Cold temperatures and weather processes on human bone: An analysis of the literature

by Blanka Stepankova

Amongst research on forensic skeletal material found in a variety of environmental conditions, cold climate contexts and the effects of various associated weather processes are very under-researched. This paper will examine existing sources on the effects of cold and freezing weather conditions on forensic anthropology analyses. It will review the various taphonomic processes that occur from sub-zero temperatures, like snow, ice, and freeze-thaw cycles on bone, as well as the associated challenges that could arise in identifying important features and analyzing skeletal remains when found in these conditions. Finally, this paper will discuss the research gap of the effects of cold weather climates on bone and will explore some much-needed new and expanding avenues of research on this topic, which could aid forensic identifications and analyses on human remains in cold climates.

Extensive research has been conducted on the effects of perimortem and postmortem processes like burning, cutting, and fracturing of bone, as well as taphonomic processes like soil staining, organic plant growth, root etching, and scavenging activity on skeletal remains (Byers, 2016). Research and reports also exist on bone weathering processes relating to hot and dry climates, hot and humid climates, and wet or submerged regions (Behrensmeyer, 1978). However, as large swaths of land or entire regions become blanketed with snow annually or remain constantly snowed over, such as Canada, an extensive body of work on the subtopic of cold climate weathering and its different chemical and physical effects on bone is needed.

This paper will critically examine the limited sources on cold climate bone weathering and suggest novel paths forward within this research area in relation to human skeletal remains and forensic contexts. As more literature exists on the effects of cold climates on human tissues like desiccation, mummification, or freezing, this paper will primarily focus on human bone, though it is important to note that bones found in cold climates may still have some associated tissues attached at the time of recovery (Micozzi, 1991).

Regarding forensic contexts, it is helpful to imagine scenarios when bone exposed to cold conditions could be found or recovered. Situations such as deposition and subsequent scavenger activity could lead to the extensive maceration of soft tissue, and thus, the exposure of bones to the environment. Factors like scattering, animal transport, glacial processes and fluvial transport can also act to further expose, abrade, fracture, fragment, and deposit bone away from the initial deposit (Byers, 2016).

It is important to note that this review is meant to be as encompassing as possible; however, there are inevitably sources that could not be included within this formatted review, and is thus not meant to be an exhaustive list of all the sources to date. Additionally, this paper unintentionally has a geographical bias to the origins of some sources because of the climate type being explored, and thus presents data from

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mainly North America. This literature review is meant to be a starting point to the literature that exists on the topic and how it can be applied to modern forensic anthropology.

Background

Numerous studies investigating the effects of cold temperature and weathering on bone have been conducted, primarily on the bones of animals deemed to be human experimental proxies, such as pigs. This is perhaps because of the many factors involved in academic approval, ethics, and sensitivities around the destruction of human skeletal remains for science. However, certain studies like that of Tersigni (2007) have had access to human bone and while their results are important, should not necessarily be deemed more credible simply because of their use of human bone. Sometimes generality of the bone being studied can be useful to decentralize the anthropocentric nature of this research and instead bring focus to the processes acting on bone in cold environments, of course barring situations where specific human bone features like histology and microstructure are specific and important.

Firstly, research does exist surrounding the themes of cold climates, temperatures, processes on bone including forms of cold exposure, the effects of freezing on bone histology, effects of freeze-thaw cycles, effects of freeze-drying processes, microcracking and exposure duration, and bone mineral density of frozen skeletal material (Pokines et al., 2016; Tersigni, 2007; Turpin, 2017). While these topics have drawn academic interest, many of these studies have been conducted experimentally in laboratories and are usually focused in their scope and methods. They are not representative of real climates, temperature fluctuations, seasons and weather patterns. Ultimately, there are few realistic outdoor studies which account for regional weather specificity and features, and trends in taphonomy like scattering due to animal scavenging. Though helpful in different climates, research done in outdoor settings in warmer and humid areas of North America have not been able to greatly serve anthropologists, both forensic and archaeological, police search management teams, and forensic analyses in understanding cold climate weather effects on bone. Nonetheless, the work that has been done needs to be examined and reviewed for understanding and gauging how future experimental studies could be done effectively to fill this research gap.

