CHEMICAL CHARACTERISTICS OF BULK PRECIPITATION IN THE MOJAVE DESERT REGION, CALIFORNIA

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Abstract.—Analyses of 41 samples of bulk precipitation from 12 places in the Mojave Desert region show wide ranges of dissolved-solids concentration and a variety of chemical types, although the calcium bicarbonate type water dominates. Specific conductance of the solutions analyzed ranged from 8.9 to 823 micromhos and shows strong inverse correlation with quantities of rain but no discernible correlation with time of exposure of the gage between samples. Dust that locally includes saline materials appears directly to govern the chemical type and concentration of a few samples. Bulk precipitation in the Mojave is closely similar to bulk precipitation sampled at Menlo Park, Calif., near the coast, in the San Francisco Bay area.

In a study of the chemical composition of precipitation in desert areas, for which information generally is scanty, analyses were made of 39 samples of bulk precipitation from 12 places in the Mojave Desert region, California (fig. 1). Of the total, 22 samples were from storage-type gages where a layer of oil was used to retard evaporation and 17 from standard U.S. Weather Bureau gages serviced after each rain. The data indicate that concentration by evaporation was probably negligible and that most of the variations in gross concentration as well as concentration of individual constitutents resulted from variations in the kind and amount of dry fallout and in the quantity of rainwater that collected in the gages between samples.

Bulk precipitation has been defined by Whitehead and Feth (1964, p. 3320) as the solution that results when "melting snow, or rain falling on the land surface—whether in its native state or modified by man—collects and incorporates the products of dry fallout." The same authors commented further that "Bulk precipitation displays the combined effects of all water-soluble airborne components of precipitation. It is the most significant fluid to study in evaluating contributions of atmospheric mineralization to the chemical quality of natural water [and] * * * is the geochemically active agent in rock weathering and formation of soil and is the solution that provides moisture to growing vegetation."

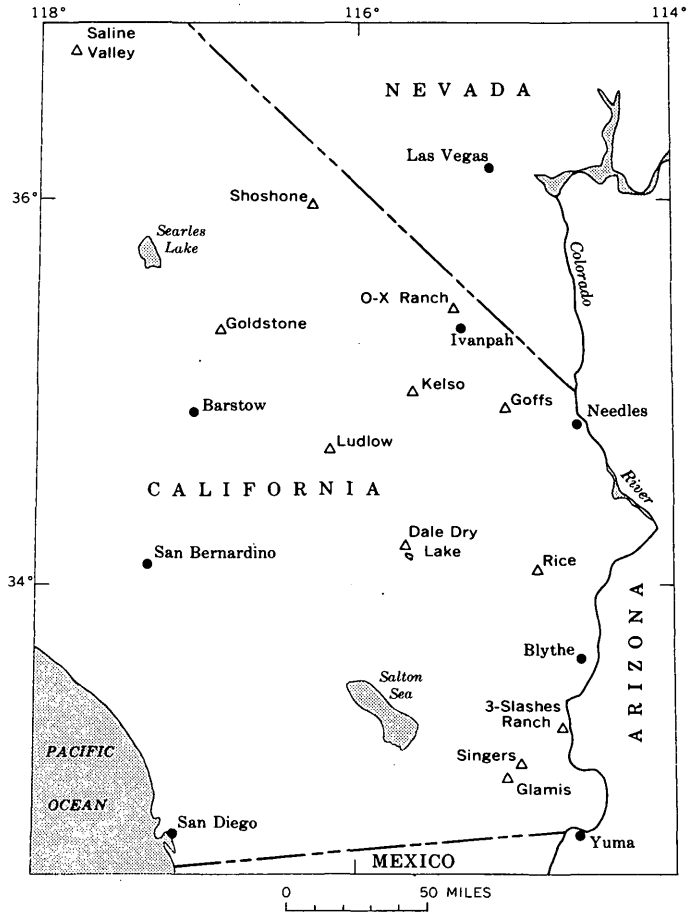

FIGURE 1.—Sketch map of the Mojave Desert region, California, and adjacent areas, showing locations of rain gages (triangles).

