



Project Summary

Deterioration of Marble: A Retrospective Analysis of Tombstone Measurements in the New York City Area

R. B. Husar, D. E. Patterson, and N. S. Baer

A data base of tombstone thickness and depth of emblem inscription at Veterans Administration cemeteries has been compiled by New York University. A subset of measurements for two cemeteries in the vicinity of New York City was selected for analysis in this study. For comparable meteorological conditions, different weathering rates of fine grain marble tombstones were observed for the two cemeteries. Tombstones in the Cypress Hills cemetery, which is located within an industrial area, were observed to have higher rates than similar stones in the semi-rural area of the Long Island cemetery. By using a retrospective air quality model, which is described in another publication, to predict SO₂ concentrations in New York City from 1880 to 1980, concentration trends of SO₂ were estimated for both cemeteries. A linear relationship was found to exist between the weathering rates and estimated SO₂ concentrations. A value of 10 mm per century per ppm of SO₂ was derived as the best estimate for the weathering coefficient of fine grain marble for the New York City area.

This Project Summary was developed by EPA's Atmospheric Sciences Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

New York University, through a program with Task Group G, Effects on Materials and Cultural Resources, within the National Acid Precipitation Assessment Program has compiled measurements of thickness and depth of emblem inscription of marble tombstones in over 23 U.S. Veterans Administration (VA) cemeteries. The marble tombstones used in these cemeteries provide a standardized material, i.e., of uniform composition and prepared under controlled conditions, which are useful for studying stone deterioration over the last century as a function of geographic locations.

In this study, measurements of tombstones recorded by New York University for Cypress Hills and Long Island cemeteries were analyzed. Furthermore, only tombstones prepared from Vermont marble, which is a fine grain stone, were analyzed. The objectives of this investigation were to determine weathering rates of marble and to establish whether a relationship existed between the weathering rate and SO₂ concentrations that were estimated for the cemeteries.

Discussion

In this investigation, the marble deterioration rate was obtained from the difference between the bottom and the top thickness measurements for the tombstone. Weathering of most stones was most pronounced at the top. This was

most apparent from the rounded tombstone edges and from decreasing depth of inscriptions. The part of the stone which was in the ground usually exhibited very little weathering. In most cases, the surface near the ground still had its original smoothness.

In this analysis, considerable scatter was observed for marble loss for each inscription year for both cemeteries. In fact, the standard deviation of the bottom-top difference was comparable to the deviation of the mean from zero, i.e., the noise was comparable to the signal. It was therefore necessary to select representative years with large sample sizes for both cemeteries before computing mean loss in millimeters for each group. The increase in marble loss between successive representative years then yielded the loss rate representative for the intervening range of years. For the 1930 to 1955 time period, the Cypress Hills cemetery showed a weathering rate of about 1.5 mm per century, while the Long Island cemetery was about half of that rate. For the period 1955 to 1980, the corresponding weathering rates were about a factor of 2 lower for both cemeteries.

An estimate of the ambient concentrations of SO₂ for both cemeteries between 1930 and 1980 was needed in order to derive the weathering rate of Vermont marble in terms of SO₂ concentration. In another study, ambient concentrations were estimated using regional and local modeling techniques for New York City, specifically Manhattan's Central Park, from 1880 to 1980. In order to establish the concentration trends for the Cypress Hills and Long Island cemeteries, it was assumed that the concentration ratio between Central Park and the two cemeteries had remained constant over the past years. A concentration ratio was

obtained from SO₂ concentration maps drawn for the years 1969 to 1971. Based on these maps, the SO₂ concentration at Cypress Hills was about 60% ± 20% of Central Park concentration while the Long Island site concentration is approximately 30% ± 20% of the Central Park SO₂ concentration.

Since SO₂ is known to promote marble deterioration, the influence of SO₂ concentration on the weathering rate of Vermont marble was explored. For this part of the study, it was assumed that the meteorological conditions for the Cypress Hills and Long Island cemeteries did not differ greatly for the period 1930 to 1980. Since the cemeteries are located less than 40 miles apart, the average meteorological conditions were expected to be similar over this time period.

A linear relationship that clearly indicates increased weathering with increasing SO₂ concentration was obtained for a plot of the weathering rate of Vermont marble and the corresponding SO₂ concentration. The slope of the linear relationship was 10 mm per century per ppm of SO₂. This value constitutes the best

estimate of the erosion rate of Vermont marble as a function of SO₂ concentration that could be derived from this analysis.

Conclusions

Other researchers have estimated the weathering rate of marble from tombstone measurements to range from 1 to 2 mm per century. The rates obtained in this investigation are within this range. Unfortunately, studies to correlate environmental parameters, especially SO₂ concentrations, with weathering rates are not reported. However, a stoichiometric rate relationship is reported for the erosion in terms of SO₂ flux, rainfall amount and pH, and surface wetness. Assuming conditions that are considered typical of the Northeastern U.S., an upper limit of 11 mm per century per ppm SO₂ was obtained for the erosion of marble. On the basis of these recent studies, the value of 10 mm per century per ppm SO₂ that was derived in this investigation appears to be a reasonable estimate of marble deterioration that has occurred in the New York City area.

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The complete report, entitled "Deterioration of Marble: A Retrospective Analysis of Tombstone Measurements in the New York City Area," (Order No. PB 85-174 134/AS; Cost: \$8.50, subject to change) will be available only from:

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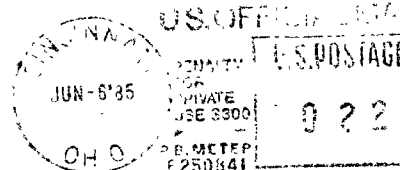
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