CHEMICAL CONSTITUENTS IN SNOW FROM SIERRA NEVADA, CALIFORNIA AND WASATCH MOUNTAINS, UTAH

By

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INTRODUCTION

A study of inorganic chemical constituents determinable in snow has been made by the Water Resources Division, U. S. Geological Survey. Ninety-eight snow samples have been analyzed at the Geological Survey's Pacific Coast field center, Menlo Park, California, as part of a larger investigation of the geochemistry of selected segments of the hydrologic cycle. Attention has been centered on evaluation of chloride concentration, but where the volume of the sample allowed, a more detailed study of the chemistry of the snow has been made. Results of the analyses to March 1, 1959, are shown in table 1.

Chemical analyses were made by S. M. Rogers, C. E. Roberson, J. P. Schuch, and H. C. Whitehead, chemists, Quality of Water Branch.

SAMPLING PROCEDURES

In early stages of the work the samples for chemical analysis were taken by forcing snow into a 4-liter serum bottle where it was permitted to melt. Later, the samples were collected in chemically clean polyethylene buckets, covered with a plastic-sheet protector, and permitted to melt before being decanted into glass for storage until analysis. The samples from the Wasatch Mountains, Utah, were collected by personnel of the U. S. Soil Conservation Service during snow-course measurements, the snow cores being transferred directly from the coring tube to widemouth bottles which were then tightly covered with plastic-lined screw-on lids.

ANALYTICAL PROCEDURES

Water resulting from melting of the snow samples was analyzed by prescribed methods[2] used in laboratories of the Quality of Water Branch. Chloride was determined in later stages of the study, however, by a colorimetric method (Bergman and Sanik, 1957) in which the color is developed by displacement of the thiocyanate ion from mercuric thiocyanate by the chloride ion in the presence of the ferric ion. The color is stable and proportional to the original chloride-ion concentration.

INFERENCES DERIVED FROM THE DATA

Figure 1 shows the distribution of chloride concentrations found in 96 samples of snow. The concentration ranges from below the threshold of detection to 2.1 ppm (parts per million). The mean value calculated was 0.6 ppm. Two additional analyses (table 1, Nos. 671, 960) show chloride concentrations of 3.7 and 5.0 ppm. The sample containing 3.7 ppm of chloride was collected adjacent to a road in Oregon giving access to a lodge, and may have been contaminated. The sample having 5.0 ppm of chloride was from the Provo River drainage basin in Utah. The origin of the high chloride value is uncertain.

The general range of chloride values found, and unpublished analytical data in the files of the U. S. Geological Survey at Menlo Park representing the chemical quality of lakes and streams in the Sierra Nevada, suggest that a mean value for the chloride concentration of snowfall in those mountains is about 0.5 ppm. Data from the Wasatch Mountains, Utah, are less complete. All samples analyzed were taken in the first week of January 1959 and may not represent the average quality of snows in the area. The tentative conclusions drawn from the samples analyzed, however, is that the range of chloride content of snow is slightly higher in Utah than along the Sierra Nevada, perhaps because moderate amounts of sodium chloride dust are blown aloft from the Great Salt Lake Desert and become incorporated in the snow crystals as they form.

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2/. U. S. Geol. Survey Water-Supply Paper 1454, manuscript in preparation.

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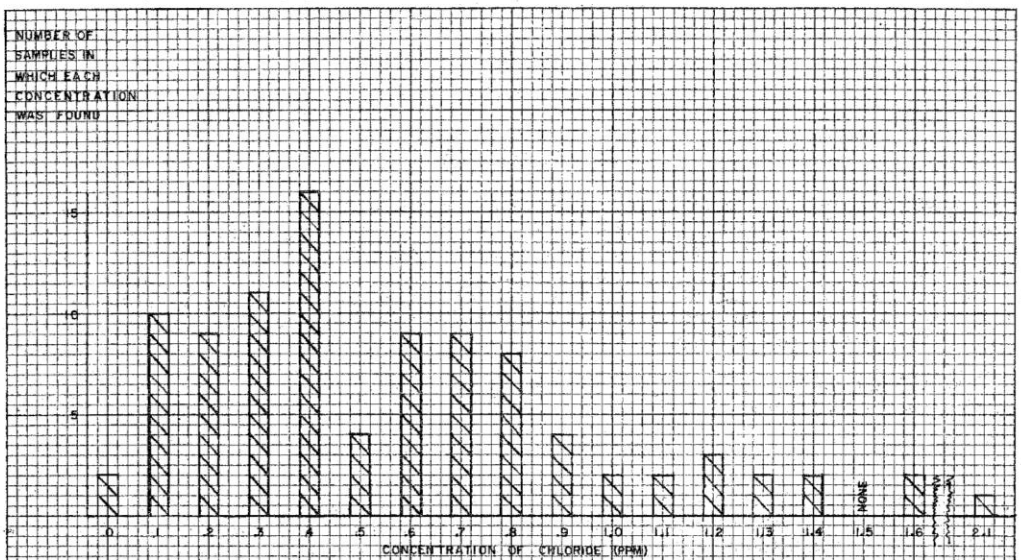

