Chemical Composition of Snow in the Northern Sierra Nevada and Other Areas

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By J. H. FETH, S. M. ROGERS, *and* C. E. ROBERSON

GEOCHEMISTRY OF WATER

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CHEMICAL COMPOSITION OF SNOW IN THE NORTHERN SIERRA NEVADA AND OTHER AREAS

By J. H. Feth, S. M. Rogers, and C. E. Roberson

ABSTRACT

Melting snow provides a large part of the water used throughout the western conterminous United States for agriculture, industry, and domestic supply. It is an active agent in chemical weathering, supplies moisture for forest growth, and sustains fish and wildlife. Despite its importance, virtually nothing has been known of the chemical character of snow in the western mountains until the present study.

Analysis of more than 100 samples, most from the northern Sierra Nevada, but some from Utah, Denver, Colo., and scattered points, shows that melted snow is a dilute solution containing measurable amounts of some or all of the inorganic constituents commonly found in natural water. There are significant regional differences in chemical composition; the progressive increase in calcium content with increasing distance eastward from the west slope of the Sierra Nevada is the most pronounced. The chemical character of individual snowfalls is variable. Some show predominant influence of oceanic salt; others show strong effects of mineralization from continental sources, probably largely dust. Silica and boron were found in about half the samples analyzed for these constituents; precipitation is seldom analyzed for these substances.

Results of the chemical analyses for major constituents in snow samples are summarized in the following table. The median and mean values for individual constituents are derived from 41–78 samples of Sierra Nevada snow, 6–18 samples of Utah snow, and 6–17 samples of Denver, Colo., snow.

Comparison of median and mean concentrations of selected constituents in snow from the Sierra Nevada, Utah, and Denver, Colo.

[Concentrations, in parts per million]

Constituent	Sierra Nevada		Utah		Denver, Colo.	
	Median	Mean	Median	Mean	Median	Mean
Silica (SiO_2)	0.0	0.16	----------	----------	----------	----------
Calcium (Ca)	.2	.39	2.0	2.23	----------	----------
Magnesium (Mg)[1]	.0	.16	.35	.33	----------	----------
Sodium (Na)	.2	.46	.55	.60	1.1	1.24
Potassium (K)[1]	.2	.31	.35	.47	----------	----------
Bicarbonate (HCO_3)	2.0	2.90	5.0	6.29	11	10
Sulfate (SO_4)	.65	.93	2.2	2.25	1.5	2.88
Chloride (Cl)	.4	.50	.7	.97	1.0	1.60
Dissolved solids (Calculated)	4.0	4.70	9.1	10.58	----------	----------

[1] Values reported for magnesium and potassium cannot be compared statistically because variances in the analytical methods available exceed variances in sample concentrations.

The sodium, chloride, and perhaps boron found in snow are probably incorporated in moisture-laden air masses as they move over the Pacific Ocean. Silica, although abundant in the silicate-mineral nuclei found in some snowflakes, may be derived in soluble form largely from dust. Calcium, magnesium, and some bicarbonate are probably added by dust of continental origin. The sources of the other constituents remain unknown.

When snowmelt comes in contact with the lithosphere, the earlier diversity of chemical type largely disappears. The melt water rapidly increases its content of dissolved solids and becomes calcium magnesium bicarbonate in type. Silica, whose concentration increases more than tenfold, shows the largest gain; calcium and bicarbonate contents also increase markedly. Most of the additional mineral matter is from soil and weathered rock; bicarbonate, however, is largely from the soil atmosphere.

Investigators, some reporting as much as a century ago, concentrated attention largely on nitrogen compounds and seldom reported other consituents except chloride and sulfate. The Northern European precipitation-sampling network provides the most comprehensive collection of data on precipitation chemistry, but it does not segregate snow from other forms of precipitation. The present study establishes with confidence the chemical character of snow in the Sierra Nevada, and suggests that the dissolved-solids content of precipitation increases with increasing distance inland from the Pacific Coast.

INTRODUCTION

Melting snow supplies a large part of the water vital to the economy of the western conterminous United States. Snowmelt is also one of the chief reactive agents in rock weathering and formation of soil in many of the western mountains. In addition, water from melting snow provides most of the moisture that, stored in the root zone, nourishes the great evergreen forests of the Western States except those in the coastal belt where snow seldom falls. Inland, rain falling during the warmer months of the year may make up more than 50 percent of the yearly precipitation. During these months, however, evaporation rates generally exceed precipitation rates; hence, rainfall is regionally of much smaller significance than is the annual snowpack in the hydrologic economy of the region.

Thus the chemical composition of melted snow provides a necessary point of departure for many geochemical considerations, not only those of strictly geologic interest. It is equally necessary both for considerations that relate to water supply for domestic use, industry, and agriculture throughout the Western States, and for considerations of interest to foresters, ecologists, and fish and wildlife specialists. Despite its significance, virtually nothing has been known, to the present time, of the chemical composition of western snow or snowmelt. This study reports the results of analysis of 79 samples of snow collected along routes of winter travel available during 1958–59 and 1959–60, in the northern Sierra Nevada, California and Nevada. These results are compared with analyses of smaller numbers of samples from mountainous areas in Utah, from Denver, Colo., and from a scattering of points in Oregon, California, and Arizona to furnish a general picture of the concentrations of major and minor constituents dissolved in western snow. Significant variations in concentrations from region to region permit tentative assignment of sources from which some of the constituents are derived. Comparisons of 10 pairs of snow samples with melt water flowing a short distance below the respective snowbanks, show the large and immediate influence of the lithosphere upon chemical composition of natural water.

FIELD AND LABORATORY PROCEDURES

The location of points from which snow samples were taken are shown on plate 1. The samples from Denver, Colo., were taken from the grounds of the U.S. Federal Center, just west of the city, and from a few other points within the confines of Denver. They were analyzed in the Denver laboratory of the Geological Survey by standard methods (Rainwater and Thatcher, 1960). Results of these analyses (Hem, J. D., 1960, written communication) were made available for the present study.

The snow samples from Utah were taken from snow-survey cores; each snow core was immediately placed into a bottle, which was then capped, and allowed to melt. These samples, made available through cooperation of personnel of the U.S. Soil Conservation Service, were shipped to Menlo Park, Calif., for analysis.

The remainder of the samples were collected by the writers and analyzed at Menlo Park. Initially, snow was taken in a plastic scoop and forced through the neck of a hard-glass 4-liter jar. The jar was then stoppered, and the sample was allowed to melt. After the first two months of fieldwork, the samples were taken by scooping snow from the source directly into a wide-mouthed polyethylene bucket; a sheet of thin plastic was then placed across the orifice and held in place by the taped-down polyethylene bucket lid. The moisture content of the snow, therefore, determined the volume of sample available for analysis when the snow melted. After the snow had melted, the water so formed was poured into a hard-glass 4-liter serum bottle. The bottle was then stoppered, and the sample was stored until analysis. The water was passed through a Millipore filter before being analyzed for its chemical constituents.

Analytical procedures [1] in the laboratory were those standard in the Geological Survey (Rainwater and Thatcher, 1960) except as follows:

Chloride: Because concentrations were characteristically less than those that can be determined with confidence using the Mohr titration, a colorimetric method (Iwasaki and others, 1952; Bergman and Sanik, 1957) was adopted.

Sulfate and bromide and iodide (as bromine): Determined using standard procedures but employing larger sample volumes (aliquots) because of dilute character of the melted snow.

EVALUATION OF SAMPLING PROCEDURES AND ANALYTICAL RESULTS

The sample sites in the Sierra Nevada and adjacent areas were restricted to areas of easy access during the winter. They extended (pl. 1) as lines oriented principally along the two major transcontinental all-weather highways, U.S. 40 and U.S. 50. Smaller numbers of samples were taken from highways maintained during the winter to provide access to ski areas or along routes connecting with the transcontinental highways. The individual samples were taken from places beyond the range of snow thrown by snow-removal equipment and are thought to be representative of uncontaminated snowfall.

Samples were taken more than once from individual sites throughout two winters. The samples include newly fallen snow and old snow, early-season and late-season snow, crust formed on old snow, and snow in open areas as well as snow beneath forest cover. Samples from these varied sources in the Sierra Nevada region were generally similar in chemical composition to snow from scattered localities throughout Oregon, California, and Arizona. The Sierra-region snow samples probably represent the spread in chemical composition

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[1] The following table shows the approximate precision of the analytical methods employed:

Constituent	*Approximate precision (± mg)*	*Sample size (ml)*
Silica	0.005	10
Aluminum	Not determined	25
Iron	Not determined	25
Calcium	.025	50
Magnesium	.025	
Sodium	.02	
Potassium	.2	
Lithium	.02	
Ammonia	.1 (as nitrogen)	250
Bicarbonate (as alkalinity)	1.0	
Sulfate	.2	1,000
Chloride	.002	20
Fluoride	.0005	10
Bromide, or bromide plus iodide	.05 (as bromine)	1,000
Iodide	.02	100
Nitrite	.0002	10
Nitrate	.005	50
Orthophosphate	.0005	25
Boron	.0001	5

NOTE.—Specific conductance at 25° C accurate and reproducible to 2 or 3 percent; pH values reproducible to ±0.05 pH unit.

and the overall chemical character that is to be expected in most of the far western States where the influence of man's activities is minimal and where local conditions do not impose unusual concentrations of some constituents.

All the samples from Utah were taken on January 1, 1959, except two, taken a month later. Their geographic spread is adequate to represent the characteristic of show falling on the mountainous central backbone of Utah. They may not, however, represent the yearly average composition of snow in Utah.

The snow from Denver was collected over a period of time sufficiently long to be representative. The snow samples were all taken in or near the city and were all within the range of potential influence of industrial air pollution. Although they represent what may be expected of snow in Denver, they may not indicate accurately the chemical character of snow in the Rocky Mountains.

The analytical methods used yield results that are considered statistically significant for silica, calcium, sodium, bicarbonate, sulfate, and chloride. They are not statistically significant for magnesium or potassium. These conclusions are based on application of the *F* ratio (Snedecor, 1946, p. 218–226), in which variance of the analytical procedure was compared with the variance of the results obtained from the samples. The resulting ratios for the various major constituents, except magnesium and potassium, indicate that the variance among the samples is statistically real. The results of the analyses are shown in table 1.

TABLE 1.—*Chemical analyses of snow and melt water,*

Lab No.	Source[1]		Date of collection	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
	Material, location, and altitude in feet	Part of Sierra Nevada[2]											
													Snow and snowmelt,
	Samples along U.S. 40 and access highways												
222	Snow, 2.5 miles west of Emigrant Gap, U.S. Highway 40, Calif. Altitude 6,300.	W	5-21-57	----	-----	-----	----	----	----	----	----	----	-----
223	Snowmelt, same location as No. 222.	W	...do...	----	-----	-----	----	----	----	----	----	----	-----
765	Snow, 2.0 miles east of Cisco Grove, U.S. Highway 40, Calif. Altitude 5,900.	W	6- 5-58	----	-----	-----	----	----	0.5	0.5	----	3	----
1020	Snow, coarsely granular, same location as No. 765.	W	3-25-59	----	-----	-----	0.2	0.0	.2	.2	----	1	0.7
225	Snow, 2.5 miles east of Cisco Grove, U.S. Highway 40, Calif. Altitude 5,900.	W	5-21-57	----	-----	-----	----	----	----	----	----	----	-----
226	Snow, 2.0 miles west of Soda Springs, U.S. Highway 40 Calif. Altitude 6,300.	W	...do..	----	-----	-----	----	----	----	----	----	----	-----
301	Snowmelt, 1.5 miles west of Soda Springs, U.S. Highway 40, Calif. Altitude 6,400.	W	...do..	6.5	-----	-----	1.6	.5	1.4	.7	----	4	2.6
694	Snow, 4.0 miles west of Norden, U.S. Highway 40, Calif. Altitude 6,200.	W	4- 8-58	.0	-----	-----	.0	.5	.7	.3	----	8	5.3
749	Snow, 1.0 mile west of Soda Springs, U.S. Highway 40, Calif. Altitude 6,600.	W	5-27-58	.0	-----	-----	.4	.0	.3	.3	1.0	4	.5
750	Snowmelt, location near No. 749..	W	...do...	3.3	0.00	0.00	.8	.0	2.6	.4	.0	6	.0
762	Snow, west end Van Norden Lake, U.S. Highway 40, Calif. Altitude 6,900.	C	6- 4-58	.1	-----	-----	----	----	.4	.2	----	2	.2
763	Snow, 2.0 miles west of Donner Pass, U.S. Highway 40, Calif. Altitude 7,000.	C	...do...	.1	-----	-----	----	----	.2	.1	----	2	.1
1019	Snow same location as No. 763 except altitude 8,000.	C	1-13-59	----	-----	-----	.2	.0	.2	.2	----	2	.7
1083	Snow, 1.0 mile east of Norden, U.S. Highway 40, Calif. Altitude 7,050.	C	4-22-59	.0	-----	-----	.0	.0	.2	.3	----	3	.7
1084	Snowmelt, same location as No. 1083.	C	...do...	5.5	-----	-----	1.2	1.1	.5	.3	----	8	-----
1085	Snowmelt, same location as No. 1083.	C	...do...	14	-----	-----	2.2	.6	1.4	.6	----	13	.8
747	Snow, 2.5 miles east of Donner Pass, U.S. Highway 40, Calif. Altitude 6,000.	E	5-27-58	.0	-----	-----	.4	.0	.3	.3	.0	4	.3
1081	Snow, 1.8 mile west of west end, Donner Lake, U.S. Highway 40, Calif. Altitude 6,800.	E	4-22-59	.1	-----	-----	.0	.0	.2	.5	----	3	.5
1082	Snowmelt, same location as No. 1081.	E	...do...	1.9	-----	-----	.0	.0	.9	.2	----	4	1.1
1086	Snow, 4.8 miles north of Hobart Mills, State Highway 89, Calif. Altitude 6,200.	E	4-22-59	.1	-----	-----	.0	.0	.2	.1	----	2	.7
764	Snow, Squaw Valley, Calif. Altitude 6,400.	C	6- 4-58	.2	-----	-----	1.0	.7	1.4	.7	----	3	.1
1018	Snow, same location as No. 764 except altitude 8,000.	C	1-13-59	----	-----	-----	.4	.0	.3	.3	----	3	.7
941	Snow, 0.5 mile east of Floristan, U.S. Highway 40, Calif. Altitude 5,300.	E	11-21-58	.0	.00	.00	.8	.0	.3	----	.0	3	.5
1031	Snow, 1 mile north of Geiger Summit, State Highway 17, Nev. Altitude 6,500.	E	2- 3-59	----	-----	-----	.4	.1	.2	.2	----	2	1.0

