
Taphonomic Bone Staining and Color Changes in Forensic Contexts

12

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*I know for sure that I have an instinct for color, and that it will come to me more and more,
that painting is in the very marrow of my bones.*

—Vincent van Gogh, letter to Theo van Gogh, 3 September 1882

Introduction

A component of forensic skeletal analysis is to identify various postmortem modifications and to reconstruct the depositional history of the remains. Describing any color changes associated with bones is important to this process, as it may provide clues when reconstructing the post-depositional environment of skeletal remains. The purpose of this chapter is to discuss the common types of taphonomic bone stains and color changes and discuss the causative agents for those stains. The aim of this chapter is not to provide an exhaustive list of every example of stain that has been discussed in the literature but rather to highlight examples of bone staining such as organic, metal, and soil, which are more commonly encountered by the forensic anthropologist.

To understand how bone changes color, it is important to be familiar with the normal color of unstained bone when describing staining found on bones. Normal fresh bone devoid of flesh has been described as having a yellowish-white to yellowish-brown color (Figure 12.1a through c) due to the retention of lipids and other fluids (Byers 2008; Schafer 2001). Interestingly, fresh skulls with a bright yellow color have been associated with individuals who suffered from diabetes (Gruspier 1999). While Schafer (2001) did not find an increased yellow coloration in a small sample of fresh diabetic skulls compared to a sample of nondiabetic skulls, he did find a correlation of increased yellow hue with increased age at death.

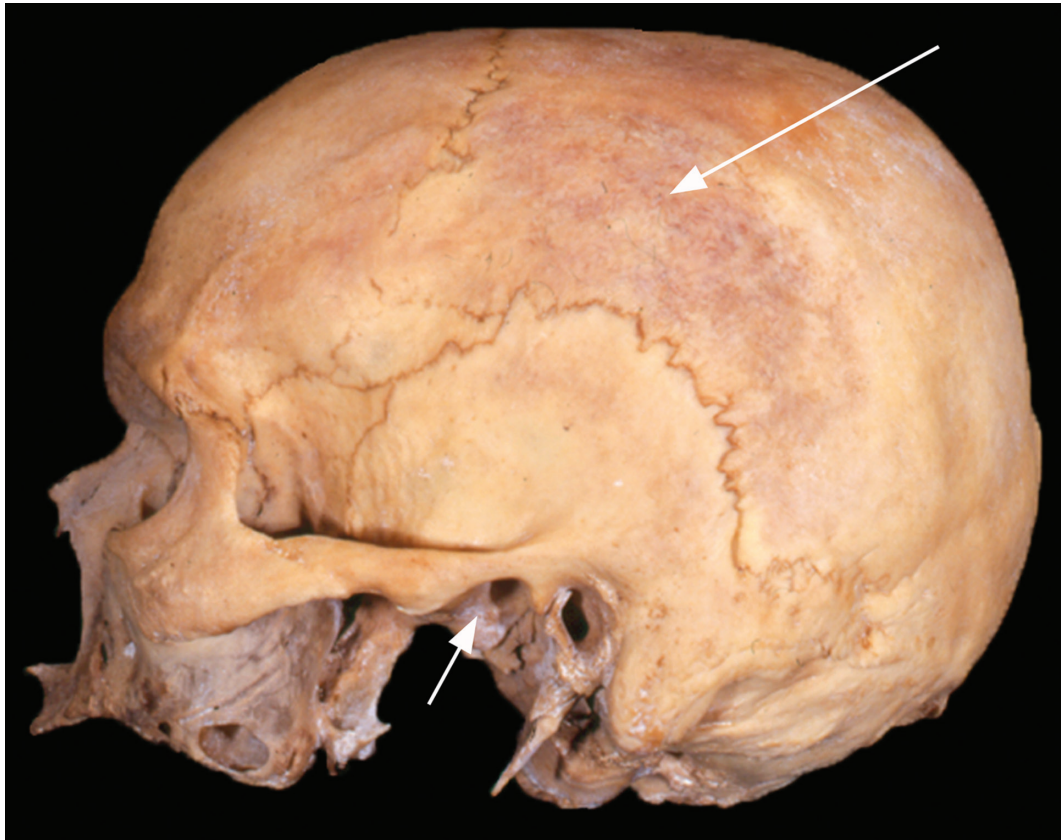
A suggested method to document bone color is by the use of a Munsell® Color chart (e.g., Cain 2005) which identifies color based on three dimensions: value, hue and chroma. The color of bone will change during the decomposition process and when the bone is completely dry. In a controlled study designed to analyze the early postmortem interval (PMI) up to 8 weeks, Huculak and Rogers (2009) concluded that color changes occurring on various skeletal elements that were either on the ground surface or buried were the result of soil, sun, hemolysis, decomposition, and fungi. During decomposition, bones can display areas of dark reddish brown coloration due to hemolysis, or the breakdown of red blood cells (Figure 12.1a), and a dark reddish gray coloration due to decomposition staining (Huculak and Rogers 2009). When bones become dry during the postmortem period, the yellowish hue may change to an ivory or off-white color (Figure 12.1b) (Byers 2008). There are, however, many taphonomic and environmental conditions which can cause a myriad of color changes to bone. In fact, bones recovered from outdoor environments often display differential patterns of staining that represent multiple taphonomic processes (Figures 12.2a and b). At the same time, it is important to recognize that different taphonomic processes can cause similar color changes to bone. For example, a variety of taphonomic processes can result in a white coloration to bone such as adipocere remnants, burning, sun bleaching, adhered concretions, and commercial preparation of skeletal remains for teaching (discussed below).

Chemical Staining and Natural Bleaching

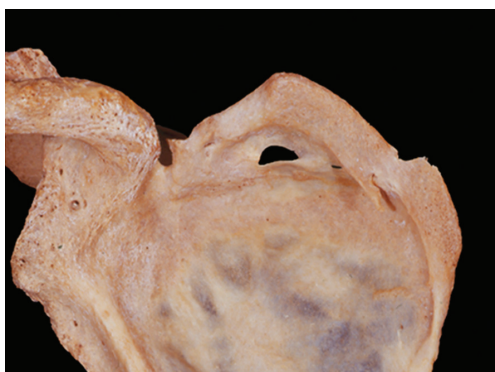
Sun Bleaching

In some cases bones may appear to be a variant of the color white, from gray to brilliant white. Ultraviolet radiation from sunlight will cause natural bleaching of exposed bones (see Chapter 11, this volume). Solar UV radiation can be responsible for the degradation and/or decomposition of many organic compounds, and it does so by breaking chemical bonds during photolytic and photo-oxidative reactions (Zayat et al. 2007). In bone, UV radiation assists in breaking down the organic components that contribute to the color of bone such as blood, lipids, and proteins. Eventually, after substantial exposure to UV radiation and other environmental conditions, all that may remain is the mineral portion of bone, hydroxyapatite, which is naturally white in color.

