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Mineral Composition of Rainwater

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Abstract

Analyses of 62 rainwater samples collected at the University of Illinois Airport near Savoy, Ill., showed that on the basis of equivalent concentrations, the chloride is equal to the sum of sodium and potassium. Sodium was three times the potassium. Calcium plus magnesium was 10 times the chloride and equal to the sum of the bicarbonate and sulfate. The sulfate was equal to twice the sum of ammonium and nitrate.

These results indicate salt from sea mist to constitute a negligible proportion of the mineral content. They also indicate the presence of air pollution by the combustion of fuel.

Introduction

A number of hypotheses exist on causes for the inception of rainfall. Laboratory studies indicate that relative humidities of up to 500 percent may be reached with no condensation, "Condensation does not begin until water vapor has a suitable surface (nucleus of condensation) on which to condense" (JOHNSON, 19). One school of thought suggest sodium chloride (as sea salt) as the principal nucleus of condensation. (WOODCOCK, 1950 and 1952, WRIGHT, 1940).

For the purpose of determining its presence and the general mineral composition of rainwater, a series of 64 samples were collected over the period from Oct. 26, 1953 to Aug. 11, 1954 at the Illinois Water Survey Meteorological Laboratory at the University of Illinois, Airport near Savoy, Illinois. Most of these samples received a more complete mineral analysis than has ever been previously attempted. A thorough review and bibliography on the composition of atmospheric precipitation has been published by ERIKSSON (1952 and 1955).

The results of these analyses proved to be interesting although not entirely conclusive. A number of relationships were established from the data. The most significant appear to concern the relative low concentration of sea salt and also the abnormal air pollutants present in a non-industrial midwestern atmosphere.

Sampling

Samples were collected in a rigid 48 inch diameter stainless steel pan which delivered the rainwater by plastic tubing to one gallon borosilicate glass bottles previously cleaned and thoroughly rinsed with ammonia-free water (600,000 ohm-cm). The location of the sampling pan was 50 feet above the ground surface on the southwest corner of a 47 foot radar tower during the collection of the first 21 samples. For the remainder, the sampling pan was located in an open field, 90 feet east of the nearest building and 10 feet above the ground. Sample 14 was collected at the base of the tower.

Except for the periods of collection during rainfall, the pan was covered tightly with a stainless steel cover. Prior to sampling, the pan and drain tube were rinsed with 4 liters ammonia-free water.

Rainfall rates and synoptic conditions are indicated in Appendix B.

Storage

After collection, the samples were delivered to the Water Survey Chemistry Laboratory and stored at room temperatures until analysis. The bottles were glass stoppered and protected from dust by aluminum foil.

Several composition changes probably occurred during storage. Since loss or gain of carbon dioxide is uncontrollable in storage as well as during collection of samples, pH determinations are worthless and are not reported.

Although it is conceivable that some causticity and silica may have been dissolved by long contact with the bottles, it did not appear to be significant since at least three samples were found to have less than 0.05 ppm sodium.

It is probable that changes occurred in the form of nitrogen during storage. It is well known that bacteria often convert ammonia to nitrate. Therefore, since no provisions were made for sterilization, all considerations of ammonia and nitrate are made on the basis of the sum of equivalents of the ammonia and nitrate. It should be recognized also that conversion of ammonia to nitrate results in an increase in acidity which in turn produces free CO_2. For example, in sample 49 the absence of ammonia and presence of appreciable nitrate may have induced a low value in the determination of alkalinity. It should be noted that the nitrate determination also includes nitrites.

Filtration

With the exception of samples 1 to 12 and 17 to 20 and all sulfate determinations, the aliquots were obtained for analysis by pipetting from supernatant water after allowing a long period for turbidity to settle. The chloride, sodium, and potassium results for filtered samples are considered unreliable since subsequent experiments indicated that no amount of rinsing of filter paper would completely eliminate contamination therefrom. These results of the first 12 samples were not used in correlation. Chloride contamination was reduced after thorough washing to .03-.07 ppm from filter papers used for samples 17 to 20. Sodium contamination by filtration appeared to be difficult to avoid.

Methods

Results (Appendix A) of determinations for various components are expressed as equivalents per billion[1] (epb) or micro-equivalents per liter ($\mu\, eq. l^{-1}$). The maximum difference between the sum of cations and that of anions was 3 epb (No. 57) and in general was less than 12 epb. Fig. 1 shows that in almost every sample the total cations were less than the anions. Several reasons may be suggested for this. First, the previously discussed error introduced by storage conversion of ammonia to nitrate; second, a possible but unlikely negative error in hardness or positive error in sulfate and/or nitrate; third, the possible presence of an unidentified component. The belated discovery of 0.14 ppm (15.6 epb) aluminum (as Al) in sample 62 aided the balance considerably after repeated determinations of hardness failed to provide a satisfactory endpoint.

Dark room techniques and the use of low actinic glassware were necessary for the determination of chloride, ammonia, and nitrate.

The analytical methods were constantly being modified and improved. All procedures were modifications of procedures in Standard Methods of Water Analysis (1946), with the following exceptions: Chlorides were determined by the Mercuric nitrate procedure (CLARKE, 1950). Sodium and potassium were determined with a flame photometer. The

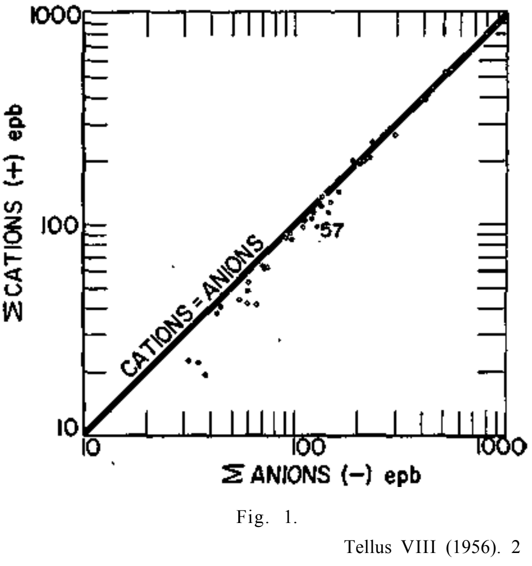

Fig. 1.

