STUDY OF DROPSIZE DISTRIBUTION IN WARM CLOUDS SUBJECTED TO REPEATED SEEDING

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ABSTRACT

Warm seeding experiments, using aircraft, were conducted in three different regions in India during the summer monsoon of 1973. Cloud drop samples were obtained, during these experiments, in a few cases of isolated cumulus/cumulus complexes while they had been repeatedly seeded. For this purpose, glass slides coated with magnesium-oxide smoke were exposed by hand operated gadgets through the window of the seeder aircraft.

Analysis of the data collected pointed out marked changes in the microstructure of the clouds following seeding. The drop size distribution broadened. The median volume diameter increased. The drop concentration decreased. The liquid water content increased.

It was argued that the features noticed as above could be due to the combined effect of the accelerated condensation and coalescence processes following seeding.

INTRODUCTION

In-cloud measurements during cloud seeding experiments, besides improving our understanding of the cloud microstructure, may help provide a physical basis for the evaluation of the experiments conducted. Valuable knowledge has been gained from the seeding experiments recently reported on cold clouds (Sax et al., 1973, Dennis and Schleusener, 1973) as well as on warm clouds (Cunningham and Glass, 1972) which had embodied measurements on various cloud physical parameters. Evaluation done was, sometimes, based extensively on the changes noticed in the cloud physical parameters following seeding (Hobbs et al., 1972).

Experiments on warm clouds, using aircraft, were undertaken in three different regions in India during the summer monsoon (June to September) of 1973. Drop size distributions were measured, during the experiments, in a limited number of cases of isolated cumulus/cumulus complexes while those had been repeatedly seeded. Analysis of the data revealed marked changes in cloud microstructure following seeding. All the measurements made are presented and discussed.

EXPERIMENTAL REGIONS

The experiments were conducted in the regions of Poona ($18^{o}32'$N, 73^{o} 51'E, 559 m MSL), Bombay ($18^{o}54'$N, $72^{o}49'$E, 11 m MSL) and Rihand ($24^{o}12'$N, $83^{o}03'$E,*). Poona is in the rain shadow belt of the Western Ghats, and it is about 150 km from the coast. Bombay is on the coast. Rihand is well inland and is about 500 km from the coast. Measurements were made from the middle of the monsoon at Poona and towards the end of it at Bombay and Rihand.

SEEDING EXPERIMENT

The details of the seeding experiment conducted in each of the three regions mentioned are given (Krishna et al., 1974a, b; Kapoor et al., 1974). The experimental operation for repeated seeding entailed dispersal of seeding material, at a nearly constant altitude of a few hundred feet above the cloud base, by following a flight path which involved a given number of traverses through the cloud at that altitude. The duration of initial traverse through the cloud varied from 1 to 8 minutes, depending upon the thickness of the cloud under question. The seeding material used was a pulverised mixture of common salt and soapstone taken in the ratio of 10:1 with particle mode diameter of about 10 microns. The rate of seeding varied up to 10 kg per km of flight path.

METHOD OF MEASUREMENT

Size distribution of cloud drops was measured by the impaction technique on magnesium-oxide coated slides. A spring loaded sampler, which is hand operated (Srivastava and Kapoor, 1960), was employed for exposing the slides. The slides used were of width 6 mm and exposed to the cloud, subjected to seeding, through a window of the DC-3 seeder aircraft for a period of 200 milli-seconds. A sample each was obtained for every traverse made through the cloud. As the main attention of the party working on board the aircraft was concentrated on the seeding operation, it did not become possible to sample the cloud drops more than once in a traverse.

The drop size distribution was determined by measuring the crater sizes on the exposed slides under an optical microscope, and by applying corrections for flattening factor (May, 1950) and collection efficiencies of the slide for droplets of various sizes (Ranz and Wong, 1952). The average cruising speed of the seeder aircraft was 54 m sec^{-1}.

Drops of size 2 microns and less were not collected by the slide. The number concentrations given by the measurements are, therefore, underestimated. The size measurements made were at intervals of 7 microns for clouds at Poona and Bombay and 5 microns for clouds at Rihand.

The collection efficiency of the slide is nearly unity for drops of

* 310.5 m MSL

diameter 25 microns and above. The changes indicated in the spectrum width in the higher size end are, therefore, considered to represent the true picture. The estimated values of the liquid water content are also considered to represent the true picture, as the contribution by the missing drops in this regard is negligible.