Concerning the education of students on these processes, some textbook sources give information about general bone weathering, such as Blau (2017), Micozzi (1997), and Byers (2016). Blau's (2017) chapter on bone weathering includes the weathering scales from Behrensmeyer (1978), showing the various stages of weathering and their characteristics. However, in the researching of cold climate effects on bone, the frequent citing of these particular tables is less than helpful, as they seem to have been created considering almost every type of environment except for snow-covered or freezing subarctic regions. While Blau (2017) acknowledges the limits of applying these weathering stages to any specific environment, again the absence of any mention of cold climate environments persists. Micozzi (1997), however, does extend some specificity to cold weather environments, but only with regards to soft tissue preservation. Byers (2016), fortunately does give a bit more information, citing Komar's (1993) study with the Edmonton, Alberta Medical Examiner's Office.

The trend of many textbooks failing to include even an overview on cold exposure to bone could stem from the often cursory, introductory, or general nature of some textbooks. However, the issue of not including substantial introductory information on this topic may simply be due to the lack of information relative to other climates and weather processes on bone. The absence of this information from textbooks shows the forgotten nature of the topic, despite that nearly 25% of Earth is covered by snow seasonally or permanently, and in Canada alone, 65% of its land mass is covered by snow for more than six months annually (Encyclopedia Britannica, 1998; Environment and Climate Change Canada, 2022).

General Cold Processes on Remains

There are some reports on how human remains and bones exposed in cold settings experience processes such as freeze-thaw cycles, fractures, cracking, changes to microstructure, and more. Some general reports to help explain cold climate processes and weathering of human remains and bone include those by Micozzi (1986), Janjua and Rogers (2008), and Woollen (2019). These studies are important for contributing to the foundational knowledge of macroscopic cold weather processes acting on tissues and bone.

One of the most-cited sources on the decomposition processes experienced by a body in cold weather is Micozzi's (1986) experiment using rats, both freeze-thawed and freshly killed. The study ultimately concluded that while the usual documented stages of anaerobic decomposition (putrefaction) and aerobic decomposition (decay) act on a body from the "inside out," a previously frozen body left to thaw in an environment will rather decompose from the "outside in," starting with external decay. This is due to the warming of the tissues from the outside air, first acting on the exterior of the body and working inwards as the tissues thaw and lose their mechanical structure. The rats were placed in cages on the ground surface in a deciduous woodland environment in Philadelphia, PA in late summer. Occasionally, homicides or accidental deaths sometimes involve the freezing of a body for concealment prior to deposition somewhere at a later date, thus initiating thawing and the second part of a freeze-thaw cycle. Additionally, the implications for determining the post-mortem interval for human remains that may have 'wintered over' and frozen throughout the season and begin thawing naturally with warmer temperatures could have important effects for forensic investigations. However, by having placed the remains outdoors in summer, a comparison for spring warming temperatures after natural freezing winter conditions is absent. Micozzi (1986) also observed that while occurring in the same sequence of decomposition events, freeze-thawed remains exhibited faster rates of joint disarticulation than freshly-killed ones, again thought to be as a result of biomechanical factors. After six days outdoors, the fresh rats showed a weight loss of 72%, and the frozen rats showed a higher weight loss of 87%. Not only could the differences in decay pattern from fresh and frozen-thawed bodies be useful to help establish the post-mortem interval (PMI) within a human forensic investigation, these findings could also be useful in estimating when remains were deposited in an environment.

To draw from a forensic case as an example, Zugibe and Costello (1993) worked on the "Iceman Murder": a homicide case in which a human body was found deposited in a wooded area wrapped in layers of plastic bags. Employing standard autopsy analyses and microscopic examinations, aerobic decomposition was shown to be occurring before anaerobic decomposition, and ice crystal artifacts were found within the heart muscle tissue. In this instance, the victim's body was frozen for over two years prior to being deposited and discovered. This conclusion was corroborated with other case details including the time and date of the last sighting of the individual to establish a PMI of the remains (Zugibe and Costello, 1993).