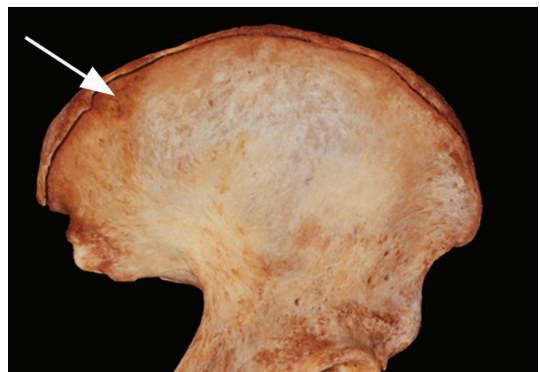
The color of bleached bones will depend on the length of exposure, and it is observed that the longer the exposure, the more bleached the bones can become. After significant exposure bones may appear a brilliant white color (Beary 2005; Haglund et al. 2002; Ubelaker 1997). Several authors note changes in bone color due to sun bleaching



(a)



(b)



(c)

Figure 12.1 Examples of natural bone coloration reflecting the presence of lipids: (a) cranium showing examples of hemolysis (top arrow) and adipocere (bottom arrow); (b) scapula with tissue and lipid retention; and (c) ilium with darker coloration representing concentrated areas of lipid retention (arrow).

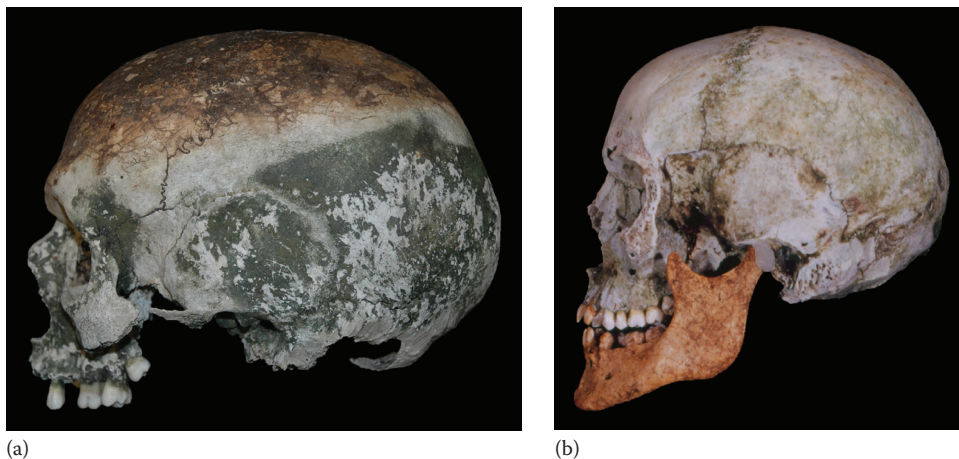


Figure 12.2 Differential staining: (a) sun-bleached cranium exhibiting a darker soil stain on the superior aspect due to contact with an organic soil horizon, algae staining on the face and sides of the cranial vault; and (b) sun-bleached skull with minimal algae staining on the vault and face and prominent soil staining of the mandible and dentition.

(e.g., Calce and Rogers 2007; Galloway et al. 1989; Huculak and Rogers 2009; Quatrehomme and İşcan 1997; Schultz 2012). Figure 12.3a through c shows the effects of sun bleaching on bones from different contexts. Figure 12.3a shows a left femur from an archaeological context in Egypt in which the bone had been exposed on the surface for over a year. In addition to bleaching, bones may show substantial surface cracking and exfoliation due to exposure to additional environmental conditions such as cold, heat, moisture, and wind (Figure 12.3a) (see Chapter 11, this volume). Bones may also be differentially bleached dependent on their position relative to the ground surface. For example, Figure 12.3b shows a skull from a forensic context in which the left side of mandible remained in contact with the soil, while the cranium was resting on the surface with the left side exposed to the sun. Figure 12.3c shows a differentially stained sacrum from an archaeological context. In this case the sacrum remained partially buried with only the superior aspect exposed to the sun.

It is important to note that bones may also appear white due to other circumstances. For example, exposure to intense heat or fire may also change bones to a variant of the color white (calcined). Much like UV radiation, intense heat can destroy organic materials in and associated with bone, therefore leaving only the inorganic component (see Chapter 14, this volume). Figure 12.3d shows a vertebra exposed to fire and the associated white color which could be easily mistaken for sun bleaching. Bone also may have a white appearance due to the presence of adipocere, the remnants of the process of lipid hydrolysis during decomposition (Aufderheide 2011; Ubelaker and Zarenko 2011; see also Chapter 5, this volume). While bleaching and fire change the entire constitution of the bone, adipocere is normally adhered only to the internal and external surfaces of the bone, and has a waxy, greasy texture that turns friable when dried. Figure 12.4 shows examples of adipocere associated with bones from forensic contexts. Figure 12.4a shows adipocere on the proximal end of a right ulna, while Figure 12.4b shows adipocere on the internal surface of the medullary cavity of a femoral diaphysis. Adipocere also can be noted on the inferior surface and external auditory meatus of the cranium in Figure 12.1a.



Figure 12.3 White coloration due to sun bleaching and fire exposure: (a) archaeological left femur displaying sun bleaching with surface cracking and exfoliation; (b) skull with sun bleaching on face and cranial vault; (c) archaeological sacrum showing sun bleaching of superior aspect; and (d) calcined thoracic vertebra.

Other Chemical Staining

During the process of preparing skeletal remains from forensic contexts for examination, or for commercial preparation (e.g., teaching specimens), chemical agents may be used for the purposes of degreasing and/or whitening bones (Figure 12.5). Dependent on the amount of soft tissue and lipids remaining, different chemicals may be used to treat skeletal remains. As more organic components are removed, the bone will become increasingly white; however, it is very difficult to remove all the organic material associated with or in bone without altering the chemical composition, surface, or shape of the bone (see Figure 12.5a). In the preparation of skeletal materials for forensic examination, once an acceptable level of soft tissue and lipids are removed with the use of a degreasing agent, preparation will cease (Mairs et al. 2004). This is imperative for the preservation of evidence and molecular structures such as DNA (Fenton et al. 2003; Steadman et al. 2006). A mixture of detergent, sodium carbonate, hot water, boiling

