Capture of Aerosol Particles by Ice Crystals

by

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Abstract

The ice crystals in a snow storm act to remove aerosol particles by 1) enclosing within the crystals those particles which act as freezing nuclei and which then fall by sedimentation and, 2) by acting as a "filter"; that is, providing a surface on which airborne particles may diffuse. After the particles have diffused to the surface, they become tightly attached and fall to the ground with the crystal. This is a major natural process for cleansing the atmosphere of particulate matter.

Three techniques are being applied to the study of the capture of particles by the ice crystals; 1) electron microscopy of Formvar replicas, 2) electron and light microscopy of the residue from sublimed bulk snow and, 3) light scattering analysis of melt water. While the first technique has proven to be a reliable tool in nucleation studies, the second two techniques are being developed to facilitate study of the aerosol collection by ice crystals around sources.

INTRODUCTION

A major question in atmospheric chemistry and physics is the role of several mechanisms in removing gases and particles from the atmosphere. Sedimentation is the dominant mechanism for removing the large (>10μ) particles; the precipitation process removes many of the .1μ to 10μ particles which act as active condensation and freezing nuclei; and the cloud itself appears to be dominant in reducing the number, and therefore increasing the size, of the smaller (<.1μ) particles.

The cloud removes these small particles by acting as a diffusion filter. The large (relatively) cloud drops present a great amount of surface area upon which the smaller particles of high diffusion coefficient can impinge and be collected. These particles are then precipitated if that particular cloud drop is also precipitated, or agglomerated into a much larger particle upon the evaporation of the drop. The effectiveness of this method can be determined using the formula of Junge (1963); these calculations show that one-half of the small particles collide with cloud drops in one-half hour, in a typical cloud.

Snowpack, and falling snow, appear to be natural phenomena well suited to studying the relative effectiveness of these removal mechanisms. The snowpack contains all of the material precipitated on a given area since the year's first snow; glaciers have been used to determine the history of dustfall in several areas by Langway and his many colleagues at CRREL, and Landsberg in his recent review of climatic change. Consequently, snowpack should be a useful tool in determining the downwind fallout of particles from combustion sources, as well as the dustfall from natural sources. Falling snow can be collected to determine the relative magnitude of aerosol collection by the precipitation processes. If the snow is not collected as it falls, representative samples may be present in the snowpack if a surface crust forms, or if no wind drifting occurs before the snow pit is dug and the specimens collected.

TECHNIQUES AND INSTRUMENTATION

The mass concentration of particles in falling snow is much lower than that found in surface snow which has lain exposed to sedimenting aerosols for a few days. The mass can be determined by melting a large quantity of snow, collected in an extremely clean container, filtering through a small membrane filter and determining the increase in mass of the membrane. This technique is most reliable with snow containing more than 1 mg/litre of nonsoluble particles, unless huge quantities of melt water are obtained.

A faster technique, which is sensitive to the small, less massive particles, is the Tyndall beam, or light scattering method. As small particles near the wavelength of light scatter light as a function of a multiple of their radius, they are easily detected by this technique. The Atmospheric Sciences Research Center has used a Brice-Phoenix Universal Light Scattering Photometer, with a square cell of 3 x 3 cm. This technique requires about 35 cm^3 of sample and is sensitive to around .01 mg/litre. It occasionally encounters difficulties when many large, or filamentous particles are present, or when florescence is present.

A field technique was developed during this study, to facilitate microscopy, and electron microscopy, of not only the nonsoluble aerosol particles, but also of the dissolved material. This technique utilizes a pellet of snow collected from a snow pit, or from the snow core. This pellet is made in a simple pellet press, constructed from two 25 to 50 ml plastic syringe pistons, and one syringe barrel, from which the tip end has been removed. The syringe barrel is inserted in the snowpack and the pellet is formed by re-inserting the pistons at each end, and compacting the snow within the cylinder. The pellet is released from the barrel by removing one piston, and pressing out the specimen with the other. The pellet is kept frozen in a labeled bottle until ready for examination. The device for accomplishing this is shown in Figures 1 and 2.