Janjua and Rogers (2008) studied the outdoor weathering of bone in Southern Ontario, Canada to examine PMI decomposition patterns pertaining to the research of 25 defleshed pig (*Sus scrofa*) metatarsals and 25 defleshed femora for 291 days between October of 2004 and July of 2005. Some elements of tendons and pieces of muscle were unable to be defleshed from the bones. The lower limbs were chosen because these elements are often among the most recovered during forensic investigations. Within this study, it was concluded that the pig femora were more resilient to weathering and exhibited more physical changes during the weathering process than the metatarsals. Janjua and Rogers (2008) argue that femora were hence better indicators of an accurate PMI than metatarsals and that the degree of weathering ultimately observed can be influenced by bone size. This is a useful source in considering which elements are most likely to be reliable for estimating PMI in human death investigations with the degree of weathering changes appearing on them. However, the prior defleshing treatment of the limbs in addition to placing wire cages over them to deter scavengers is not necessarily transferable to common real-world forensic situations.

Woollen (2019) also conducted a study using pig remains, wherein they examined cold temperature (outlined here as <37°F/2.8°C) decomposition processes of 10 partial remains (comprising of bone, muscle, and skin) over five months in Illinois, between January and May. Four specimens were wrapped in cotton shirts, four were wrapped in plastic bags, and two were left on the ground surface. The eight covered specimens were then buried at depths of six inches and 18 inches. Interestingly, the study concluded that remains buried at 18 inches of depth were more decomposed than those buried at six inches of depth. Also, the types of coverings showed that remains wrapped in plastic bags had decomposed slower than those wrapped in cotton shirts because of more air being introduced to the specimens and allowing for more chemical decomposition processes. The ground surface specimens showed to have decomposed at the slowest rate of all the specimens. This was attributed to the soil acting as an insulative barrier from cold conditions, and as the temperatures of soil increased in warmth with the increasing depth of burial, decomposition occurred at a faster rate in the buried specimens—an entirely contrasting decomposition system to that of warmer conditions. Notably, the surface specimens became freezer-burned, desiccated, leathery and almost mummified in appearance through their subjection to winter conditions like cold and rainfall (Woollen, 2019).

Laboratory Studies of Cold Processes on Bone

Further studies on microscopic effects of cold environments on bone include those by Pokines et al. (2016) about the effects of freeze-thaw cycles on bone, and Tersigni (2007) and Turpin (2017) on microscopic cracking in bone as a response to cold stresses.

Regarding how freeze-thaw cycles affect bone, Pokines et al. (2016) conducted a study using white-tailed deer (*Odocoileus virginianus*) metapodials, which were exposed to 75 freeze-thaw cycles in a laboratory setting, with histological examinations done after 25 cycles. Importantly, the remains were first frozen after collection, then placed outdoors in cages to decompose naturally, and then softly scrubbed and left to soak in distilled water before commencing the laboratory freeze-thaw cycles. This is pertinent, as Pokines aims to study the freeze-thaw processes on bone in isolation from other factors. Initially, however, one can see how the absence of studying the natural outdoor processes, realistic scavenger variables (placing specimens in a cage) and the use of fleshed remains that had been frozen prior to starting the study clearly contrast the common situations encountered forensically. The study concluded that microscopic and macroscopic parallel cracking resulted from subjecting the bones to repeated freeze-thaw cycles. Additionally, while given amounts of exposure to laboratory-simulated freeze-thaw cycles generated cracking within the bone's microstructure, there came a point when continued repetition of these cycles did not substantially increase cracking that appeared, and instead the process plateaued.

Tersigni (2007) conducted a study with human limb samples on the microstructure of nonfrozen bone and bone subjected to prolonged freezing and eventual thawing. Once thawed, scanning electron microscopy (SEM) found the presence of cracking in the previously frozen samples around the center of Haversian canals in all frozen bones.

Similarly, Turpin (2017) concluded in their study that freezing caused microcracking in all lamb femur bone samples subjected to various types of cold exposure (freeze-thawing, freeze-drying, and aqueous immersion). Their study found that transverse cracks (Figure 1A) occurred in all forms of cold exposure, while osteonal cracks (Figure 1B) around Haversian canals only occurred in flash-frozen and freeze-dried samples and were increased in samples that were freeze-dried and freeze-thawed. This research is important for forensic anthropologists to help establish accurate PMI or more specific case details by distinguishing microstructure changes between nonfrozen and previously frozen bone (Tersigni, 2007). These studies also show that there are differences in microscopic cracking and its frequency associated with various types of cold exposure (Turpin, 2017).

