Technical Note

Characteristics of Snow and Their Influence on Casting Methods for Impression Evidence

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Abstract: Casting impression evidence in snow can be challenging for many investigators. Understanding the medium of snow and how its properties may influence the success of casting methods can assist the investigator in choosing techniques that offer the best chances of successfully casting track impressions. Various snow types are defined with recommendations for the appropriate casting methods best suited for the characteristics of the snowpack. The terms "impression perimeter" and "penetration" are introduced as they relate to snow casting.

Introduction

Snow impressions have presented a myriad of challenges to criminalists for decades [1]. Snow impressions are usually only encountered seasonally or at high elevations. Therefore, investigators do not have many opportunities to develop or hone their snow-casting expertise. As a result, casting in snow has, in many ways, become a lost art. Modern criminalists are losing their capacity to recognize the characteristics of snow and how those characteristics dictate the choice of appropriate casting methods. Many examiners and instructors have become too dependent on the exclusive use of aerosol wax products and dental stone to cast snow impressions. As a result, alternative methods that may

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provide better results have been essentially abandoned. Because snow impressions are more susceptible to short-term change than impressions in soil or other materials because of local environmental conditions (temperature, solar exposure, precipitation, and wind), understanding snow morphology and the effects of environmental influences on impression conditions may assist the investigator in choosing an appropriate technique for casting under site-specific conditions.

This paper will explore the art of snow impression casting in terms of the varying properties that can occur in snowpacks. Linking the complexities of a snowpack near a crime scene with the various casting techniques available may provide for a more informed decision of what technique(s) might best render a high-quality cast. To this end, this paper will provide a detailed discussion of snowpack characteristics and morphology that the investigator may consider. This discussion will be followed by a description of casting techniques that can be employed under different snowpack conditions. Closing remarks and conclusions will then be presented.

Snowpack Properties

In the literature, several property classifications have been noted that are pertinent to snowpack evaluation. Metamorphic and bulk properties provide the investigator with information on the evolution of a snowpack with time. Mechanical properties are important in understanding the deformation of a snowpack for casting purposes. Frictional properties often associated with engineering projects or sliding activity (such as skiing) could provide an investigator with information of deformation characteristics that contribute to the quality of an impression. Chemical properties are often the result of snowpack pollution or contamination. Each of these property classifications is discussed below.

Metamorphic Properties and Influences

Conditions external to a snowpack can have an influence on its physical character and metamorphism through time. Wind speed near the surface, for example, influences how crystals arriving at the surface are packed. At high speeds, crystals can be bounced and dragged over the surface, reducing their size and making a more dense pack [2].

Other conditions, such as rain on snow events, temperature of the ground under the pack, and varying temperatures and humidity through time, can also influence snowpack structure. Snowpack is remarkable in that it often has layers that vary in character (e.g., a lower layer of slush with an upper layer of dry, powder snow). Duration and rate (or intensity) of melting also have an influence on a snowpack's characteristics [2]. Elements influenced by these factors include density, specific gravity, water content, impurities, grain shape and size, pack temperature, and layer lithology [3]. Based on the result of these influences and variables, snowpacks can be segregated into four metamorphic classes [4].

1. Unmetamorphosed snow: This classification consists of fragile crystal forms that are easily distinguished and may be characterized by surface or hoar ice. Unmetamorphosed snow forms under conditions with no wind.

2. Equi-temperature metamorphism: This classification consists of a change in grain size through time. In snowpacks with decreasing grain size, original crystals are recognizable with increasing corner rounding. In packs with increasing grain size, original crystals are usually not recognizable and are equi-dimensional in quality. With time, a uniform grain tendency develops.

3. Temperature-gradient metamorphism: Under changing temperature conditions, a strong thermal gradient can develop. This phenomenon is usually associated with newly fallen snow occurring early in the winter season. Advanced properties of temperature gradient conditions often result in packs that are composed of medium or large grains, with large grains predominating through time.

4. Firnication: This classification consists of two types of metamorphism: melt-freeze and pressure. Melt-freeze metamorphism can vary depending on the number of freeze-thaw events. As the number of events increases, the pack gains density and mechanical strength. Pressure metamorphism often leads to minimal pore space, limited permeability, and high density.