Acknowledgments.—Collection of the samples was made possible by my colleague, C. T. Snyder, who established the network of rain gages in connection with his own investigations. Mr. Snyder collected many of the samples during periodic rounds of the network,

and arranged with members of the guard force at Goldstone Tracking Station, with several ranchers, and with other individuals to collect samples periodically. The chemical analyses were made at the U.S. Geological Survey laboratory, Sacramento, Calif. The cooperation of all is much appreciated.

ANALYTICAL RESULTS

The samples from the Mojave (table 1) show in their variations in dissolved-solids concentration and chemical type some of the expected effects of saline dust from local sources, but they do not depart from the overall dominance of calcium bicarbonate type water that is generally characteristic of precipitation throughout the world.

The influence of saline dust is most apparent in the single sample from Saline Valley (table 1). The dominant constituents of the saline materials in Saline Valley are sodium sulfate and sodium chloride (G. I. Smith, oral commun., 1966); sodium, sulfate, and chloride are dominant in the water analysis. The gage was exposed continuously for 11 months, and concentration by evaporation might have contributed to the relatively high salinity. However, 8 other

TABLE 1.—*Chemical composition of samples of bulk precipitation from the Mojave Desert region, California, March 1965–March 1966*

[Chemical constituents in parts per million. Stations are arranged in order from north to south]

Period of exposure	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Specific conductance (in micromhos at 25° C)	Remarks [1]
Saline Valley, lat 36°45′ N., long 117°47′ W.											
Apr. 29, 1965–Mar. 23, 1966.	3. 4	35	4. 5	132	18	179	108	90	0. 3	823	Near spring northeast of salt flats. Rain, 2.1 in. Boron, 1.3.
Shoshone, lat 35°58′ N., long 116°16′ W.											
Apr. 28–Oct. 13, 1965	-----	------	68	-------	------	330	-------	2. 8	1. 5	642	Southeast end of airstrip. Water, 0.05 in., Apr. 28–July 17, 1965 (not poured up); 0.6 in., July 18–Oct. 13, 1965. Boron, 0.8.
Oct. 13, 1965–Mar. 22, 1966.	1. 6	16	1. 2	11	6. 0	58	11	5. 9	. 2	158	Rain, 5 in. Boron, 0.3; fluoride, 0.7.
Goldstone, lat 35°17′ N., long 116°48′ W.											
Mar. 31–April, 1965	-----	------	------	1. 7	0. 6	-----	2. 6	1. 3	4. 0	34	Rain, 0.19 in.
Mar. 1–Apr. 4, 1965	0. 1	1. 6	0. 0	. 2	. 1	35	. 8	. 3	. 5	8. 9	Rain, 0.90 in. Boron, 0.0.
Apr. 4–8, 1965	-----	------	------	. 5	. 6	3	2. 0	. 6	1. 0	14	Rain, 0.32 in. Boron, 0.0.
Apr. 8–11, 1965	. 5	------	------	. 4	. 2	6	1. 2	. 5	. 7	15	Rain, 0.58 in. Boron, 0.1.
Apr. 11–12, 1965	. 1	------	------	1. 0	1. 0	7	1. 1	1. 4	1. 2	22	Rain, 0.55 in. Boron, 0.1.
Apr. 12–May 24, 1965	-----	------	------	3. 8	1. 0	-----	-------	1. 4	12	70	Rain, 0.10 in.
May 24–25, 1965	-----	------	------	3. 8	1. 0	-----	-------	3. 8	10	81	Rain, 0.18 in.
Apr. 25–July 17, 1965	-----	------	------	2. 0	1. 9	-----	-------	3. 6	------	199	Rain, 0.08 in.
July 17–30, 1965	-----	------	------	1. 2	. 9	-----	1. 0	2. 8	------	122	Rain, 0.11 in.
July 30–Nov. 14, 1965	-----	1. 0	. 0	. 3	. 2	8	1. 4	1. 0	. 9	19	Rain, 1.20 in.
Nov. 14–23, 1965	-----	2. 0	. 0	. 2	. 2	4	1. 0	. 4	. 8	12	Rain, 1.20 in. Boron, 0.0.
Nov. 23–Dec. 10, 1965	-----	------	------	. 2	. 2	5	1. 6	. 4	. 9	15	Rain, 1.16 in. Boron, 0.0.
Dec. 10–29, 1965	. 0	1. 6	. 0	. 6	. 2	5	3. 6	. 5	1. 7	16	Rain, 0.82 in., Dec. 29, 1965. Boron, 0.0.
O-X Ranch, lat 35°12′ N., long 115°12′ W.											
Mar. 21–Apr. 1, 1965	1. 2	------	------	8. 3	3. 7	74	27	17	0. 9	218	Rain, Apr. 1, 1965. Boron, 0.1.
Apr. 1–4, 1965	. 2	2. 4	0. 0	. 6	. 8	12	2. 3	1. 8	. 3	36	Rain, 1.35 in., Apr. 4, 1965. Boron, 0.0.
? –Dec. 9, 1965	. 0	2. 0	------	. 2	. 2	5	4. 6	. 2	. 4	16	Boron, 0.0.
Dec. 4–16, 1965	. 1	1. 2	. 0	. 2	. 2	4	3. 0	. 2	. 4	11	Snow. Boron, 0.0.