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[1] 10^9 milliliters.

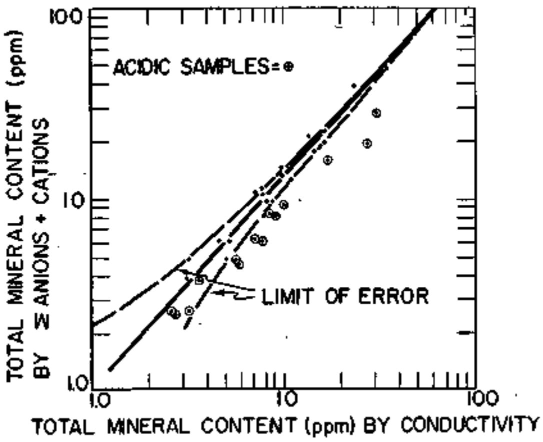

Fig. 2.

most significant improvement occurred in the determination of alkalinity and acidity (LARSON and HENLEY, 1955) which improved the accuracy to ±.05 ppm (1 epb).

Although the accuracies of most determinations were good to excellent, the possible errors were significant and any correlation must consider these as well as the possible changes in quality during storage.

In general the following limits of accuracy prevailed:

chloride, ±1.1 epb (excluding samples 8, 11, 13, 14, 16, 18, 19, 20, 23, 45, 50, and 51 where the error may have been ± 4 to 8 epb).

sulfate, ±0.8 epb (excluding samples 5, 14, 22, 22 A, 28, 32, 37, 43, 47, and 57 where the error may have been ± 2 to 6 epb depending on the available volume of sample)

nitrate, ±3.9 epb.

alkalinity, 10 epb for sample 1 - 12A and 1 epb for the remainder.

sodium, ±0.8 epb.

potassium, ± 0.4 epb.

ammonia, ±1.7 epb.

hardness, ± 10 epb (excluding 6, 11, 12A, and *62* where the error may have been ± 16 to 28 epb and 49 - 61 where the error was no more than 1 epb).

The total mineral content was estimated by converting the 25° C. resistivity to ppm (parts per million) using an empirical factor of 56430. This factor, although adequate for normal ground waters in Illinois, requires adjustment for rainwater samples (Fig. 2) and is not applicable for acidic samples due to the presence of significant concentrations of highly conductive hydrogen ion.

Correlation

It is obvious that the absolute concentrations of various components of each sample are not of significance for correlation purposes, since a certain amount of washout of water-soluble dust particles occurs at the beginning of each rainfall. In eight rainfalls two or more consecutive samples were collected:

Table I

light	1, 2, 3, 4, 5 35, 36, 37
steady rains	8, 9 41, 42
thundershowers	24, 25 38, 39 45, 46, 47 58, 59

The hardness and chloride of the successive samples were, *within analytical error,* usually less and in any event not more than that of preceding samples.

Correlations therefore were attempted on the basis of relative concentrations of the various components. It became evident, as data were accumulated, that a fairly consistent pattern was developing which, with few exceptions, favored all samples.

In general, on the basis of equivalent con-

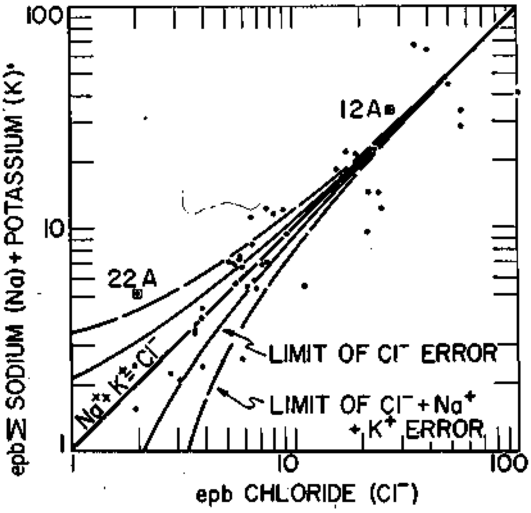

Fig. 3.

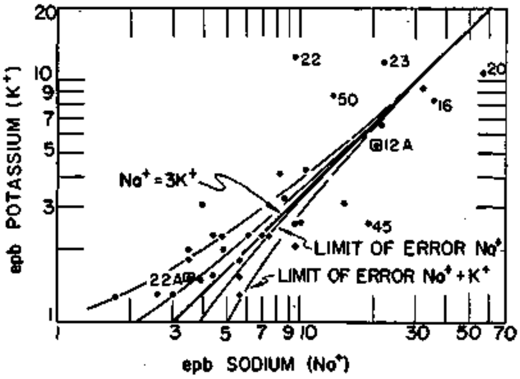

Fig. 4.

