Michael Trinkley

Marble and Its Deterioration

My last Conservation Talk discussed some of the problems we encounter with many sandstones. In this column I'd like to describe some of the issues often associated with marble.

Geologists apply the term marble to certain crystalline rocks composed primarily of calcite or dolomite-metamorphosed limestone. In the stone trade, almost any marble-like or limestone-like rock that will take a polish is called "marble" (a definition consistent with ASTM C 503). Distinguishing between marble and limestone may be difficult, although generally marble is finer in texture and doesn't contain fossils. Limestone cannot be polished like marble.

One of the purest—and some believe the most beautiful—marble is statuary grade marble, typical of the area around Carrarra, Italy. Most marbles, however, contain impurities that produce a variety of patterns and colors. A good example: the Georgia marbles with their characteristic gray veining.

Because marble is so soft, it can be easily worked and has been used for monuments since at least the first quarter of the nineteenth century. The Mohs Scale rates marble between 3 and 4. In comparison, granite is between 6 and 8 (which is actually intended for minerals, not rocks). Marble, however, is both expensive and susceptible to a wide range of atmospheric pollutants.

One of the most commonly noted problems associated with marble is the development of a gypsum crust. When water containing carbon dioxide evaporates from the porous marble, small amounts of carbonate are transferred to the surface as bicarbonate. On the surface in combination with soot and other dusts, sulfur dioxide from air pollution creates an oxidizing atmosphere that transforms the carbonate into gypsum. The soot (and other debris, such as fly ash) gives the crust its black or gray color. For chemists out there, this reaction may be written:

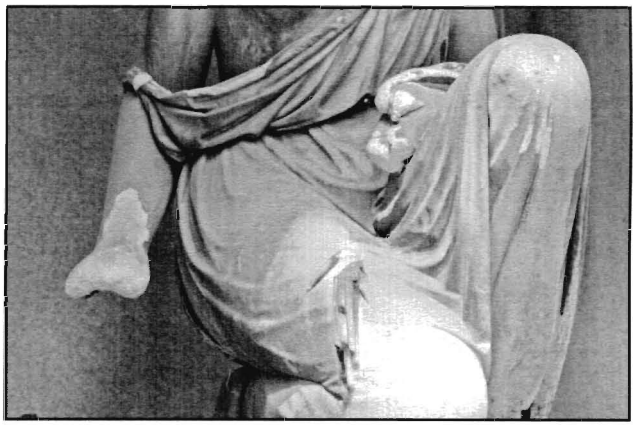
$$CaCO3 + H2SO4 + H2O \rightarrow CaSO42H2O + CO2$$

During the 1980s research in Italy found that oil-fired carbonaceous particles gave gypsum crust its black color. One researcher even commented that they were the most important, if not determinant agent of deterioration and noted that this indicates marble deterioration started after World War II. An interesting analysis using data from this country is the article, "Marble Tombstone Weathering and Air Pollution in North America," published in the 1993 issue of Annals of the Association of American Geographers by Thomas C. Meierding. Looking at Vermont marble in a variety of locations and correlating locations with air pollution, he found that heavily polluted areas have stone recession at a mean rate of >3 mm/100 years. Research on this issue in Russia found that air pollution was at the root of gypsum crusts.

Where water runs over the marble, the gypsum crust is frequently not observed because it has been removed by the water. In sheltered areas, however, the marble may appear gray in color. Protruding parts, like fingers, noses and flowers may exhibit the most serious damage. One conservator has explained that these details have a large surface to volume ratio that offers advantageous conditions for a large transfer of carbonate from the marble to the surface.

Reasonable assessments of the probable impact of gypsum formation can be made knowing pollution levels, exposure to rain or washing, the geometry of exposed stone surfaces and the permeability of the stone. Unfortunately, preventing gypsum crust is difficult because of pollution. Research suggests that some surfactants, such as potassium oxalate and sodium oleate,

Examples of gypsum crust found in areas where water doesn't wash it away.



Gypsum crust may be washed or abraded away, but the underlying marble is soft and powdery, resulting in the loss of details, such as the fingers on this statue.

make marble less susceptible to gypsum formation, while other researchers are examining the possible benefit of using sulfate-reducing bacteria. Neither approach, however, offers immediate hope.

Although removal of the gypsum crust is relatively easy using fine water mists, the underlying marble may be compromised and include cavities where calcite was selectively dissolved. Often the underlying marble is soft and may require consolidation—an issue for a future column.