See footnotes at end of table.

in parts per million, except pH *and specific conductance*

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH (in laboratory)	Remarks
Sierra Nevada region											
0.5	----	----	----	----	----	----	----	----	6	4.2	Sampled beneath trees. Snowfall within 48 hours.
1.0	----	----	----	----	----	----	----	----	18	5.6	Melt water in ruts of dirt road.
.7	----	----	----	----	----	----	----	1.5	7.5	5.9	Sampled from granitic-rock surface 500 ft off highway; ski slope.
1.2	----	----	0.01	0.0	----	0.10	3.1	.8	3	5.5	Sampled from grass on ski slope 200 ft off highway.
.7	----	----	----	----	----	----	----	----	5	4.7	Sample scraped from bare granodiorite ledge.
.8	----	----	----	----	----	----	----	----	5	4.7	Snowfall within 48 hours. Sampled in open area.
2.4	0.0	----	----	.0	----	----	18	6.0	21	5.3	Seasonal brooklet; dry after snowmelt runoff ceases.
.6	----	----	.00	.0	----	.02	11	2.0	10	6.5	Sampled from snowplow cut; probably includes road dirt.
.8	.0	----	.06	.0	0.04	.02	4.9	1.0	5.9	8.3	In evergreen forest. Topmost 1 in of dirty snow removed.
.9	.0	----	.00	.1	.02	.00	11	2.0	16	6.4	Seepage through granitic saprolite and soil. Lithium=0.0.
.5	----	----	----	----	----	----	----	1.0	3.9	6.0	Sampled on ski slope 0.5 mile south of highway.
.3	----	----	----	----	----	----	----	.5	2.3	5.9	Sampled on slope of Mt. Disney, near lower end of Sugar Bowl ski lift.
.3	----	----	.03	.0	----	.00	2.6	.6	4.3	5.7	Sampled near upper end of Sugar Bowl ski lift. Fresh snow; not packed.
.2	----	----	----	----	----	----	2.9	.0	3.0	5.5	Section top, to bottom, of 2-ft snowbank in open field.
.9	----	----	----	----	----	----	14	7.3	15	6.5	Melt water dripping from snowbank of sample No. 1083.
.2	----	----	----	----	----	----	26	8.0	23	6.2	Runoff from sample No. 1083, 50 ft down channel in granitic soil; decaying vegetation abundant.
.7	.1	----	.00	.0	.14	.00	4.2	1.0	6.8	5.9	Section, top to bottom, of 3-ft snowbank under trees.
.1	----	----	----	----	----	----	2.9	.0	2	6.0	Section, top to bottom, of 1-ft snowbank, coarsely granular; dirt on surface.
.5	----	----	----	----	----	----	6.6	.0	7	5.8	Runoff from No. 1081 through granitic pebbles and soil; vegetable debris common.
.2	----	----	----	----	----	----	2.3	.0	2	5.5	Section, top to bottom, of 2-ft snowbank in evergreen forest.
1.6	----	----	----	----	----	----	----	1.0	9.8	6.3	Sampled on slope above lodge; snow lying on granitic saprolite and soil.
.5	----	----	.03	.1	----	.00	3.8	1.0	7.6	5.9	Sampled at top of ski lift on Hill KT-22. Fresh snowfall of preceding night.
.8	----	----	----	----	----	.00	3.9	2.0	3.9	5.7	Sampled 60 ft from highway. Thin early-season snow.
.3	----	----	.00	.1	----	.02	3.3	1.6	6.0	5.6	Patches of snow in shade of pinon pines.

See footnotes at end of table.

TABLE 1.—*Chemical analyses of snow and melt water, in parts*

Lab No.	Source [1]: Material, location, and altitude in feet	Source [1]: Part of Sierra Nevada [2]	Date of collection	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
	Snow and snowmelt, Sierra												
1017	Snow, Geiger Summit, State Highway 17, Nev. Altitude 6,800.	E	1-13-59	----	-----	-----	1.0	0.3	0.3	0.9	----	4	0.4
1030	Snow, 1.9 miles north of Virginia City, State Highway 17, Nev. Altitude 6,500.	E	2- 3-59	----	-----	-----	.2	.1	.1	.2	----	2	.9
1029	Snow, north edge of Virginia City, State Highway 17, Nev. Altitude 6,500.	E	do	----	-----	-----	.3	.2	.2	.2	----	2	.9
1027	Snow, 0.75 mile north of Silver City, State Highway 17, Nev. Altitude 5,000.	E	do	----	-----	-----	1.8	.3	.7	.2	----	4	2.1
1028	Snow, same location as No. 1027	E	do	----	-----	-----	3.8	.3	.2	.2	----	8	4.3
	Samples along U.S. 50 and access highways												
927	Snow, 0.5 mile east of Kyburz, U.S. Highway 50, Calif. Altitude 4,200.	W	11-19-58	0.3	0.06	0.03	.0	.5	1.1	.7	0.0	1	.7
558	Snow, 2.0 miles east of Kyburz, U.S. Highway 50, Calif. Altitude 4,500.	W	1-20-58	1.7	-----	-----	----	----	.8	.8	----	2	-----
1013	Snow, 3.1 miles east of Kyburz, U.S. Highway 50, Calif. Altitude 5,000.	W	1-12-59	----	-----	-----	.4	.1	.4	.1	----	1	.3
928	Snow, Twin Bridges Lodge, U.S. Highway 50, Calif. Altitude 6,000.	W	11-19-58	.0	.03	.02	.0	.5	.6	.4	.0	3	.3
559	Snow, 0.5 mile east of Twin Bridges, U.S. Highway 50, Calif. Altitude 6,100.	W	1-20-58	.1	-----	-----	----	----	.6	.4	----	2	-----
560	Snow, same location as No. 559	W	do	1.2	-----	-----	----	----	.8	.9	----	8	-----
929	Snowmelt (as icicles), same location as No. 559.	W	11-19-58	1.9	.04	.00	.0	.5	.4	.1	.0	2	.3
1014	Snow, same location as No. 559	W	1-12-59	----	-----	-----	.2	.0	.1	.0	----	0	.3
220	Snow, 2 miles east of Twin Bridges, U.S. Highway 50, Calif. Altitude 6,500.	W	1-20-58	----	-----	-----	----	----	----	----	----	----	-----
561	Snow, 17 miles east of Kyburz, U.S. Highway 50, Calif. Altitude 7,000.	W	do	.3	-----	-----	----	----	.5	.3	----	2	-----
562	Snow, same location as No. 561	W	do	.1	-----	-----	----	----	.5	.4	----	2	-----
758	Snow near Echo Lake, near U.S. Highway 50, Calif. Altitude 7,400.	C	6-3-58	.2	-----	-----	----	----	.9	.4	----	3	.4
767	Snow, same location as No. 758	C	do	.0	-----	-----	----	----	.2	.1	----	1	.6
571	Snow, Echo Summit, U.S. Highway 50, Calif. Altitude 7,400.	C	1-21-58	.0	-----	-----	----	----	.4	.3	----	2	-----
572	Snow, same location as No. 571	C	do	.0	-----	-----	----	----	.2	.1	----	2	-----
752	Snow, same location as No. 571	C	6-2-58	.1	-----	-----	----	----	.4	.3	----	2	.2
930	Snow, same location as No. 571	C	11-19-58	.0	.02	.00	.4	.0	1.2	.5	.0	0	2.8
931	Snowmelt (as ice), same location as No. 571.	C	do	[3]3.8	[3]1.2	[3]3.1	3.6	1.0	1.8	3.3	.0	18	9.0
1015	Snow, same location as No. 571	C	1-12-59	----	-----	-----	.5	.0	.3	.1	----	2	.3
1079	Snow, same location as No. 571	C	4-20-59	----	-----	-----	----	----	.4	----	----	----	-----
219	Snow, 2.6 miles west of Meyers, U.S. Highway 50, Calif. Altitude 6,900.	C	5-15-57	----	-----	-----	----	----	----	----	----	----	-----

See footnotes at end of table.

per million, except pH *and specific conductance*—Continued

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH (in laboratory)	Remarks
Nevada region—Continued											
0.6	----	-----	0.07	0.3	-----	0.02	5.9	4.0	14	5.4	Sampled in thick brushy vegetation. Snow sparse, melting.
.4	----	-----	.01	.2	-----	.02	3.1	.8	6.0	5.6	Sample of Clean, topmost 1 in.; fell 3 days before sampling. Lithium=0.00.
.4	----	-----	.01	.2	-----	.03	3.4	1.8	7.0	5.7	Sampled in area shaded by brush. Thin, patchy snow. Lithium=0.00.
.4	----	-----	.07	.2	-----	.06	7.8	5.5	13	6.2	Snow 1½-in. thick; small patch in shade, overlying No. 1028.
.4	----	-----	.10	.2	-----	.10	14	11	28	6.5	Ice and icy snow in contact with gravel. Underlies No. 1027.
1.1	0.0	-----	.00	.0	0.00	.02	5.0	2.0	11	5.5	Snow 2 in. thick in shade of evergreens.
1.4	----	-----	-----	.0	-----	.13	------	-----	9.0	7.5	Topmost 3 in. of 12 in.; snow lying only in shaded areas. Basal 9 inches hard-frozen.
.0	----	-----	.01	.0	-----	.07	1.9	1.5	2.0	5.4	Snow in open area.
.4	.0	-----	.00	.0	.00	.05	3.8	2.0	7.0	5.6	Snow 2-3 in. thick under evergreens.
1.0	----	-----	-----	.0	-----	.08	------	2.5	9.0	7.7	Powdery snow, topmost 1 ft of 5-ft thickness, open area, granitic boulders.
1.2	----	-----	-----	.0	-----	.00	------	8.5	23	6.4	Snow at roadside, very dirty.
.2	.0	-----	.10	.0	.00	.00	4.8	2.0	18	5.7	Icicles suspended from ledge of granitic rock in highway cut.
.1	----	-----	.01	.0	-----	.00	.9	.5	3.0	5.3	Melting snow on bare granitic rocks.
.4	----	-----	-----	-----	-----	-----	------	-----	3.3	4.2	Upper foot of snowbank, under trees.
.7	----	-----	-----	.0	-----	.32	------	2.0	5.0	6.4	One foot of snow underlying 1-in. crust which was removed. Open area.
.7	----	-----	-----	.1	-----	.10	------	3.0	8.0	5.9	Equivalent to No. 561, but sampled under evergreens.
.8	----	-----	-----	-----	-----	-----	------	1.0	7.2	6.5	Clean snow from hillside near Echo Lake Lodge. Dirty crust removed.
.1	----	-----	-----	-----	-----	-----	------	1.0	5.1	5.3	Clean snow, about a quarter of a mile down road grade from No. 758.
.4	----	-----	-----	.0	-----	.07	------	2.0	4.0	5.1	Topmost 10 in. loose snow under evergreens. Probably represents single snowfall.
.4	----	-----	-----	.3	-----	.00	------	1.4	4.0	5.6	Snow on evergreen boughs. Had not touched the ground.
.3	----	-----	-----	-----	-----	-----	------	.5	3.6	6.0	Snow hard packed, ½-in. surface crust removed.
.6	.1	-----	.00	.1	.00	.04	5.7	1.0	6.6	5.7	Six inches of snow, crusted. Rests on 1 in. of ice which was not sampled.
[3]2.6	.1	-----	[3].02	[3].8	[3].34	[3].17	40	13	34	6.3	Ice underlying No. 930; included soil and pine needles frozen in ice.
.3	----	-----	.03	.2	-----	.08	2.8	1.4	4.0	5.9	Powder snow.
.1	----	-----	-----	-----	-----	-----	------	-----	5.0	----	Old snow, including surface dust and evergreen litter.
.5	----	-----	-----	-----	-----	-----	------	-----	4.0	4.6	Sample includes 2 in. of ice lying on rock and basal 1 ft of 4-ft snowbank.

