Ocean Water as a Source of Ice Nuclei

Abstract. Preliminary tests indicate that ocean water may release an abundance of ice nuclei to the atmosphere. These results may explain the observation that marked anomalies often accompany an influx of marine air in the Washington, D.C., area and the fact that abnormal counts are often associated with widespread precipitation.

The origin and nature of ultramicroscopic particles in the atmosphere which contribute to the formation of crystals (glaciation) in supercooled clouds and the effect of these nuclei with respect to subsequent rainfall remain obscure. Large fluctuations in the concentration of ice nuclei have been attributed to factors such as windblown dust and industrial effluents. Laboratory investigations summarized by Mason (*1*) have led to the tentative conclusion that ice nuclei active in natural clouds may be relatively insoluble substances of a rather special crystal structure, such as particles found in clay and other siliceous dusts. The evidence does not appear to be entirely consistent in this regard, particularly in the temperature ranges within which natural-cloud glaciation typically occurs. An extraterrestrial source for these nuclei was suggested by Bowen (*2*), who advanced the hypothesis that world-wide precipitation is enhanced about 30 days after meteor showers as a result of an increase in meteoritic debris which provides additional nuclei for the formation of ice crystals in accordance with the Bergeron-Findeisen ice-crystal growth mechanism.

Kline and Brier (*3*) summarized the few available series of daily observations on ice nuclei during several Januaries and indeed found a trend toward higher values around the dates on which such values are predicted by the meteoritic dust theory. However, pronounced increases in concentrations of ice nuclei, which were not associable with any known meteor showers, were detected on several days in February and March 1958 near Washington, D.C. We noted a tendency for higher counts to exist when the air at the surface came from easterly quadrants in the preceding 24 hours, a recent marine trajectory thus being implied. However, low concentrations also were observed during such flow regimes. Further observations during the past year suggest a relationship between the occurrence of high nuclei counts of ice nuclei and the total amount of precipitation over the United States in a 24-hour period. Widespread precipitation is of course frequently associated with moist air which has recently been in ocean areas.

Since it is known from the work of Junge (*4*) and others that the aerosol content of the atmosphere can be increased by a factor of at least 10 to 100 over marine storm areas, the question arises as to what role the state of the sea may play in the observed variations in concentration of ice nuclei. Birstein and Anderson (*5*) reported that sea salt might act as an ice nucleus at a threshold temperature of about −15°C. The aerosol was generated directly from sea salt in the crystalline state by grinding and heating procedures. But a short series of summer observations on the west coast of Ireland by Georgii and Metnieks (*6*) showed no obvious relationship between sea salt and ice nuclei. No further tests of the ice-nucleating properties of particles of marine origin are known to have been made, although hygroscopic particles from oceanic sources are known to be active nuclei for the condensation of water vapor to the droplet state.

Because of these uncertainties, we decided to perform experiments in which we would utilize a particle-generating mechanism analogous to the foaming and bubbling process associated with whitecaps. Bubbling action is known to produce salt particles, from the experiments reported by Mason (*7*) and others. About ½ lit. of ocean water was placed in a bowl and agitated by the blades of an ordinary electric mixer. The air intake of a 10-lit. refrigerated expansion-type cloud chamber of the basic design described by Warner (*8*) was located a few inches above the foam and bubbles formed by the churning action of the blades. Figure 1 shows typical results compared with background counts obtained in an air mass that had recently been in a maritime tropical area. The fact that the warmest temperature observed for the commencement of nucleating activity with sea salt is comparable to that found in marine air in our local series of daily observations on ice nuclei may be significant. The use of carefully distilled water in lieu of ocean water gave negative results. Tests now under way tend to show that a number of soluble substances, including NaCl and $MgCl_2$, yield counts of ice nuclei through this technique that are significantly higher than counts for the surrounding air.

