it goes through different processes that can lead to its deterioration (Lambert *et el.* 1985). These include physical, chemical, and biological processes (Lambert *et al.* 1985). These processes can be separated into two different categories: intrinsic and extrinsic factors (Von Endt and Ortner 1984). The intrinsic factors are those that take place within the bone such as "the spontaneous rearrangement of the crystalline matrix and the action of internal water on the proteins of bone" (Von Endt and Ortner 1984:248). The extrinsic factors are those that based on the environment surrounding the bone, such as the pH level of the soil and different organisms, might lead to deterioration (Von Endt and Ortner 1984). This paper will deal with how different soils effect the preservation of bones as well as which factors aid or slow down the decomposition of bone. This paper will start with a description of the characteristics of soils that effect bone preservation, which will be followed by a brief description of the different types of soil. The information gathered for the composition will come from various books and articles dealing with the subject.

## Characteristics of Soils

*Temperature*

Chemical reactions, for the most part, speed up as temperature rises (Mays 1998). Usually, it takes a rise in temperature of $10^{\circ}$ C for the rate of the chemical reaction to double (Mays 1998).

One investigation into the effect that heat has on bone was performed by David W. Von Endt and Donald J. Ortner, in the *Journal of Archaeological Science* in 1984. For their experiment, the researchers used bones from recently butchered bovines (Von Endt and Ortner 1984). They prepared the bones by cleaning, drying, and grinding them into small particles (Von Endt and Ortner 1984). They then used fire in order to seal the particles in test tubes along with water (Von Endt and Ortner 1984). Due to the fact that it would take several centuries for the experiment to be carried out with the same temperatures found at archaeological sites, hotter conditions were utilized in order to make the time it would take for the experiments completion more realistic (Von Endt and Ortner 1984). The researchers used three different temperatures to compare the effects of heat on the loss of nitrogen on bone: $100^{\circ}$, $120^{\circ}$, $130^{\circ}$ C (Von Endt and Ortner 1984). From this, it was discovered "that the rate at which bone is degraded, as indicated by nitrogen loss, is dependent on the protein content at any given time..." and

"the rate at which nitrogen, and thus protein is lost from bone is dependent to a marked degree on the temperature at which this loss is occurring" (Von Endt and Ortner 1984:252). Another conclusion derived from their experiment was that as the temperature rises, the deterioration of bone increases as well (Von Endt and Ortner 1984). Using equations described in their article, the researchers discovered that bones kept 14.5$^{o}$ C as the mean temperature would loose 63% of their nitrogen content after 4600 years (Von Endt and Ortner 1984).

*Bone Size*

In the same article that they discuss their finding on temperature's effects on bone preservation, David W. Von Endt and Donald J. Ortner also discuss an experiment into what effects bone size has on preservation, specifically the loss of nitrogen (Von Endt and Ortner 1984). The researchers prepared the bone using the same methods for their experiment that dealt with the effects of heat (Von Endt and Ortner 1984). Once the bone was ground, the researchers used different screen sizes in order to separate the bone particles based on size and then placed them into test tubes with water and then used flame to seal them (Von Endt and Ortner 1984). The samples were brought to 120$^{o}$ C and were analyzed hourly (Von Endt and Ortner 1984). The researchers discovered that the size of bone was inversely proportional to the amount of nitrogen lost (Von Endt and Ortner 1984).

*Acidity and Soil pH levels*

The pH scale measures acidity on a scale of 1 to 14 (Mays 1998). A value of 7 is considered to be neutral, any below it to be acidic and any above it to be alkaline (Mays 1998). Most of the soils found in archaeology range in between 3.5 and 8.5 on the pH scale (Mays 1998). One source of acidity is the secretion from roots (Schiffer 1987). This can cause there to be etching on the bones due to direct contact with the root (Schiffer 1987).