Bulk and Thermal Properties

Bulk properties of a snowpack include the homogeneity of the snow, its response to stress and compression, and the properties of fluid transmissivity (the ability of water to move through the snow pack) due to porosity. Thermal properties are linked to the specific and latent heat properties of snow, which contribute to the pack's thermal conductivity, ablation, and sublimation characteristics. Other thermal characteristics can result from physical properties, such as packing at the surface, that can inhibit the flow of vapor or convection of heat from the ground. These conditions ultimately influence the rate of heat loss or gain from a snowpack [2]. For example, wet snow cannot sustain temperature gradients as well as dry snow. Therefore, wet snow cannot conduct heat as well as dry snow, and melting usually only occurs at the surface, which is in contact with the air or exposed to solar radiation. Dry packs can absorb heat and may transform internally because of conduction properties.

For the investigator, density is one of the most important properties of fresh snow. Density can be defined as the relationship between snow depth and its water equivalent. The density of water is 1, or a water equivalence of 1.0. The upper range of density of snow is 4 inches of water for 10 inches of snow, or 40 percent (0.4 water equivalence). New snowpacks often have a water equivalent of 10 percent or a water equivalence of 0.1. The compactness of snow directly relates to the likelihood that the impression perimeter will retain the casting material with little or no penetration. The denser the compaction, the less penetration should occur. As a rule, densely compacted impressions are easier to cast than impressions with a loose or incompact matrix.

Mechanical and Frictional Properties

Snow may deform elastically when subjected to loads. In the case of small stresses, recovery from the deformation may be possible because of grain structure [2]. However, for most stresses encountered at a crime scene, snow deformation is usually permanent [2]. Structural failure of the snowpack can vary with its physical properties.

Frictional properties are often important to engineering applications. The sliding or kinetic properties of snow are considered low because of the presence of a liquid film [5]. Frictional properties vary with temperature and the composition of the material in contact with the snowpack.

Chemical Properties

Snowpacks may often contain impurities. Dust, atmospheric or soil pollution, or spills may influence a pack's physical properties. New snow falling through polluted air can be contaminated, either changing an existing pack's character or influencing the character of a new snowpack. The color of the contaminant may influence the snowpack's albedo or its solar reflectivity, affecting its melting characteristics. Other contaminants may cause melting or density changes in a snowpack. An investigator should consider timing and possible contaminants within the snowpack when casting impressions [2].

Relating Snow Properties to Casting Methods

There is no definitive method for choosing the most effective casting method for given snow conditions. Each impression may have different properties from one location and time to the next. In fact, impressions of the same walking path may possess different properties influenced by conditions as simple as some being shaded while others are in full sun. Investigators also may not know the history of the snowpack, contaminants, or past environmental influences with any reliable degree of certainty. Several casting methods may perform well under the same conditions, making the choice more subjective in nature. Additionally, the choice of casting methods may be influenced by the availability of materials and the investigator's proficiency in using them. As such, casting may be reduced to the investigator's "best efforts". Nonetheless, investigators who make an attempt to assess the properties of the snow impression and have access to a variety of casting materials are more likely to reproduce the best possible cast for the given conditions.

Several authors have described available casting techniques for snow impressions based on site-specific characteristics of a snowpack. For example, Daulby [6] categorized snowpack ranging from "powder", "old", and "corn" snow types. Because of this variability, Daulby recommended a field test in which the investigator compresses a handful of snow for two seconds to gauge its compactness. Hueske [7] discussed the reflective nature of snow in photography and mentioned that texture, age, and ambient temperature can all affect impression quality.

These descriptions and categorizations, however, must be viewed with caution. For example, Hueske's statement that fresh powder snow is best suited for leaving impressions may be misleading, because the term "powder snow" can describe a wide range of snow densities. Powder snow can be dry and loose in density, making it difficult to compact and retain the impression, whereas Doesken and Judson [8] noted that fresh powder snow does not have to contain a large percentage of liquid water to pack into a ball. Rather, they stated that the key element for packable snow is that it be near the freezing point. Hueske [7] also described the aging of snow into a coarse granular medium as a potential element in changing a snowpack's category for casting. Although this aging process can occur through alternating phases of melting and refreezing and other external influences, snow does not always evolve into a coarse texture [4].