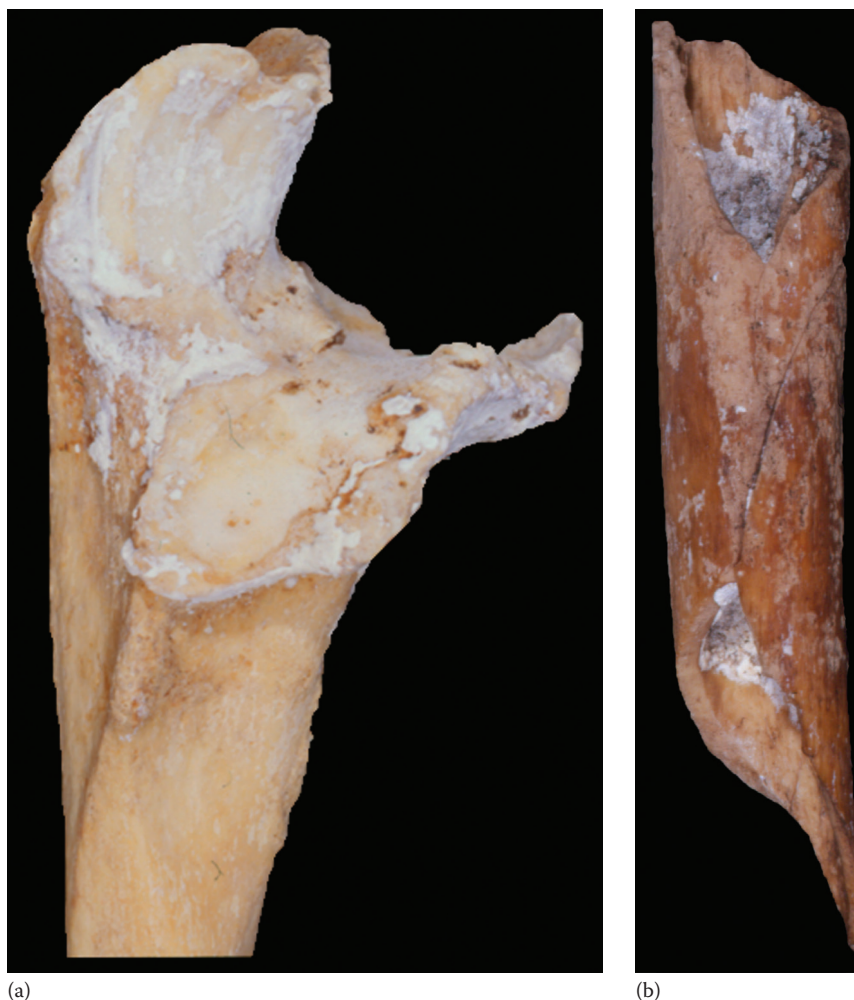


Figure 12.4 Adipocere: (a) proximal right ulna with minimal adipocere development (white areas); and (b) femoral shaft exhibiting adipocere in the medullary cavity.

water, and microwaving has been found to be one of the most efficient methods of maceration that also yielded the most total DNA (Lee et al. 2010; Steadman et al. 2006). Methods such as this will degrade the proteins of soft tissues and lipids, and caution must be taken so that over-processing does not affect the structural integrity of the bone (Figure 12.5a). After this process the bone may still have a yellowish hue due to the retention of some lipids.

If the skeletal remains are commercially prepared for sale as teaching materials, the next step after lipid removal will be to treat the bones with a bleaching agent such as sodium hypochlorite (NaClO) or hydrogen peroxide (H_2O_2) (Rennick et al. 2005). A bleaching agent is a chemical which can whiten or decolorize any substances which contains *chromophores*—groups of atoms which absorb visible light, and reflect or transmit the light that is not absorbed, as color. Bleaching agents destroy chromophores through oxidation or reduction, resulting in the removal of color (Joiner 2006). Unfortunately, many bleaching agents also attack and destroy the organic and mineral component of

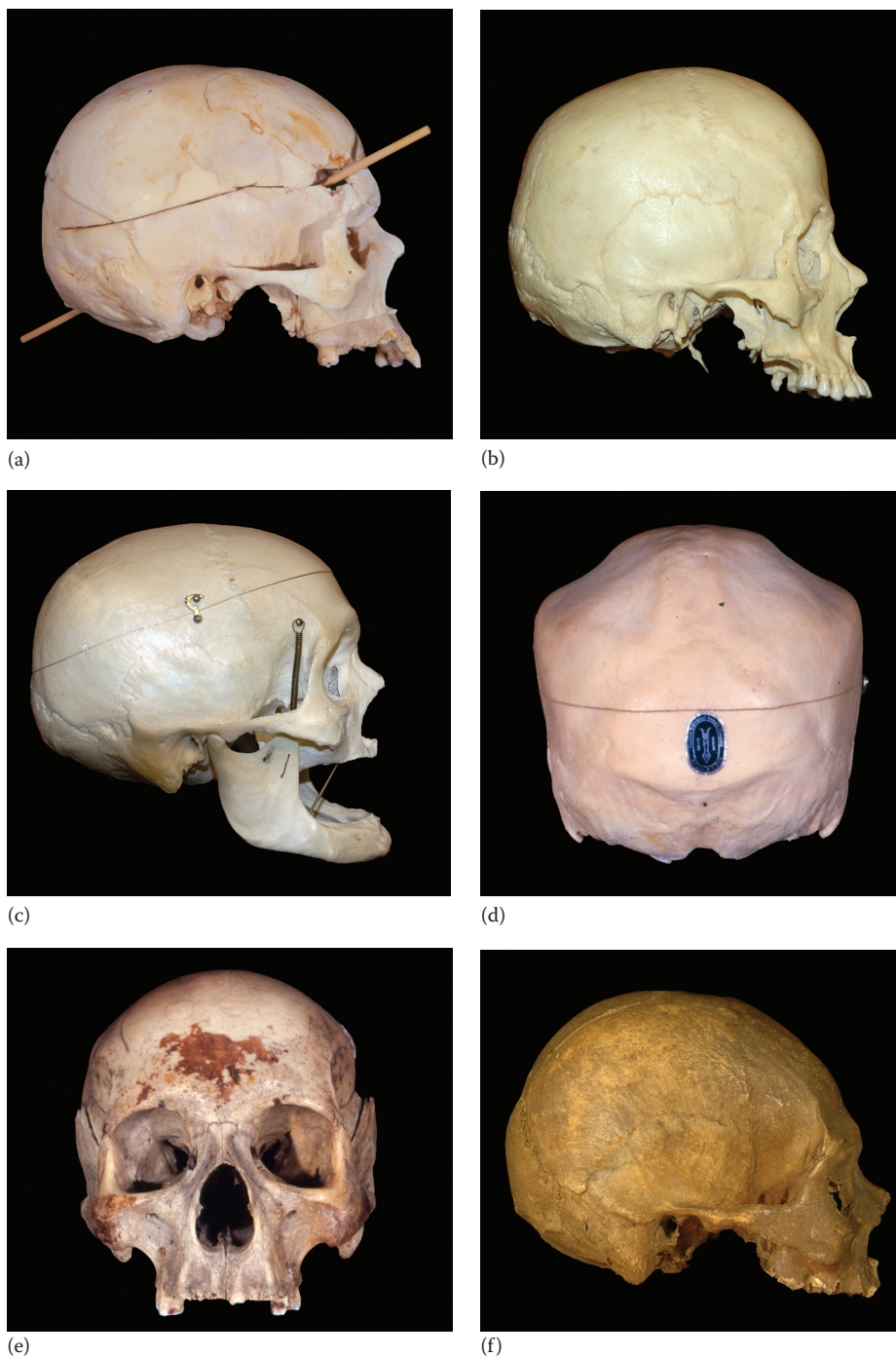


Figure 12.5 Chemically treated crania showing differential coloration: (a) forensic skull displaying white coloration due to over-processing; (b) commercially prepared teaching cranium from China, bleached off-white; (c) commercially prepared teaching skull most likely from India, bleached white; (d) commercially prepared teaching cranium most likely from India, bleached white; (e) slightly dirty commercially prepared teaching cranium bleached white with adhered packing material; and (f) commercially prepared teaching cranium that is dirty from handling.



Figure 12.6 Cranium from forensic context showing chemical staining produced by hydrochloric acid that was used in an attempt to dissolve identifying features.

bone, so this step is not advised for treating materials from forensic contexts (Rennick et al. 2005; Steadman et al. 2006). After this process skeletal materials are usually a bright white color (Figure 12.5c,d).