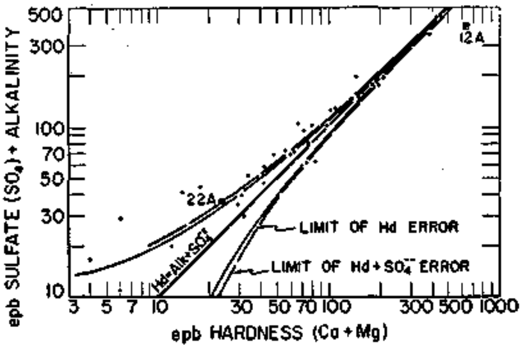

Fig. 6.

centrations in epb, it may be said that for samples collected at this point, the chloride was equal to the sum of the sodium and the potassium (Fig. 3), and the sodium was about three times the potassium (Fig. 4). The hardness (calcium and magnesium) was about 10 times the chloride (Fig. 5) and equal to the sum of the bicarbonate plus the sulfate (Fig. 6). The sulfate was equal to twice the sum of the nitrate plus the ammonium (Fig. 7).

Twenty one of the 52 samples (nos. 13-62) used for these relationships showed significant deviations. No sample deviated in more than three relationships of the five and there were only four (nos. 13, 14, 20[1], 28) with three deviations. In all four the chloride was low (no. 20) or high (13, 14, 28) both with respect to hardness and to sodium plus potassium content, indicating probably contamination in the chloride determinations. In sample 23 sodium was low with respect to the sum of potassium and sodium and low with respect to chloride, indicating a possible error in the sodium determination.

Certain other exceptions were explainable. In three of the greatest deviations from the hardness-chloride relationships, the atmosphere was reported very dusty prior to collection of the samples (nos. 18, 20, 49). In control samples No. 12A and 22A, the collection pan was left exposed under conditions of no rainfall for 36 hours and 5 hours, respectively,

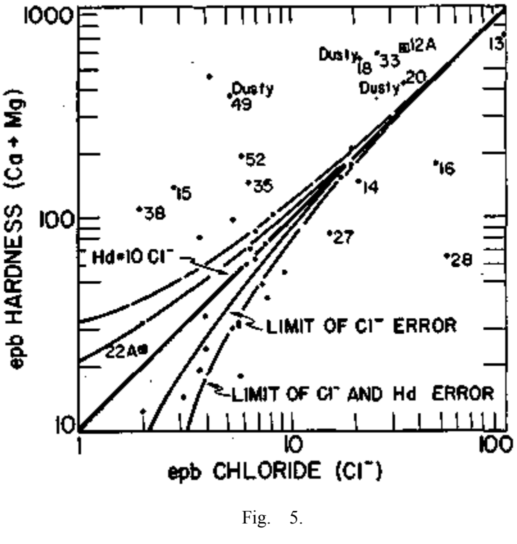

Fig. 5.

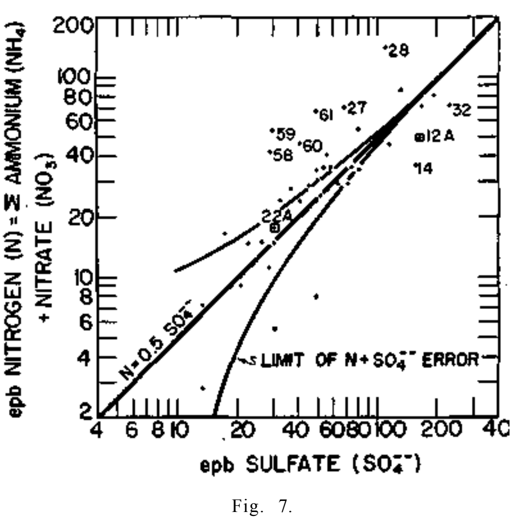

Fig. 7.

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[1] Filtered.

Table II

No.	Date	SO_4 epb	No.	Date	Acidity epb
8	12/ 2/53	131			
12 A	12/21/53	168.5			
13	1/20/54	100			
			25	4/ 5/54	4
			26	4/ 6/54	3
			27	4/ 7/54	6
28	4/10/54	110	28	4/10/54	6
			29	4/10—11/54	12
			31	4/15/54	3
32	4/22—23/54	233	32	4/22—23/54	55
35	5/16/54	131			
			36	4/16/54	11
			37	4/16/54	2
			39	4/27/54	3
			43	6/1/54	11
			59	8/3, 4/54	4
			60	8/4/54	17
			61	8/4/54	10
62	8/12/54	166	62	8/12/54	96

and washed with 2,000 and 1,200-ml portions of water. Sample 12A also had an excessive hardness.

Discussion

Sodium, Potassium. Since the sodium to potassium ratio of 3:1 and the chloride to sodium plus potassium ratio of 1:1 are so consistent there is little reason to believe that ocean spray salt (Na:K::47:1) is the source of chloride in the atmosphere[1] on this vicintiy, unless a base-exchange equilibrium is established with minute particles of insoluble clay in the samples. This should be unlikely, since potassium generally replaces sodium on the insoluble clay and also since it would not be expected that a uniform proportion of sea salt and clay particles would be present in the atmosphere.

Hardness-Sulfate, Alkalinity. If it is assumed that the presence of sulfates results from oxidized sulfur from the combustion of coal, gasoline, oil, and gas, sulfur trioxide will react quantitatively with any dissolved or undissolved calcitic or dolomitic particles to release carbon dioxide. The sulfate content plus the bicarbonate content (alkalinity) therefore should equal the hardness plus excess hydrogen ions (acidity or negative alkalinity). This relationship appears to be very good over the wide range of concentrations recorded. It would appear to confirm the conclusion that the greatest percentage of the water-soluble atmospheric particles is of calcitic or dolomitic origin.

Sulfate, Nitrate-Ammonia. The sulfate concentrations 'were not related to the chloride nor the hardness. Therefore the presence of sulfate is considered to be abnormal. The high concentrations did not appear to be seasonal as shown in Table II.