Considerations in Selecting a Casting Technique

Once the investigator arrives on scene, he or she should make an effort to evaluate the type of snowpack containing the impression. Proper methods of photography should precede any attempts at casting. Photography is generally considered a nondestructive process, whereas casting ultimately destroys, although hopefully reproduces, the original impression. Investigators should realize, however, that their actions may also cause changes to the impression through the application of various techniques and materials. For example, spray paint applied to an impression to highlight features for photography will likely retain solar heat and may accelerate the melting process. The senior author has observed that good-quality impressions may deteriorate to an unrecognizable form in less than twenty minutes under mild temperature (45 to 55 °F) conditions and full sun exposure. Therefore, first responders should be trained to protect impressions by the use of a cover, such as a sheet of cardboard, until the arrival of investigators. This will help to minimize physical changes to the impression through environmental or human influences.

Aside from photography, a preliminary snowpack testing method to consider is the compaction test described by Daulby. Additionally, investigators should listen to the snow under foot to better recognize its characteristics both en route to and at the scene. The compaction of the snow can be gauged by how it responds to the investigator's footsteps. Doesken and Judson [8] described this as the investigator's ability to "listen" to the snow as he or she walks over it to judge its properties. It should be remembered that these snow conditions may not be the same as when the perpetrator left his or her impressions. Accordingly, investigators should evaluate the condition of the crime scene impression, as well as present snow conditions, to the best of their abilities.

The investigator should also consider the different types of snow in the vicinity of the crime scene. As noted by Hammer and Wolf [9], different "types" of snow can pose unique challenges for collection and capture of details within an impression. These conditions can change throughout the day as temperatures rise and fall and as the snow impression is shaded and exposed to full sun. If the investigator is uncertain of how the casting material will interact with the snowpack, a test impression should be made if there is a nearby area of undisturbed snow near the questioned impressions. Do not hesitate to experiment with various casting methods in adjacent areas to determine the best approach. This kind of testing takes time. The properties of the snowpack containing the original impression may change during this time, so investigators should make a reasonable attempt to protect it.

The properties of snow have a tremendous influence on its ability to retain the form of a footwear or tire impression. Thus, an understanding of the link between snowpack type, local conditions, and the physical characteristics of snow described above is important for the investigator to decide what casting technique is appropriate. One primary concern is the permeability of the impression perimeter. The impression perimeter is defined as the layer of the impression retaining the shape and features of the outsole or tire or that which is immediately exposed to air. The permeability of that layer is directly related to the casting material's tendency to penetrate that layer. Penetration occurs when the casting material cures at levels below the impression perimeter (Figures 1, 2). This may be caused by a combination of factors, including the physical properties of the snow,

Figure 1

Impression perimeter.

Figure 2

Granular and coarse topography.

casting material, or the method in which it is applied. The resulting cast may have a granular and coarse topography in the outsole or tread area. Oftentimes, penetration occurs with loosely packed impressions such as a dry powdery snow or slush. In such impressions, the snow crystals are loosely packed and allow for casting material to penetrate into areas of snow below the impression perimeter. This is not to be confused with the phenomenon of "undercutting", which occurs when a casting material such as dental stone seeps onto the impression side of a sulfur cast when poured as a backing. It should be noted that with some snow impressions, some measure of penetration may be unavoidable.

Before presenting general definitions of snow types, it seems prudent to briefly define the casting techniques discussed in the following sections. These brief definitions are not intended to represent complete instructions regarding the technique, rather they are presented to familiarize those unfamiliar with these terms. Beginners should read more about each technique, and then practice under an examiner who is familiar with the technique before employing it on impression evidence.

1. "Sulfur" casting is achieved through the melting of powdered or prill sulfur to a liquid state. The liquid is removed from the heat and as crystallization occurs, the liquid is rapidly poured into a pour channel leading to the impression.

2. "Dry casting" refers to the process of applying alternating layers of powdered dental stone and misted water into an impression. Dental stone is sifted into the impression in shallow layers, typically not more than 1/8" in depth. The water is then misted on the dental stone to absorb into the casting material. This process is repeated until a firm base is created over the impression. Once this base has cured to a sufficient depth, a normal mixture of dental stone can be poured over the base to strengthen it.

3. "Aerosol wax and dental stone" refers to the common practice of spraying an aerosol wax product (commonly referred to as snow print wax) into a crime scene impression from multiple angles. This process is repeated in successive layers until a base of wax is developed on the impression. Once a suitable base of wax is created, then a mixture of dental stone is poured over the wax base for added support.

4. "CO_2 bursting" refers to the use of a carbon dioxide fire extinguisher to dispense short bursts of CO_2 into a wet impression in an effort to freeze and strengthen the impression perimeter. Although this is not a casting technique per se, it is a reliable method of preparing some impressions for sulfur or dental stone casting.