A number of authors have discussed how assailants have used corrosive chemicals in an attempt to dispose of or mutilate a body (e.g., Maples and Browning 1994; Ubelaker and Sperber 1988). At present there are very few publications that reference the clandestine use of corrosive chemicals on human remains, and research in this area only briefly mentions associated color changes (e.g., Cope and Dupras 2009; Hartnett et al. 2011). Areas of dark brown staining have been noted on remains which have been exposed to hydrochloric acid (HCl) (Figure 12.6), while suspected exposure to sodium hydroxide (NaOH) is thought to whiten bone (Christensen and Meyers 2011; Cope and Dupras 2009).

Staining—Skeletal Teaching Materials

Most material in skeletal teaching collections, particularly those in North America, were likely procured from India or China. Due to variation in commercial preparation techniques, the color of this material may vary (Schultz 2012). [Figure 12.5](#) shows several examples of skeletal material legally purchased from clearing houses for the purposes of teaching. Figure 12.5b shows a cranium that originated in China, and it is common that the color of these materials vary from white to yellowish-white. Figure 12.5d,e show the materials that were prepared in India, and these materials are usually a bright white color, although they may show dark staining on the alveolar region due to the chewing of betel nut (Schultz 2012). Figure 12.5e is also interesting in that the cranium has

paper (appearing as dark areas) adhered to the frontal and right zygomatic due to the long term storage of this particular specimen. It is also important to note that after significant handling in the classroom setting, teaching material that was once bright white may become very dirty, forming a *patina* of residual skin oils and dust or other particle and showing as a dark brown or gray color with variable glossiness (Figure 12.5f). These color changes likely will be accompanied by other, physical alterations to remains professionally prepared for teaching, including sectioning and mounting (see Chapter 8, this volume).

Soil Staining

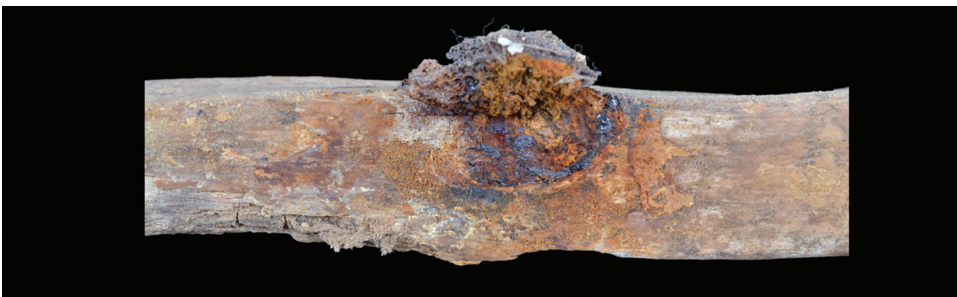
It is very common to observe staining on bones from outdoor contexts resulting from burial of the remains, or bone surfaces that are in contact with the soil surface (e.g., Figures 12.2a,b and 12.3b,c). The coloration of the staining is related to the soil composition which can include various minerals and organic matter. Color is the most obvious characteristic of soil that we first notice, which is the result of either clean soil particles or the coatings of the soil particles (Schaetzl and Anderson 2005). For example, white soil coloration can be due to sodium salts, carbonates, and silt-sized or smaller quartz grains without pigmenting coatings. Dark soils with a black or brown coloration are the result of organic matter (humus) as well as magnetite (Fe_3O_4). Black or bluish-black colorations are the result of reduced manganese (Mn^{2+}). Bright red and brown colorations are associated with well-drained soils and oxidizing conditions (iron-bearing).

In forensic contexts, soil staining on bone may be represented by various colors. The organic horizons of a mineral soil profile begin at the ground surface and are formed from the residues of decaying plant and animal remains (Brady and Weil 2002). A black or darker brown coloration on bones in contact with the ground surface is associated with the darkly colored organic matter that comprises the organic horizons (see Chapter 5, this volume). It should be noted that teeth also may be stained differentially by soil contact. It is common for the anterior (single-rooted) teeth to be soil-stained, since they may be in contact with or become buried under the ground surface after detaching from the alveolus during decomposition (Figure 12.7).

It is common for buried skeletal remains from forensic contexts to exhibit brownish colorations. At the same time, buried skeletal remains from historical contexts have been described as displaying a uniform medium to rich chocolate brown coloration resulting from either tannins in the soil solution (soil water and dissolved load) or iron oxides in the soil (Schultz et al. 2003; see also Chapter 5, this volume). The interaction of bone within an environment is dominated by water, which transports ions, molecules, and particles in and out of bone (Millard 1996). Further, the chemical interaction between buried objects and the burial medium is mainly the result of the chemical nature of the soil solution (Pollard 1996), as the chemistry, pH, and Eh of the soil solution will control the diagenetic change to bone (Millard 1996). Therefore, in the burial environment bone staining will occur due to contact with the soil and through the interaction with the soil solution. While darker-colored minerals and organic matter present in the soil solution will result in darker staining such as dark brown, buried bone exhibiting a lighter-colored staining such as tan (e.g., Figure 12.8) may be buried in a lighter colored mineral soil low in organic matter and comprised of smaller quartz grains without



Figure 12.7 Sun-bleached cranium showing differential staining of teeth. After decomposition the incisors detached from the alveolus and were stained by contact with the soil.



(a)



(b)

Figure 12.8 Iron staining: (a) large mass of iron corrosion products adhered to femoral diaphysis; and (b) prominent orange area of iron staining with adhered rust on long bone diaphysis. The light brown color is most likely due to exposure to sandy soil matrix.

pigmentation coatings. Soil staining on bones that have been in contact with the ground surface is also important in determining if skeletal remains had been moved prior to discovery by investigators. For example, if the soil-stained surface is facing up and not in contact with the ground surface, this would be a clear indication that the remains had been disturbed.

Manganese, present in many minerals, is one of the most abundant metals in soil (Emsley 2001). Depending on its state, manganese can form compounds with different colors, and these compounds may stain bone different colors. For example, manganese dioxide (MnO_2) will stain bone a black color (Cukrowska et al. 2005; Shahack-Gross et al. 1997), manganese (II) carbonate (MnCO_3) can stain bones a pink to red or brown color (Anthony et al. 2010), and permanganate ions (KMnO_4) may stain bone a purple color (House 2008).

Metal Staining from Artifacts

According to Goffer (2007), corrosion is a natural destructive environmental process resulting in decay or waste of most metals and alloys. This natural tendency of metal and alloy corrosion, with the exception of noble metals such as gold and platinum, results by combining them with an oxidizing substance (e.g., oxygen, fluoride, etc.). This corrosion process is a reversal of the metallurgical process back to the natural chemically combined form found in the crust of the earth. For example, rust found on the surface of exposed iron and steel has the same chemical composition as natural iron ore (Goffer 2007). Corrosion of metal in contact with bone results in metal staining and possibly adhered corrosion products to the bone. In a forensic context, common metals that stain bone are iron (Schultz 2012; Schultz et al. 2003) and copper (Buikstra and Ubelaker 1994; Schultz 2012; Schultz et al. 2003), with mercury staining less commonly reported (Ubelaker 1996).