RESULTS

The designs of the seeding experiments at Poona and Rihand were such that they entailed seeding of all the clouds which were present in the flight path. There were, therefore, no cases of unseeded clouds in these regions for measurement during the period of the experiments. In the experiment at Bombay, which made use of radar for analysis, no penetrations were made through unseeded clouds. Measurements were made in four cases of seeded clouds at Poona and in one such case each at Bombay and Rihand.

The number of traverses through the cloud, when measurements were made, varied from 3 to 7, and sampling was done once in each such traverse. The individual samples correspond to horizontal path lengths of about 10 meters and represent a cloud volume of about 2 litres.

POONA

The values noted of maximum drop diameter, drop concentration, liquid water content and median volume diameter in the successive seeding traverses made in the cloud cases on August 4, 5, 16 and October 24, are given in Table 1. The number concentration in different size groups is shown in Figure 1 to 4. The minimum mean diameter noted in each traverse in all the cases was 2 microns.

August 4: The cloud complex was of vertical thickness 3 km and length 25 km. It was seeded with 1,500 kg of material in 6 traverses. Measurements were made in traverses I, II, III and V. The size spectrum progressively broadened from 42 to 245 microns. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse III. The liquid water content was maximum in traverse II.

August 5: The cloud complex was of vertical thickness 1 km and length 16 km. It was seeded with 1,300 kg of material in six traverses. Measurements were made in traverses I to IV. The size spectrum progressively broadened from 91 to 168 microns. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse III. The liquid water content was maximum in traverse II.

August 16: The cloud complex was of vertical thickness 2 km and length 10 km. It was seeded with 400 kg of material in three traverses. Measurements were made in all the traverses. The size spectrum progressively broadened from 42 to 175 microns. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse III. The liquid water content was maximum in traverse III.

October 24: The cloud complex was of vertical thickness 1 km and length 6 km. It was seeded with 850 kg of material in 9 traverses. Measurements were made in the first 7 traverses. The size spectrum broadened from 84 to 224 microns with the peak in traverse VI. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse IV. The liquid water content was maximum in traverse VI.

Table 1: Variation of microstructure, following seeding, in the clouds at Poona

Date	Traverse No.	Maximum drop diameter (microns)	Drop Concentration (number per cc)	Liquid water content (gm per m^3)	Median volume diameter (microns)
August 4	I	42	29.7	0.04	13.4
	II	224	21.8	3.08	70.5
	III	224	9.9	2.37	77.4
	V	245	18.8	2.88	66.3
August 5	I	91	91.3	0.35	19.4
	II	140	92.6	0.64	23.6
	III	154	14.8	0.27	34.9
	IV	168	29.7	0.62	34.1
August 16	I	42	12.6	0.02	15.4
	II	98	12.6	0.17	29.4
	III	175	10.6	0.25	35.3
October 24	I	84	12.5	0.17	29.6
	II	126	37.8	0.98	36.7
	III	182	16.5	0.32	33.2
	IV	91	11.2	0.16	29.8
	V	161	30.4	1.08	40.8
	VI	224	28.1	1.86	50.2
	VII	161	32.2	0.69	34.5

BOMBAY

The data relating to the cloud case on September 29 are given in table 2 and figure 5. The minimum drop diameter noted in each traverse was 2 microns.

The cloud was of vertical thickness 1 km and length 3 km. It was seeded with 600 kg of material in 8 traverses. Measurements were made in traverses I, III, IV, VI and VIII. The size spectrum broadened from 56 to 224 microns with the peak in traverse VI. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse IV. The liquid water content was maximum in traverse VI.

Table 2: Variation of microstructure, following seeding, in the cloud at Bombay

Date	Traverse No.	Maximum drop diameter (microns)	Drop concentration (number per cc)	Liquid water content (gm per m^3)	Median volume diameter (microns)
September 29	I	56	52.0	0.31	22.5
	III	196	27.1	0.52	33.2
	IV	112	20.0	0.13	23.4
	VI	224	36.2	0.68	33.1
	VIII	77	48.2	0.31	23.1

RIHAND

The data relating to the cloud case on September 22 are given in table 3 and figure 6. The minimum mean diameter noted in each traverse was 5 microns.