See footnotes at end of table.

TABLE 1.—*Chemical analyses of snow and melt water, in parts*

Lab No.	Source[1]		Date of collection	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
	Material, location, and altitude in feet	Part of Sierra Nevada[2]											
												Snow and snowmelt, Sierra	
221	Snow, same location as No. 219	C	5-15-57	----	----	----	----	----	----	----	----	----	----
217	Snowmelt, same location as No. 219 except altitude 7,000.	C	do	----	----	----	----	----	----	----	----	5	<2
218	Snowmelt, same location as No. 219 except altitude 7,000.	C	do	----	----	----	----	----	----	----	----	4	<2
293	Snowmelt, same location as No. 219.	C	do	4.0	----	----	0.8	0.1	0.4	0.2	----	5	.7
753	Snow, 2.0 miles west of Meyers, U.S. Highway 50, Calif. Altitude 7,600.	C	6-3-58	.4	----	----	----	----	.2	.1	----	1	.3
754	Snowmelt, same location as No. 753 except altitude 7.000.	C	do	1.9	----	----	----	----	.4	.1	----	3	----
755	Snowmelt, same location as No. 753 except altitude 6,700.	C	do	2.3	----	----	----	----	.4	.2	----	3	----
756	Snowmelt, same location as No. 753 except altitude 6,600.	C	do	10	----	----	----	----	1.2	.4	----	10	----
216	Snowmelt, 1.7 miles west of Meyers, U.S. Highway 50, Calif. Altitude 6,750.	C	5-15-57	----	----	----	----	----	----	----	----	----	----
573	Snow at Meyers, U.S. Highway 50, Calif. Altitude 6,300.	C	1-28-58	.1	----	----	----	----	1.0	.2	----	2	----
575	Snow, same location as No. 573	C	do	.1	----	----	----	----	.2	.1	----	2	----
574	Snow, same location as No. 573	C	do	.1	----	----	----	----	.6	.2	----	2	----
760	Snow, 2.7 miles west of Mt. Rose summit, State Highway 27, Nev. Altitude 8,000.	C	6- 4-58	.0	----	----	----	----	.2	.4	----	2	.5
759	Snow, Mt. Rose summit, State Highway 27, Nev. Altitude 9,000.	C	do	.2	----	----	----	----	.1	.2	----	2	.2
766	Snow, same location as No. 759	C	6- 5-58	----	----	----	----	----	----	----	----	----	----
570	Snow, at Glenbrook resort, east shore Lake Tahoe. Altitude 6,300.	C	1-21-58	.4	----	----	----	----	.6	.2	----	2	----
563	Snow, 0.5 mile west of junction, U.S. Highway 50 and State Highway 28, Nev. Altitude 7,000.	C	do	.5	----	----	----	----	.5	.2	----	2	----
564	Snow, same-locations as No. 563	C	do	.4	----	----	----	----	.3	----	----	3	----
565	Snow, 0.25 mile east of Spooner Summit, U.S. Highway 50. Nev. Altitude 7,100.	C	do	.0	----	----	----	----	.3	.2	----	2	----
932	Snow, Spooner Summit, U.S. Highway 50, Nev. Altitude 7,100.	C	11-20-58	.0	0.01	0.00	.0	.2	.6	.6	0.0	3	1.6
1016	Snow, same location as No. 932	C	1-12-59	----	----	----	.3	.0	.4	.1	----	1	.5
1025	Snow, same location as No. 932	C	2- 2-59	----	----	----	.2	.1	.9	.1	----	1	1.2
1080	Snow, same location as No. 932	C	4-20-59	----	----	----	----	----	.2	----	----	----	----
742	Snow, 9.2 miles west of junction of U.S. Highways 50 and 395, Nev. Altitude 6,800.	E	5-26-58	.0	----	----	.0	.2	.9	.7	----	4	.6
566	Snow, 4.5 miles west of junction of U.S. Highways 50 and 395, Nev. Altitude 6,000.	E	1-21-58	.4	----	----	----	----	.3	.4	----	3	----

See footnotes at end of table.

per million, except pH *and specific conductance*—Continued

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH (in laboratory)	Remarks
Nevada region—Continued											
0.9	----	----	----	----	----	----	----	----	4.0	4.4	Topmost 1 ft of 4-ft snowbank; includes some dirt.
1.4	----	----	----	----	----	----	----	----	22	5.7	Seepage through debris of rock and vegetation in small channel; pale yellow.
.3	----	----	----	----	----	----	----	----	12	5.9	Runoff over about 1,000 ft of bare granitic-rock surfaces.
.3	0.1	----	----	0.2	----	----	9.3	3.0	9.0	6.0	Runoff in another small melt-water stream about 25 ft from No. 216.
.2	----	----	----	----	----	----	----	1.5	3.4	5.8	Snowpack on bare granitic rock about half a mile and 900 ft (vertically) above highway grade.
.2	----	----	----	----	----	----	----	----	7.9	6.0	Runoff over about ¼ mile of bare granitic rock.
.2	----	----	----	----	----	----	----	2.0	5.1	5.9	Runoff near highway grade, after passage through immature granitic soil.
.1	----	----	----	----	----	----	----	7.0	17	6.2	Runoff after passage through granitic debris of highway fill. Organic debris present.
.4	----	----	----	----	----	----	----	----	9.0	5.6	Runoff over bare granitic-rock surfaces.
.6	----	----	----	.1	----	0.00	----	2.0	4.0	5.9	Powder snow, 2 ft thick, on ground in open field.
.4	----	----	----	.1	----	.00	----	.6	3.0	5.9	Hard, crusty snow, 3 in. thick; overlies No. 573.
.9	----	----	----	.1	----	.00	----	2.0	5.0	6.1	Powder snow, 6-8 in. thick, overlying No. 575.
.2	----	----	----	----	----	----	----	.4	2.8	5.7	Sampled in evergreen forest 150 ft off highway.
.1	----	----	----	----	----	----	----	1.0	2.6	5.7	Sampled on granitic-rock hilltop 300 ft north of highway.
A= .8 B=1.4	----	----	----	----	----	----	----	----	A=13 B=11	----	(A) Determinations made on water when about one-half the sample had melted. (B) On water melted from remainder of sample.
.4	----	----	----	.0	----	.13	----	3.0	5.0	6.4	Sample from open area; resort closed for winter.
.6	----	----	----	.0	----	.08	----	2.1	7.0	6.5	Sample from open meadow.
.6	----	----	----	.1	----	.05	----	4.3	12	5.9	Sample taken under evergreen forest, south edge of meadow near No. 563.
.3	----	----	----	.0	----	.00	----	.2	4.0	6.1	Sample from open field. Compare Nos. 932, 1016, 1025, and 1080.
.2	.0	----	0.02	.1	0.01	.01	4.8	1.0	3.9	5.6	Sampled from clearing on unused dirt road. Lithium=0.0.
.1	----	----	.03	.1	----	.02	2.1	1.0	5.0	5.4	Sampled in grove of evergreens. Snow sparse, granular.
1.3	----	----	.03	.1	----	.06	4.5	1.0	8.0	5.5	Sampled in open area. Section, top to bottom, of 18-in. wind-packed snow.
.0	----	----	----	----	----	----	----	----	----	----	Old snow; dirt and forest litter on surface. Snow 1-1½ ft thick.
.3	----	----	.00	.1	----	.00	4.8	1.0	6.9	5.7	Sample from patch of coarsely granular snow about 1 ft thick. Removed topmost 1 in. (dirty).
.2	----	----	----	.1	----	.06	----	7.4	7.0	6.2	Snow patch in shaded area; bare ground nearby.

See footnotes at end of table.

TABLE 1.—*Chemical analyses of snow and melt water, in parts*

Lab No.	Source[1]		Date of collection	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
	Material, location, and altitude in feet	Part of Sierra Nevada[2]											
													Snow and snowmelt, Sierra
567	Snow, 1.9 miles on abandoned U.S. Highway 50 west of junction with U.S. Highway 395, Nev. Altitude 4,800.	E	1-21-58	1.0	-----	-----	----	----	0.5	0.6	----	4	-----
568	Snow, same location as No. 567	E	do	.0	-----	-----	----	----	1.6	1.5	----	----	-----
569	Snow, 4.4 miles on abandoned U.S. Highway 50 west of junction with U.S. Highway 395, Nev. Altitude 5,500.	E	do	.1	-----	-----	----	----	.3	.2	----	2	-----
933	Snow, 1.0 mile east of Carson City, U.S. Highway 50, Nev. Altitude 4,700.	E	11-20-58	.0	0.07	0.00	0.4	0.5	.6	.4	0.0	3	1.4
1026	Snow, 10 miles south of Gardnerville, U.S. Highway 395, Nev. Altitude 5,500.	E	2- 3-59	----	-----	-----	2.2	2.5	.7	.2	----	9	1.5
934	Snow, 11 miles east of Yerington, U.S. Highway 95-Alternate. Altitude 5,000.	E	11-20-58	----	-----	-----	.4	.2	.2	.1	----	2	.8
	Samples along California Highways 88, 4, and 108 and in Yosemite area												
714	Snow, 4.2 miles west of Peddler Hill, State Highway 88, Calif. Altitude 6,100.	W	4-29-58	.0	-----	-----	.0	.5	.2	.3	.0	3	1.8
712	Snow, near Peddler Hill, State Highway 88, Calif. Altitude 6,800.	W	do	.0	-----	-----	.0	.0	.4	.1	.0	3	1.8
713	Snowmelt, same location as No. 712.	W	do	3.4	-----	-----	.0	.7	.4	.1	.0	5	2.0
718	Snow, 5.0 miles west of Camp Connell, State Highway 4, Calif. Altitude 4,000.	W	do	.0	-----	-----	.0	.5	.1	.1	.0	3	1.7
716	Snow, 0.25 mile east of Camp Connell, State Highway 4, Calif. Altitude 5,500.	W	do	.0	-----	-----	.0	.5	.1	.1	----	3	1.6
715	Snowmelt (as flow in San Antonio Creek), same location as No. 716.	------	do	17	.00	.00	2.4	1.5	1.7	.7	.0	17	.4
701	Snow, 22 miles east of Sonora, State Highway 108, Calif. Altitude 5,100.	W	4-28-58	.0	-----	-----	.4	.0	.6	.3	1.4	4	.5
711	Snow, 1.0 mile east of Strawberry, State Highway 108, Calif. Altitude 6,100.	W	do	.0	-----	-----	.0	.5	.4	.1	.0	3	1.8
703	Snow, 1.5 miles east of Strawberry, State Highway 108, Calif. Altitude 5,500.	W	do	.0	-----	-----	.0	.0	.4	.0	----	4	.5
709	Snow, 36 miles east of Sonora, State Highway 108, Calif. Altitude 5,800.	W	do	.0	-----	-----	.0	.0	.3	.1	.0	3	.3
710	Snowmelt, same location as No. 709.	W	do	12	-----	-----	2.4	1.0	1.6	1.0	.0	16	1.3
704	Snow, 38 miles east of Sonora, State Highway 108, Calif. Altitude 6,200.	W	do	.0	-----	-----	.0	.0	.3	.1	.0	4	.5
705	Snowmelt, same location as No. 704.	W	do	.0	-----	-----	.8	1.9	.3	.2	.0	4	-----
707	Snow, same location as No. 704	W	do	.0	-----	-----	.0	.0	.3	.2	.0	2	.3
708	Snow, same location as No. 704	W	do	.0	-----	-----	.0	.0	.9	.5	.0	4	.8
953	Snow, on ridge south of Hetch Hetchy Reservoir, Yosemite National Park, Calif. Altitude 5,500.	W	3-18-59	----	-----	-----	1.0	.4	.7	.2	----	7	1.4

See footnotes at end of table.