According to Janaway (2008), corrosion of metal in a burial environment is influenced by a number of variables that include the PMI, the chemical nature of the burial environment, and the composition and structure of the metal artifact. If the burial environment contains high levels of moisture, metals will corrode much faster, and corrosion products such as oxides, carbonates, and sulphates are produced when metals react with environmental chemicals such as oxygen, carbon dioxide, and salts (Cronyn 1990). In forensic contexts, the burial environment will obviously contain moisture related to the decomposition process, as well as percolating rainwater and possible proximity to shallow water tables. Further, Edwards (1996) and Banwart (1996) assert that the combination of pH and redox (an increase in oxidation or the loss of electrons) are chemical variables of the burial environment that will influence metal corrosion. For example, metal will not corrode in a burial environment with low redox (decrease in oxidation or a gain in electrons) values, while metals with high redox values will be more susceptible to corrosion (Janaway 2008). At the same time, while an alkaline (higher pH) burial environment will tend to stabilize the corrosion matrix in most metals, acidic (lower pH) conditions will corrode metals (Janaway 2008).

Janaway (2008) further emphasizes how the chemical nature of the buried object will influence corrosion, by dividing metals into three groups based on their susceptibility to corrosion. The first group of metals is classified as corrosion-resistant and common examples include gold or surgical steel used for body piercings and titanium alloys used for

implants. The second group of metals is susceptible to an initial rapid corrosion phase, followed by the creation of a layer of stable corrosion products (e.g., copper). In addition, these metals can have an extensive metallic core preserved hundreds of years after burial. The third group of metals corrodes rapidly and does not form a layer of protective corrosion products. Iron would be an example of a rapidly corroding metal that can be characterized as completely lost over an extended PMI, or it can remain as a large mass of corrosion that may cover a reduced metallic core (Figure 12.8a).

Iron

Rust, a brown, crumbly corrosion product composed of hydrated iron oxide, is formed when iron and its alloys are exposed to a moist, oxygenated environment (Cronyn 1990; Goffer 2007). As corrosion proceeds into the metal, a thick overlying concretion of corrosion products can be formed over the iron artifact (Figure 12.8a) (Cronyn 1990). Eventually, the metal can be completely corroded and only represented by a void within the overlying concretion. According to Cronyn (1990), in moist and oxygenated environments, the oxidized iron can produce an area of corrosion products that can be considerably larger than the dissolved metal. Hence, staining of bone can occur (Figure 12.8b) when the item is in direct contact with the corroding iron object or in proximity to the corrosion products in the soil. Iron staining of bone also may be used to recognize out-of-context cemetery remains, as iron artifacts associated with the coffin such as nails (see Chapter 5, this volume) can stain bone an orange color, and adhered corrosion products also may be present (Schultz 2012; Schultz et al. 2003).

Corrosion of iron results in a layer/crust of corrosion products that can display a variety of colors (Cronyn 1990). Iron excavated from damp, aerated sites is commonly recovered as a mass with a red/brown coloration composed of iron oxides and carbonates. The corrosion products consist of iron (III) oxyhydroxides ($\text{FeO}\cdot\text{OH}$), with the main component in the form of red/brown/yellow goethite ($\alpha\text{FeO}\cdot\text{OH}$), including orange lepidocrocite ($\gamma\text{FeO}\cdot\text{OH}$). A black coloration to the corrosion products of iron can occur from a number of different compounds. When iron objects are subjected to a wet, anaerobic burial environment because of iron (II) sulphide (FeS) formed by sulphate-reducing bacteria, a black layer can be formed. Also, a black coloration due to the formation of black oxide magnetite (Fe_3O_4) can form at marine sites with low oxygen. Interestingly, Cronyn (1990) further mentions that green-colored rust is also possible as a mixture of iron (II) and iron (III) hydrated oxides. While it is observed occasionally on marine cast and wrought iron, it also has been observed on wrought iron from land sites. Considering that the green coloration from copper and copper alloys found on bone is most often a stain and not an adhered green corrosion product, this rare example more than likely does not have to be considered when interpreting green staining as copper-derived.

Lastly, a bright blue to blue-black coloration is much rarer and can be displayed on bone resulting from deposits of vivianite (iron phosphate). In the form of iron (II) phosphate ($\text{Fe}_3(\text{PO}_4)_2\cdot 8\text{H}_2\text{O}$), vivianite exhibits a whitish-gray coloration in its unoxidized condition when first excavated, but when exposed to air the mineral changes color to a brilliant blue (Cronyn 1990; Guthrie 1990). When referring to paleontological bones, this mineral staining occurs on buried organic remains that are high in phosphates and low in iron and that are buried in damp soils rich in iron and low in phosphates (Guthrie 1990). With the combination of a phosphate and iron source, there must be a reducing and acidic

environment for vivianite to form (Courty et al. 1989). Examples of a reducing environment include acid groundwater, deep water, waterlogged soil, and anaerobic conditions (Courty et al. 1989; Johanson 1976; Mann et al. 1998; Martill 1991; Thali et al. 2011). While vivianite staining traditionally has been reported in the paleontological literature (Guthrie 1990; Martill 1991), this staining also has been sampled on skeletal remains from U.S. servicemen listed as missing in action from the Vietnam War, which indicates that this staining can be produced on bone during much shorter PMIs than previously believed (Holland et al. 1997; Mann et al. 1998). According to Mann et al. (1998) based on experience and summarizing the literature, the iron source for the formation of vivianite on bone can also come from a nearby piece of iron in addition to the soil, a common occurrence on battlefield and air crash sites.

Copper and Copper Alloys

Copper and copper alloy staining is fairly recognizable on bone as a green to green-bluish coloration (Buikstra and Ubelaker 1994; Schultz 2012; Schultz et al. 2003). Copper staining has been reported in the literature dealing with taphonomic clues to recognize out-of-context cemetery remains as artifacts comprised of copper, including coffin hardware or jewelry, can corrode and stain bone a greenish coloration (Figure 12.9) (Schultz 2012; Schultz et al. 2003). In forensic contexts copper staining may be present on bone as a result of the copper alloy-based clothing artifacts such as buttons and zippers and also from the copper jacket of a bullet (Figure 12.10).

The two most common alloys of copper are bronze and brass. Brass, which is stronger and harder than copper, is primarily a mixture of copper and zinc, while bronze, which is harder and has a higher tensile strength than copper, is primarily a mixture of copper and tin (Goffer 2007). While copper and copper alloys are generally resistant to corrosion under normal atmospheric conditions, these metals will tarnish by contact with pollutants such as hydrogen sulfide and/or carbon dioxide (Goffer 2007). Eventually, corrosion will produce a green surface layer referred to as a patina with the metallic core remaining unchanged. Compounds such as copper carbonates, oxides, and chlorides comprise the copper patina, while the patina for bronze and brass also includes oxides of tin and lead (Goffer 2007). Slow, controlled corrosion to the surface of copper and copper alloys is due to moisture, carbon dioxide, oxygen, air pollutants, and sea water (Cronyn 1990; Goffer 2007). Conversely, buried copper objects may become severely corroded as they react with soil pollutants and components of the soil (Goffer 2007).