One article about the effects of acidity was written by Claire C. Gordon and Jane E. Buikstra published in *American Antiquity* (1981). The bones used for the study were found in silty loam and the "soil samples were recovered from feature fill in direct association with bone for burials comprising 63 adults and 32 children" (Gordon and Buikstra 1981:566). Each of the soil samples was combined with distilled water and then had its pH taken using "a Heath-Schlumberger portable pH meter" (Gordon and Buikstra 1981:568). Bones were then separated into six categories based on their preservation, with one representing bone that had not been damaged and six being bones of which there is no longer a trace (Gordon and Buikstra 1981). From the data the researchers gathered, it was shown that there was a significant correlation between the pH of the soil and the preservation of bone for both the adult and children's bones (Gordon and Buikstra 1981). The effect of the pH soil "...explains 84% of the variation in mature bone preservation...," but "...explained only 23% of the preservational variation..." in the bones of the children (Gordon and Buikstra 1981:569). With the information gained from their study, the researchers were then able to create equations that represented the preservation for adults, children, and both. For adults, the preservation is equal to -1.3pH + 12.5, for children, preservation is equal to -1.5pH + 14.9 (Gordon and Buikstra 1981). The non-age specific equation for bone preservation is more complex than the previous two because it has an extra variable: preservation equals -1.3pH - .14AGE + 13.2 (Gordon and Buikstra 1981).

In 1967, J. P. Watson wrote an article about the investigation of a termite

mound. The mound was located at a burial in Rhodesia that dated back to the Iron Age in a sub-tropical climate (Watson 1967). One of the characteristics of a termite mound is that the soil within it often is different from that surrounding it (Watson 1967). The soil on the inside of the termite mound was darker and had a texture that was finer than that outside the mound (Watson 1967). Underneath the mound, there was a horizon of stones which was at a higher elevation on the outside of the termite mound than the inside due to movement of soil by the termites (Watson 1967). To measure the soil's pH, the researchers used "a 1:5 suspension of soil and m/100 calcium chloride" (Watson 1967:667). The pH of the termite mound was found to be 6.2 at higher elevations in the mound and 7.5 at lower elevations within the mound (Watson 1967). Outside of the mound the pH was 4.8 at higher elevations and 5.4 at lower (Watson 1967). From the excavation of the grave site it was discovered there were no bones found outside of the termite mound but there were inside, which demonstrates the effect of acidity on bone (Watson 1967).

*Other*

Part of what makes up a bone is inorganic hydroxyapatite ($Ca_5$ $(PO_4)_3$ OH) (White and Hannus 1983). Two of the ions within the hydroxyapatite near the surface of the bone that are also in the soil are Ca and $PO_4$ and are thus in equilibrium (White and Hannus 1983). The ratio of these ions within the bone can change depending on how many of each ion are within the soil (White and Hannus 1983). If there are more or less of one ion, then the amount within the bone will change in order for it and the soil to be within equilibrium (White and Hannus 1983). This is important because the hydroxyapatite is contained within organic collagen, which helps to support the bone and make it more ridged (White and Hannus 1983). The place where hydroxyapatite is densest is the outer portion of the bone, where it is packed together tightly (White and Hannus 1983). Because of this, the weathering of hydroxyapatite reduces the rigidity of bones. There are other ways that both Ca and $PO_4$ can be lost from hydroxyapatite than from becoming in equivalent with the same ions in the soil (White and Hannus 1983). Ca within the hydroxyapatite can be leached if the bone is in an environment that is high in hydrogen ions within acids (White and Hannus 1983). Ca can be replaced by hydrogen in the hydroxyapatite, especially in the outside of the bone (White and Hannus 1983). However, the Ca could return to the hydroxyapatite if the environment were to become less acidic (White and Hannus 1983). $PO_4$ ions can be "precipitated as Fe and Al phosphates" if the soils are acidic enough (White and Hannus 1983:316).