Figure 1 .- Graph showing frequency of occurrence of various concentrations of chloride in 96 samples of snow.

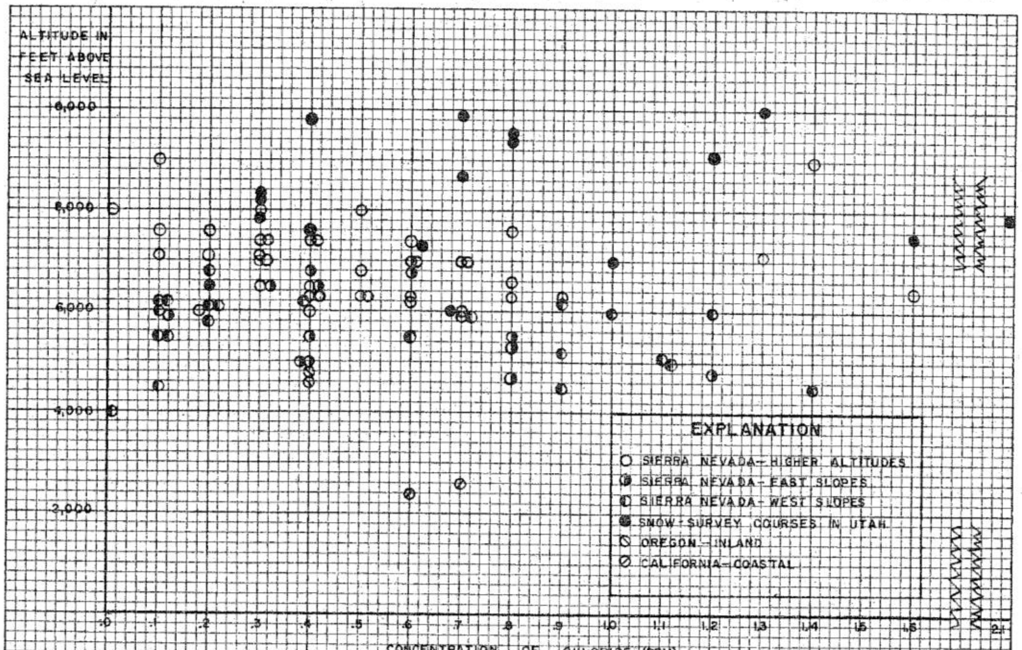

Figure 2 .- Graph showing distribution of chloride concentration with altitude.