per million, except pH *and specific conductance*—Continued

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH (in laboratory)	Remarks
Nevada region—Continued											
0.2	----	-----	-----	0.1	-----	0.12	------	4.5	12	6.2	Snow, icy in patches, 1-2 in. thick. Under bunch grass and brush.
1.2	----	-----	-----	-----	-----	.02	------	-----	10	6.4	Powdery snow, half an inch thick, overlying No. 567.
.4	----	-----	-----	.0	-----	.00	------	1.5	4.0	6.1	Snow on abandoned roadway; no car tracks; snow cover continuous.
.8	0.0	-----	0.01	.2	0.06	.04	6.0	3.0	11	5.7	Sample from patch of snow in shade of fence.
.8	----	-----	.03	.3	-----	.04	11	7.5	20	6.2	Snow reportedly fell 3 days before sampling; 2 in. thick, powdery.
.2	----	-----	.00	.1	-----	.00	3.0	2.0	4.0	6.1	Snow in shaded areas; bare ground nearby.
.2	.0	-----	.00	.1	.00	.00	4.6	2.0	3.3	5.6	
.2	.0	-----	.00	.0	.00	.02	4.0	.0	5.1	5.7	Snow 5-8 ft thick, lying on rock.
.4	.0	-----	.00	.0	.00	.00	9.5	3.0	6.6	6.5	Melt-water stream flowing about 5 gpm.
.0	.0	-----	.00	.0	.00	.03	4.0	2.0	5.1	5.5	Collected on hillside below highway.
.1	.0	-----	.00	.0	.00	.03	3.9	2.0	3.5	5.6	Snow 2 ft thick, collected on hillside above highway.
.2	.0	-----	.00	.1	.03	.00	33	12	28	7.3	Flow estimated as 30 second-feet. Consists mostly of snowmelt runoff. Lithium=0.0.
1.1	.0	-----	.00	.0	.05	.08	6.4	1.0	7.0	6.0	Old snow about 16 in. thick, in contact with soil.
.2	.0	-----	.00	.0	.00	.10	4.6	2.0	4.4	5.6	Snow about 18 in. thick.
.1	.2	-----	.00	.0	.01	.25	3.6	.0	3.0	6.6	Old snow about 2 ft thick, lying in patches.
.2	----	-----	.00	.0	.01	.07	3.1	.0	2.3	5.8	Old snow.
.3	.0	-----	.00	.1	.17	.00	28	10	29	7.0	Melt-water runoff from snow in area of No. 709.
.1	.2	-----	.00	.0	.04	.09	3.4	.0	4.6	5.8	Old snow about 18 in. thick.
.9	.1	-----	.00	.2	.02	.02	6.4	10	11	5.7	Small runoff stream from below snow sample No. 704.
.1	.2	-----	.00	.0	.02	.07	2.2	.0	3.0	5.6	Snow, fairly freshly fallen, about 4 ft deep.
.4	.2	-----	.00	.0	.04	.15	5.2	10	6.7	6.0	Old snow near highway, dug from near base of 4 ft snowbank.
.6	----	-----	.00	.0	-----	.01	7.8	4.0	14	6.5	

See footnotes at end of table.

TABLE 1.—*Chemical analyses of snow and melt water, in parts*

Lab No.	Source[1]		Date of collection	Silica (SiO_2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
	Material, location, and altitude in feet	Part of Sierra Nevada[2]											
Snow and snowmelt, Sierra													
721	Snow, Sentinel Rock, Yosemite National Park, Calif. Altitude 4,500.	W	4-30-58	0.0	-----	-----	0.4	0.0	0.9	0.8	1.9	6	0.4
720	Snowmelt, same location as No. 721.	W	---do---	11	0.02	0.00	.8	1.9	.7	.9	.0	10	.9
Snow samples [Taken by U.S. Soil													
979	Lower Bear River area, Garden City Summit. Altitude 7,900.	------	1-1-59	----	-----	-----	1.2	.2	.3	.2	----	4	1.0
993	Ogden River area, Lower Ben Lomond. Altitude 6,000.	------	---do--	----	-----	-----	----	----	.7	----	----	----	-----
994	Ogden River area, Snow Basin. Altitude 6,500.	------	---do--	----	-----	-----	----	----	.5	----	----	----	-----
978	Weber River area, Beaver Creek Ranger Station. Altitude 7,500.	------	---do--	----	-----	-----	----	----	.4	----	----	----	-----
984	Great Salt Lake area, Lower Farmington Canyon. Altitude 7,000.	------	---do--	----	-----	-----	----	----	.6	----	----	----	-----
957	Weber River area, Smith and Moorehouse Reservoir. Altitude 7,600.	------	---do--	----	-----	-----	----	----	.5	----	----	----	-----
959	Wasatch Mountains, main range, Parleys Canyon Summit. Altitude 7,500.	------	---do--	----	-----	-----	----	----	.9	----	----	----	-----
988	Provo River area, Timpanogas Divide. Altitude 8,200.	------	---do--	----	-----	-----	2.0	.2	.4	.2	----	5	2.0
960	Provo River area, Daniels-Strawberry Summit. Altitude 8,000.	------	---do--	----	-----	-----	4.0	----	.4	----	----	11	---
956	Duchesne River area, Indian Canyon. Altitude 9,100.	------	---do--	----	-----	-----	----	----	1.1	----	----	----	-----
958	Duchesne River area, Trail Lake. Altitude 9,800.	------	---do--	----	-----	-----	----	----	.5	----	----	----	-----
986	Duchesne River area, Julius Park. Altitude 10,000.	------	---do--	----	-----	-----	2.8	.5	1.2	1.0	----	7	2.4
1012	Price River area, Gooseberry Reservoir. Altitude 8,700.	------	---do--	----	-----	-----	2.6	.5	.7	.6	----	8	3.8
1022	Price River area, Dry Valley Divide. Altitude 7,800.	------	2-1-59	----	-----	-----	----	----	.6	----	----	----	-----
1023	Price River area, Mud Creek No. 2. Altitude 8,300.	------	---do--	----	-----	-----	----	----	.5	----	----	----	-----
983	Fremont River area, Farnsworth Lake. Altitude 9,900.	------	1-1-59	----	-----	-----	----	----	.6	----	----	----	-----
985	Escalante River area, Widtsoe-Escalante Summit. Altitude 9,500.	------	---do--	----	-----	-----	1.2	.2	.6	.6	----	4	1.8
980	Virgin River area, Midway Valley. Altitude 9,400.	------	---do--	----	-----	-----	1.8	.4	.3	.2	----	5	2.5
Snow samples from													
347	Denver Federal Center, north of visitors' parking area.[4]	------	2-3-55	----	-----	-----	----	----	----	----	----	----	1.5
360	971 Winona Court	------	3-6-55	----	-----	-----	----	----	----	----	----	14	2.6
390	Denver Federal Center, near entrance B, Bldg. 25.	------	3-20-55	----	-----	-----	----	----	----	----	----	4	1.1
391	Denver Federal Center, entrance B, Bldg. 25.	------	3-23-55	----	-----	-----	----	----	----	----	----	15	1.3
409	Denver Federal Center, entrance B, Bldg. 25.	------	3-25-55	----	-----	-----	----	----	----	----	----	8	1.3
484	Denver Federal Center, roof of Bldg. 25.	------	4-12-55	----	-----	-----	----	----	----	----	----	15	9.1

See footnotes at end of table.

per million, except pH *and specific conductance*—Continued

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO_4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos at 25°C)	pH (in laboratory)	Remarks
Nevada region—Continued											
0.9	0.1	-----	0.00	0.0	0.13	0.04	8.7	1.0	9.9	6.0	Snowslide about 6 ft deep, resting on talus.
.4	.2	-----	.00	.0	.02	.02	22	10	21	6.4	Melt-water runoff, about 50 gpm, over granitic talus. Lithium=0.0.
from Utah Conservation Service personnel]											
1.1	----	0.000	0.01	0.1	-----	0.00	6.1	4.0	10	6.5	
.7	----	-----	-----	-----	-----	-----	------	-----	22	----	
.2	----	-----	-----	-----	-----	-----	------	-----	42	----	
.6	----	-----	-----	-----	-----	-----	------	-----	12	----	
1.0	----	-----	-----	-----	-----	-----	------	-----	18	----	
.4	----	-----	-----	-----	-----	-----	------	-----	9	----	
1.6	----	-----	-----	-----	-----	-----	------	-----	24	----	
.3	----	.000	.01	.7	-----	.00	8.4	6.0	19	6.4	
5.0	----	-----	-----	-----	-----	-----	------	-----	39	7.2	
1.2	----	-----	-----	-----	-----	-----	------	-----	44	----	
.4	----	-----	-----	-----	-----	-----	------	-----	7	----	
1.3	----	.000	.01	5.6	-----	.00	18	9.0	36	6.2	
.7	----	.000	.00	.6	-----	.01	13	8.5	25	6.6	
.3	----	-----	-----	-----	-----	-----	------	-----	18	----	
.3	----	-----	-----	-----	-----	-----	------	-----	21	----	
.7	----	-----	-----	-----	-----	-----	------	-----	18	----	
.8	----	.000	1.0	.3	-----	.01	8.5	4.0	18	6.2	
.8	----	.000	-----	.00	.9	.03	9.5	6.0	18	6.3	
the Denver, Colo., area											
1.0	----	-----	-----	-----	-----	-----	------	-----	17	----	
2.4	----	-----	-----	-----	-----	-----	------	-----	42	6.4	
.9	----	-----	-----	-----	-----	-----	------	-----	16	6.0	
1.5	----	-----	-----	-----	-----	-----	------	-----	30	6.9	
1.5	----	-----	-----	-----	-----	-----	------	-----	16	6.6	
1.6	----	-----	-----	-----	-----	-----	------	-----	51	7.1	

See footnotes at end of table.

TABLE 1.—*Chemical analyses of snow and melt water, in parts*

Lab No.	Source[1] Material, location, and altitude in feet	Source[1] Part of Sierra Nevada[2]	Date of collection	Silica (SiO^2)	Aluminum (Al)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Ammonia nitrogen (as NH_4)	Bicarbonate (HCO_3)	Sulfate (SO_4)
Snow samples from													
1070	Denver Federal Center, Bldg. 25.	------	12-5-55	----	-----	-----	----	----	----	----	----	4	3.4
2229	Denver Federal Center, snow of 10-24-57 and 10-25-57.	------	10-25-57	----	-----	-----	----	----	0.5	----	----	----	-----
2235	Denver Federal Center, snow of 11-7 to 11-8-57.	------	11-8-57	----	-----	-----	----	----	1.3	----	----	----	-----
2236	Denver Federal Center, snow of 11-14 and 11-15-57.	------	11-15-57	----	-----	-----	----	----	1.1	----	----	----	-----
2251	Denver Federal Center	------	11-27-57	----	-----	-----	----	----	1.2	----	----	----	-----
2273	405 Emerson Street	------	12-8-57	----	-----	-----	----	----	3.7	----	----	----	-----
2291	Denver Federal Center, snow of 1-14-58.	------	1-14-58	----	-----	-----	----	----	.4	----	----	----	-----
2292	Denver Federal Center, snow of 1-18 to 1-20-58.	------	1-20-58	----	-----	-----	----	----	.2	----	----	----	-----
2420	Denver Federal Center; snow storm from New Mexico area. Denver area clear as of 0800 on 3-17-58.	------	3-17-58	----	-----	-----	----	----	.3	----	----	----	-----
2445	Denver Federal Center, snow of 3-28-58.	------	3-28-58	----	-----	-----	----	----	1.5	----	----	----	-----
2482	Denver Federal Center	------	4-11-58	----	-----	-----	----	----	2.5	----	----	----	-----
2501	Denver Federal Center	------	4-23-58	----	-----	-----	----	----	1.0	----	----	----	-----
Other snow													
666	Odel Summit, U.S. Highway 97, Oregon. Altitude 4,800.	------	3-26-58	0.0	-----	-----	0.8	0.0	.4	0.3	----	2	-----
671	Rosary Trail Lodge road, U.S. Highway 97, Oregon. Altitude 4,500.	------	3-30-58	.2	-----	-----	.0	.0	.6	1.5	----	2	2.1
665	Diamond Lake road junction with U.S. Highway 97, Oregon. Altitude 4,600.	------	3-26-58	.3	-----	-----	.0	.0	.7	.0	----	4	9.6
1096	Mt. Shasta Ski Bowl, Siskiyou County, Calif., 400 yd east of Ski Lodge. Altitude 7,600.	------	5- 5-59	.0	-----	-----	.0	.0	.1	.0	----	3	.8
1097	Mt. Shasta, Siskiyou County, Calif. Panther Meadows. Altitude 7,500.	------	do	.0	-----	-----	.0	.0	.2	.0	----	1	.8
1098	Lassen National Park, Calif., 300 yd above Lassen Marker 41 on Lassen Park Highway.	------	5- 6-59	.0	-----	-----	.0	.0	.2	.3	----	2	1.0
1035	Saratoga, Calif., junction of California Highways 9 and 5. Altitude 2,600.	------	2-13-59	----	-----	-----	.5	.3	.2	.3	----	2	.4
1036	Junction of Jamison Creek Road and Empire Grade, Ben Lomond Mt., Santa Cruz County, Calif. Altitude 2,400.	------	do	----	-----	-----	.4	.0	.3	.1	----	2	.5
1054	14 miles south-southeast of Kingman, Mohave County, Ariz., at Hualapai Mountain Park.	------	3-26-59	----	-----	-----	.8	.1	.3	.1	----	3	.9
1055	3.0 miles north-northeast of Parks, Coconino County, Ariz., 100 ft south of U.S. Highway 66.	------	do	----	-----	-----	.4	.0	.3	.1	----	3	.7
1057	7.4 miles south of Flagstaff, Coconino County, Ariz., at Lindberg Springs, on U.S. Highway 89-A.	------	3-27-59	----	-----	-----	.5	.0	.1	.0	----	3	.8
1064	10 miles east-northeast of Pinetop, Apache County, Ariz., beside Forest Service Rd.	------	3-29-59	----	-----	-----	1.0	.0	.2	.0	----	4	.6

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[1] Samples are reported in order from west to east (see pl. 1) on each of the following traverses: along U.S. Highway 40 and its access highways near the Sierra Nevada crest, extending into the Virginia City area, Nevada; along U.S. Highway 50 to the vicinity of Carson City, Nevada; along California Highways 88, 4, and 108 and in the Yosemite area. Samples from Utah and those from miscellaneous locations are reported in order from north to south within each group.