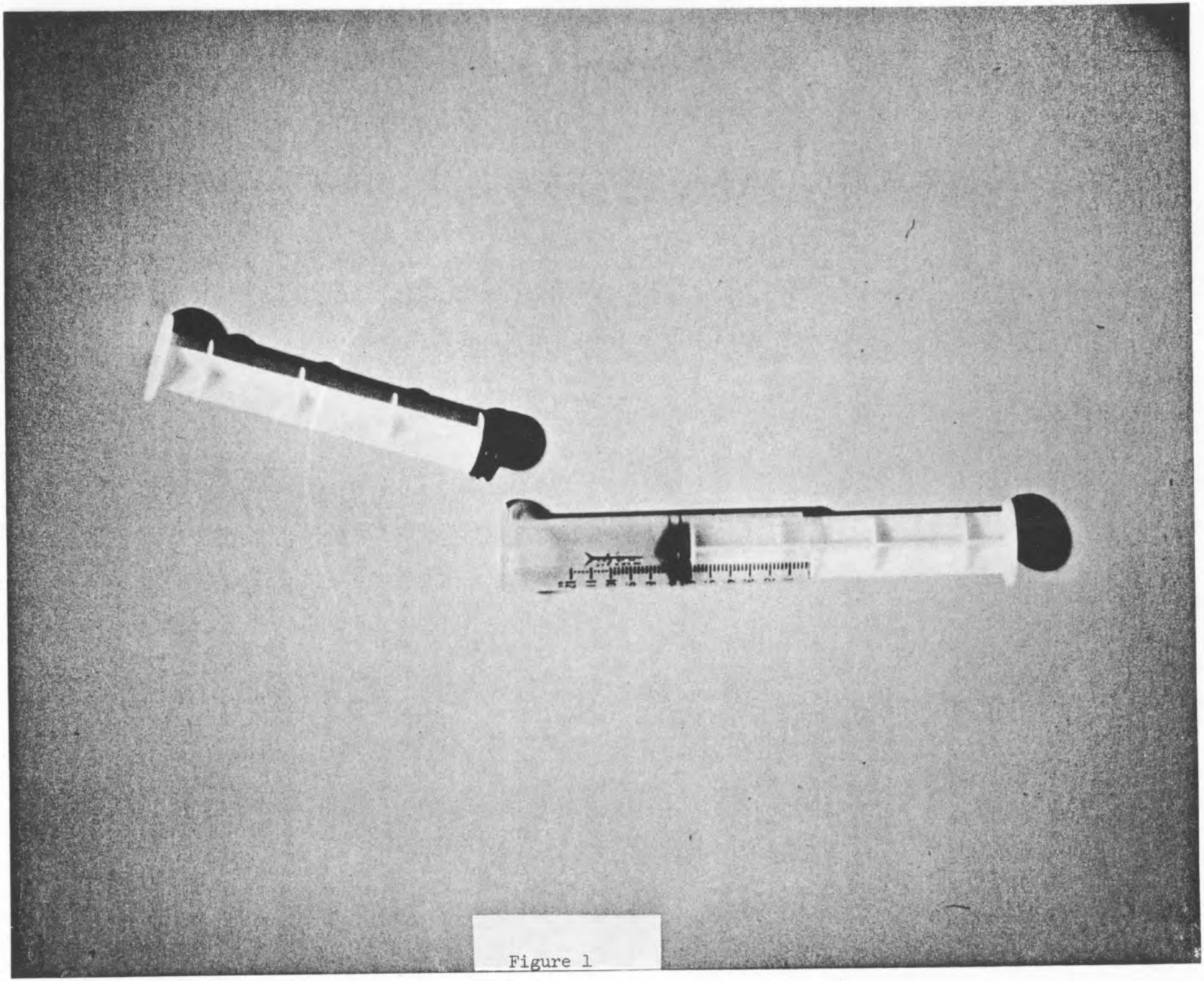

Figure 1

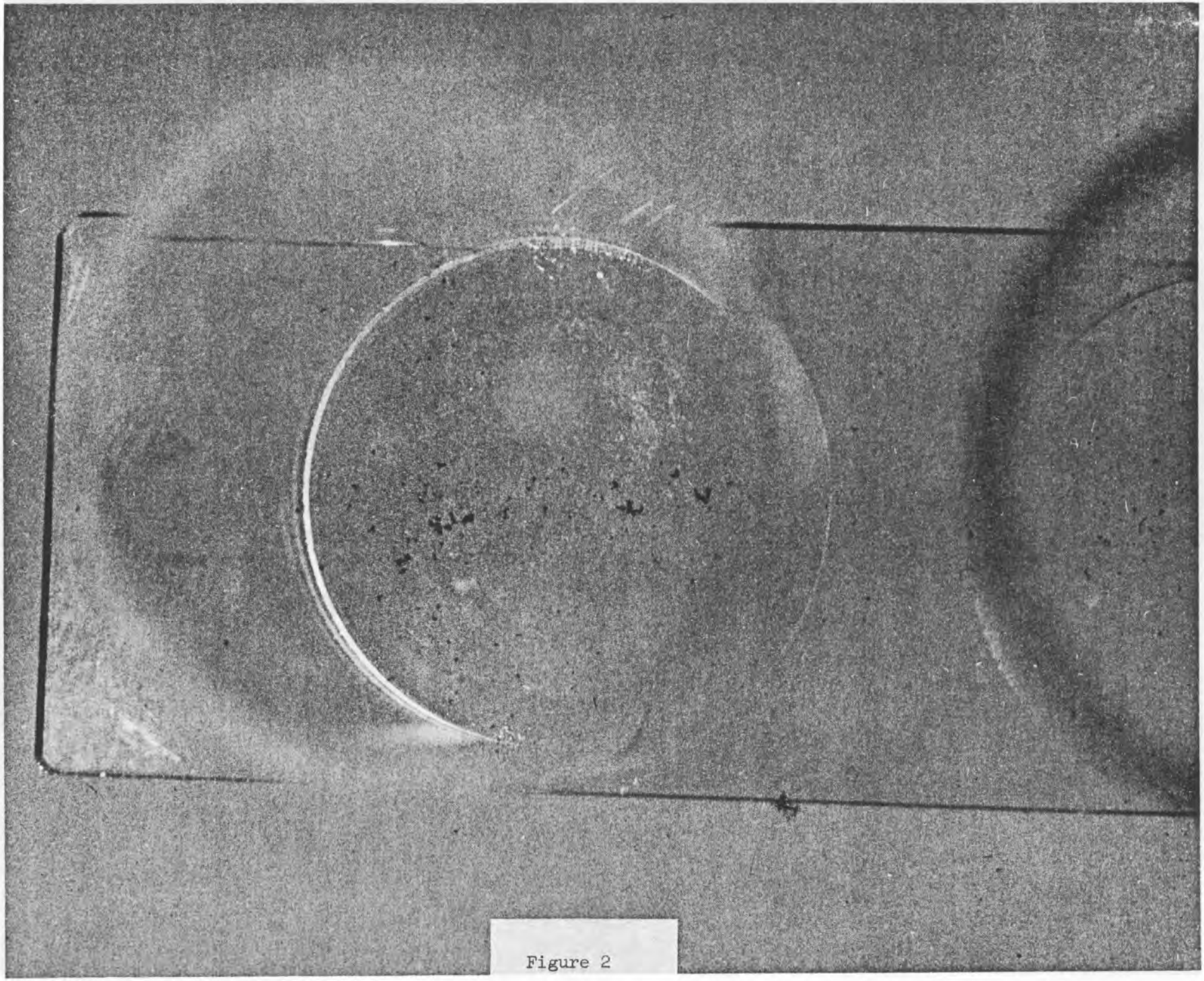

Figure 2

The still frozen pellet is placed in a holder atop a microscope slide and/or electron microscope grid, and the unit put in a desiccator jar. The specimen is then "freeze dried" causing all of the suspended and dissolved material to be deposited along a line, facilitating microscopy. Six 10 gm specimens can be prepared simultaneously, using a small desiccator jar, a dry ice cold trap and a large mechanical vacuum pump. An electron micrograph of particles prepared for microscopy in this way is shown in Figure 3.

A case study of the nonsoluble sediment load of falling snow was conducted during the storms of 22, 23 and 24 December 1970 in the northern New York State area. On the 21st through 23rd of December, 1970, a cold arctic high pressure air mass moved across Ontario and Quebec provinces in Canada with a short ridge down over New York and New England. Temperatures were near or below zero in northern sections of New York during the 22nd and 23rd. An area of low pressure with attendant precipitation moved up the Ohio Valley on the 22nd and the warmer air associated with the low was forced to overrun the colder high pressure air over the northeast. This led to a major snowfall in eastern and northeastern sections of the state. In western and southeastern sections there was freezing rain and drizzle.