Similarly the nitrate and ammonia concentrations had little relation to chloride or to hardness, and again the high concentrations did not appear to be seasonal.

The nitrate plus ammonia content does appear to be related to sulfate in a 1:2 proportion (Fig. 7).

In six samples (Nos. 27, 28, 58, 59, 60, 61)

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[1] Since preparing this manuscript the excellent paper by Emanuelsson, Eriksson and Egner (*Tellus* 6, p. 261, 1954) has been called to our attention. It appears clear that sodium chloride from sea mist falls out at a more rapid rate than potassium chloride. This should be highly conceivable due to the formation of larger crystals of sodium chloride than potassium chloride, since the greater concentration of sodium in the mist droplets would cause sodium chloride crystallization and growth within the droplet on evaporation before potassium chloride crystallization. The tormenting enigma of increasing sodium to chloride ratios still exists. It detracts from the above concept only to a minor extent.

which showed a higher than "normal" ratio of nitrogen to sulfur (Fig. 7) all but one (No. 28) were associated with thunderstorms. It is probable that the combined nitrogen overshadowed that which may have been produced by lightning in the other samples collected during thunderstorms.

Since the sulfur-nitrogen ratio was fairly constant, and did not appear to be related to "normal" constituents, it is probable that the greater portion of both result from combustion of fuels and probably primarily from a single source.

It has been established that nitrogenous products, as well as sulfur products, result from combustion of various fuels other than coal in the Los Angeles atmosphere (MAGILL and BENOLIEL, 1952). (Table III.)

Table III

	Sulfur (as SO_2) tons/day	Nitrogen (as NO_2) tons/day	Ammonia (as NH_3) tons/day	Sulfur/Nitrogen (epb ratio)
Fuel Oil (1)	220	100	—	2.8
Fuel Gas (2)	84	140	4	.8
Gasoline...	30	40	4	.85*

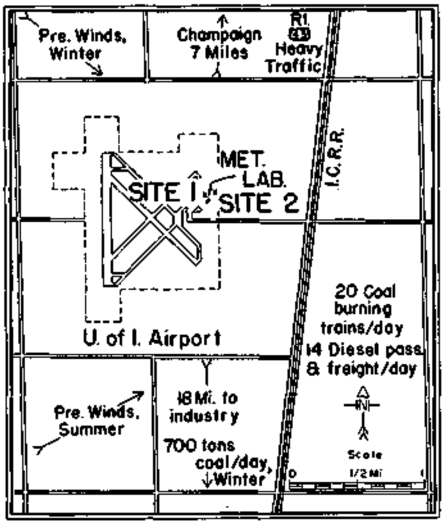
* At road speeds this ratio is lower due to greater fixation of nitrogen.

Also on the basis of 4% sulfur and 1.7% nitrogen in eastern Illinois coals, the equivalent ratio of sulfur to nitrogen would be 2. 1:1.

In Diesel fuel sulfur is quantitatively converted to oxides on combustion (SCHRENK and BURGER, 1941) and nitrogen oxides are formed in various concentrations depending on the fuel—air ratio and speed. In a series of five tests by the Bureau of Mines (BURGER, ELLIOT, HOLTZ and SCHRENK, 1943) using fuel of 2.4 % sulfur content, the exhaust gases had equivalent ratios of sulfur oxides to nitrogen oxides of 1.8 to 9.2.

No information appeared to be available on the expected ratio from railroad Diesel engines or from aviation gasohne. It may be expected, however, that the sulfur content of these fuels is negligible.

A sketch showing the collection pan locations and relative distances to sources of sulfur and nitrogen combustion gases is shown in Fig. 8.



LOCATION OF RAINWATER SAMPLING EQUIPMENT
ILLINOIS STATE WATER SURVEY
1955

Fig. 8.

Considering the two separate parameters: 1, sulfate, as an indication of unnatural mineral or gaseous content of rainfall; and 2, chloride, as an indication of the natural mineral content of rainfall, it was of interest to further correlate these components with an approximation of the rates of rainfall during the periods of collection of samples (Appendix B).

In Fig. 9, it appears conclusive that the sulfate concentration of rainwater decreases with increased rate of rainfall. This appears to indicate the presence of a limited quantity in the lower atmosphere which is removed at each period of precipitation. The spread in

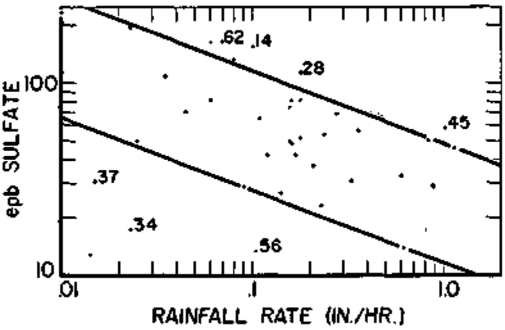


Fig. 9.

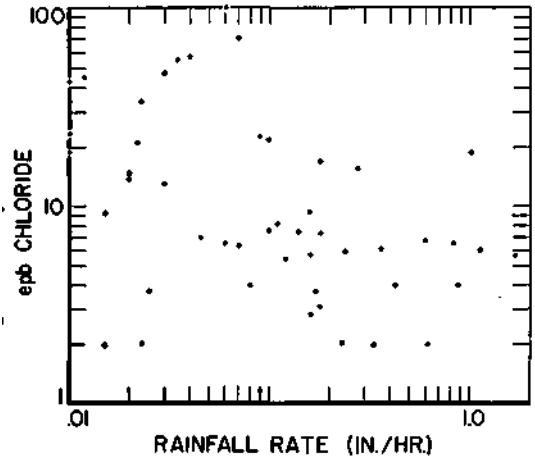


Fig. 10.

values is to be expected due to 1, the approximation of rates of rainfall (This would mean the rate at which the bulk of the sample was collected was usually higher than indicated.) and 2, an expected variability of sulfur gases in the atmosphere.