TABLE 1.—*Chemical composition of samples of bulk precipitation from the Mojave Desert region, California, March 1965–March 1966*—Continued

Period of exposure	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Nitrate (NO_3)	Specific conductance (in micromhos at 25° C)	Remarks [1]
Kelso, lat 35°01′ N., long 115°39′ W.											
Mar. 24–Apr. 22, 1965	0.8	7.6	0.7	8.0	4.9	34	12	3.9	2.3	118	Rain, 1.30 in. Boron, 0.2.
Oct. 13, 1965–Mar 22, 1966.	1.9	9.2	1.0	.8	1.1	16	5.0	2.2	3.1	77	Rain, 3.4 in. Boron, 0.2; floride, 0.0.
Goffs, lat 34°55′ N., long 115°03′ W.											
Mar. 24–Apr. 23, 1965	0.4	3.9	1.9	4.1	3.9	19	10	2.6	0.9	70	Rain, 2.4 in. Boron, 0.1.
Apr. 23–Oct. 13, 1965	-----	-----	-----	4.5	8.0	26	15	2.2	4.7	144	Rain, 0.8 in. Boron, 0.6.
Oct. 13, 1965–Mar. 22, 1966.	.5	2.8	.0	.4	.6	6	1.0	1.2	1.2	31	Rain, 6.4 in. Boron, 0.1.
Ludlow, lat 34°43′ N., long 116°10′ W.											
Mar. 17–Apr. 8, 1965	-----	-----	6.8	2.3	-----	40	20	7.8	13	179	Rain, 1.22 in., Mar. 31–Apr. 8, 1965. Boron, 0.1.
Apr. 8–14, 1965	-----	-----	1.6	1.2	-----	22	4.2	2.4	1.4	57	Rain, 0.70 in., Apr. 13–14, 1965.
Apr. 14–July 17, 1965	-----	-----	8.4	6.2	-----	-----	21	16	-----	281	Rain, 0.60 in.
July 17–Nov. 17, 1965	-----	-----	10	5.0	-----	58	16	14	29	250	No data.
Nov. 17–Dec. 31, 1965	1.1	6.8	.7	1.2	.8	21	1.0	2.1	.6	46	No data.
Dale Dry Lake, lat 34°09′ N., long 115°44′ W.											
Mar. 17–Oct. 14, 1965	-----	7.0	3.0	8.4	5.4	30	16	4.8	1.4	142	Rain, 1.1 in., Mar. 17–July 19, 1965; additional 0.5 in., July 19–Oct. 14, 1965. Boron, 0.3.
Oct. 14, 1965–Mar. 21, 1966.	0.7	4.8	.7	2.9	4.5	10	6.0	4.5	.1	60	Rain, accumulated, 2.7 in.
Rice, lat 34°05′ N., long 114°50′ W.											
Mar. 17–Oct. 13, 1965	-----	9.6	2.2	6.3	6.6	12	9.4	3.0	4.3	115	Rain, 2.5 in., Mar. 17–July 18, 1965. No rain to Oct. 13, 1965, when sampled. Boron, 2.3.
Oct. 13, 1965–Mar. 22, 1966.	0.3	2.8	.0	1.1	1.3	14	4.0	3.2	1.0	85	Rain, 3.2 in. Boron, 0.3; fluoride, 0.0.
3-Slashes Ranch, lat 83°17′ N., long 114°43′ W.											
Mar. 17–Apr. 18, 1965	0.2	10	1.0	4.6	3.8	10	13	4.8	8.7	111	Boron, 0.0.
Apr. 4–Nov. 23, 1965	-----	18	1.7	12	11	94	16	16	2.5	259	Rain, 0.35 in., Nov. 17, 1965; 0.85 in., Nov. 23, 1965.
Singers, lat 33°03′ N., long 114°43′ W.											
Mar. 17, 1965–Mar. 21, 1966.	1.0	4.8	0.0	1.0	0.8	8	4.0	0.8	1.5	44	Rain, 3.8 in. Plastic gage. Boron, 0.0.
Glamis, lat 33°00′ N., long 115°04′ W.											
Mar. 17–Apr. 4, 1965	0.6	-----	-----	5.0	2.0	29	18	4.1	4.5	99	Boron, 0.0.
Apr. 4, 1965–Jan. 20, 1966.	.3	8.8	0.5	1.0	1.8	2	8.0	3.8	12	72	Fluoride, 0.0.