[2] "W" indicates location on west slope of Sierra Nevada; "C" location near the crest of the range; "E"

per million, except pH *and percific conductance*—Continued

the Denver, Colo., area—Continued

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO^4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO^3$	Specific conductance (micromhos at 25°C	pH (in laboratory)	Remarks
2.2	----	-----	-----	-----	-----	-----	------	-----	32	6.1	
1.0	----	-----	-----	-----	-----	-----	------	-----	16	----	
2.0	----	-----	-----	-----	-----	-----	------	-----	40	----	
1.0	----	-----	-----	-----	-----	-----	------	-----	25	----	
1.8	----	-----	-----	-----	-----	-----	------	-----	23	----	
6.1	----	-----	-----	-----	-----	-----	------	-----	90	----	
1.5	----	-----	-----	-----	-----	-----	------	-----	17	----	
.5	----	-----	-----	-----	-----	-----	------	-----	20	----	
.1	----	-----	-----	-----	-----	-----	------	-----	8	----	
2.5	----	-----	-----	-----	-----	-----	------	-----	23	----	
1.0	----	-----	-----	-----	-----	-----	------	-----	54	----	
1.0	----	-----	-----	-----	-----	-----	------	-----	33	----	

samples

Chloride (Cl)	Fluoride (F)	Iodide (I)	Nitrite (NO_2)	Nitrate (NO_3)	Orthophosphate (PO^4)	Boron (B)	Dissolved solids (calculated)	Hardness as $CaCO^3$	Specific conductance (micromhos at 25°C	pH (in laboratory)	Remarks
.4	----	0.0	0.00	0.0	-----	0.10	3.0	2.0	3	6.4	
3.7	----	-----	.00	.4	-----	.24	9.7	.0	4	6.0	
.4	----	-----	.00	.0	-----	.28	15	.0	4	5.9	
.2	----	.000	-----	-----	-----	-----	2.6	.0	2	5.8	
.1	----	.000	-----	-----	-----	-----	1.6	.0	3	5.6	
.3	----	.000	-----	-----	-----	-----	2.8	.0	2	5.6	
.7	----	.000	.00	.2	-----	.04	3.6	2.6	8	5.8	
.6	----	.000	.01	.1	-----	.04	3.0	1.2	5	6.7	
.1	----	.000	.00	.1	-----	.02	3.9	2.4	7	5.8	
.3	----	.000	.01	.1	-----	.02	3.5	1.0	5	6.0	
.3	----	.000	.01	.1	-----	.02	3.4	1.2	4	6.0	
.4	----	.000	.00	.1	-----	.02	4.3	2.4	7	6.1	

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location east of the crest of the range. Only Sierra Nevada snow samples are so marked. Snow-melt sample locations (Sierra Nevada only) are referred to nearby snow samples.

[3] Sample 931: Determinations footnoted were made on part of sample treated with H_2SO_4, H_2O_2, and charcoal because of abundant organic matter present. Iodide=0.4; Bromide=0.00; Lithium=0.0.

[4] Snow samples from Denver were analyzed by the Quality of Water Branch laboratory in Denver. Sample numbers and descriptions follow notations received from Denver.

TABLE 2.—*Summary of ranges of concentrations, in parts per million, of major chemical constituents found in snow*

Constituent	SIERRA NEVADA																
	West slope					Crest					East slope					All	
	Max.	Median	Min.	Mean	Analyses	Max.	Median	Min.	Mean	Analyses	Max.	Median	Min.	Mean	Analyses	Median	Mean
Silica (SiO_2)	1.7	0.0	0.0	0.18	21	0.5	0.1	0.0	0.14	21	1.0	0.1	0.0	0.17	10	0.0	0.16
Calcium (Ca)	1.0	.0	.0	.15	20	.5	.2	.0	.22	9	3.8	.4	.0	.84	14	.2	.39
Magnesium (Mg)	.5	.0	.0	.20	20	.2	.0	.0	.03	9	.5	.2	.0	.19	14	.0	.16
Sodium (Na)	1.1	.45	.1	.49	26	1.4	.35	.1	.46	28	1.6	.3	.1	.43	18	.2	.46
Potassium (K)	.9	.30	.0	.32	26	.7	.2	.1	.25	25	1.5	.2	.1	.41	17	.2	.31
Bicarbonate (HCO_3)	8.0	3.0	.0	3.31	26	3.0	2.0	.0	2.0	26	9.0	3.0	2.0	3.59	17	2.0	2.90
Sulfate (SO_4)	5.3	.6	.3	1.06	21	2.8	.5	.1	.63	19	4.3	.85	.3	1.14	14	.65	.93
Chloride (Cl)	1.4	.6	.0	.54	29	1.6	.5	.0	.48	31	1.2	.4	.1	.47	18	.4	.50
Dissolved Solids (Calculated)	11	4.0	.7	4.60	20	5.7	3.35	2.1	3.65	8	14	4.2	2.3	5.52	13	4.0	4.70
	Utah					Denver, Colo.					Miscellaneous localities						
Silica (SiO_2)	----	----	----	----	0	----	----	----	----	0	0.3	0.0	0.0	0.08	6		
Calcium (Ca)	4.0	2.0	1.2	2.23	7	----	----	----	----	0	1.0	.4	.0	.37	12		
Magnesium (Mg)	.5	.35	.2	.33	6	----	----	----	----	0	.3	.0	.0	.03	12		
Sodium (Na)	1.2	.55	.3	.60	18	3.7	1.1	.2	1.24	11	.7	.25	.1	.30	12		
Potassium (K)	1.0	.35	.2	.47	6	----	----	----	----	0	1.5	.1	.0	.23	12		
Bicarbonate (HCO_3)	11	5.0	4.0	6.29	7	15	11	4.0	10	6	4.0	3.0	1.0	2.64	11		
Sulfate (SO_4)	3.7	2.2	1.0	2.25	6	9.0	1.5	1.1	2.88	7	9.5	.8	.4	1.71	10		
Chloride (Cl)	5.0	.7	.2	.97	18	6.1	1.0	.1	1.60	17	3.7	.35	.1	.62	12		
Dissolved Solids (Calculated)	18	9.1	6.1	10.58	6	----	----	----	----	0	15	3.45	1.6	4.70	12		

Comparisons were made of the mean concentration of a constituent in one sample population with its mean concentration in another population (tables 2, 3); each comparison was tested for significance using the *t* test proposed by "Student" (Dixon and Massey, 1957, p. 119–120).

The results of tests for pH and for electrical conductivity are reported in table 1, but they have not been compared from one sample population to another. This is because pH values change during storage of water samples, especially, in the experience of the writers, when the mineral content of the water is small.

TABLE 3.—*Comparisons of the means* [1]

Areas compared	Ca	Na	HCO_3	SO_4	Cl	Dissolved solids
Sierra Nevada						
West slope–crest	[2] n.s.	[2] n.s.	>0.01	[2] n.s.	[2] n.s.	[2] n.s.
Crest–east slope	<0.10 >.05	[2] n.s.	>.01	>0.10 <.05	[2] n.s.	[2] n.s.
West slope–east slope	<.01	[2] n.s.	[2] n.s.	[2] n.s.	[2] n.s.	[2] n.s.
Sierra Nevada–Utah	>.01	>0.10 <.05	>.01	>.01	>0.01	>0.01
Sierra Nevada–Denver	----------	>.01	>.01	>.01	>.01	----------
Utah–Denver	----------	>.05 <.01	[2] n.s.	[2] n.s.	[2] n.s.	----------

[1] These comparisons were made using "Student's" "t" test (Dixon and Massey, 1957, p. 119). Silica showed no statistically significant differences among the areas for which data are available. Magnesium and potassium were not considered because the variations in values obtained were not significant when compared with the variations inherent in the analytical methods used.

[2] Not significant. The difference in the means is not significant at the 0.10 level.

In water samples having a dissolved-solids concentration ranging from a few tens to a few thousands of ppm (parts per million), electrical conductivity tends to be roughly proportional to mineral content. A rule of thumb is that dissolved-solids concentration, in parts per million, is equivalent to about 0.7 times the conductivity, in micromhos. Examination of the results shown in table 1, however, makes it clear that no consistent relation between dissolved-solids content and electrical conductivity prevails in water having a mineral content as small as that of the melted snow. Dissolved gases, not determined in the analytical procedures, may be a controlling factor in the conductivity of these waters.

ACKNOWLEDGMENTS

The help of H. C. Whitehead and J. P. Schuch in making chemical analyses of some of the snow samples is acknowledged with appreciation. The present report has benefited from critical review by Arlo Gambell, Jr., Elmer Robinson, and H. E. Thomas.

CHEMICAL CHARACTER OF THE SNOW

The melted snow from all the localities sampled is a dilute solution containing some or all of the major constituents usually found in surface and ground water. The maximum reported concentration of dissolved solids is 18 ppm, in one sample from Utah, and the minimum is 0.7 ppm, in a sample from the Sierra Nevada. The dissolved-solids content of samples from Denver was not determined; it would be higher than the average from the other areas, but it would still undoubtedly average less than 50 ppm and probably less than 30 ppm. The mineral load brought into the mountainous western areas and deposited with the snow, even in years of heavy precipitation, therefore, is modest on a unit-area basis, even though regionally the total load no doubt reaches considerable size.

The general chemical character of the melted snow is indicated in tables 2 and 3 and is illustrated for 39 samples from the Sierra Nevada area and for 6 samples from Utah in figures 1, 2, and 3. There is

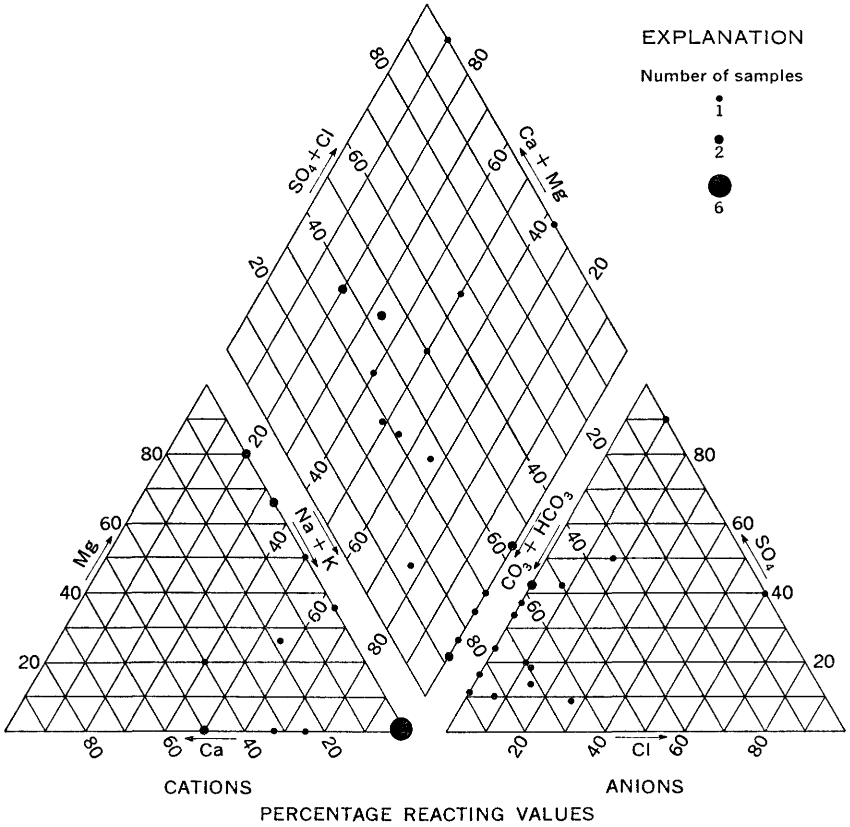

FIGURE 1.—Diagram showing general chemical character of snow from west slope of Sierra Nevada.