Although these results do not shed much light on the meteor dust hypothesis and the observed recurrence of certain weather events on or near the same calendar date (weather singularities), they suggest a mechanism that might account in part for the high nuclei counts during periods of widespread precipitation, since such precipitation is frequently associated with general storminess and high surface winds. Wahl

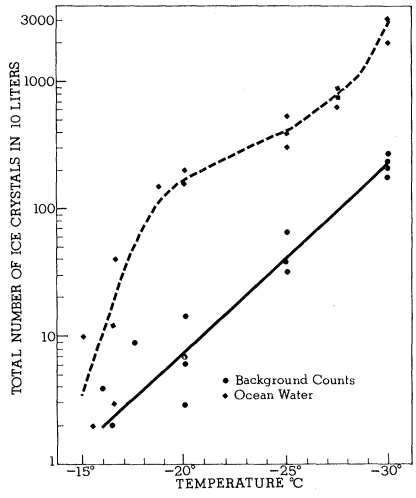

Fig. 1. Temperature-spectrum comparison between the number of ice nuclei in air samples drawn from near the surface of agitated ocean water and the number observed concurrently in ambient air. These data were obtained on 15 March 1959, during an influx of maritime tropical air in the Washington, D.C., area.

(*9*) has pointed out that the weather singularities in the month of January are closely related to changes in the general circulation, and Brier (*10*) indicated that during this month worldwide precipitation was at a maximum, during periods when there was the greatest transport of air at 50° north latitude at the earth's surface.

Although it is too early to generalize, these clues suggest that nucleation of natural clouds may be brought about in part by hygroscopic aerosols acting in the dual role of efficient condensation nuclei and ice nuclei. There is also a possibility that siliceous or other active nucleants may exist in colloidal suspension in certain oceanic areas due to erosion of the shore line by the action of wind, wave, and ocean currents, and that these nucleants are released to the atmosphere as minute particles. More direct identification techniques will be required to resolve the current uncertainties (*11*).

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11. The study reported here is a preliminary phase of an investigation of ice nuclei being undertaken jointly by the National Science Foundation and the U.S. Weather Bureau.

13 May 1959

Effect of Strontium Replacement for Calcium on Production of Motile Cells in Protosiphon

Abstract. Protosiphon botryoides Klebs grows without evident zoosporogenesis in inorganic media in which strontium is substituted for calcium. Growth is 50 to 90 percent of that obtained with calcium; when sodium is substituted for calcium, there is no appreciable growth. Motility was observed at or above $CaCl_2 \cdot 2H_2O$ levels of 5 mg/lit., with or without strontium.

Earlier reports of partial or complete substitution of strontium for calcium as a required nutrient in certain plant species (*1*) led, in connection with a study of the mineral nutrient requirements of *Protosiphon botryoides* Klebs, to an attempt to substitute $SrCl_2 \cdot 6H_2O$ in the growth medium for the $CaCl_2 \cdot 2H_2O$ ordinarily supplied in Bold's inorganic salt medium for the culture of algae (*2*). Three treatments were set up, one with calcium chloride, a second with a molar equivalent of reagent-grade strontium chloride, and a third lacking both added calcium and strontium. A uniform inoculum, obtained from medium containing calcium was washed and added in equal small quantities to each of the three preparations. The preparations were placed under illumination of approximately 300 ft-ca from cool white fluorescent bulbs at 22°C, under a light-dark cycle of 12 hours of light and 12 hours of darkness (*3*). By 12 days after inoculation a phototactic ring of *Protosiphon* cells, indicating zoospore formation, became evident in the preparation containing calcium chloride but did not appear in either of the other two preparations, although growth was evident in the medium containing strontium chloride. Microscopic examination of the cultures revealed an abundance of zoospores in the calcium-containing medium; however none were seen in the medium containing strontium. Turbidimetric growth measurements, reported as total cell volume per liter, were made 37 days after inoculation, with results shown as replicate 1 of Table 1. Subsequent replicates, which showed the same responses in relation to zoospore production, are also shown in the table.