[1] U.S. Weather Bureau 8-in. standard gages used at Goldstone and O-X Ranch; U.S. Geological Survey-Bureau of Land Management 5-in. pipe gages used at other locations.

samples in which specific conductance was less than 100 micromhos came from gages exposed for periods of from 5 to 8 months between samplings. It appears, therefore, that dust blowing from the saline playa accounts for most of the concentration found in the single sample from Saline Valley. As will be shown below (see fig. 2), the accumulation of 2.1 inches of water in the Saline Valley gage should have sufficed to put that sample in the lower range of concentrations rather than at the top. The fact that similar concentrations were not obtained from the gage at Dale Dry Lake, where salt was harvested in the past and saline residues remain on the surface, is puzzling. As the Dale Dry Lake gage was located at the chemical plant north of the playa, it may be that prevailing winds kept saline dust away from the gage.

The wind-movement recording station nearest to Saline Valley is at Bishop, Calif., 40 miles away, on the other side of a high range of mountains. The wind-movement recording stations nearest to Dale Dry Lake are at Thermal, Calif., 40 miles away, and at Daggett, Calif., 80 miles away. Therefore, it is not feasible to estimate the degree to which prevailing wind directions and movement actually account for the differences observed at the two collection sites involved.

The high (158 micromhos) and very high (642 micromhos) conductances recorded from samples gathered at Shoshone most likely resulted from the location of the gage near an airstrip where propwash from airplanes contributed to movement of dust in the vicinity. The differences in concentration in the other samples, as indicated by specific conductance, cannot, from the available data, be explained by dust movement except, perhaps, the low concentrations of all but two samples from Goldstone. The generally low concentrations of the group of samples from Goldstone reflect the fact that the gage at Goldstone was serviced after each precipitation event, so there was less chance for dry fallout to accumulate there than at the stations which were equipped with storage-type gages.