The cloud complex was of vertical thickness 2.5 km and length 3 km. It was seeded with 150 kg of matreial in four traverses. Measurements were made in traverses I to III. The size spectrum progressively broadened from 45 to 70 microns. The median volume diameter was minimum in traverse I. The drop concentration was minimum in traverse III. The liquid water was maximum in traverse III.

Table 3: Variation of microstructure, following seeding, in the cloud at Rihand.

Date	Traverse No.	Maximum drop diameter (microns)	Drop concentration (number per cc)	Liquid water content (gm per m^3)	Median volume diameter (microns)
September 22	I	45	38.3	0.10	17.3
	II	50	47.5	0.22	20.6
	III	70	21.8	0.26	28.4

DISCUSSION

The following physical changes took place, after the first traverse, in all the cases of the seeded clouds. The drop size distribution broadened.

The median volume diamter increased. The drop concentration decreased. The liquid water content increased. The changes noticed are systematic. Keeping in view that the data obtained in the first traverse, in each case, would represent conditions of the cloud in its natural state, the changes noticed in the subsequent traverses may be attributed to seeding.

There is justification to consider that the data relating to the first traverse represent the natural conditions of the cloud because, in the seeder aircraft, the location of drop-sampling was ahead of the seed-releasing location, besides being at higher elevation. The sampling gadget was operated from a window near the cockpit whereas the outlet of the seed releasing gadget was situated below the fuselage near the tail. The portion sampled of the cloud in the first traverse was, therefore, unlikely to have been affected by the seeds released. The processes which would have contributed for the changes noticed in cloud microstructure in subsequent traverses are considered below.

The maximum drop size noted in the initial traverses was 91 microns in the clouds at Poona (Table 1, Figure 2) and 56 microns in the cloud at Bombay (Table 2, Figure 5). The presence, in the cloud, of such big size drops initially suggests that the process of coalescence would have set in, in the natural course, early in its active growth stage. It is not known whether the process was progressing or it became inefficient by the time seeding was undertaken. The possibility of coalescence process starting early in the natural course and becoming rapidly inefficient subsequently, as was found to be the case in continental warm clouds by Takeuchi (1972), may not be ruled out in maritime clouds also, specially in the absence of favorable circulation features. Such possibility appears to be strong in the case of clouds at Poona, for, the station is situated in a rain-shadow belt on the lee of the Western Ghats. It could also be so in the case of clouds at Bombay during the period of measurement because that period coincided with the withdrawal of the monsoon there. But, following seeding, the size spectrum spectacularly broadened in the clouds both at Poona and Bombay. The finding suggests that the process of coalescence became accelerated in the clouds after they had been seeded with common salt. The seeded cloud at Rihand did not exhibit spectacular broadening (Table 3, Figure 6). This cloud was different from the clouds experimented at Poona and Bombay in that it was located in a region which is far inland.

Temperature measurements were made inside clouds at Poona during the seeding experiment. The measurements showed rise up to 2°C, in portions of clouds, following seeding pointing out the possibility of updraft development inside as a result of warm seeding (Ramachandra Murty et al., 1974). It is noted that the condensation, induced by even a gentle updraft, could help change the cloud drop spectrum in such a way that coalescence would be accelerated (Kovetz and Olund, 1969). Also, the combined effects of condensation and coalescence on the development of droplet-size spectra in cumulus cloud have been stressed (Jonas and Mason, 1974). The marked changes in the size spectrum noticed after seeding, in the present measurements, appear to be due to the combined effect of the accelerated condensation and coalescence processes brought about by seeding.

The size spectrum in one extreme case, namely, August 4, broadened up to 224 microns after the first traverse (Table 1, Figure 1). Keeping in view that the duration of the traverse alone in this case was 8 minutes and that it would take some minutes before the second traverse could commence and sampling was done, the finding suggests that drizzle size drops were produced in a period of about 10 minutes following seeding. The feature noticed seems to be in order in view of the recent model calculations reported (Leighton and Rogers, 1974) according to which, under suitable conditions, drops approaching precipitation size form in warm clouds by the combined process of condensation and coalescence in time periods of 10-15 minutes.