E. M. White and L. A. Hannus performed a study to understand "mechanisms for the chemical decompositions or preservation of bone in archaeological soils" (White and Hannus 1983:316). This study specifically centered on deterioration of hydroxyapatite (White and Hannus 1983). The bones used for the study were collected from three archaeological sites in South Dakota which were all from large mammals believed to be bison (*Bison bison*), while cows that had drowned a couple years prior were used for modern samples (White and Hannus 1983). The bone for the first site was examined underneath a microscope so that each could be classified as to 1) what type of fragment the bone was, 2) how severe the weathering was, 3) how porous the bone is, and 4) how much charcoal is on the surface of the bone (White and Hannus 1983). The bones were ground up, put in acid, and then different tests were preformed on them in order to find out how much Ca and P were in each

(White and Hannus 1983). Also, the researchers separated bones that contained carbonates from those that did not by use of a binocular microscope (White and Hannus 1983). Bones from the second site were categorized according to which part they were from, how porous they were, and how much charcoal was evident (White and Hannus 1983). The amount of organic matter, Ca and P, were also discovered for bones from sites two and three (White and Hannus 1983). Normally bone would have a Ca:P ratio of 2.15, but the ratios ranged from 0.97 to 6.89 for the first site and have a mean of 2.37 (White and Hannus 1983). For the first site, the researchers also found that there appeared to be no correlation between the Ca:P ratio in the different bones and said bones' pore size or amount of charcoal (White and Hannus 1983). The soil at a higher elevation had a pH of around 6 to 7.5 but as the elevation decreased the pH level did as well (White and Hannus 1983). However, there is a possibility the soil was originally more acidic when the bones were discarded and then became more neutral due to leaching (White and Hannus 1983). The second site had only two bones that had exceeded the normal ratio of Ca:P in a bone and had a mean of 1.77 (White and Hannus 1983). The third site had a mean of 2.8 for the Ca:P ratio, however, the bones were more deteriorated than would be expected from this information (White and Hannus 1983). The researchers believed that this had to do with a changing of the ratio, and that despite the fact that that ratio is close to what it should be, the previous weathering had left its mark (White and Hannus 1983). The cow bone was found to have a Ca:P ratio of 2.16 (White and Hannus 1983). The researchers believed the acids that initially started the weathering of the bones in the study originated from microorganisms that had created it while they were decomposing the collagen in bones (White and Hannus 1983).

At the end of their article, the researchers described the weathering of bone "as overlapping reactions that are controlled by water, acid, oxygen, and Ca contents in the bone and soil" and created a sequence for decomposition of bone due to weathering (White and Hannus 1983:321). The first step is that with the presence of water and oxygen, microorganisms start decomposing the organic collagen in the bone which creates "$CO_2$, $HCO_3$ ions, and H ions" (White and Hannus 1983:321). Next, the elements created by the microorganisms react with the hydroxyapatite "to form $(Ca_{5-x}H_{2x})\ (PO_4)_3$ (OH) and Ca ions" (White and Hannus 1983:322). There are two other reactions that could happen next, either Ca in the soil enters the hydroxyapatite and stops the bone's dissolving or the microorganism-created elements can continue to decompose the hydroxyapatite into Ca and $HPO_4$ ions (White and Hannus 1983).

In 1985 an article was published that described an analysis done by researchers into the exchange of metal ions within the laboratory (Lambert *et al.* 1985). The ions used in the study were Al, Ca, Fe, K, Mg, Mn, Na, Pb, Sr, and Zn in order to find out what effects "pH, temperature, excess ion concentration, buffer structure, and surface area of bone" have on them (Lambert *et al.* 1985:86). Due to concern about fresh bone causing problems, the researchers decided to use bone from the woodland period found in Illinois (Lambert *et al.* 1985). They exposed fragments from three bone samples "to metallic ions in unbuffered aqueous solution," fragments from one sample to both a pH-buffered solution with imidazole/HCl and another with Bis-Tris/HCl (Lambert *et al.* 1985:86). The first tests performed used variations of metal ion concentrations, heat, and pH; however, it

was decided to limit the concentration to "three times that found in untreated bone", $24^{\circ}$ C, and a pH within the range of five to seven (Lambert *et al.* 1985:86). Both crushed bone and whole bone fragments were used since the exchange of ions depended on how much surface was exposed (Lambert *et al.* 1985). The unbuffered solutions were studied for ion exchange in all of the elements except for Fe and Al because of their acidity (Lambert *et al.* 1985). In the buffered solution, Fe was the only ion the researchers could not study due to the fact that it had a low solubility (Lambert *et al.* 1985).