On the contrary it appears in Fig. 10 that the chloride content does not appear to be dependent on rate of rainfall.

Suggestions

If this study were to be repeated, a number of samples should be collected aloft near the point of inception of ice or rain. Washed samples of hail should provide similar information uncontaiminated by wind-blown soil or the majority of air pollution.

Analyses for silica and alumina should be included for possible identification of clay types. It may be desirable to employ spectrographic means to identify silt sediments from the samples.

All determinations should be made sensitive to less than 1 epb with standard deviation less than 1 epb.

Acknowledgment

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REFERENCES

BURGER, L. B., ELLIOT, M. A., HOLTZ, J. C, and SCHRENK, H. H., 1943: Bureau of Mines Report of Investigation, P. 3713.

CLARKE, F. E., 1950: Determination of Chloride in Water. *Anal. Client.,* 22, p. 553.

ERIKSSON, E., 1952: Composition of Atmospheric Precipitation. *Tellus,* 4, pp. 215 and 280.

ERIKSSON, E., 1955: Air Borne Salts and the Chemical Composition of River Waters. *Tellus,* 7, pp. 134 and 395.

JOHNSON, J. C, 19..: *Physical Meteorology.* New York, The Technical Press of the Massachusetts Institute of Technology and John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., p. 206.

LARSON, T. E., and HENLEY, L., 1955: Determination of Low Alkalinity or Acidity in Water. *Anal. Chem.,* 27, p. 851.

MAGILL, P. L., and BENOLIEL, R. W., 1952: Air Pollution in Los Angeles County, I. & E. C, 44, p. 1347.

STANDARD METHODS OF WATER ANALYSES, 9 ed., 1946: New York, American Public Health Association, Inc.

SCHRENK, H. H., and BURGER, L. B., 1941: Composition. of Diesel Engine Exhaust Gas, *Am. J. Pub. Health,* 31, p. 669.

WOODCOCK, A. H., 1950: Condensation nuclei and precipitation. *J. Meteor.,* 7, p. 161.

WOODCOCK, A. H., 1952: Atmospheric salt particles and raindrops. *J. Meteor.,* 9, p. 200.

WRIGHT, H. L., 1940: Sea salt nuclei. *Quart. J. Roy. Meteor. Soc,* 66, p. 3.