According to Cronyn (1990), there also can be color variation of the corrosion products resulting from the environment and type of copper alloy. For example, the common green coloration observed on bone is the result of emerald/dark-green malachite, basic copper (II) carbonate ($\text{CuCO}_3 \cdot \text{Cu(OH)}_2$). The hue of the green can be darkened by the addition of sulphides of copper and lead, or lightened by the addition of lead carbonate and other compounds. A blue color can also develop from another basic copper (II) carbonate, azurite ($2\text{CuCO}_3 \cdot \text{Cu(OH)}_2$), while yellow-green patinas can form on copper alloys exposed to the atmosphere from basic copper (II) sulphate, brochantite ($\text{CuCO}_4 \cdot 3\text{Cu(OH)}_2$). Further, corrosion of copper artifacts can also produce a crust of corrosion products that usually contain the same minerals as the patinas (Cronyn 1990).

On occasion, the presence of copper also will aid in the preservation of organic materials (McIntosh 1999). For example, if cotton clothing is present, the copper may act



Figure 12.9 Copper staining on historic-era remains: (a) copper staining and fabric preservation on the diaphysis of a right humerus; (b) copper staining and fabric preservation on the superior pubic ramus and ilium of a left innominate; and (c) copper staining along the anterior axial border of a right scapula.

as a preserving agent, and it is not uncommon to see small pieces of cloth adhered to areas that are stained green. For example, both the historic-era humerus and innominate in Figure 12.9a and b show preservation of cotton material adhered to the stained areas.

Mercury

Mercury staining from dental amalgam restorations is one of the less commonly reported chemical stains. A dental amalgam is classified as a solid emulsion metal mixture comprised



Figure 12.10 Copper staining on remains from forensic contexts: (a) prominent staining of the superior pubic area (arrow) most likely from clothing fasteners; decomposition staining is notable on the iliac blade; and (b) faint staining on the spinous process of a thoracic vertebra from a copper bullet jacket (arrow).

of approximately 50% metallic mercury (Hg^0) by mass (Richardson et al. 2011). While the formulations will vary in the Hg content from 43% to 50.5% by mass, the powder mixture typically will contain a variety of metals such as silver (40%–70%), copper (12%–30%), tin (12%–30%), indium (0%–4%), zinc (0%–1%), and palladium (0.5%) (Berry et al. 1994). Although it is now accepted that there is a continual release and therefore exposure of Hg^0 in living persons with amalgam fillings (USFDA 2009), it is not common to see mercury staining of the dental anatomy.

Mercury stains on osseous material have been the result of postmortem deterioration of the amalgam fillings. In the only case study describing the causative agent of mercury stains to the dental anatomy, Ubelaker (1996) described a metallic black stain to the oral cavity of an exhumed cemetery skeleton with a significant number of dental amalgam restorations. Staining was present on the anterior dentition of both the maxillary and mandibular teeth, as well as the mandible. In addition, it was reported that the dental amalgam restorations were deteriorated. While the causative agent for the deterioration of the amalgam fillings and resultant staining of the osseous surfaces was not known, Ubelaker (1996) suggested that the staining may be produced from the presence of sulfuric acid (H_2SO_4) in the burial environment. For example, sulfur dioxide (SO_2) could have been released from decomposition, producing sulfuric acid in the humid environment of the vault. The interaction of the sulfuric acid, or possibly some other compound, released the mercury from the amalgam restorations, producing the staining. Figure 12.11a through c shows an example of the deterioration of

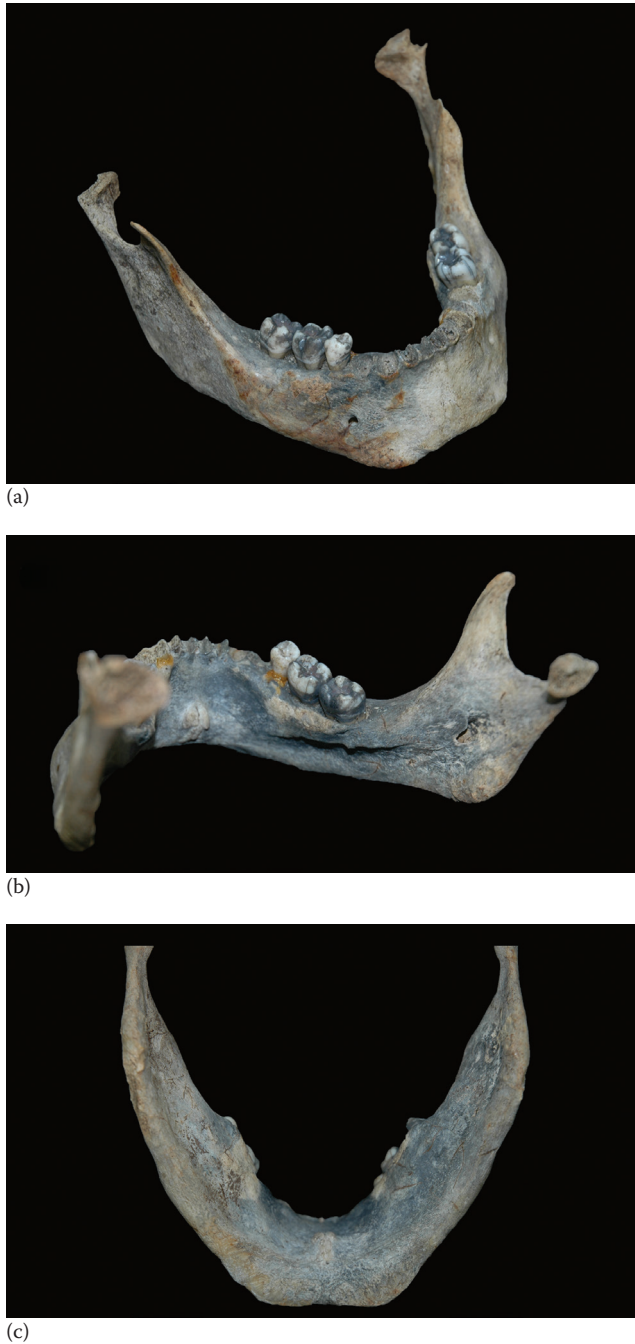


Figure 12.11 Mandible with amalgam mercury staining: (a) anterior view showing staining on buccal side of enamel; (b) posterior view showing staining on the lingual surfaces of enamel and alveolus; and (c) inferior view showing bone staining.

amalgam fillings of the mandible in a forensic case. In this example, there is a grayish stain on the enamel of the teeth with amalgam fillings and the concomitant bone surfaces. In particular, there is a prominent stain on the lingual surface of the mandible. It is important to note that this stain was only located on the mandible and may be the result of a unique compound in the postmortem environment reacting with the amalgam fillings.

Organic Staining

Bones from outdoor contexts typically will interact with plant and tree materials, resulting in organic stains on the bone. According to Bass (1997), bones in shady areas may exhibit moss or green algae growth (see Chapter 11, this volume) during the first year of exposure. Green staining from moss and algae is the result of pigments such as chlorophyll (greens), xanthophylls (yellows), and carotenoids (oranges and reds) (Davies 2004) invading and binding tightly with the bone surface. Other examples of organic staining present on bones can be due to the interaction of bone with roots or the decomposition of pine needles (see Chapter 5, this volume).