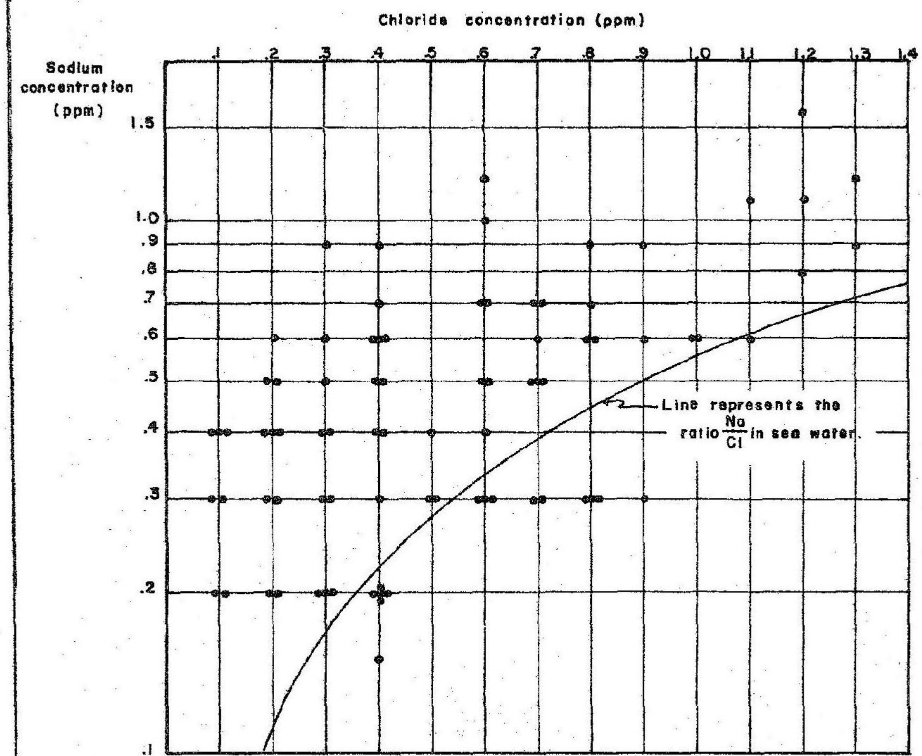

Figure 3 .- Graph showing relations of chloride and sodium by weight. in snow samples studied

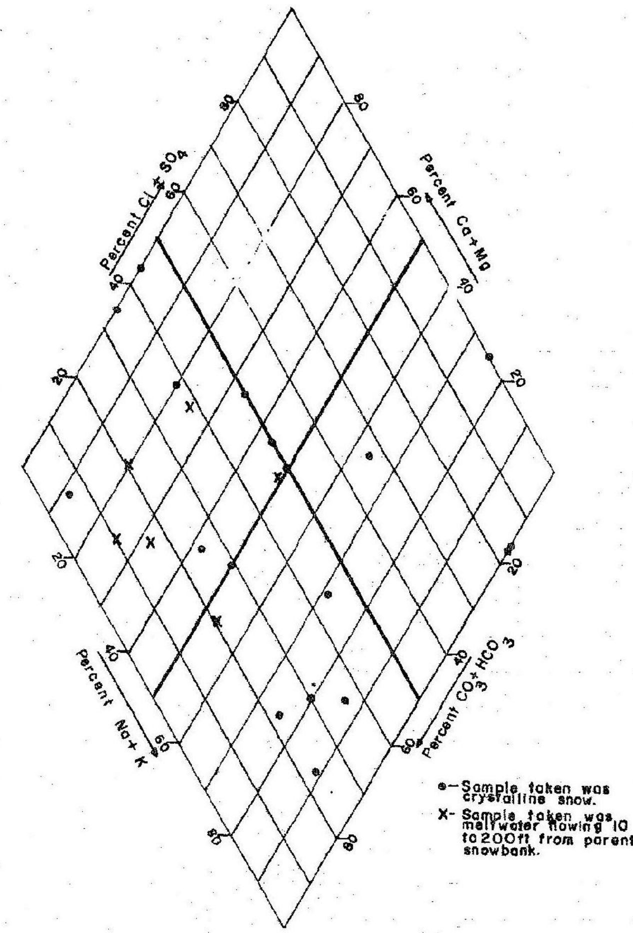

Figure 4 .- Graph showing chemical properties of crystalline snow (melted) and of meltwater.

Table 1.- Mineral constituents and related physical measurements of snow samples after melting.

[Analytical results in parts per million except as indicated.]