Appendix A

Date & Approx. Volume	No.	Cl^-	$SO_4^=$	NO_3^-	Alk.	Na^+	K^+	NH_4^+	Hd	TMC	Totals		
												(—)	(+)
		epb	epb	epb	epb	epb	epb	epb	epb	ppm	ppm	epb	epb
10-26-53; 4 liters	1	11.3	72.8	17.7	90.	8.7	2.6	2.8	214	11.1	20.6	191.8	228.1
10-26-27-53; 3 l..	2	14.1	101.9	20.9	30.	8.7	3.6	47.7	86	11.2	13.7	166.9	146.0
10-27-53; 4 liters	3	2.8	37.4	22.5	30.	8.7	1.0	3.3	36	5.7	6.8	92.7	49.0
10-27-53; 4 liters	4	2.8	45.8	3.1	20	4.4	1.0	2.8	4	7.3	3.8	71.7	12.2
10-27-53; 1,400 ml	5	2.8	49.9	9.0	0.0	13.1	1.8	7.2	—	8.7	—	61.7	—
11-20-53; 500 ml	6	—	—	31.1	—	69.6	15.4	29.4	352	—	—	—	—
11-29-53; 1 liter.	7	—	—	21.4	60	8.7	3.3	50.5	126	14.4	—	—	—
12-2-53; 12-3-53; 2,700 ml.....	8	42.3	131.0	20.4	10	52.2	3.3	18.0	126	17.6	11.9	203.7	200.4
12-3-53; 4 liters.	9	11.3	47.8	5.2	20	17.4	1.8	7.8	38	7.0	6.5	84.3	65.0
12-5-53; 4 liters.	10	2.8	31.2	4.7	40	8.7	0.8	2.8	50	3.6	6.7	78.7	62.3
12-5-53; 2,300 ml	11	36.7	91.5	20.1	30	13.1	5.9	18.3	126	12.3	15.6	178.3	163.3
12-9-53; 2,800 ml	12	5.6	68.6	11.8	10	8.7	2.3	11.1	—	8.8	—	—	—
12-21-53; 2 liters	12A	33.8	168.5	31.2	230	21.8	5.4	18.9	644	37.9	56.	463.5	690.1
1-20-54; 600 ml.	13	100.5	—	55.5	—	32.2	9.2	47.2	740	53.2	Anal.	incomp	829
1-26-54; 1,500 ml	14	21.4	156	16.3	—	7.4	2.3	20.6	150	15.2	Anal.	incomp	180
2-15-54; 4 liters.	15	2.8	50	7.4	99.4	1.7	0.5	0.6	138	9.7	14.9	160	141
2-19-54; 800 ml.	16	47.9	—	33.5	49.2	36.1	8.4	42.2	178	21.2	Anal.	incomp	262
2-25-54; 100 ml.	17*	13.0	—	—	—	—	—	—	—	—	Anal.	incomp	—
3-10-54; 600 ml.	18*	21.4	—	45	—	10.4	4.3	35.0	572	38.3	Anal.	incomp	622
3-11-54; 200 ml.	19*	45.1	—	—	—	40.4	—	—	—	—	Anal.	incomp	—
3-12-54; 3,300 ml	20*	33.8	196	36.2	244	56.9	10.7	47 2	420	34.3	48.6	510	535
3-18-54; 4 liters.	21	6.8	70.8	11.6	2.0	3.5	1.8	17.8	64	7.9	8.1	91	87
3-19-54; 1,500 ml	22	16.9	115	19.8	35.6	9.6	12.5	27.2	152	14.5	17.9	187	201
3-25-54; 1,200 ml	22A	2.0	31.2	5.6	6.4	3.5	1.5	12.2	24	3.6	3.8	45	41
3-29-54; 200 ml.	23	56.7	—	—	—	22.2	11.8	—	—	—	—	—	—
4-5-54; 4 liters..	24	6.5	49.9	6.8	47.6	6.1	2.3	24.4	72	8.2	9.7	110.8	104.8
4-5-54; 3,500 ml.	25	5.9	45.7	8.5	(—4.0)	4.4	2.3	25.6	18.	5.8	4.7	60.1	54.3
4-6-54; 3 liters..	26	9.3	74.9	12.1	(—3.0)	7.0	2.3	23.9	56	8.4	8.3	93.3	92.2
4-7-54; 3,500 ml.	27	15.5	68.6	48.9	(—6.4)	15.2	3.1	22.8	84	11.0	12.8	133.0	131.5
4-10-54; 2 liters.	28	55.	110.2	44.7	(—6.4)	21.8	6.7	98.9	66	17.1	16.2	210	200
4-10-54; 4-11-54; 4 liters.......	29	7.3	81.1	20.3	(—11.8)	4.8	2.0	36.1	48	10.0	9.3	108.7	102.7
4-14-54; 4-15-54; 4 liters.......	30	5.4	41.6	12.7	61.0	4.8	.8	11.1	98	7.7	11.3	120.7	114.7
4-15-54; 4 liters.	31	2.0	22.9	7.7	(—2.8)	0	.5	7.8	12	2.6	2 6	32.6	23.1
4-22-54; 4-23-54; 2 liters.......	32	18.9	233.	44.7	(—54.6)	3.5	2.0	28.3	180	30.1	28.1	296.6	268.4
4-30-54; 5-1-54; 1 liter.........	33	24.8	—	33.2	276	8.3	4.1	22.8	596	32.2	—	—	631
5-2-54; 3,300 ml.	34	2.0	17.5	10.5	13 0	0	.3	6.1	32	3.1	3.93	43.0	38.4
5-16-54; 4 liters.	35	3.94	131.0	22.6	66.0	2.18	.23	64.5	146	16.2	19.81	223.5	212.9
5-16-54; 3,700 ml	36	1.13	29.2	5.0	(—11.2)	.43	.26	6.1	4.	3.2	2.64	35.3	22.0
5-16-54; 1,700 ml	37	1.97	31.2	5.6	(—2.6)	1.31	.26	9.4	6.	2.7	2.56	38.8	19.6
5-27-54; 4 liters.	38	1.97	31.2	5.0	105.2	2.18	.23	0.6	110	8.9	12.79	143.4	113.0
5-27-54; 4 liters.	39	1.97	13.7	2.7	(—2.6)	.43	.26	0.3	6.	.15	1.36	18.4	9.6
5-27-54; 500 ml.	40	6.48	—	21.0	6.2	10.9	.26	14.4	—	—	—	—	—
5-31-54; 4 liters.	41	6.77	33.3	12.4	67.4	4.35	1.54	12.2	88.	7.7	10.76	119.9	106.1
5-31-54; 4 liters.	42	5.36	37.4	15.5	2.0	5.66	1.28	12.2	30.	5.0	4.95	60.3	49.1
6-1-54; 1,700 ml.	43	3.10	52.0	11.3	(—10.8)	1.74	1.28	14.4	14.	5.6	4.90	66.4	42.2
6-2, 3-54; 4 liters	44	7.61	81.1	20.8	—	3.92	3.08	13.9	76.	8.7	9.72	109.5	96.9
6-7-54; 3,500 ml.	45	18.9	58.2	16.9	138.8	19.2	2.56	18.9	208.	16.5	22.74	232.8	248.7
6-7-54; 4 liters..	46	5.64	20.8	6.3	27.6	5.66	1.54	2.8	32.	3.6	4.81	60.1	42.0
6-7-54; 2 liters..	47	7.61	27.0	6.8	31.8	9.57	2.56	8.3	42.	4.6	6.15	73.21	62.4
6-8-54; 2,800 ml.	48	8.18	64.5	15.0	61.6	9.57	2.05	14.4	102.	9.8	13.06	149.3	128.0
6-15-54; 3,200 ml	49	5.08	56.2	41.5	298.2	4.8	2.3	0.0	382.	23.3	39.7	401.	389.1
6-20-54; 400 ml.	50	23.1	—	—	—	13.9	8.7	0.5	—	—	—	—	—