Another common problem observed in marble is what is called "**sugaring**." The stone crumbles and there are loose granules. This is typically caused by the binder material in marble being dissolved by acidic water intrusion. The surface takes on a rough granular, crystalline or sometimes powdery appearance. Wiping the surface of the stone, even lightly, will produce abundant grit. While acidic water is the main culprit, another potential contributor is the presence of salts deposited between the crystals, causing further damage. A significant contributor is thermal hysteresis. This involves the permanent volume changes that occur during marble's heating and cooling. The interlocked crystalline calcite grains fracture during thermal cycling; grains dislocate and don't return to their original position. There is uneven expansion and uneven surface erosion. The separation of the crystals allows increased water penetration, leading to additional problems such as strength loss and more sugaring.

Sugaring can vary from friable surfaces all the way to complete dissolution of the marble, leaving behind little more than crystals.

Sugaring may be addressed through consolidation, especially with the use of the Prosoco HCT product. This two-component treatment forms a stable, well-adhered, hydroxylated, conversion layer on carbonate mineral grains that increases resistance of the marble to acid attack, has a consolidation effect, is stable and promotes additional consolidation treatments if they are necessary.

Very severe sugaring resulting in the near completion dissolution of the marble.

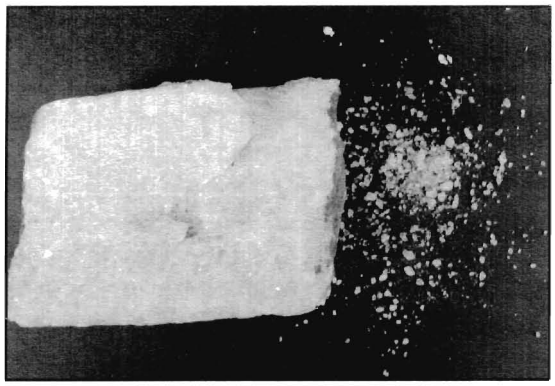
Weathering is another common marble problem. The natural effects of wind, rain, even thermal change will affect marble through a loss of polished surfaces, as well as the loss of crisp edge details. Measuring weathering can be challenging, but in Great Britain researchers have used the Lead Lettering Index (LLI) to measure the amount of material removed over time. This type of monument isn't found here in the U.S., so a more useful approach is Perry Rahn's Index for Weathering, published in the 1971 Journal of Geological Education. Unlike the LLI, the Rahn's Index is semi-quantitative since it can't provide an absolute measurement of weathering. It can, however, provide a useful measure of relative deterioration.

Rahn's Index for Weathering

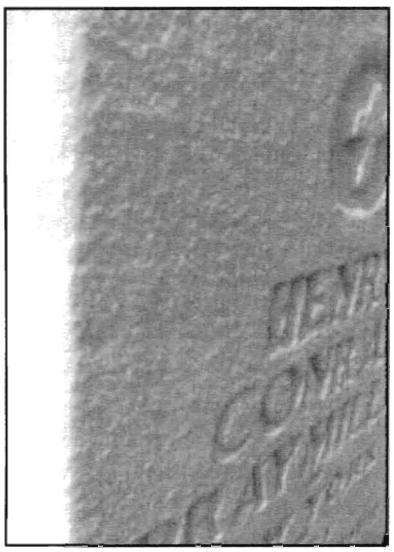
1. Unweathered; lettering is sharp and distinct with no evidence of change.
2. Slightly weathered; lettering is slightly rounded with evidence of some removal of grains, but still legible and clear.
3. Moderately weathered; lettering is rounded with some edges clearly being removed and others removed completely.
4. Badly weathered; lettering is rounded with all or most edges removed; although the lettering remains legible it is increasingly becoming indistinct from the surface of the stone; difficult to read.
5. Very badly weathered; lettering is disintegrating, although still just about legible; almost indistinguishable from surface of the stone.
6. Extremely weathered; lettering has virtually disappeared and there may be scaling.

Erosion is another problem found commonly in marble and may be considered a type of erosion. It is the wearing away of the surface, edges, corners or carved details of the stone over time, giving the stone an overall granular texture. It is typically caused by the natural action of wind and the particles wind carries or water. As the surface texture roughens, there is an increase potential for sugaring. Depending on your definitions, erosion and sugaring may be similar, or perhaps even identical.

Cracking, another common marble issue, is indicated by narrow fissures that can range from less than 1/16 inch to 1/2 inch or more in width. Cracks may result from a variety of causes including the use of mortar that is too hard, the corrosion of internal ferrous iron pins or reinforcements and structural issues such as settlement. Even thermal hysteresis, previously described, may contribute to cracking of marble.



More typical sugaring of marble.