The close resemblance between bulk precipitation sampled on the Mojave Desert and that sampled at Menlo Park, Calif., near the coast, in the San Francisco Bay area, is shown in table 2. The somewhat lesser content of chloride in the general run of desert samples may be due to the fact that the Mojave stations are farther from the sea than is Menlo Park. The dominance of sulfate over chloride in both median and mean values of the Mojave samples is not readily explained. Whitehead and Feth (1964, p. 3326) attributed much of the sulfate content of bulk precipitation at Menlo Park to the influence of industry in the San Francisco Bay region. Such influences certainly are not close at hand in the Mojave Desert. The sulfate in the Mojave samples may in part result from movement of sulfur-laden airmasses from the Los Angeles–San Diego metropolitan complex over the desert, but more likely the sulfate is caused by local sources of sulfate-bearing dust. There is no obvious regional pattern to distribution of the sulfate or chloride when their values are plotted on a map.

TABLE 2.—*Comparison of values of selected constituents and specific conductance in bulk precipitation samples from the Mojave Desert region and Menlo Park, Calif.*

[Menlo Park data from Whitehead and Feth, 1064, p. 3326; specific conductance values calculated from p. 3323-3324]

Values	Sulfate (ppm)	Chloride (ppm)	Specific conductance (micromhos at 25° C)
Mojave Desert region; 41 samples, 1965–66 [1]			
Maximum	108	90	832
Median	4.2	2.6	70
Mean	10.7	5.85	118
Minimum	0.8	0.2	8.9
Mojave Desert region; 40 samples, 1965–66, omitting Saline Valley [2]			
Maximum	27	17	642
Median	4.0	2.4	70
Mean	8.03	3.50	101
Minimum	0.8	0.2	8.9
Menlo Park; 25 samples, 1957–59			
Maximum	106	30	540
Median	2.8	3.0	45
Mean	12.2	7.28	93.7
Minimum	0.4	0.2	7.0

[1] Sulfate, 37 determinations.
[2] Sulfate, 36 determinations.

The maximum exposure of the sampling surface at Menlo Park between collection of samples was about 2 months, but the duration of exposure commonly ranged from 1 day to about 2 weeks. In the Mojave, sample containers were exposed from 1 day to 11 months between samples. Average exposure time for 23 samples (time exceeding 1 month) was 4.5 months; for the remaining 14, exposure time was about 4 days. The resemblances suggested by table 2 are remarkable, Indeed, the comparison—considering exposure times—suggests that the rates of dry fallout in the San Francisco Bay area exceed those on the Mojave Desert. If—as is thought—the Bay area fallout is derived largely from industry, the conclusion that dry fallout is greater in the Bay area may be warranted.

The concentrations of the Mojave samples, indicated by their respective specific conductances, bear a close inverse correlation with the quantity of water that

accumulated between samplings (fig. 2), but have no discernible correlation with duration of exposure between samplings—in other words, a dilution effect is apparent. To what extent those relations represent rainout of mineral constituents in the early part of a heavy storm followed by accumulation of more dilute water, and to what extent they represent mere dilution of approximately constant amounts of dry fallout, cannot be determined. The data in figure 2 plot, for the most part, in two fields. The lower field represents samples collected at Goldstone, and the upper field, the remainder of the samples for which depth of water in the collector was reported. The differences in collecting procedures, described below, explain the groupings.

COLLECTION AND ANALYSIS OF SAMPLES

The samples of bulk precipitation used in this study were collected under two sets of circumstances. Those from Goldstone and the O-X Ranch were collected in 8-inch standard U.S. Weather Bureau rain gages, and were poured into shipment containers immediately after each precipitation event. Accumulation of dry fallout between sampling was less than that at the other stations where, in general, the collectors remained for weeks and even months between sampling. The collectors at the other stations were U.S. Geological Survey–Bureau of Land Management gages made of lengths of 5-inch soft-steel pipe welded to a steel base plate. All the rain gages were thoroughly washed with distilled water before being put into service. The storage-type gages were serviced upon installation with a small volume of transformer oil (Shell DIALA-AX) that floated on the surface of the rainwater in the gage and retarded evaporation. After each sampling, a new charge of oil was placed in the gage.