Date & Approx. Volume	No.	Cl^-	$SO_4^=$	NO_3^-	Alk.	Na^+	K^+	NH_4^+	Hd	TMC	Totals		
												(--)	(+)
		epb	epb	epb	epb	epb	epb	epb	epb	ppm	ppm	epb	epb
6-30-54; 75 ml..	51	69.9	—	—	—	—	—	76.6	—	—	—	—	—
7-2-54; 3 liters..	52	5.92	54.1	35.9	124.2	10.0	2.6	0.0	197.0	13.5	21.4	220.1	209.6
7-2-54; 200 ml..	53	13.8	—	—	—	—	—	47.7	—	—	—	—	—
7-3-54; 1 liter...	54	9.02	—	49.9	43.4	8.7	3.3	21.1	—	—	—	—	—
7-7-54; 200 ml..	55	Sample was polluted during collection											
7-21-54; 4 liters.	56	0.85	13.3	7.2	33.8	1.3	0.3	0.0	42.4	3.2	4.97	55.2	44.0
8-2-54; 1,500 ml.	57	3.67	49.9	[1]22.5	52.0	3.0	0.5	12.2	81.4	7.1	10.9	128.1	97.1
8-3-54; 4 liters..	58	3.95	29.1	18.0	23.0	2.6	1.3	25.0	34.0	5.2	6.07	74.1	62.9
8-3, 4-54; 4 liters	59	3.95	—	[2]26.2	(—4.4)	3.0	1.3	28.9	24.0	7.0	6.23	[2]	61.6
8-4-54; 4 liters..	60	3.67	41.6	24.3	(—17.4)	2.6	0.8	23.2	19.4	7.7	5.99	69.6	63.5
8-4-54; 4 liters..	61	5.64	49.9	41.5	(—9.8)	5.7	1.8	37.7	30.8	9.0	8.19	97.0	85.8
8-12-54; 3 liters.	62 (3)	6.20	166.4	37.5	(—96.0)	3.9	1.5	35.0	60.0	27.3	9.13	200.1	196.4
8-8-54; 200 ml..	63	43.4	—	—	—	—	—	42.2	—	—	—	—	—
8-11-54; 300 ml.	64	14.7	—	—	--	—	—	0.5	—	--	—	—	—

Analyses on supernatent pipetted from original sample except for Nos. 1—12, 17, 18, 19 and 20.

* Determinations were made on sample which had been filtered through washed and dried filter paper.
Total Mineral Content by conductivity (TMC)

ppm parts per million
epb equivalents per billion

[1] Small Sample (375 ml)
[2] Bits of glass chipped from stirring rod invalidated $SO_4^=$ detr. (est. conc. 30 + epb)
[3] 0.14 ppm (15.6 epb) Al^{+++}

Appendix B. Rainfall Rates and Synoptic Conditions

By STAN CHANGNON

Sample No.	Rainfall Rate (in/hr)		Total[1] Rain(in)	Prior Rain		Brief Synoptic Conditions (final analysis)
	Average	Intermittent[1]		Time	Amount (in)	
13 B[2]	0.06	Yes	0.02	7 hrs.	0.73	Post cold frontal, R, CP with MT aloft
14 B	0.10	No	0.60	4½ hrs.	0.05	Post cold front, RW-, CP air
15 C	0.05	Yes 2 storms	0.05	9 days	T	Pre-frontal squall line, TRW, MT
	0.16	5½ hrs. later	0.66	5½ hrs.	0.05	Post cold frontal, RW, MT
16 D	0.03	No	0.04	3 days	0.71	Warm front overrunning, RW-, CP & MT aloft
17 D	0.03	No	0.03	7 hrs.	0.02	Overrunning low in S. Ill., R-, S-, E-, MP with modified MP aloft
18 D	0.022	Yes	0.14	6 days	0.32	Overrunning on Stationary front, RW-, R-, with CP & MT aloft
19 C	0.012	Yes	0.06	18 hrs.	0.14	Warm front overrunning, RW-, R-, CP & MT aloft
20 C	0.023	Yes	0.14	19 hrs.	0.06	Low center passage, TRW, RW, CP & MT aloft *(new location of pan)*
21 D	0.045	Yes	0.24	7 days	0.14	Pre-cold frontal, RW-, MT air
22 B	0.18	No	0.09	9 hrs.	0.24	Secondary cold front, RW-, TRW-, CP
23 C-B	0.04	No	0.02	4 hrs.	0.03	Post cold frontal, R-, CP with modified CP aloft
24 B-C	0.84	No	0.42	3 hrs.	0.57	Warm front overrunning, RW, TRW, MT air aloft

Sample No.	Rainfall Rate (in/hr)		Total[1] Rain(in)	Prior Rain		Brief Synoptic Conditions (final analysis)
	Average	Intermittent[1]		Time	Amount (in)	
25 C-B	1.13	No	0.15	Rain at Beginning	0.42	Same as No. 24, MT, total continuous rain No. 24—25 = 0.57
26 A	0.16	No	0.35	Rain at Beginning	0.18	Squall line, TRW, MT
27 A	0.28	No	0.14	22 hrs.	0.35	Squall line, TRW, MT air (close to cold front)
28 B	0.035	Yes, varied .01 to .36	0.078	2½ hrs.	0.03	Warm front in Central Ill. decelerating RW, MT aloft
29 B-A	0.16	3 separate storms	0.16	7½ hrs.	0.078	Stationary front Central Ill., cold front W. Ill., MT air, RW & TRW
	0.18	2nd storm	0.09	1½ hrs.	0.16	(Same as above)
	0.02	3rd	0.10	1½ hrs.	0.25	Post frontal (cold), RW, MT aloft
			0.35			
30 C	0.12	No	0.30	2 hrs.	0.60	Squall line and Pre-frontal, RW-, TRW-, R, MT air
31 A-B	0.23	No	0.73	Rain at time of sample	0.23	Cold frontal passage, R to RW, MP replacing MT
32 A	0.01	Yes .004 to .01	0.07	1 hr.	0.10	Overrunning stationary front, post frontal (cold) RW-, R-, CP and MT aloft
33 D	0.02	Yes 2 cells	0.01	3 days	T	Overrunning warm front, RW-, MT aloft
	0.09	2nd storm	0.015	5 hrs.	0.01	Overrunning warm front, RW-
			0.025			
34 C	0.023	No	0.81	Rain at time of sample	0.67	Overrunning warm front, R, MT aloft
35 C	0.08	No	0.40 end of sample	8 days	T	Stationary frontal zone, R, R-, MT air
36 C	0.09	No	0.25 end of sample	Rain at Beginning	0.40	Stationary frontal zone, R, R-, MT air
37 C	0.015	No	0.03	Rain at Beginning	0.65	Samples 35—37 all from 1 continuous rain = 0.68″, synoptic conditions all similar
38 B	0.33	No	0.33 end of sample	7 hrs.	0.08	MT Air Mass Showers, R, TRW
39 B	0.61	No	0.37 end of sample	Rain at Beginning	0.33	MT Air Mass Showers, R, TRW
40 B	0.06	No	0.02	Rain at Beginning	0.92	Samples 38—40 from 1 continuous storm = 0.94 (.20″ fell during time between No. 39 & 40)
41 B-A	0.04	Yes 2 separate cells	0.02	20 hrs.	T	Squall line, RW, MT air
	0.60	2nd storm cell of sample	0.61	1 hr.	0.02	Squall line, RW, MT air
			0.63 end of sample			
42 B	0.21	No	0.29	Rain at Beginning	0.63	Squall line, RW, MT air
43 A	0.04	Yes 2 cells	0.05 (0.02)	Rain at Beginning	0.03	Post cold-frontal, RW, CP air
	0.18	2nd cell of sample	0.03	1 hr.	0.05	Post cold-frontal, RW, total storm rainfall 0.08″ in sample 43
			0.08			
44 A	0.06	Yes 4 cells	0.014	28 hrs.	0.08	Low center, CP air, RW-
	0.10	2nd cell	0.12	5 hrs.	0.014	Low center, CP air, RW-