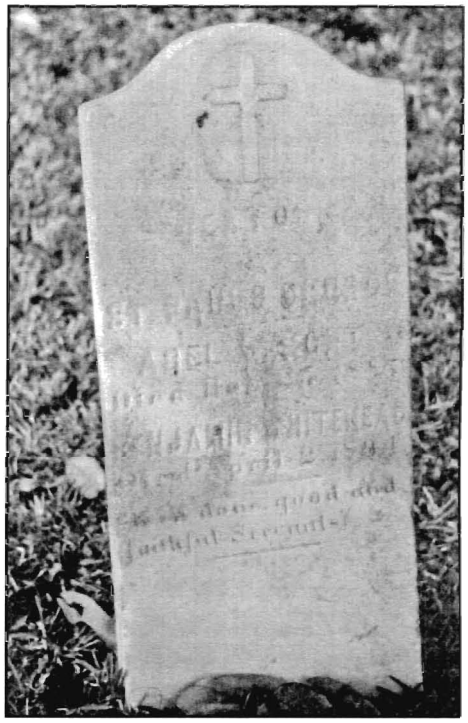


Marble weathering or erosion.

Cracking may also be associated with natural veining in the marble and range from very minor (less than 1/16 inch) to severe (where the crack is wider than 1/4 inch). These veins may be either horizontal or vertical. In marble these veins are often composed of mineral impurities such as clay, sand, silt or chert that were present in the limestone prior to metamorphism. Such veins in marble can have very different physical properties than the surrounding marble and may weather at different rates. Consequently, cracks may also be accompanied by erosion along the vein and it is possible that at least some cracks are simply differential erosion of the vein compared to the surrounding marble.

Cracking may allow water and salts to enter the stone, increasing the possibility of failure along the planes with subsequent spalling. Repairs will typically include patching using an appropriate infill. Often conservators will use a grout such as Jahn M30 or M40, although another option is the use of dispersed hydrated lime (DHL) injection mortar distributed by U.S. Heritage. The use of grouts may be accompanied by opening cracks to allow application of patching mortars such as U.S. Heritage MT15 or Jahn M120.

Warping is still another issue of marble, typically seen in veneer facades by architectural conservators, but also



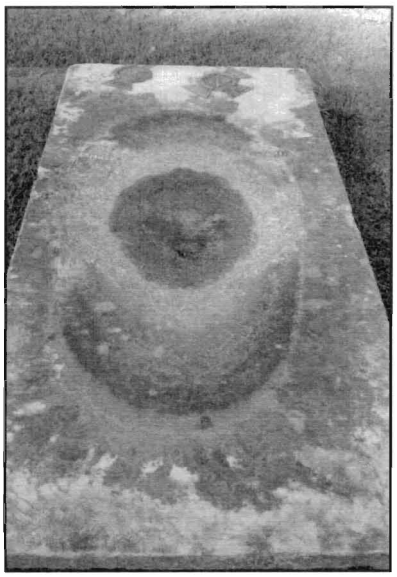
Erosion that is the result of exposure to a landscape sprinkler.

found in the graveyard. Examples include ledgers that are poorly supported, marble plaques attached to tombs and mausoleums, and even the marble crypt covers. Stone is fluid and will warp over time; the warping is further exacerbated by thermal hysteresis and water vapor.

While in theory it is possible to relax marble, the process of removal and long-term storage is fraught with problems and often in the process of moving the weaken marble it will break. Prior consolidation may provide some additional strength. The problem can be mitigated through the use of thicker slabs, preventing water penetration from the back, and better supports and attachments.

Salts are yet another major deterioration force in marble. When salts crystallize within the pores of the stone, stresses may be created that can fragment the marble. At times the presence of salts may be relatively harmless, an example: the hazy, white blotching sometimes observed and known as efflorescence. Far more troubling is cryptoflorescence or salt crystallization within the pores of the stone. Since fine pores can't accommodate the growing amount of salt, the stone eventually breaks apart from the force of the salt crystals. Wetting and drying is particularly troubling and eventually the stone will begin breaking down.

Sources of salt damage include fertilizers, herbicides (yes, particularly that Roundup so many cemetery superintendents are fond of), deicing salts and other sources. Using bleach to clean stones results in chloride salt damage. Most common are sulfates, nitrates, chlorides, sodium, potassium, and magnesium.



Marble warping.

Biologicals may also damage marble in a variety of ways. As biologicals grow, they can exert pressure on the mineral grains, weakening the intergranular structure. Some organisms produce acid compounds that dissolve the calcium carbonate. Many of the lichen and algae allow water to migrate into cracks and crevices of the stone, leading to freeze-thaw damage.

In summary, just like the sandstones discussed in the last column, marbles are affected by both people and nature. The geology and chemistry of the stone, the presence of water and pollutants and lack of appropriate care all combine to turn beautiful monuments into dust. The key is appropriate conservation intervention, recognizing that not all deterioration can be stopped, although it can typically be slowed.

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Marble with vein cracks.