From their study, the researchers found that the exchange of ions happened more in crushed bone than it did in whole or fragmented bone (Lambert *et al.* 1985). For individual elements in an unbuffered solution, the elements that increased the most were Pb, Sr, and Zn, followed by Mg and Mn, and Ca, K, and Na had the least amount of increase out of the elements studied (Lambert *et al.* 1985). Compared to bone that had been buried, only Na and Ca reacted similarly in conditions from both the laboratory and the field (Lambert *et al.* 1985). Part of the reason for the observed differences might have been the fact that the conditions in the laboratory were not the same as the conditions in the field (Lambert *et al.* 1985). Those differences include the fact that the unbuffered solutions "were slightly more acidic" than the soils, the pH level "varied from element to element," the concentrations of elements were not the same in the experiments and the soils, and metals that would be found in the soil may have been less available chemically (Lambert *et al.* 1985:89). From this, the researchers discovered, that "under conditions of slightly acidic medium and high ionic concentrations, with soluble metal ions (nitrates), large amounts of exchange are seen for Sr, Zn, and Pb... the large amount of exchange of these elements suggests that the laboratory conditions may stimulate more advanced stages of diagensis than occurred in..." the soil (Lambert *et al.* 1985:90). For Ca, Mg, Na, Pb, Sr, and Zn in buffered solutions, the amount of exchange was similar to that of the same elements in the unbuffered solutions; however, the exchange documented with Al, K and Mn was high (Lambert *et al.* 1985). From their study, the researchers concluded that Sr and Zn, which are both useful in determining diet, were more likely to be contaminated "through diagenetic processes in acidic soils" (Lambert *et al.* 1985:91).

Other factors that effect bone preservation are pressure and oxygen (Henderson 1987). When a roof collapses in a tomb, it adds more pressure on top of bone than was already there (Henderson 1987). This can lead to the bone becoming warped out of shape (Henderson 1987). Although oxygen affects soft tissue more than it does bone, the lack of it slows down decomposition considerably (Henderson 1987). Denser soils may act to stop oxygen from effecting both soft and hard tissues where as soils that are lighter in weight and more porous do not (Henderson 1987).

## Types of Soils

*Sand*

Clastic sediments are either rock or solid mineral grains and vary in there properties (Waters 1992). The different properties are particle or grain size, morphology, and the "arrangement of particles in the matrix" (Waters 1992:27). Sand is a term used to describe classic particle size (Waters 1992). Sand is clastic particles where the grain size is "between 2 and 0.0625 mm" in diameter (Waters 1992:21). Through eolian processes, the wind can cause the creation of sand dunes (Waters 1992). The pH level of sand varies

between regions (Brothwell 1972). Both Egypt and South America have hot sands that have lead to preservation of not just bone, but hair and skin as well (Brothwell 1972).

*Gravels*

Like sand, gravel is also a description of clastic particle size (Waters 1992). In order for a soil to be considered gravel, the particles need to be larger than 2 mm in diameter (Waters 1992). When the gravel is on top of a stable surface and is in a concentration that is only "one-pebble-thick", it is considered to be a stone pavement (Waters 1992:204). There are several different conditions that can vary within gravels and affect the state of bone preservation (Brothwell 1972). These conditions include permeability, acidity and if it's either waterlogged or anaerobic (Brothwell 1972). If the acidity is low, then the preservation would be good (Brothwell 1972). However if there were high acidity then there would be poor preservation (Brothwell 1972). If the gravels are water logged, it may lead to staining of the bones but can also help in preservation (Brothwell 1972).