The original low pressure center moved across southern New York and merged with a secondary low that formed over Maryland and moved northeastward. Winds were generally N to NE over the state during the period of precipitation. The snow, which was rather of fine structure, was nevertheless more dense than usual. It accumulated to just over five inches at the Albany Airport while six to eight inches fell in northeastern New York.

Meanwhile, on the 22nd, another low had started to organize over the northern plains states and by the afternoon of the 23rd was over northeastern Wisconsin fully developed and with a frontal system trailing southeastward. As the frontal system moved eastward a secondary low pressure center formed along it over Virginia and it intensified to become a coastal storm as it moved northeastward. It pulled moist air in from over the Atlantic in the easterly circulation around its northern side to produce rain in the Boston area but moderate to heavy snow inland. At the Albany Airport there was six to seven inches of new snow by 7:00 AM on the 24th, but amounts of up to 11 inches were reported from surrounding areas. Rimed stellar crystals were falling around sunrise on the 24th along with some snow pellets. Once again winds were mainly from the NE during this period of snow but shifted to W and NW after the frontal passage.

A turbidity analysis of the collected snow is tabulated below:

Date	Location	Relative Turbidity at Wavelength 365 mu	436 mu	546 mu	578 mu	Approx. colloidal equiv., mg/L.
12/22	Whiteface	25.5	15.5	7.0	3.2	1.2mg/kg H_2O
	Boonville	29.0	17.0	8.0	3.6	1.6mg/kg H_2O
	Albany	65.0	30.0	14.0	6.8	4.0mg/kg H_2O
12/23	Whiteface	24.0	13.0	6.0	3.0	1.0mg/kg H_2O
12/23-4	Boonville	36.0	23.5	11.5	5.5	2.3mg/kg H_2O
	Burnt Hills	29.0	16.0	6.5	3.0	1.6mg/kg H_2O
	Albany	32.0	18.5	8.0	4.0	2.0mg/kg H_2O

The masses of nonsoluble particles shown in the last column are expressed as equivalent masses of prepared dispersions of small particles. If the size distribution or refractive index of the atmospheric particles vary greatly from the "standards" (sedimentation classified clay, and colloidal soap solution), then of course, the equivalent mass will be altered; the relative concentrations should not be greatly influenced.

The tabulated data shows that, during the snow of 22 December 1970, more material was brought down by the falling snow over Albany than at the two more remote sites; but the data for the following days shows that the continuing precipitation has brought the