Outdoor Bone Weathering Studies

Fortunately, there are a couple of studies that have been conducted with clearer forensic implications of outdoor cold weather processes on human bone and remains, including studies from Komar (1998) on forensic data from cases around Edmonton, AB; Weitzel (2005) on an experimental field burial of pig remains within Edmonton, AB; and Calce and Rogers (2007) on

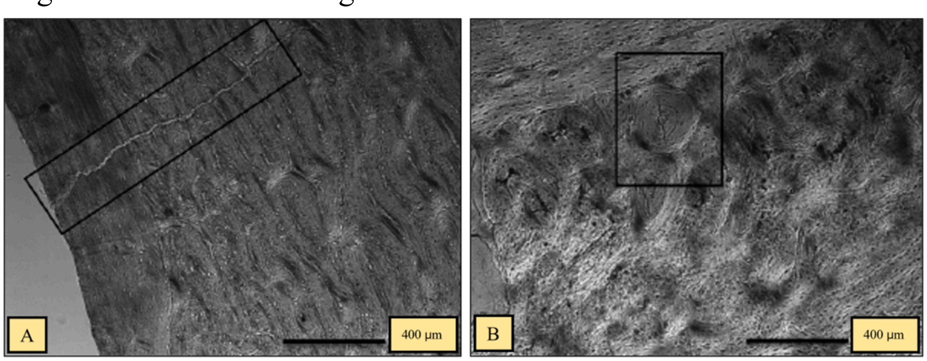

Figure 1. A) Transverse microscopic cracking in bone at a magnification of 50x. B) Osteonal microscopic cracking in bone at a magnification of 50x. Reproduced with permission from Turpin (2017).

the effects of taphonomic processes on blunt force trauma.

In 1998, Komar published a study on a sample of 20 cases from the Edmonton region that included remains in varying stages of advanced decomposition, specifically between partial and complete skeletonization of remains deposited in various environments (buried, aqueous river locations, riverbanks, and wooded areas). Komar examined cases with an elapsed time range of six weeks to eight years and used the local meteorological data available to conclude that within the region of Edmonton, skeletonization could occur in as little as six weeks in mild summer temperatures, and within a minimum of four months during extreme winter temperatures. Factors like clothing were observed to have slowed decomposition, while animal activity accelerated decomposition. Byers (2017) illustrates this rough timeline of decomposition in cold climates with case data from Komar in *Introduction to Forensic Anthropology*. This is perhaps one of the only proposed and outlined rates of decomposition from cold climates that were created by examining human remains, both of accidental and criminal origins. While certainly helpful, it should be mentioned that giving minimum time spans for the various stages may be misleading as skeletonization may have occurred sooner (as Komar acknowledges), and retroactive data-based studies may not be representative of more general patterns, and weather processes, as well as variables like scattering and scavenging that could be tested in field experiments.

Similarly exploring the effects of cold conditions on bone, Weitzel (2005) conducted a study using pig remains that were buried for 15 months in Edmonton, AB. The study found that skeletonization and mummification was most common and could occur within approximately three to five weeks when buried in June, and five weeks to three months when buried in May.

Perhaps one of the most telling field experiments for forensic anthropology in cold climates was that of Calce and Rogers (2007), on how taphonomic changes affect the appearance and preservation of evidence of blunt force trauma on bone. Five fleshed and five defleshed pig crania were used for this study and prior to surface deposition were hit in documented regions of the skull to mimic blunt force trauma (BFT). Researchers noted the types of fractures created and their locations with images to compare with any later taphonomic changes. The heads were exposed outdoors for 12 months starting in October 2003, in an enclosure on a property designated for research in Ontario, Canada. Various taphonomic processes and their effects on the skulls were set to be tested and observed, including rodent-gnawing, carnivore scavenging, freeze-thaw cycle, soil weight or presence, precipitation weight or presence, bone discolouration from bleaching and grass staining, and any movement of the bones. BFT sites were examined throughout the 12 months with taphonomic changes being marked in notes and with photographs. Secondary observers were recruited to later hypothesize the causes and appearances of BFT sites as being either inflicted or resulting from taphonomic processes. Among the findings, it was concluded that all taphonomic processes affected the skulls in some way. Some of the most extreme effects were from the freeze-thaw cycle the bones were exposed to that produced flaking, wedging, cracking, and linear fractures on areas that had not been sites of inflicted BFT and obscured clear evidence of other true BFT sites (Figures 2 and 3).