Algae

While algae growth on human remains in aquatic environments has been associated with the determination of the postmortem submersion interval (PMSI) (Casamatta and Verb 2000; Haefner et al. 2004; Zimmerman and Wallace 2008; see also Chapter 7, this volume), green staining from algae is also commonly found on terrestrial bones in moist shaded areas (Bass 1997; Janjua and Rogers 2008; Ubelaker, 1997). Algae are nonvascular plants without true roots, stems or leaves that typically possess chlorophyll and are photosynthetic (Hall 2012). Forensically, algae also may be important botanical evidence. For example, algae can be important when linking a suspect to a specific aquatic scene, as well as placing a suspect at a scene during a specific time of year (Hall 2012; Hardy and Wallace 2012; Siver et al. 1994). Algae typically are associated with different types of aquatic ecosystems and also can grow in wet terrestrial environments (Hall 2012; Hardy and Wallace 2012). While it is common to find green algae growth on submerged remains, it is also common to observe green organic staining from algae growing on bone in terrestrial environments (Figure 12.12a), and this would indicate that the bones had been in a moist, shady environment.

Mosses

Mosses are nonvascular and flowerless plants of the class Musci that can grow on bone and also produce green staining (Bass 1997). Mosses grow in moist and shady areas (Coyle 2004), and are usually the first plants to colonize newly exposed bare rocks, ground, and other abiotic surfaces (Hallingbäck and Hodgetts 2000). While mosses may appear to have stems, roots, and leaves, they are a small green organism lacking these structures (Hall 2012). Although they have no true roots, they contain root-like structures that allow them to cling to various surfaces (Hallingbäck and Hodgetts 2000). Also, while they are usually small organisms, mosses can grow as large mats across the ground and are on average only a few centimeters in height from their surface of attachment (Coyle 2004).

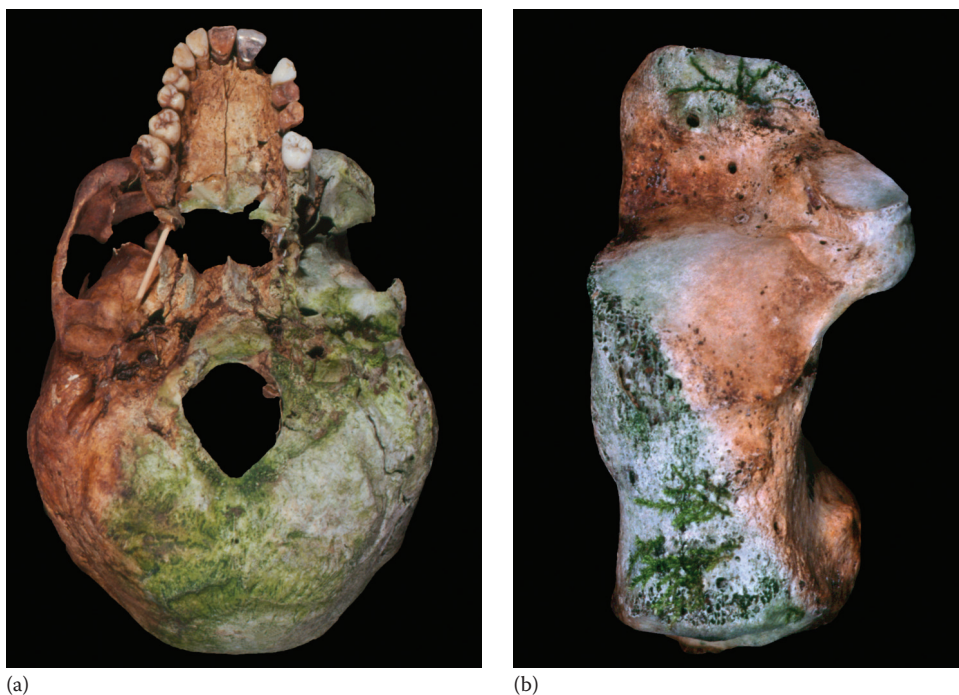


Figure 12.12 Organic staining: (a) inferior cranium showing algae staining; and (b) sun-bleached left calcaneus with moss and soil staining. Note that the moss growth corresponds with the exposed (sun-bleached) areas.

Forensically, mosses also can be useful in establishing a portion of the PMI (Cardoso et al. 2010; Hall 2012). Green organic staining also may occur from mosses adhered to and growing on bone (Figure 12.12b).

Root and Decomposing Plant Material Staining and Etching

Root etching is a common taphonomic modification that is recognized on the bone surface as a dendritic pattern of shallow grooves or tracts (Behrensmeyer 1978; Buikstra and Ubelaker 1994; Schultz 2012; Schultz et al. 2003; White and Folkens 1991; see also Chapter 5, this volume). According to Behrensmeyer (1978:154), the pattern results from “dissolution by acids associated with the growth and decay of roots or fungus in direct contact with the bones surfaces.” Discoloration of the tracts may also occur through acid decalcification of the bone (Buikstra and Ubelaker 1994). Root etching is more commonly observed on archaeological material, and it is not common to observe this taphonomic modification on forensic remains due to shorter PMIs (Schultz 2012; Schultz et al. 2003). It is possible, however, to observe dendritic patterns of darker staining from plant roots on the bone surface of forensic remains (Figure 12.13a).

Another example of organic staining found on bones can be the result of decomposing plant materials, including leaves and pine needles (see Chapter 5, this volume, for discussion of tannins as they relate to coffin burials). In addition to discoloration, pine needles will also etch the bone, and this taphonomic change can be observed as an unorganized pattern of linear staining with shallow etching (Dupras et al. 2011).

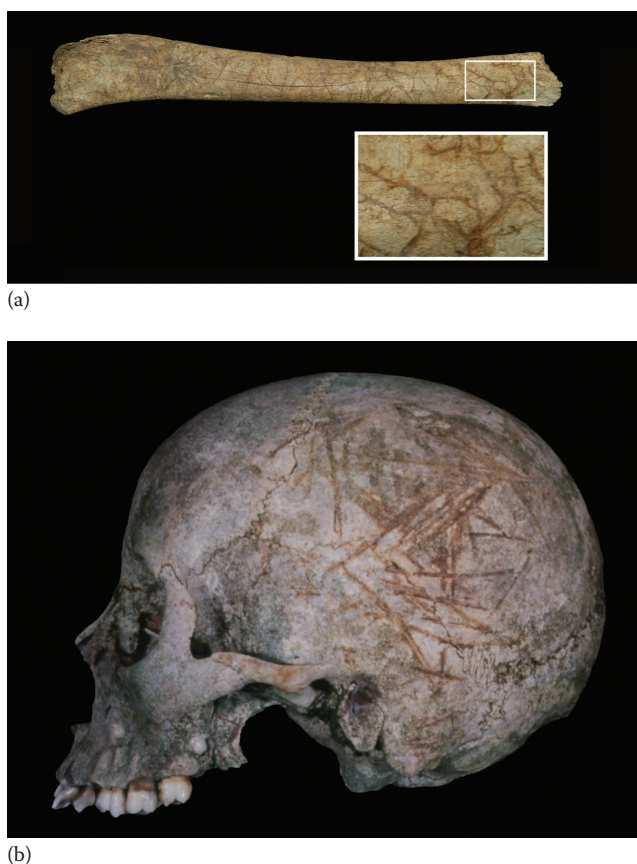


Figure 12.13 Organic staining: (a) juvenile deer (*Odocoileus virginianus*) tibia showing dendritic pattern of root staining; and (b) sun-bleached cranium with minimal algae staining and pine needle etching with accompanying tan-colored staining.