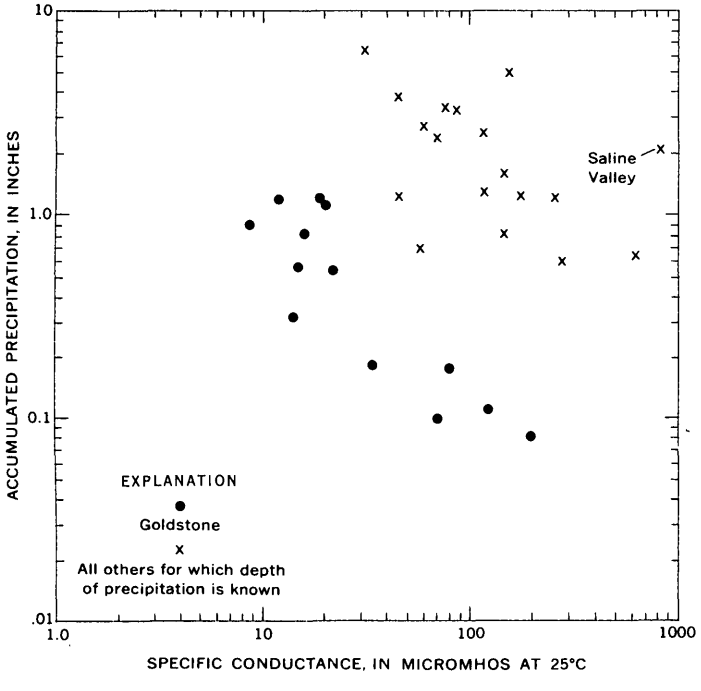

FIGURE 2.—Relation of specific conductance of samples to depth of precipitation at Goldstone and at other sites in the Mojave Desert region.

The possibility that the transformer oil contributed to contamination of the samples was considered. The oil was reported to be highly refined, with only organic inhibitors added. A test for possible contamination was made in the laboratory by shaking 10 milliliters of the oil with 200 ml of deionized water in a separatory funnel. After standing for a week, a specific conductance determination showed no contamination when the aqueous fraction was compared with a blank not in contact with oil. The oil may have trapped some dry fallout. However the turbulence and mixing as raindrops fell into the collector must have incorporated most of the fallout in the aqueous phase, otherwise the chemical concentrations of the under-oil samples would not have been as large or as variable as those that were determined.

Many of the samples were reported to be "rusty" when received in the laboratory, and they included part or all of the oil that had protected them from evaporation. Under the circumstances, it was not feasible to analyze the samples for iron. Values for pH are not reported in table 1. Those for bicarbonate and nitrate are indicative only, and not necessarily representative of the rain as it fell. Bicarbonate, pH, and nitrogen compounds in water are notoriously unstable during storage (Roberson and others, 1963; Feth, 1966).

The samples were analyzed by methods (Rainwater and Thatcher, 1960) standard in the U.S. Geological Survey, except that chloride was determined by the more sensitive method (for low concentrations) described by Bergman and Sanik (1957) and by Iwasaki and others (1952). The alkalinity end point was chosen from the titration curve, and sulfate was determined by a method described by Gambell and Fisher (1964).

CONCLUSIONS

The results of this study show that bulk precipitation throughout the Mojave Desert region is strikingly similar in concentration and chemical type to bulk precipitation in the far different environment of Menlo Park, Calif., near the coast. The unavoidably crude collecting procedures seem not to have vitiated the results, although the present study yields values that must be considered first approximations only. Locally, dust that contained saline materials appears over-

whelmingly to have governed the composition and concentration of bulk precipitation. Some variations among the samples cannot be explained from present knowledge. The fairly high concentrations of sulfate in the desert samples remain unexplained. The influence of the sea in contributing chloride to precipitation is perhaps less apparent in the desert samples than in those from Menlo Park. Bulk precipitation in the desert varies widely from place to place and with time (see especially Goldstone samples, table 1) but is mostly a calcium bicarbonate type as is precipitation generally, except at stations within range of the immediate influence of the sea.

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