*Clay*

Clay describes clastic particles that are smaller than 0.0039 mm in diameter (Waters 1992). Depending upon the acidity of the clay, bone preservation can vary between good and bad (Brothwell 1972).

*Salt*

When a lake or other large body of water dries up, the soil left behind can be high in salt content (Henderson 1987). The salts that are left behind from this process can be highly destructive to bone (Henderson 1987). It has been suggested that bones found in soils with high salt should be bathed in fresh water until all of the salt has been removed (Brothwell 1972). However, depending on the state of bone preservation, this technique could cause disintegration of bone (Brothwell 1972). In order to judge the bone preservation, it is suggested to test one of the bones and if the researcher is worried about disintegration, then it might be prudent to soak the bone for a short time and apply "a coat of water-permeable nylon" to help give the bone support (Brothwell 1972; 10).

*Chalk*

Chalk soils can cause bones to become both fragile and eroded (Brothwell 1972). It may be hard to completely clean the bones and if the process is too vigorous, it can cause either damage to, or loss of, information from the bone (Brothwell 1972). There are times which other factors can cause the bones to be preserved better than expected (Henderson 1987). One example of this was found at a site in Yorkshire (Henderson 1987). The soil was composed of chalk, but other factors caused the bone to be preserved better than expected (Henderson 1987).

*Cave Soils*

Caves are recesses that are formed naturally in bedrock and extended into below ground passageways (Waters 1992). The mouth of caves receive sunlight and are influenced by the weather outside of the cave (Waters 1992). Further within caves, the atmosphere differs from that at the mouth and tends to be more damp (Waters 1992). Human habitation of caves tended to be at the mouth, the sites further within the cave system were used for ritualistic activities (Waters 1992). The sediments within the cave are often created through the weathering of the walls and ceilings; however, soils from the outside can enter the cave through fissures found on the walls or ceilings (Waters 1992). Also, stalagmites

and stalactites can be created from the dripping of calcium from the ceilings of caves (Waters 1992). There is a wide variety of deposits that could be found in caves that include clay, gravel, and sand as well as others (Brothwell 1972). Bones that were found to have been completely covered up by a stalagmite often have very good preservation (Brothwell 1972).

## Conclusion

Bones deteriorate at different rates depending on what the environment is like surrounding them. There are several characteristics of soil that will effect the preservation of bone. Bone deterioration worsens as the temperature rises (Von Endt and Ortner 1984). The pH level of a soil can effect the preservation and where it is highly acidic it will completely destroy bones (Watson 1967). The amount of certain elements in bones can change in certain circumstances and thus effect preservation (Lambert *et al.* 1985; White and Hannus 1983). Pressure on the bone can cause it to loose its original shape and the lack of oxygen can slow down its destruction (Henderson 1987). Different soils can affect bones in various ways. Depending on the pH of sand, the preservation can vary (Brothwell 1972). An example of this are the sands in Egypt and South America where soft and hard tissues are preserved (Brothwell 1972). The pH level of gravel can also vary, which well effect preservation (Brothwell 1972). However, if the gravel is waterlogged, the preservation can be good (Brothwell 1972). Clay's effect on bone preservation is dependent on its pH level (Brothwell 1972). If a body of water dries up and leaves behind large amounts of salt, it can cause the deterioration of bone (Henderson 1987). Bone commonly becomes both fragile and eroded when in chalk soils (Brothwell 1972). There can be many different kinds of soils and conditions within caves that can effect their preservation (Brothwell 1972; Waters 1992). While most books on the subject of excavating bones discuss the effects of soil characteristics, it was hard to find one that talked about individual soils. It is important to know how different characteristics effect bone preservation, but it would be helpful if there was a work that went in-depth into both. It would also be helpful for an archaeologist to know what effects can be expected from individual soils. An article or book containing this information was not found during research for this paper. Because of this, it would be helpful for people who are interested in this subject to have a comprehensive collection of material in a well circulated document.

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