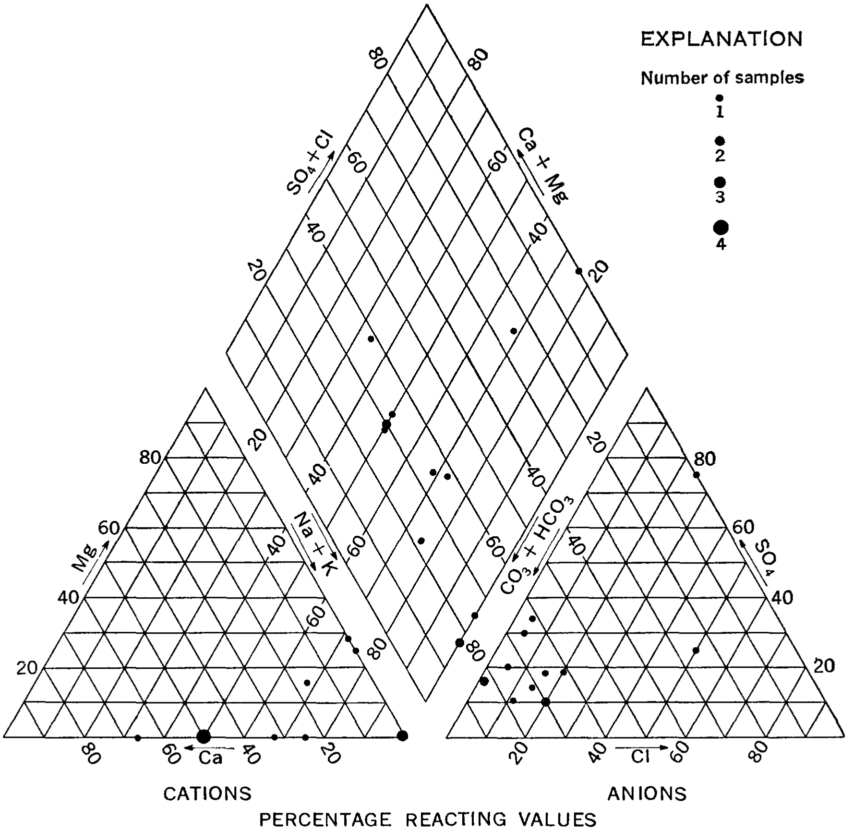

FIGURE 2.—Diagram showing general chemical character of snow from crest of Sierra Nevada.

considerable diversity in chemical type among samples from the west-slope and the creast areas in the Sierra Nevada. Samples from the east slope and from Utah, however, show (fig. 3) a preponderance of calcium, magnesium, and bicarbonate. The samples from Denver were not analyzed for calcium, magnesium, or potassium and therefore cannot be classified as to type.

VARIATIONS WITH LOCALITY

Comparison of calcium contents in samples taken from west to east across the Sierra Nevada (table 2) shows that the calcium content increases progressively and that the increase from the west slope to the east slope is statistically significant. An even larger increase is found when all the Sierra Nevada samples are compared with those from Utah; the Utah samples have on the average more than five times as much calcium as do those from the Sierra Nevada. If the highest 20 values for calcium concentration in Sierra Nevada snow are compared

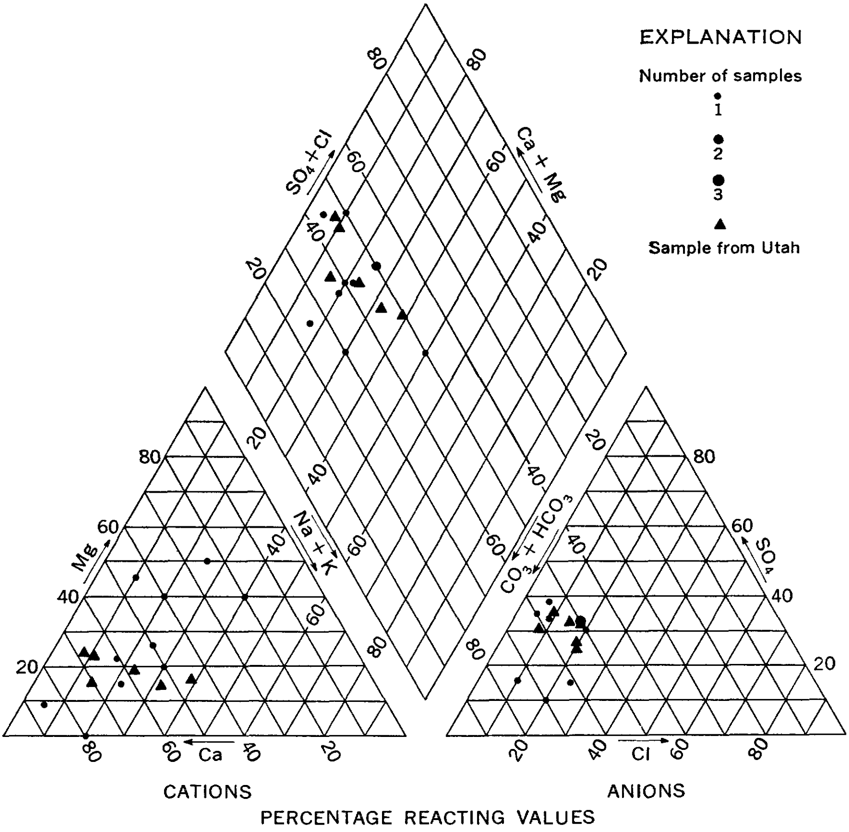

FIGURE 3.—Diagram showing general chemical character of snow from east slope of Sierra Nevada and from Utah.

with the values for the 20 samples from Utah, the Sierra average (0.79 ppm) is only about one-third that (2.23 ppm) found in the Utah samples. The increase in calcium content progressively from west to east is the most persistent and pronounced trend recognized in a comparison of individual constituents in terms of the geographic location of the samples.

Concerning most other major constituents, the trend (tables 2, 3) is for samples taken near the crest of the Sierra Nevada to have smaller concentrations than are found in samples from either the west or the east slope. Not all the differences in mean concentration noted have statistical significance. The differences reported, however, are apparently relative to the crest of the range—not to altitude alone. Comparisons of the concentrations of constituents with the altitude at which samples were taken showed no correlation.

As with calcium, the concentrations of the other major constituents—and of dissolved solids—are significantly larger in the samples from

Utah than in samples from the Sierra Nevada. The observed mean differences (tables 2, 3) are statistically significant at or beyond the 0.01 level except for sodium; the level of significance for sodium lies between 0.05 and 0.01. The greater concentration in samples from Utah persists with respect to calcium, bicarbonate, sulfate, and dissolved solids, even when Utah averages are compared with the averages of the 20 highest values obtained in the Sierra Nevada samples. Sodium is higher in the selected 20 Sierra Nevada samples, and chloride is equivalent in this comparison.

	Average concentration (ppm), all 20 Utah samples	*Average concentration (ppm), 20 highest values obtained in Sierra Nevada samples*
Calcium	2. 23	0. 79
Sodium	. 60	. 88
Bicarbonate	6. 3	4. 9
Sulfate	2. 25	1. 77
Chloride	. 97	1. 02
Dissolved solids	10. 6	6. 54

All four constituents reported in the Denver samples show a greater average concentration than the average in the Sierra Nevada snow, and the differences are statistically significant at levels exceeding 0.01. With respect to Utah snow, the samples from Denver have greater average concentration of the four constituents determined. The difference in mean concentration of sodium, however, is the only one of the group having demonstrated statistical significance. The Denver samples are from an urban environment whereas those from the Sierra Nevada and from Utah are not. The observed differences, therefore, may reflect local influences rather than a regional trend.

Sets of samples (analyses 565, 932, 1016, 1025, and 1080 being one set and analyses 571, 572, 752, 930, 1015, and 1079 being the other set; see table 1) were taken at each of two localities along U.S. Highway 50 at various times during the study. These show variations in concentrations of constituents within the groups and suggest that, irrespective of locality, individual falls of snow differ in chemical character and concentration. Some, but probably not all, of the differences may result from additions from dry fallout, itself varying in kind and amount.

NEW SNOW VERSUS OLD SNOW

Thirteen samples are identified in table 1 (Remarks column) as newly fallen snow, as snowfall within 48 hours, or by a similar commentary; and 19 are identified specifically as old snow that was in place in the sample site for an appreciable time prior to collection. The mean concentrations of the major constituents, and of dissolved solids, in these groups of "new snow" and "old snow" were compared.

The numbers of analyses of individual constituents ranged from 6 to 19. The comparisons of mean concentrations in parts per million, are shown below:

	Average in new snow (6-13 samples)	*Average in old snow (6-19 samples)*
Silica	0.0	0.2
Calcium	.6	.1
Magnesium	.2	.0
Sodium	.5	.6
Potassium	.3	.3
Bicarbonate	2.8	2.6
Sulfate	.7	.5
Chloride	.6	.5
Dissolved solids	4.0	5.0

Considered statistically, using the *t* test, only the difference in calcium content has significance. The confidence level for it is greater than 0.01. The appearance of the snow sample is not necessarily indicative of its mineral content; some samples of clean, newly fallen snow were high in dissolved-solids content relative to the average for all snow samples, and some samples, old and dirty in appearance, showed little mineralization upon analysis (analyses 1018 and 1081, U.S. Highway 40 group; 1079 and 1080, U.S. Highway 50 group. See table 1).

pH

The pH values reported in table 1 were recorded in the laboratory at the time the samples were analyzed for their mineral content. It is unlikely that they represent the true pH of the newly melted snow, because pH is a physical property that varies in response, for example, to changing degrees of equilibration of the water with the partial pressure of carbon dioxide in the atmosphere, as well as in response to other variables including temperature. In the writers' experiences with water low in mineralization, the pH measured in the field is commonly different from the pH of the sample measured upon return of the sample to the laboratory. For these reasons the writers feel that an elaborate consideration of the significance of pH of the snow is not warranted in this paper—and, indeed, that the pH of samples of precipitation, as usually determined, cannot be used as a property of the water in geochemical considerations, except with reservations. However, pH measurements of precipitation samples are commonly reported in the liteature, and the writers conform to the practice.

In the Sierra snow samples, laboratory determinations of pH ranged from 4.2 to 8.3. The median value was 5.8. The pH of 7 Utah snow samples ranged from 6.2 to 7.2. The median value in the Utah group was 6.4. At Denver, pH was from 6.0 to 7.1. In the group of 12 samples from various localities in Oregon, California, and Arizona, the pH range was from 5.6 to 6.7; the median value was between 5.9 and 6.0.

These determinations indicate that, in common with precipitation generally, the pH of snow in the West is for the most part less than 7.0. The progressive increase of median values from west to east that is indicated by the data may have significance, but the uncertainties mentioned above preclude too great reliance upon the data obtained. The median pH values of the Sierra Nevada, the Utah, and the miscellaneous samples are not far different from the pH (5.8) of pure water in equilibrium with the carbon dioxide of the atmosphere at 25°C.

MINOR CONSTITUENTS

Analyses were made for 12 minor constituents in a few to most of the snow samples from the Sierra Nevada and vicinity. The results are summarized in table 4. For the low concentrations of the various constituents, the sensitivity and accuracy of analytical methods impose a severe restriction on the confidence that can be placed in the results obtained. The maximum values reported (table 4) for the minor constituents probably set an upper limit to concentrations existing in the samples analyzed. All values reported for nitrite, nitrate, and boron are thought to be valid within the accuracies indicated by significant figures. Other median and mean values appearing in table 4 may not be real.

Aluminum silicates, especially kaolin minerals, are reportedly significant in nucleation of snowflakes (Kumai, 1951, 1961; Isono, 1955). Eight snow samples were analyzed for aluminum. The apparent presence of measurable amounts of aluminum in seven of the eight suggests that clay-mineral nuclei may indeed contribute to mineralization of melting snow. An alternate possible source of aluminum, however, is dust falling on the snow. A more sensitive and dependable method for aluminum determination is prerequisite, however, to further useful search in this direction.

Silica was determined in 52 samples from the Sierra Nevada and in six samples from the miscellaneous group. Silica was sought in each of the eight samples in which aluminum content was determined, and it was found to be present in three. The contribution of aluminum silicate minerals to mineralization of snow cannot be evaluated from existing data. Whatever its source, silica appears to be a fairly common constituent in melted snow. Determination of silica concentrations in snow is of particular interest in the later comparison (p. J27) of snow with melt-water runoff.