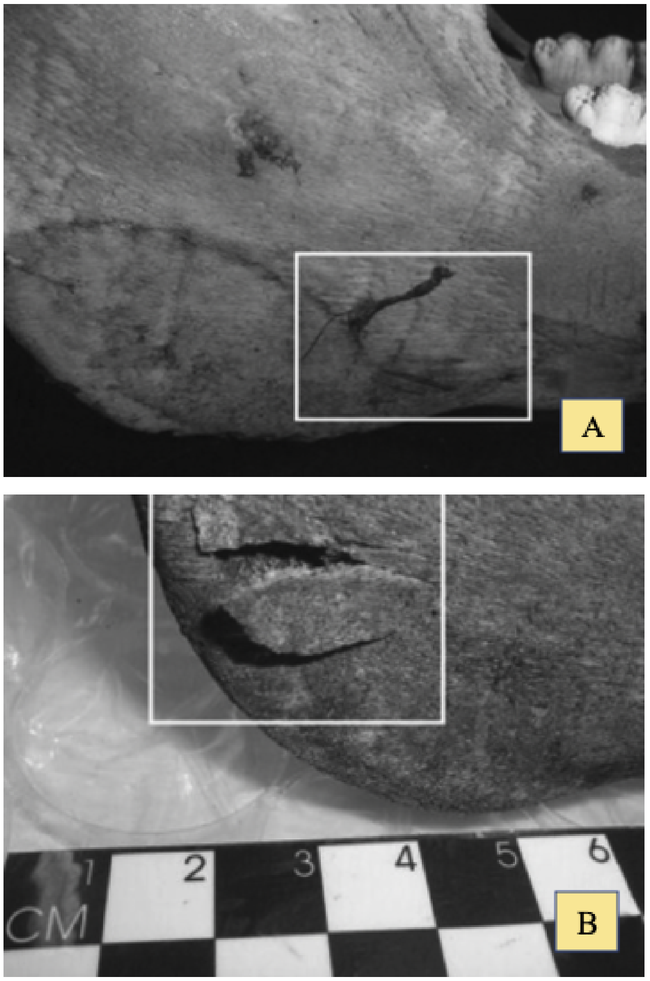

Figure 2. Images A) and B) show pseudo-BFT from cold condition weathering in the form of flaking and cracking on mandibles. Reproduced with permission from Calce and Rogers (2007).