CONCLUSION

The features pointed out above suggest that the changes noticed in the cloud microstructure after seeding could be due to seeding and that such changes become detectable by a simple observational program as in the present study.

Non-homogeneity in microstructure is characteristic of cumulus cloud (Squires, 1958 and Vulfson et al., 1973). The portion covered inside a given cloud might not and could not necessarily be the same in each traverse. The possibility of the observed change in microstructure from one traverse to another resulting from non-homogenity alone in the cloud cannot, therefore, be eliminated. Extensive measurements should, therefore, be made in many cloud cases, including unseeded ones, before definitive conclusions becomes possible of the effect of seeding on the microsturcture of the cloud.

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FIGURES 1-6

VARIATION OF DROPSIZE DISTRIBUTION IN DIFFERENT TRAVERSES. THE ORDINATE IS SHIFTED FOR CLARITY BY ONE SCALE EACH FOR SUCCESSIVE TRAVERSES INDICATED.

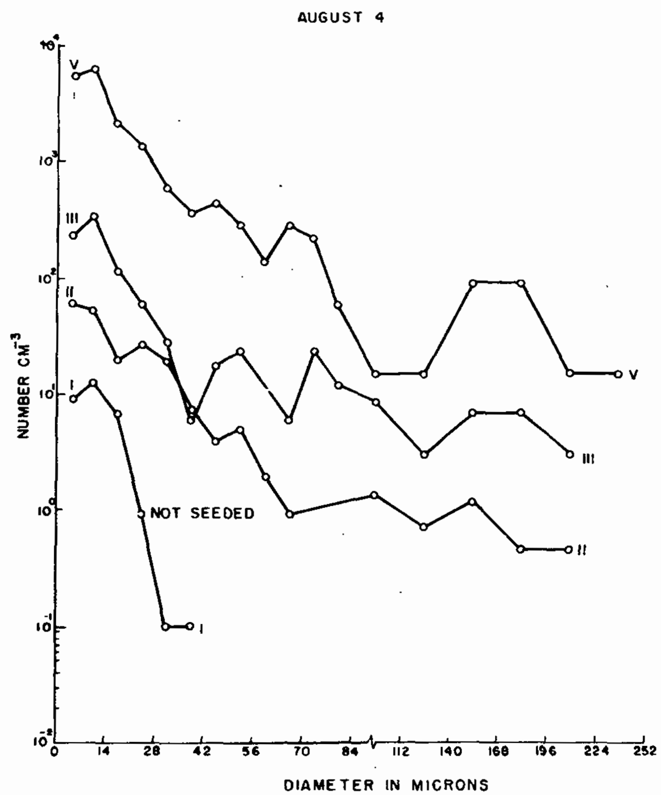

Figure 1

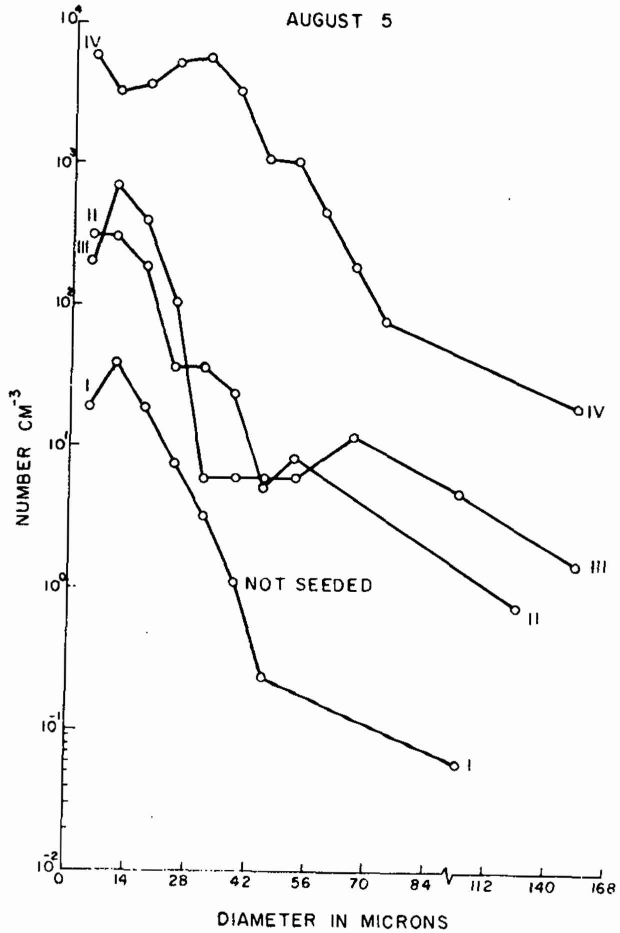

Figure 2

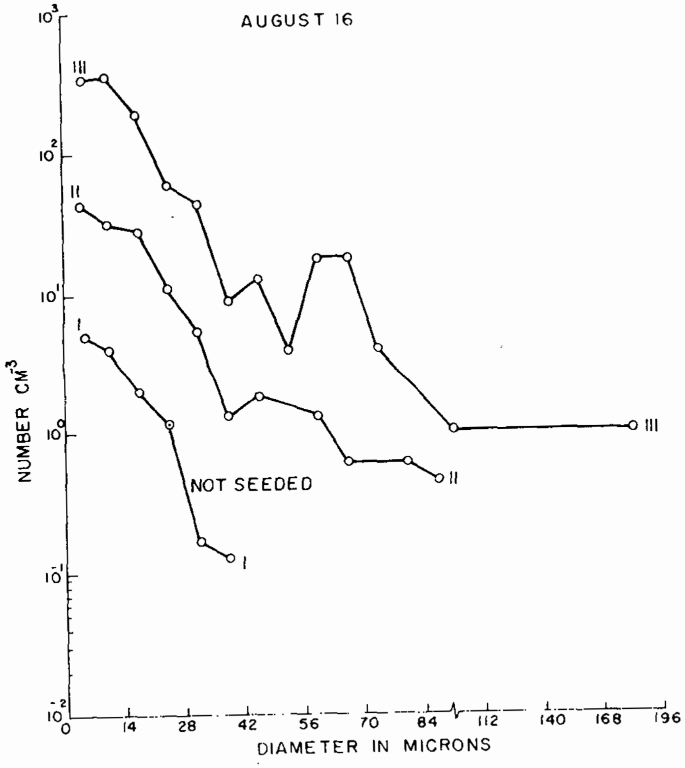

Figure 3

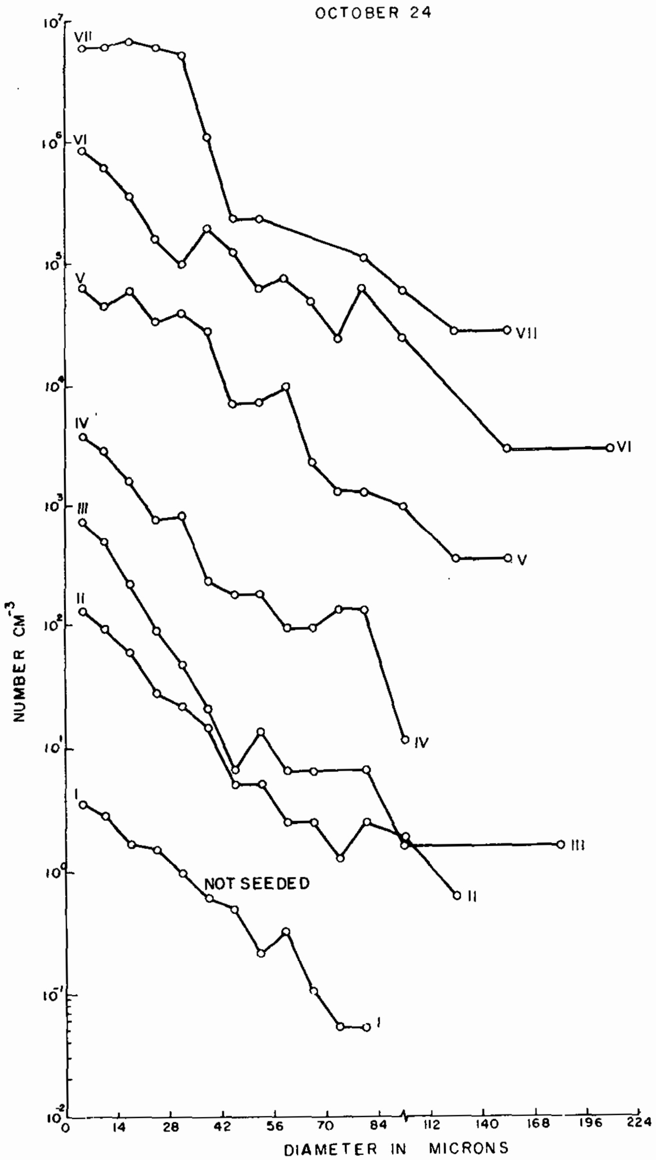

Figure 4

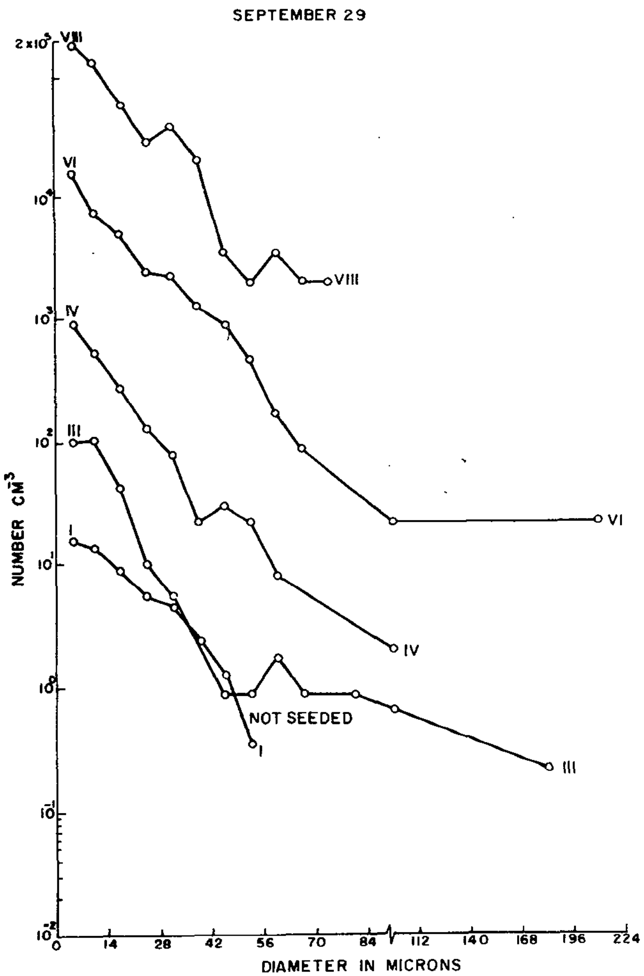

Figure 5

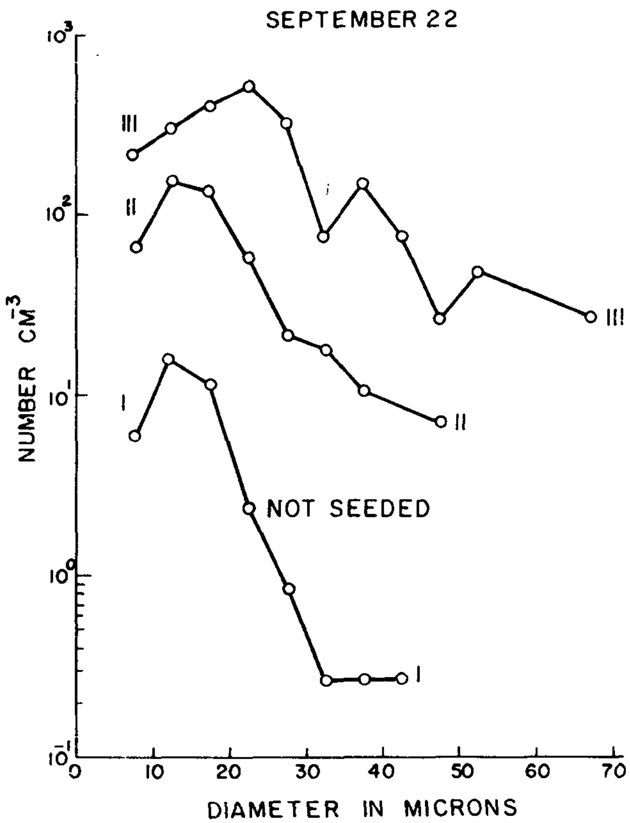

Figure 6