That the growth of *Protosiphon* in the presence of the strontium chloride was not due directly to the addition of calcium as a contaminant in the strontium salt is clear from a study of the growth response to different levels of calcium chloride (Fig. 1) and from spectroscopic analysis of the reagent-grade strontium chloride used (*4*). The rate of growth in the strontium chloride was equivalent to what was obtained at a calcium level of about 0.4*M* equivalent, whereas the spectroscopic analysis revealed a calcium contamination of the reagent-grade strontium chloride of only 10 to 20 parts per million. Replicates with Johnson Matthey, and Co.'s Specpure strontium salt containing 2 parts of calcium per million gave similar results. It appears that strontium replaces the major part, if not all, of the calicum required in this medium for optimum growth of *Protosiphon,* since the controls, containing all the other salts of the medium but the calcium or strontium salts, failed to sustain appreciable growth.

Table 1. Cell volume of *Protosiphon* in nutrient medium at end of culture period (ml/lit.).

Replicate	Medium		
	With Ca	With Sr	Without Ca or Sr
1	5.8	2.9	0
2	12.9	9.4	0
3	8.0	4.0	0
4*	7.7	6.9	0.7
5*	10.6	6.6	0

* Replicates with Specpure strontium salt.

The two curves of Fig. 1 show the relative growth rate of *Protosiphon* at varying levels of calcium chloride. To maintain the chloride content uniform in these cultures, the calcium chloride was replaced by sodium chloride in one instance and by strontium chloride in the other. Other tests have indicated that results would have been similar if the sodium chloride replacement had been omitted from the medium. Careful microscopic examination of the cultures revealed that zoospore production, whether or not strontium was present, began at a calcium level of approximately 5 mg/lit., 0.2 the concentration of the calcium supplied in the basal medium.

The results of these studies on *Protosiphon* point to a critical role for calcium, which cannot be assumed by strontium, in the production of motile cells.

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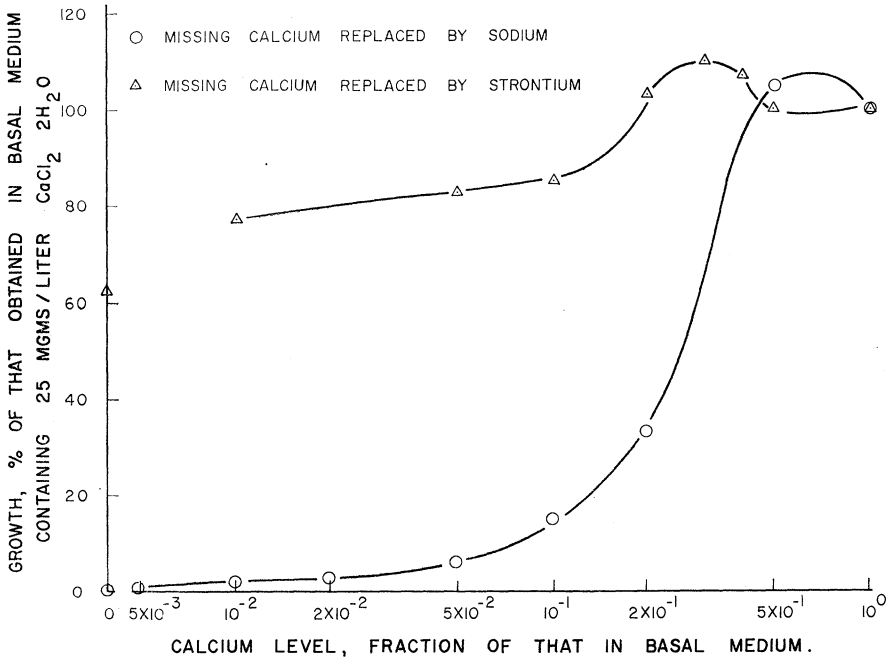

Fig. 1. Effect of strontium and sodium replacement of calcium on the growth of *Protosiphon botryoides* Klebs, measured as percentage of total cell volume obtained with 25 mg of $CaCl_2 \cdot 2H_2O$ per liter.

References and Notes

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3. We gratefully acknowledge the assistance of the research committee of the University of Alabama in providing the culture facilities used in this study.
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