With regard to the considerations described above, a variety of terms can be applied to describe various types of snowpack that may be present when deciding which casting technique is appropriate. These terms often relate to specific qualities being measured or evaluated and may not relate to casting issues. The following terms have been selected for their simplicity and ease of integration to field processing. The investigator should remember that these are general terms from which to begin an evaluation.

Ice

An impression that is formed in a snowpack that recrystallizes into ice or forms in a snowpack with a malleable, elastic ice structure typically represents a good base in which to cast. Snowpacks with elastic ice crystalline structure allow a permanent deformation to take place in the ice crystal lattice [10].

Ice impressions offer several casting options. Sulfur is the authors' recommended choice for casting impressions that are frozen as ice. Highlighting the impression with an aerosol paint may also be valuable for photography, but the paint may retain solar heat and begin to melt the impression, so care is advised. Dental stone casting may also work well in very cold temperatures and should be considered if sulfur is unavailable. If temperatures are below 0 °F, it should not be necessary to apply a coating of aerosol wax before casting. It should be noted, however, that the use of dental stone can also cause a partial melting of the snowpack because the casting material produces heat during the curing process.

Slush

Slush is best described as a near saturated or saturated snowpack or a snowpack with saturated layers (slush layers) [11], little strength, and no compactability. Slush occurs when the pack reaches a density that allows for a partial release of water. Bertle [12] observed this to occur (water-release density) at a density of 35 to 55 percent or a water equivalence of 0.35 to 0.55. On a slight slope, water can flow in a slush layer in similar fashion to flow in a saturated soil – in accordance with Darcy's law [13].

In the case of very wet slush, impressions are not likely to form. However, in the case of snow that is near the threshold of forming slush, where an impression is possible, dry casting typically works well with slush impressions, but practice is recommended. Dry casting may take 1/2 hour or more to layer an impression and fully cure before a mixture of liquid dental stone can be poured over the impression. Because of the permeability of the slush, care should be exercised when using products such as sulfur, paraffin wax, and aerosol waxes, which are more likely to penetrate the impression perimeter. This may obscure tread detail to the point of making it unusable. Investigators may also consider applying shorts bursts of CO_2 from a fire extinguisher,

as described by Skreptak [14]. If successful, the investigators may partially or fully freeze the impression, providing a better base for casting. Hammer and Wolf [9] provided additional suggestions on best practices for wet or slushy conditions, such as the use of snow print wax on impression techniques. Snow print wax can perform well under these conditions; however, moisture condition is only one aspect that needs to be considered for casting.

Incompactable Snow

Incompactable snow is best described as freshly fallen snow that is difficult to mold into a shape. This inability to compact is related to snowpack water content or wetness and crystal size and shape. For example, fresh dry snow can have a liquid water content as low as zero. This snow usually occurs in temperatures below or near 32 °F and contains disaggregated grains or crystals. Crystals under these conditions have low adherence and cannot be easily molded into shapes (e.g., a snowball) or form a stable ground impression (e.g., a shoe print or tire track). At temperatures near freezing, snowpack moisture is usually higher (less than 3 percent). No visible water is observed at magnification (10X); however, compactability increases when the snow is lightly crushed, allowing crystals to adhere together. Snowball or impression formation is possible, but stability may be lost under heavy loads [13]. Beyond a 15 percent moisture content level (0.15 water equivalence), slush is formed [13] and, as noted earlier, impressions and compressibility decrease.

Under dry conditions, it is difficult to compact the snow. Crystals do not become closely allied, allowing for the creation of numerous small gaps in the impression perimeter, causing the penetration of the casting material. For this reason, casting methods using sulfur, aerosol wax products, and dental stone should be considered last. Dry-casting methods may work well under these conditions. The technique of dry casting involves the application of shallow, alternating layers of cold water and powdered dental stone sprinkled into the impression. Each layer is allowed to dry and harden before the next layer is added. This is repeated until a sufficient base of casting material is established. Regularly mixed dental stone can then be poured onto this base layer.

Reynard [15] and Allen [16] both presented slightly different methods for dry casting snow impressions but do not discuss the influence of snow type. Skreptak [8] discussed the possibility of changing the physical properties of impressions in slush. Skreptak proposed the use of a carbon dioxide fire extinguisher to freeze the slush impression with short bursts of the compressed gas. This technique raises other possibilities of dealing with incompact snow densities. The application of a fine misting of cold water followed by short bursts of compressed CO_2 may help to freeze and strengthen the impression for other casting methods.