The staining can be present as a tannish coloration (Figure 12.13b). More than likely, the bone is etched because the decomposing pine needles are acidic and react with the base ions of the bone surface.

Mineral Precipitates and Other Encrustations

On some occasions bone surfaces may be altered by either mineral precipitates or other mineral encrustations and thus alter the bone's color. For example, in both marine and mineral-laden burial environments, sodium chloride (NaCl or "salt") may be dissolved in solution. This solution may penetrate the bone, and as the water evaporates the salt will begin to crystallize (see Chapter 7, this volume). The crystals may expand and cause damage to the bone, or form crystals on the bone surface (Figure 12.14a). Other minerals such as vivianite (see previous discussion on iron) may form encrustations on the surface. In the marine environment bones may also show color and surface alteration due to barnacles. Although not a mineral, but an animal, barnacles may grow on bone thereby altering the



Figure 12.14 Cranium showing salt precipitates with close-up (inset).

bone surface, and also affecting the color of the bone (see Chapter 7, this volume, for discussion of barnacles in marine environments).

Bones in marine or burial environments with groundwater also may have stains and encrustations associated with calcium carbonate (CaCO_3). Calcium carbonate commonly manifests as segregations in soil, and occurs in a variety of forms, sizes and consistencies (Fitzpatrick 2008). In precipitate form calcium carbonate may permeate the bone and exchange for minerals in the hydroxyapatite, or it may form layers on the bone surface where it will appear as a white or off-white encrustation (Figure 12.15a through c). This type of mineral concretion forms frequently where water pools and evaporates, and the traces of it may form a distinct ring indicating the orientation of the bone while this process occurred. Later movement of this element may be detectable by the lack of horizontal alignment of the calcium carbonate ring.

Conclusions

In forensic cases involving the analysis of human skeletal remains, it may become vital to reconstruct and interpret associated taphonomic events. Taphonomic criteria can be useful in determining information such as forensic context (Schultz 2012), body movement, identification of associated artifacts, and possible perimortem events. Bone staining and color changes may provide vital clues about the burial or depositional environment and about associated burial artifacts. Determining the cause of bone staining may be very helpful with the interpretation of taphonomic events, but it is imperative to recognize that different causative agents can create similar coloration or staining on bone. For example, bones with a white color may have been sun bleached, burnt, have mineral or adipocere adhesions, or have been chemically altered. Green staining may be related to algae or moss growth, or

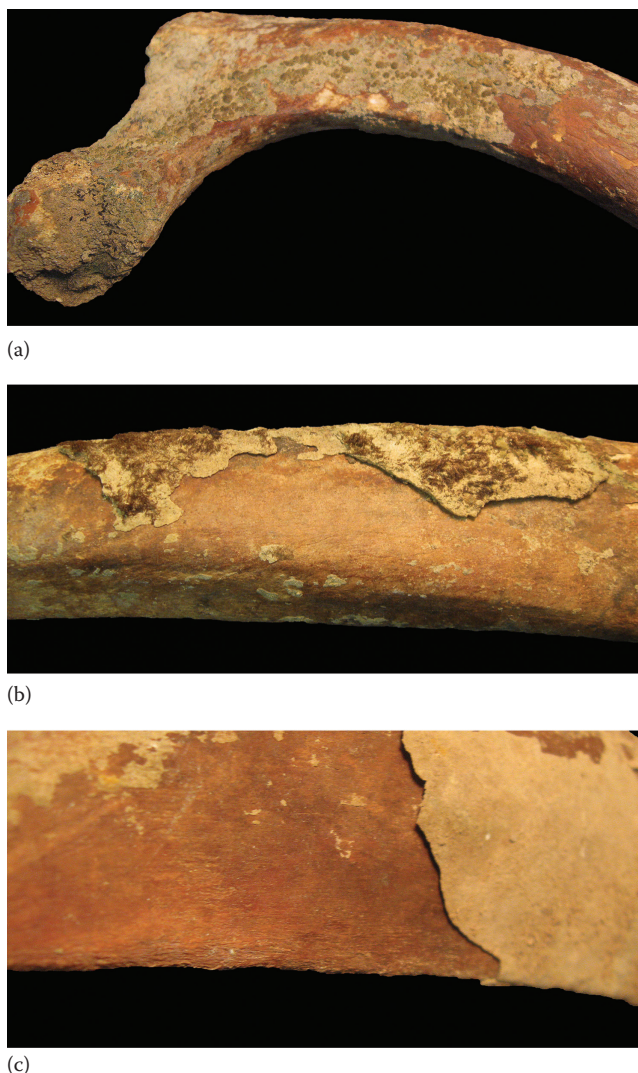


Figure 12.15 Calcium carbonate concretions from a fresh water environment: (a) cow (*Bos taurus*) rib showing calcium carbonate concretions with algae growth; (b) layer of calcium carbonate with algae growth; and (c) close-up showing layer of calcium carbonate on bone surface. Scale bar is 1 cm. (Images courtesy of Tom Evans.)

oxidation of copper artifacts. Bones with brown coloration may have been in contact with soils, water, or may be dirty from handling. It is also possible, as shown in [Figure 12.2](#), that bones may also display multiple color changes related to different taphonomic events. See [Table 12.1](#) for summary of taphonomic processes and associated color changes.

Much like differential diagnosis in paleopathology, all bone surfaces should be examined and documented for any noticeable staining or color changes. Once colors are documented it is then possible to go to the literature to identify possible causes through the process of elimination. Additional clues from the depositional context and/or associated artifacts also may be very useful to assist in interpretation. For example, a bright white skull with hardware such as springs to hold the mandible in place, and screws and hooks

Table 12.1 Taphonomic Processes and Associated Bone Color Changes

Taphonomic Process	Possible Associated Color
Chemical Staining and Natural Bleaching	
Sun bleaching	Bright white to gray
Commercial preparation	Yellow to bright white
Industrial chemicals	Brown, white (dependent on chemical)
Soil Staining	
Humic acids	Dark brown, black
Manganese dioxide	Black
Manganese carbonate	Pink, red, brown
Permanganate	Purple
Metal Staining	
Iron	Orange, red, brown, black
Vivianite	Bright blue to blue-black
Copper and copper alloys	Green to bluish-green
Mercury	Gray/silver to black
Organic Staining	
Algae	Green
Mosses	Green
Roots and decomposing plant materials	Light brown to black
Mineral Precipitates	
Salts	White (opaque crystals)
Calcium carbonates	White to off-white

to keep the calotte secured to the cranium, would indicate teaching or anatomical material (Schultz 2012; see also Chapter 9, this volume), and the bright white coloration would be due to deliberate chemical alteration from preparation. The anatomical location of the staining also may help to determine the causative agent. For example, gray staining on the alveolus and enamel most likely caused by the mercury in amalgam fillings, and it would be very unlikely to find this kind of staining on other parts of the skeleton. Forensic anthropologists should be aware of the most common types of bone staining and color alteration as part of their investigation and interpretation of taphonomic events.

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