The scarcity of ammonia nitrogen (as NH_4), a constituent that was undetected in 16 of 19 samples, runs contrary to expectation, because ammonia nitrogen has commonly been reported by other investigators. It is a transient constituent that is likely to be oxidized to nitrite (NO_2)

TABLE 4.—*Summary results of analyses for minor constituents in snow*

Constituent	Concentration (ppm)				Total analyses	Analyses in which concentration was below sensitivity of method (reported 0.00 ppm)
	Max.	Median	Min.	Mean		
Silica (SiO_2)	1.7	0.0	0.0	0.16	58	33
Aluminum (Al)	.07	.025	.00	.03	8	1
Iron (Fe)	.03	.00	.00	.01	6	4
Manganese (Mn)	.02	.00	.00	.00	5	4
Arsenic (As)	.00	.00	.00	.00	4	4
Lithium (Li)	.0	.0	.0	.0	7	7
Ammonia nitrogen (as NH_4)	1.9	.00	.00	.18	19	16
Nitrite (NO_2)	.10	.00	.00	.01	37	21
Nitrate (NO_3)	.3	.0	.0	.07	55	30
Bromide + Iodide (as Br)	.16	.04	.00	.05	19	5
Iodide (I)	.10	.00	.00	.00	39	38
Orthophosphate (PO_4)	.14	.01	.00	.03	19	8
Boron (B)	.32	.03	.00	.05	57	15

and thence to nitrate (NO_3). If the Sierra Nevada snow samples had been analyzed immediately upon return to the laboratory—or better yet, in the field when they first melted—more samples might have showed presence of ammonia nitrogen. This possibility, however, does not accommodate the experience of the Northern European precipitation-sampling network (p. J34–J35); the network analyzes samples as monthly composites, and yet it commonly reports ammonia nitrogen (as NH_3–N) in fairly large amounts. A sampling of 50 determinations made in 1958–59 by the network gave an average of 0.22 ppm of NH_3–N. In this group, 0.92 ppm was the largest concentration, and in only 2 of the 50 samples was zero concentration reported. The Sierra Nevada may be a nitrogen-deficient region—concentrations of all nitrogen species appear to be low—relative to other areas from which data are available. The small amount of nitrogen in the Sierra snow may reflect the fact that snow-bearing air masses reaching the Sierra Nevada have traveled from the ocean inland without crossing areas where continental sources could be expected to increase the concentration, in the air, of those nitrogen compounds that would react with the water in the atmosphere.

The appearance of measurable amounts of boron, in 42 of the 57 samples in which it was sought, suggests that it is a common constituent, seldom determined in other studies of the chemical content of precipitation. Orthophosphate and the several compounds containing nitrogen are natural plant nutrients and are therefore of interest in relation to maintenance of soil fertility in the areas upon which snow falls. The low concentrations of these constituents show that virtually the only function of snow in the forest economy of the Sierra Nevada is to provide moisture.

CONTACT WITH THE LITHOSPHERE

As soon as snowmelt comes in contact with the lithosphere—that is, with soil and weathered rock—the water undergoes significant changes in mineral content and chemical type. Concentrations of silica increase about thirtyfold, and concentrations of calcium, sodium, bicarbonate, and dissolved solids increase from two to nearly five times. The statistical significance of the differences of the means is high for all except sulfate and chloride (table 5). The increase in concentration of silica, calcium, bicarbonate, and dissolved solids cannot be explained on the basis of concentration by evaporation alone. The direction and amount of change involved as melt water comes in contact with the lithosphere are indicated in figure 4 and table 5.

Among the more striking differences in the samples compared is the strong tendency for melt-water samples coming into contact with the lithosphere to take on the character of calcium magnesium bicarbonate water, no matter what the chemical type of the parent snow. There seems to be in the soil and weathered rock an abundance of readily available alkaline earths as well as much available silica. The increase in absolute amount and in percentage of bicarbonate is most readily explained by the availability of carbon dioxide in the soil atmosphere. The silica, sodium, and calcium are made available by chemical weathering of the minerals that make up the granitic rocks. Magnesium and potassium—as in other parts of this study—were not considered because the variations in concentrations of these constituents are not significant when compared with the variations inherent in the analytical methods used.

TABLE 5.—*Comparison of selected constituents in paired samples of snow and snowmelt runoff*

Constituents	Snow				Snowmelt				Level of confidence of difference between means
	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean	
Silica (SiO_2)	0.5	0.5	0.1	0.4	14	4.5	0.5	6.2	>0.01
Calcium (Ca)	.5	.5	.0	.3	2.4	.8	.0	1.1	$>0.10<0.05$
Sodium (Na)	.9	.2	.2	.3	1.6	.6	.3	.8	$>0.05<0.01$
Bicarbonate (HCO_3)	6	3	1	2.8	16	8	3	7.6	>0.01
Sulphate (SO_4)	1.8	.5	.3	.7	2.0	1.1	.8	1.2	Not significant at 0.10
Chloride (Cl)	.9	.2	.1	.2	.9	.4	.1	.4	Not significant at 0.10
Dissolved solids	8.7	3.1	2.9	4.0	28	14	6.6	16	>0.01

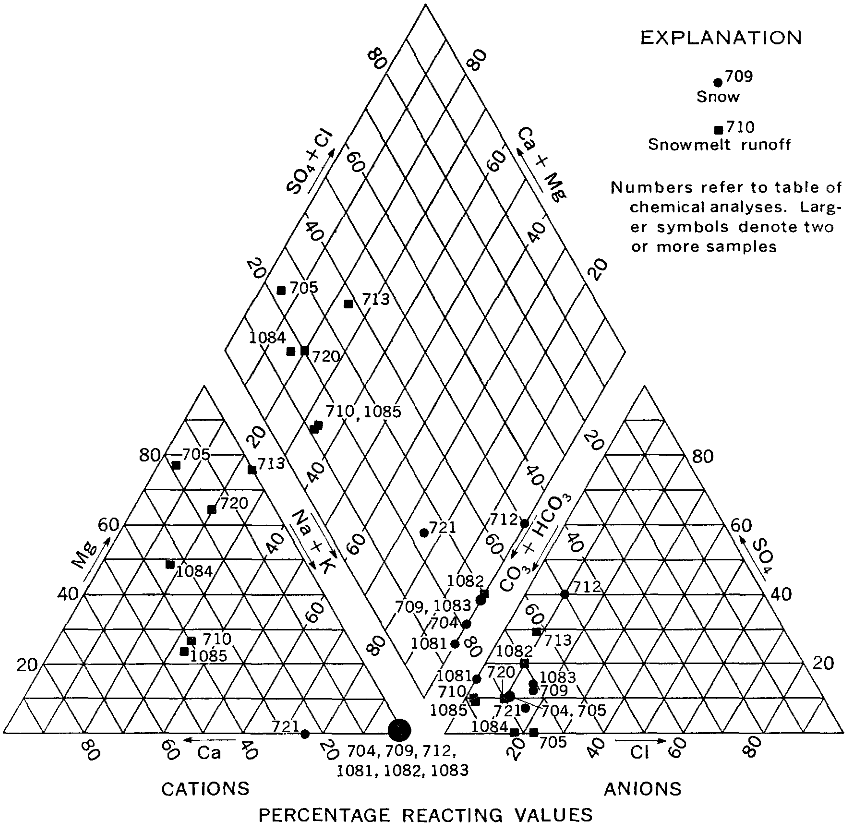

FIGURE 4.—Diagram showing general chemical character of paired samples of snow and snowmelt runoff

The data for these comparisons come from pairs or groups of samples taken with this end specifically in view. In each pair or group, the sequence starts with a sample of snow—late-season snow inasmuch as melt-water runoff was also sought. The pairs include a sample from the parent snowbank and a sample taken from a melt-water stream discharging from the snowbank. Insofar as possible, the pairs were chosen so as to eliminate the possibility of water joining the melt-water stream from sources other than the melting snowbank. In one place (analyses 753–756, U.S. Highway 50 group, table 1), a series of samples was taken which started with a sample from a bank of melting snow high on a rock face and included samples of melt-water runoff collected progressively down the rock face for a distance of about half a mile. In this sequence the possibility of increments of water from other melting snowbanks cannot be ruled out. In all the pairs or sequences used in this study the underlying rock was granitic. Other information regarding the samples compared is given in table 1.

In the following list of groups of samples considered (also see table 1), the first number given for each group is that of the snow sample; the second number (and any succeeding numbers) is that of the snowmelt sample. These groups, collected along the respective highways, are: California State highways: 704, 705; 709, 710; 712, 713; 721, 720; U.S. Highway 50: 753, 754, 755, 756; U.S. Highway 40: 1081, 1082; 1083, 1084, 1085. Calcium and magnesium were not determined in the group including analyses 753–756. The character of these samples, therefore, cannot be illustrated diagramatically.

SOURCES OF THE MINERALS

OCEANIC AND CONTINENTAL

The sources of some of the mineral constituents found in snow can reasonably be inferred from present information; the origin of others cannot. The origin of snow-bearing air masses over the Pacific Ocean and the common nucleation of snowflakes upon minute fragments of silicate minerals, especially those of the kaolin group, suggest ready sources of sodium, chloride, and silica Both Isono (1955) and Kumai (1961) identified the nuclei of individual snow crystals under the electron microscope. The nuclei consist most frequently of clay-mineral fragments having diameters ranging from about 0.05 to 0.15 micron. In addition, Kumai (1961, p. 144) mentioned "* * * innumerable very small nuclei * * * in the remainder of the crystal." Isono (1955, p. 458) identified sodium chloride (grain diameter less than 1 micron) as the component making up these tiny grains, but he noted that sodium chloride did not form the principal nucleus of any of the snow crystals he examined. Dust falling between snowstorms in the Sierra Nevada no doubt contributes silica to the snowpack. Some of the silica in dust particles may be more readily soluble than that which makes up some of the snow-crystal nuclei. The numerous samples of snow in which no soluble silica was detected suggest—if clay minerals are present as snow-crystal nuclei—that the silica in the clay minerals is nearly insoluble and that the silica content measured in snow samples probably comes from dust.

The ocean is the probable source of most, or all, of the sodium and chloride found in the snow; those snowfalls having a dominance of sodium and chloride almost surely received the preponderance of their mineral content from the sea. The addition of silica may reflect the tendency of snow crystals to form about clay-mineral nuclei, the influence of dust deposited between snowfalls, or both.

That dust is a source of calcium and magnesium as well as of silica is suggested in a study reported by Robinson (1936). On February 24, 1936, according to his report, a brown snow fell in parts of New

Hampshire and Vermont. Analysis of the silt particles responsible for the color yielded the following results, expressed in percentages: SiO_2, 48.9; Al_2O_3, 20.4; Fe_2O_3, 6.1; CaO, 5.41; MgO, 3.2; loss on ignition, 16.0. Robinson inferred from this composition, and from the presence of fragments of "silicified organic remains," that the silt originated west of the Mississippi River.

The Central Valley of California, which lies between the ocean and the Sierra Nevada, may provide some increments of dust to air masses moving over it toward the mountains. The region extending eastward from the foot of the Sierra Nevada into Utah, however, is definitely semiarid and provides a ready source of atmospheric dust in both winter and summer. The increase in calcium content of snow with increasing distance eastward from the sea has been noted in the present study. The calcium and magnesium found in snow probably originate in large part as continental dust. In the intermontane areas of the West, alkaline-earth carbonates are a major constituent of the prevailing pedocal soils, and they occur as coatings on rocks, pebbles, and sand grains in many places.

The bicarbonate content of the snow doubtless is mainly a direct result of reaction of water and carbon dioxide in the atmosphere. Additional bicarbonate may accrue from hydrolysis of minute fragments of alkaline-earth carbonate minerals in the dust.

The boron content of the snow may originate from one or both of two sources: the ocean on the one hand, and the Mojave Desert on the other. The oceanic source is suggested by research reported by Gast and Thompson (1959). Their laboratory studies imply that at temperatures of about 30° C, nonturbulent air passing over sea water may acquire, in the condensate collected, about 0.06 ppm of boron. At lower temperatures the amount of boron is less, but throughout the temperature range studied, boric acid in sea water retained a measurable vapor pressure—hence, it would be available for incorporation in the atmosphere. These authors cited Japanese and European studies indicating that the ratio B:Cl in rain and snow is commonly hundreds of times larger than the same ratio in sea water, and they repeated earlier suggestions that the boron content of precipitation may result from sea spray, volcanic activity, dust, transpiration by plants, and industrial pollution. Gast and Thompson (1959, p. 346) concluded however, that evaporation of sea water is adequate to explain the boron content of the atmosphere and, hence, that of precipitation. In the present study, 57 samples yielded B:Cl ratios ranging from 0.01 to 2.5. The ratio in sea water is about 0.0002. If the sea is indeed the source of boron found in the snow samples, the concentration mechanism is highly efficient.

In a study related to the atmospheric circulation of particles released by explosions at the Nevada Test Site near Las Vegas, List (1954, p. 315–325) concluded that, at times, air masses from the general vicinity of the test site circulate over the Mojave Desert, around the southern end of the Sierra Nevada, and thence northward over the Central Valley of California. This circulation pattern and the abundance of boron-rich dust in areas within the Mojave Desert and adjacent regions suggest another possible source for boron found in the snow. Although present data do not allow firm selection between the possible sources, the common presence and wide distribution of boron in the snow—distribution in time and space—seem to favor the Gast-Thompson hypothesis of oceanic origin. The circulation patterns favorable for the transport of boron-bearing dust from the Mojave Desert are apparently not of frequent occurrence, according to List.

Present information does not warrant discussion of sources of other individual constituents. The entire picture is obscured in part by inadequate information regarding the occurrence of the constituents in snow, especially outside the Sierra Nevada, their occurrence in the atmosphere other than in precipitation, and the patterns of air-mass movement. The overall impression in the minds of the present writers, however, is that sodium, chloride, and probably boron are largely of marine origin; that bicarbonate is largely of direct atmospheric origin; and that silica, calcium, and magnesium are derived mainly from dust of continental origin. The several compounds of nitrogen may also be continental in origin.