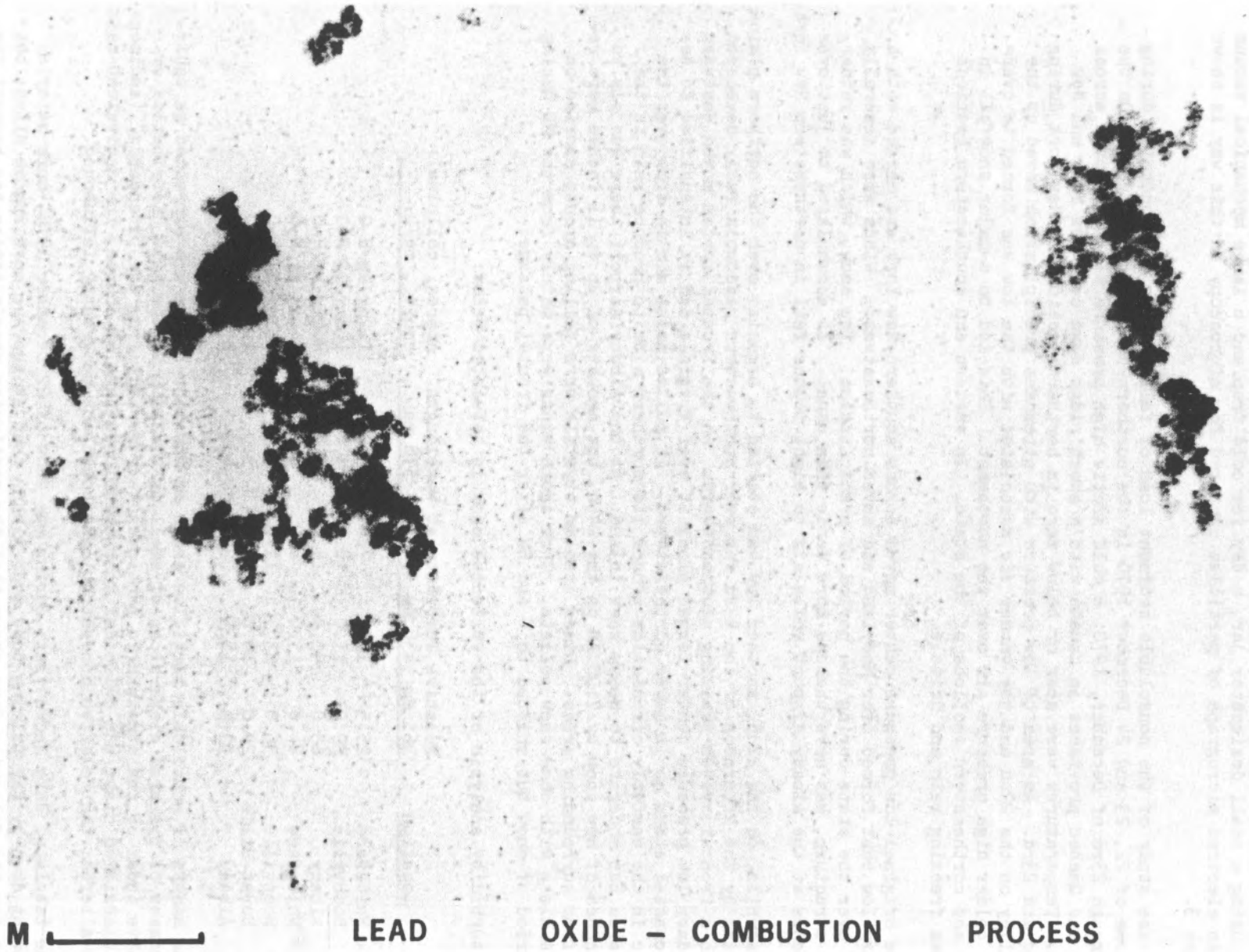

Figure 3

level of nonsoluble particulate matter to the same range for all sites. The relatively high reading obtained from the Boonville sample of the 23rd and 24th is partially due to a short exposure to dry sedimenting aerosol after snowfall ceased.

ANALYSIS OF SNOW CORES

Cylindrical snow cores, containing all the aerosol material which has fallen on the snowpack since the beginning of continuous snow cover, were collected to determine the sedimentation rate of aerosols in winter. These samples were examined by melting, forcing the melt water through a preweighed membrane filter, drying, and reweighing. As the cross sectional area of the snow core, the total mass of melt water and the number of days since first permanent snowfall are known, the sedimentation rate in ugm/cm^2/day, and sediment concentration in mg/litre H_2O can be calculated.

Analysis of Snow Cores from 3.77 cm Diameter Snow Tube Obtained
27 February 71 (85 days after snow cover commenced)

Location	Snow Depth	Suspended Part	Sedimentation Rate
Caroga Lake, town of Caroga, E. 50 yds. from East Shore, approx. 1 mi. from W. Shore	26" (12.1" H_2O equiv.)	3.081 mg/kgm H_2O	1.1 ugm/cm^2/day
9th green, Nick Stoner Country Club, town of Caroga, approx. 2 mi. from above site, 30 yds. from highway	31" (10.2" H_2O equiv.)	44.983 mg/kgm H_2O	13.70 ugm/cm^2/day
University Campus, Albany, N. Y., near biology greenhouses	10½" (4" H_2O equiv.)	6.97 mg/kgm H_2O	2.9 ugm/cm^2/day

When the sedimentation rates determined by this technique are compared with those obtained in similar areas by the sedimentation foil technique the numbers are in surprisingly good agreement.

Comparison of the mass concentrations of suspended particulates in the snowpack with that of falling snow shows that much greater mass is deposited by sedimentation near sources, but that the ratio is about 2:1 in areas removed from immediate sources of large particles.

The ease and success with which snowpack analysis has been employed shows that it can be a useful technique for evaluating the sedimentation pattern downwind of a source during winter months.

CONCLUSIONS

Analysis of falling snow and snowpack is a useful tool for determination of the amount and type of aerosol deposited with precipitation, and the amount of sediments reaching the surface during winter months. The dry sedimentation rates obtained by snowpack analysis are comparable to the rates obtained by sedimentation foils during non-winter months.

The mass of nonsoluble aerosol removed by sedimentation is about two times that falling with precipitation in these preliminary trials. A more sophisticated experiment is necessary to determine the relative amounts of aerosol in discrete size ranges removed by each mechanism.

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