Sample No.	Rainfall Rate (in/hr)		Total[1] Rain(in)	Prior Rain		Brief Synoptic Conditions (final analysis)
	Average	Intermittent[1]		Time	Amount (in)	
44 (cont'd)	0.02	3rd cell	0.01	1 hr.	0.12	Low center passage, CP air, R
	0.04	4th cell	0.02 0.16	2 hrs.	0.02	Low center passage, CP air, R total storm rain sample No. 44 = 0.16″
45 D	1.02	No	0.17	3½ days	0.01	Squall line, TRW, MT air
46 D	1.70	No	0.28	Rain at Beginning	0.17	Squall line, TRW, MT
47 D	0.14	No	0.035	Rain at Beginning	0.45	Squall line, TRW, MT, total storm rain No. 45—47 = 0.49″ (continuous)
48 C-B	0.11	No	0.105 (.085)	11 hrs.	1.04	Cold fropa, RW, MP replacing MT
49 C	0.36	No	0.12	7 days	0.10	Air Mass, RW, MT
50 C-D	< 0.01	?	T	1 day	T	Dissipating squall line, RW-, MT
51 D-C	0.07	No	0.01	1 day	T	Cold fropa, RW-, MT
52 D	0.24	No	0.11	2 days	T	Squall line, TRW-, MT
53 D	0.02	No	0.01 0.12	Rain at Beginning	0.11	Squall line, L-, MT, samples 52—53 continuous rain = 0.12″
54 C	0.015	No	0.005	22 hrs.	0.12	Squall line, TRW-, MT
55 A	< 0.01	?	T	4 hrs. approx.	0.04	Complex low in Ill., RW-
56 A	0.105	No	0.29	Rain at Beginning	0.18	Stationary front just south of CMI, RW-, MT aloft
57 A	0.025	No	0.05	4 days	0.70	Overrunning over a stationary front, R, MT aloft
58 B-A	0.88	No	0.23 (0.22)	10 min.	0.01	Stationary front in S. Central Ill., TRW + MT aloft
59 B-A	0.06	Yes, 2 cells	0.06	Rain at Beginning	0.23	Stationary front in S. Central Ill., TRW, MT aloft
	0.43	2nd cell	0.18 0.24	Rain at Beginning	0.29	Total continuous storm rain fall No. 58—59 = 0.47″
60 A	0.17	No	0.30	1 hr.	0.47	Stationary front S. Central Ill., TRW, MT aloft
61 A	0.16	No	0.25	Rain at Beginning	0.30	Same as No. 60, TRW-, RW, MT aloft. Total continuous rainfall No. 60—61 = 0.55″
62 B-A	0.06	Yes, 2 cells	0.03	1½ hrs.	0.34	Low passage in S. Ill., R, modified MT aloft
	0.07	2nd cell	0.07 0.10 total	30 min.	0.03	Low passage in S. Ill., R-modified MT aloft
63 B-A	0.01	Yes (unknown time)	T	0 to 18 hrs.	0.10	Same as No. 62, R-, Same as No. 62
64 D	0.02	No	0.01	33 hrs.	0.26	Overrunning over stationary front, R-, CP.

[1] Note: a) total rain column shows total storm rainfall, even amounts not occurring in sample period, any figure in parenthesis indicates total in *sample period* alone.

b) If yes appears in intermittent rate column and no breakdown of rates is given (by cells), continuous varying, very low rates existed at all times.

[2] HIGH LEVEL WASHOUT PROBABILITIES (700 MB)

A—*Very High*	B—*High*	C—*Average*	D—*Negligible*
Statewide rain ≧ .2″ prior day ≧ .5″ day of sample.	Statewide rain on days of sample ≧ .5″ and/or Lt. rain on prior day (T to .2″) and ≧ .3″ day of sample upwind from CMI.	1. Day prior none too T 2. Day of sample rains. 2″ to .4″ upwind from CMI.	None on day prior with scattered amts. on day of sample < 0.2″.

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MINERAL COMPOSITION OF
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