CONTAMINATION OF SAMPLES

In any work, wherein many of the concentrations reported for individual constituents hardly exceed the sensitivity of the analytical methods available, the question of contamination of samples must be considered. It was shown earlier (p. J5) that, except for magnesium and potassium, the variance of the concentrations of constituents in the snow samples has statistical significance when compared with the variance indicated by the analytical methods. There remains then the question of contamination.

Low-alkali boro-silicate glassware was used both for sample containers and in the laboratory, except that boron-free laboratory ware was used throughout determinations of boron content. Three lines of evidence suggest that the reported results remain real despite the use of glassware containing some of the constituents reported to be in melted snow. First, examination of table 1 shows that numerous samples had no measurable contents of silica, of sodium, or of boron although they were handled similarly to those samples that did yield positive values of these constituents. It is also pertinent, here, to mention that at prevailing conditions of pH, the attack by water on hard glass is negligible. Second, during this study three special samples were maintained free of contact with glass until the critical determinations were made. These samples yielded silica values of 0.06, 0.07, and 0.20 ppm, respectively; sodium values of 0.03, 0.1, and 0.4 ppm; and a boron value of 0.02 in all three. Finally, the data in table 1 show what may conveniently be termed "consistent internal inconsistency"—that is, there is no suggestion of correlation among contents of sodium, silica, and boron. Low-sodium snow samples may have appreciable amounts of silica, of boron, or both—and vice versa through the several possible combinations. Were sodium boron silicate containers the sources of these constituents in appreciable amounts, the presence of higher concentrations of one of the three should be reflected by higher concentrations of the other two in the same sample.

The possibility of sample contamination by leaching of glass containers is not entirely negated, perhaps. The writers think, however, that it is a negligible factor, if present at all. Contamination during laboratory analysis was avoided insofar as possible by taking great precaution about cleanliness of apparatus and by carefully preparing reagents. The results reported in tables 1 and 3 are thought to be significant to the accuracy to which they are reported, with certain exceptions noted. For those exceptions, the sensitivity and accuracy of the analytical methods—not contamination—appear to be the sources of possible error.

OTHER STUDIES

Occasional reports concerning mineral content of snow date back more than a century. The earliest records of which the present writers have knowledge are those of Marchand (1852) and Meyrac (1852). Marchand (1852, p. 55) reported, "The water from rain and snow generally contains an appreciable amount of iodine and bromine * * *," but he gave no quantitative values. Traces of chloride in snow, "* * * but never as much as in rain * * *," were reported by Meyrac (1852), who also noted some content of iodide, a smell of ammonia when the sample was treated with sodium bicarbonate, and some content of organic compounds. Boussingault (1882) reported the nitrate and ammonia content of five samples of Alpine snow taken during the years 1859–66.

The relation of airborne nitrogen compounds to maintenance of soil nutrients was the concern of Shutt (1908, 1914) and of Shutt and Hedley (1925) in reports giving the results of a 17-year study of rain and snow at an experimental farm near Ottawa, Canada. They concluded that, on the average, rain supplied 83 percent and snow 17 percent of the total amount of nitrogen in precipitation at Ottawa and that rain following brush fires was enriched in nitrogen. The study was terminated in 1924 because "natural conditions" no longer prevailed (Shutt and Hedley, 1925). During the 17 years, analyses were made of 495 samples of snow. Only nitrogen compounds were determined, however. The average nitrite plus nitrate (NO_2+NO_3) concentration in the 495 samples, spanning the years 1908–24, was 0.19 ppm, and the average for ammonia nitrogen (as NH_3) was 0.27 ppm.

Inspired by the work of Shutt and his associates at Ottawa, the Department of Chemistry, Cornell College, Mt. Vernon, Iowa, began a series of analyses of precipitation in 1910 (first publication: Knight, 1911) continued at least until 1936. In his second paper, Knight (1913) reported chloride concentratious as well as those of the nitrogen compounds. Thereafter throughout the series of papers of which the present writers have found record, nitrogen compounds, chloride, and sometimes sulfate were reported. The coincidence of higher concentrations of sulfate (as much as 40 ppm SO_4 in one sample in 1915) with seasons during which coal consumption was high, is impressive. A decrease in sulfate content of precipitation during the depression years was explained (Williams and Beddow, 1932) by the increased use of wood for fuel during this time when many people could not afford the more expensive coal. The papers of the Mt. Vernon series that are known to the present writers include the following, in addition to those already cited: Knox (1915), Artis (1916), Peck (1917), Trieschmann (1919), Moore and Browning (1921), Shaffer (1922), Fries (1923), Woehlk (1923), Ribble and Bowman (1926), and Knight (1936).

The relation of snowfall and its chemical composition to air pollution was the subject of a paper by Batta and Leclerc (1934), who analyzed 16 samples from a single fall of snow. The samples analyzed were taken at various places in and near Liege, Belgium. The varying concentrations of chloride, ammonia, and oxides of sulfur (reported as SO_2) were correlated with nearby industry: the oxides of sulfur, with the combustion of fuel; and the chloride, with various industrial sources utilizing hydrochloric acid. The ranges in concentrations cited, in parts per million, are: SO_4 (recalculated from SO_2), 1.5 to 81; Cl, 5.3 to 12; NH_3, trace to 4.0; dissolved solids (residue at 110° C), 54 to 252.

Twenty samples of snow taken over a 3-year period at Mt. Haldde in far northern Norway were analyzed for chloride as part of a study related principally to condensation nuclei of frost. The range in chloride concentration was from 0.0 to 5.3 ppm, and the average was 2.1 ppm. The work was reported by Köhler (1937). Atkins (1947) reported the electrical conductivity of two samples of snow falling in England, but he gave no chemical information. The chloride content of 68 samples of snow in West Germany was reported by Menzel (1948). Of the total, 59 samples were taken on Donnersberg, a small mountain east of Worms, in an area where air pollution from industry was expected. At this locality the chloride concentration ranged from 1.6 to 31 ppm; the average was 8.1 ppm. The 9 samples from an agricultural area near Haid had a range in chloride content from 1.9 to 26 ppm and an average concentration of 5.9 ppm. At these sampling points, the chloride concentration in rain averaged less than that in snow. The reported chloride values for rain were Donnersberg, 4.5 ppm, average of 37 samples; and Haid, 4.3 ppm, average of 51 samples.

The mineral content of 10 samples of snow from Finland was reported by Viro (1953, p. 36) in conjunction with a consideration of the nutrient balance in Finnish soils. Two samples were taken at each of two stations, one sample at each of six other stations. The average concentrations reported, in parts per million, are as follows: inorganic solid residue, 5.6; silica, 0.51; iron and aluminum oxides, 0.23; calcium, 0.35; magnesium, 0.23; potassium, 0.43; sodium, 0.32; phosphorous, 0.02; sulfate, 0.73; chloride, 1.0; nitrogen, 1.0. The samples were apparently not filtered before analysis. This may account for the rather high concentration reported for silica.

The average concentrations of selected constituents in 17 snow samples collected at Kentfield, Nova Scotia, were reported by Herman and Gorham (1957) and were compared, as follows, with average concentrations in 23 monthly composites (each composite pertained to all snow and rain that fell during the month); all concentrations given below are in parts per million.

	Average in snow	*Average in monthly composites*
Sulfate (SO_4) [1]	0.9	3.0
Ammonia nitrogen (NH_3–N)	.13	.29
Nitrate nitrogen ($NO\text{–}_3N$)	.07	.11
Mineral ash [2]	2.7	9.9

[1] Recalculated from reported sulfur (S) concentrations.

[2] Represents dried residue evaporated in a silica dish and ignited to 450°-500° C in a muffle.

The most extensive collection of data on the chemical composition of precipitation ever made is presumably that of the Northern European network, which was instituted in Sweden in 1948 (Rossby and Egner, 1955, p. 119). The network expanded over the years (Fönselius, 1958), and data accumulated were reported as soon as they were compiled; data appeared in most issues of "Tellus" from 1955 to 1960 (Egner and Eriksson, 1955; Svenska Geofysiska Föreningen, 1960). The network was modified, and since 1960

(Odén, Svante, 1962, written communication), the data have not been published. According to Odén, collection of data is continuing (1962), and compilations and interpretations are to be published.

In the Northern European network (Eriksson, 1955), samples of all types of precipitation during the monthly period are collected through a funnel that is electrically heated to 5°C and are stored in a sample container beneath the funnel. The resulting composite samples are then analyzed for content of sulfur, chloride, nitrate, ammonia, sodium, potassium, magnesium, and calcium. Values for bicarbonate, pH, and specific conductance are also reported. Owing to the conditions under which the samples are collected, it seems that the pH and bicarbonate values would be difficult to interpret in terms of the original precipitation because they are subject to change during storage of water samples in contact with air.

It is impossible to segregate with complete confidence those samples of precipitation, reported by the Northern European network, that represent only snow. Svante Odén (written communication, 1962) provided a list of the Scandinavian stations where, during specified periods of the year, precipitation probably consisted of virtually nothing but snow. To provide a general indication of the concentrations of some of the principal constituents in Scandinavian snow, the records (Svenska Geofysiska Föreningen, 1959) of the stations selected by Odén were recalculated to concentrations in parts per million and are summarized in table 6 for the period December 1958–March 1959.

CONCLUSIONS

Snow in the Sierra Nevada and other places in the western conterminous United States is notably low in mineral content as compared with reported concentrations from other areas both in North America and Europe. Wide variations in sampling procedures and in analytical methods preclude rigorous comparisons of results of this study with analyses of snow from other regions.

Except perhaps for samples taken in Denver, there is no detectable influence from the activities of man upon the chemical character of western snow. Continental sources of mineralization exercise some control over concentrations in most of the snow samples analyzed; the continental influence becomes increasingly evident with increasing distance eastward from the Pacific Ocean. Dustfalls between snowstorms may contribute more mineral content—especially silica and calcium—to melted snow than do atmospheric particles entrained with the falling snow.

As soon as melt water comes into contact with soil and weathered rock, the chemical diversity characteristic of individual snows largely

TABLE 6.—*Summary of chemical content of precipitation inferred to be snow, sampled at selected stations in the Northern European network, December 1958–March 1959*

[Data in parts per million. After Svenska Geophysiska Föreningen, 1959]

	Calcium				Sodium				Chloride				Magnesium			
	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean
December 1958 (13 stations)	1.7	0.8	0.5	0.90	12	0.3	0.1	1.51	20	0.9	0.4	2.87	1.4	0.1	0.0	0.23
January 1959 (25 stations)	6.6	.6	.3	.92	4.0	.4	.1	.86	7.2	1.2	.2	1.75	.5	.1	.0	.15
February 1959 (22 stations)	5.5	1.4	.3	1.86	15	.8	.3	2.67	25	2.6	.4	5.70	1.9	.2	.1	.44
March 1959 (15 stations)	3.9	1.6	.3	1.95	10	.4	.1	2.34	43	2.0	.1	6.76	2.6	.2	.0	.53
Season, composite of 4 months	6.6	1.0	.3	1.4	15	.6	.1	1.8	43	1.3	.1	3.9	2.6	.2	.0	.32

	Potassium				Nitrate				Sulfate[1]			
	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean	Max.	Median	Min.	Mean
December 1958 (13 stations)	0.8	0.2	0.1	0.36	0.3	0.1	0.0	0.12	4.2	2.4	0.3	2.4
January 1959 (25 stations)	1.9	.2	.1	.30	.4	.2	.0	.19	9.0	2.6	.0	2.3
February 1959 (22 stations)	1.5	.4	.0	.54	.7	.1	.0	.18	18	4.2	.6	4.8
March 1959 (15 stations)	1.3	.3	.1	.47	.5	.2	.1	.22	15	4.2	.9	4.9
Season, composite of 4 months	1.9	.3	.0	.42	.7	.2	.0	.18	18	3.0	.0	3.6

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[1] Reported in "Tellus" as sulfur (S), recalculated to sulfate (SO_4).

disappears. The pickup of dissolved constituents from weathering minerals tends to overpower the chemical diversity of snow—at least in those areas, as the Sierra Nevada, where the mineral content of snow is very small. In other areas, as reported in the literature, this dominance of the lithosphere might not occur.

Future detailed work in forestry, ecology, fish and wildlife management, and water-supply development for all purposes, as well as water-related geochemical considerations such as those pertaining to development of mineralization of natural water and those pertaining to mineral weathering, will require knowledge of the chemical character of precipitation as a starting point. The variations found in chemical content from area to area in this study and the variations between results obtained here and those reported from other regions of North America and Europe imply that a general knowledge of the chemical nature of precipitation is not enough. Detailed study of local areas requires knowledge of the chemical nature of the precipitation specific to those areas.

Melted snow can be successfully analyzed for 8–10 inorganic chemical constituents, and the results are suited for use in geochemical considerations. Adequately sensitive analytical procedures have not yet been developed for other consituents, although for many, maximum concentrations can be determined with reasonable assurance. Determinations of pH are generally not reliable for use in calculations. Establishment of world-wide methods of sampling and analysis would permit geochemical comparisons that cannot presently be made.

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