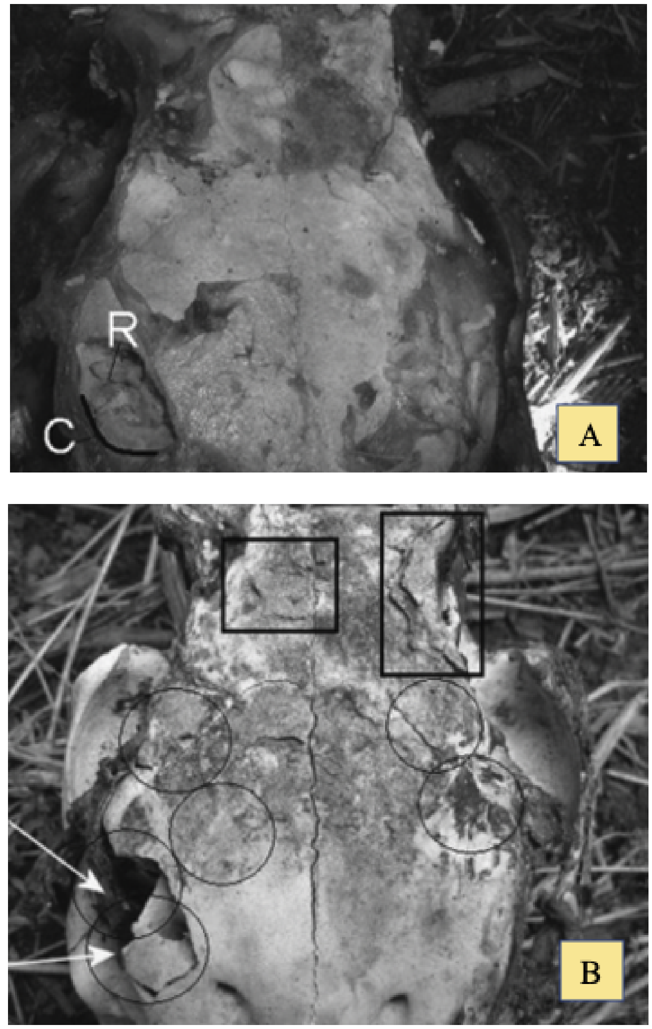

Figure 3. A) Specimen 6 on Day 6 showing radiating (R) and concentric (C) fractures from inflicted BFT. B) Same specimen on Day 347 showing element displacement by snow and rain, altering evidence of BFT (arrows). Additional flaking and radiating fractures from exposure indicated by boxes. Reproduced with permission from Calce and Rogers (2007).

Secondary observers saw sites on the frontal bone and mandible that mimicked blunt force trauma appearing as radiating and linear fractures, and were convinced that injuries had been inflicted there. This pseudo-trauma was indeed caused by freeze-thaw weathering and the associated exposure to rain and snow (Figure 3). Further analyses also showed additional significant taphonomic changes to the bones from other processes that obscured the true nature and appearance of the BFT inflicted for the study (Figure 3).

Ultimately, Calce and Rogers (2007) concluded that careful examination is required of circular and large openings in skulls that may reveal original BFT evidence.

Discussion

Overall, important work has been conducted documenting cold weather and temperature stresses on remains and bone, like decomposition (Micozzi, 1986), temperature (Woollen, 2019), bone size (Janjua and Rogers, 2008), microcracking (Pokines et al., 2016; Tersigni, 2006; Turpin, 2017) and taphonomic changes brought by freeze-thaw cycles (Calce and Rogers, 2007), as well as a data examination of 20 human forensic cases from the Edmonton, Alberta area (Komar, 1998), and a field experiment on the decomposition of pig remains from the same area (Weitzel, 2005).

However, standardized methods for dealing with human remains in cold environments are still missing. Instead, some of the studies conducted have made shaky correlations between cold climates and their effects on bone, while few have been done year-round through the variation of warm to freezing temperatures, and others were studied retrospectively with case data.

This large research gap in forensic anthropology and within the field of forensic sciences as a whole leaves a lot of questions and methods unresolved to anthropologists, death investigators, and law enforcement. Filling this gap could have the potential to answer questions for victims of homicide or accidental deaths, as well as their families in cold, rural, and northern regions of North America, Europe, Asia, and other regions.

Determining which physical changes occur due to weather and which occur due to perimortem activity and later taphonomic effects has an importance to forensic interpretations that cannot be understated. Cold regions across North America and throughout the world have few standardized processes or peer-reviewed studies to work from with relevance to the different factors involved in cold environment forensic investigations.

Studies that focus on the impact of cold weather and climate processes on human skeletal remains need to be conducted. However, even a few additional studies will likely not create a one-size-fits-all framework for all investigators in cold climate regions to draw from. Instead, differences in weather patterns and conditions like ice, snow, rain, sleet, hail and others should be considered in turn with the associated regions that exhibit them. Research done in laboratories is not sufficient for forensic anthropologists to understand how weather effects bone, much less the impacts of bone scattering, seasonal scavenging patterns and predators, and other pre- or post-depositional taphonomic effects on remains in cold climate environments.

Conclusion

Undoubtedly, lab experiments surrounding these topics have been conducted and have helped to lay the foundation of cold weather stresses on bone, but few studies have been conducted for forensic anthropological purposes outdoors, while incorporating natural temperature flux, scavenging, or accounting for regional specificity. From there, additional research questions arise about the effects of cold exposure on bone and the appearance of physical trauma on bone. All these avenues of inquiry deserve more attention to help contribute to the knowledge base of anthropologists, investigators, and law enforcement in forensic analyses. As almost one quarter of the Earth’s surface is temporarily or permanently covered by snow, it is sufficient to say that many victims, families, and death investigations could benefit from greater study on cold environment exposure and weathering processes affecting human bones.

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