Compactable Snow

Compactable snow is best described as easy to mold into shapes like a snowball. In snowpacks with moisture levels of 3 to 8 percent (0.03 to 0.08 water equivalence), liquid water is visible between crystals under magnification. Snow in this moisture range has more adherence and can be molded into snowballs or produce more stable impressions. Under molding, water cannot be squeezed out of the pack. Under moisture conditions of 8 to15 percent (0.08 to 0.15 water equivalence), snow is considered very wet and can be molded, with some water squeezed out. Typical snowfall is in the 10 percent range (0.1 water equivalence), which produces good impressions or molds. Compactable snow provides the best conditions for casting impression evidence. Virtually any of the casting techniques should work well if done correctly. Sulfur casting or the application of an aerosol wax followed by dental stone casting is recommended.

Granular or Metamorphized Snow

Granular snow is best described as snow that has gone through at least one metamorphic event such as a daily nocturnal refreeze and thaw cycle. Usually in a single event, the depth of this is only about 10 cm into the snowpack, leaving a strong crust. Over an extended period, such as a week, the depth of this effect can reach a meter or more [10]. As grain size increases, so does bonding, which can act to harden an impression or change the ability of the pack to make clear impressions.

As the name implies, crystals in metamorphized snowpacks form a granular (sandy) shape, making an uneven, less compact impression perimeter. These conditions allow for increased chance of penetration by the casting material. This type of snow can be extremely difficult to cast, depending on the degree of granular coarseness. For this reason, sulfur and aerosol wax products should be considered last. Dry-casting methods may work best under these conditions. Additionally, the investigator may consider misting the impression area with a small amount of cold water and then applying short bursts of CO_2 as described by Skreptak [14]. This will create a temporary ice base to the impression that may be better suited for traditional casting methods described earlier. It is important to inspect the impression following this procedure to ensure that an acceptable ice layer has formed.

Windblown Snow

Local effects of wind on snow can range from hardening and stabilization of the snow's surface to light rippling and dune formation to the formation of large drifts and bowls, which can damage or hide impression evidence. Obstacles such as rocks or fence posts can cause a localized effect [17].

Windblown snow has the effect of forming a very hard surface crust that may have layers with varying properties beneath. As the drag force of the wind reaches the threshold velocity to move snow crystals, moving snow particles tend to stick together [17]. The threshold velocity is affected by wetness and hardness, making older, wetter snowpack surfaces more resistant to the dislodging action of the wind. The wind hardening process causes a compaction and bonding or hardening of the snow's surface layer. This process continues to harden the surface over time, especially in the absence of snowfall [17].

Windblown snow or wind impacted packs can support heavy loads and may not show significant depth to the impression. In such cases, the best procedure may be an application of several layers of aerosol wax followed by a dental stone backing. The investigator should evaluate the coarseness of the surface texture before applying a wax product. Sulfur may simply run off the impression area, especially if a slope exists. This may result in a very thin cast, making it impossible to remove without significant breakage.

Layered Snow

A snowpack resulting from a series of snowfalls and metamorphic events usually stratifies into several layers of varying wetness, hardness, grain size, compactability, density, and textural characteristics [11]. The investigator should consider taking a core sample or making a cross section of the snow near an impression of interest to understand the properties of the snowpack. This procedure may allow the development of a strategy of casting that may better protect and preserve the impression and its casting.

Conclusion

Casting in snow can be extremely challenging to the crime scene investigator. Snow as an impression medium is more susceptible to change than is soil. Additionally, snow conditions may change rapidly because of the influence of solar heat, wind, additional precipitation, contaminants, and combinations thereof. The properties of the snowpack can influence the effectiveness of various casting methods. Many investigators have become too dependent on the exclusive use of aerosol wax products followed by dental stone casting for recording impressions in snow. Although this method may produce excellent results under some conditions, other methods may be better suited for a particular snowpack. There is no one method that serves as a perfect solution to the casting problems encountered with snow impressions. Often, the resulting casts represent the best efforts and experience of the investigator with this difficult medium. Understanding how snow conditions may influence the interaction with various casting materials will assist the investigator in choosing the best casting method. Experience, and more important, practice, will help identify these conditions and build confidence in casting techniques.

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