Lab. No.	Location	Ca	Mg	Na	K	NH_4	HCO_3	SO_4	Cl	F	Br+I as Br	I	NO_3	B	Hardness b/	Conductance c/	pH
218	2.6 mi. west of Meyers, Calif., U.S. 50	- a/	-	-	-	-	-	-	0.3	-	-	-	-	-	-	-	-
219	2.6 mi. west of Meyers, Calif.	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-
220	45 mi. Camp Ground, U.S. 50, Calif.	-	-	-	-	-	-	-	0.4	-	-	-	-	-	-	-	-
221	Nyack Lodge, U.S. 40, Calif.	-	-	-	-	-	-	-	0.9	-	-	-	-	-	-	-	-
222	2.6 mi. west of Meyers, Calif., U.S. 50	-	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-
225	Hampshire Rocks Camp, U.S. 40, Calif.	-	-	-	-	-	-	-	0.7	-	-	-	-	-	-	-	-
226	2 mi. west of Soda Sprgs, U.S. 50, Calif.	-	-	-	-	-	-	-	0.8	-	-	-	-	-	-	-	-
558	2.3 mi. east of Kyburz, Calif.	-	-	0.8	0.8	-	2	-	1.4	-	-	-	0	1.3	-	9	7.5
559	½ mi. above Twin Bridges, U.S. 40, Calif.	-	-	.6	.4	-	< 2	-	1.0	-	-	-	0	.08	2.5	9	7.7
560	½ mi. above Twin Bridges, U.S. 40, Calif.	-	-	.8	.9	-	8	-	1.2	-	-	-	0	.00	8.5	23	6.4
561	Sierra Ski Ranch, U.S. 50, Calif.	-	-	.5	.3	-	< 2	-	.7	-	-	-	0	.32	2.0	5	6.4
562	Sierra Ski Ranch, U.S. 50, Calif.	-	-	.5	.4	-	< 2	-	.7	-	-	-	0.1	.10	3.0	8	5.9
563	Spooner Junct. highways 28 and 50, Nev.	-	-	.5	.2	-	< 2	-	.6	-	-	-	0	.08	2.1	7	6.5
564	Spooner Junct. highways 28 and 50, Nev.	-	-	.3	1.2	-	< 3	-	.6	-	-	-	.1	.05	4.3	12	5.9
565	Spooner Summit, U.S. 50, Nev.	-	-	.3	.2	-	< 2	-	.3	-	-	-	.0	.00	.2	4	6.1
566	East Slope Spooner Grade, U.S. 50	-	-	.3	.4	-	< 3	-	.2	-	-	-	.1	.06	7.4	7	6.2
567	Base of Spooner Grade, U.S. 50, Nev.	-	-	.5	.6	-	4	-	.2	-	-	-	.1	.12	4.5	12	6.2
568	Base of Spooner Grade, U.S. 50, Nev.	-	-	1.6	1.5	-	-	-	1.2	-	-	-	-	.02	-	10	6.4
569	One-half mi. above base of Spooner Grade, Nev.	-	-	.3	.2	-	< 2	-	.4	-	-	-	.0	.00	1.5	4	6.1
570	Glenbrook Fire Sta., east shore Lake Tahoe	-	-	.6	.2	-	< 2	-	.4	-	-	-	.0	.13	3.0	5	6.4
571	Echo Summit, U.S. 50, Calif.	-	-	.4	.3	-	< 2	-	.4	-	-	-	.0	.07	2.0	4	5.1
572	Echo Summit, U.S. 50, Calif.	-	-	.2	.1	-	< 2	-	.4	-	-	-	.3	.00	1.4	4	5.6
573	Meyers, Calif., U.S. 50	-	-	1.0	.2	-	< 2	-	.6	-	-	-	.1	.00	2.0	4	5.9
574	Meyers, Calif., U.S. 50	-	-	.6	.2	-	< 2	-	.9	-	-	-	.1	.00	2.0	5	6.1
575	Meyers, Calif., U.S. 50	-	-	.2	.1	-	< 2	-	.4	-	-	-	.1	.00	.6	3	5.9
665	Diamond Lake Junct. U.S. 97, Oregon	.0	.0	.7	.0		4	9.6	.4	.0			.0	.28	.0	4	5.9

666	Odel Summit, U.S. 97, Oregon	.8	.0	.4	.3	0	2	-	.4	.0	-	.0	.0	.10	-	3	6.4
671	Rosary Trail Lodge Road, U.S. 97, Oregon	.0	.0	.6	1.5	-	2	2.1	3.7	.0	-	-	.4	.24	.0	4	6.0
694	4 mi. west of Norden, Calif., U.S. 40	.0	-	.7	.3	-	8	5.3	.6	-	-	-	.0	.02	.2	10	6.5
701	22 mi. east of Sonora, Calif., Calif. 108	.4	.0	.6	.3	1.4	4	.5	1.1	.0	-	.0	.0	.08	1	7.0	6.0
703	1.5 mi. east of Strawberry, Calif., Calif. 108	.0	.0	.4	.0	-	4	.5	.1	.2	.14	.0	.0	.25	.0	3.0	6.6
704	38 mi. northeast of Sonora, Calif., Calif. 108	.0	.0	.3	.1	0	4	.5	.1	.2	.06	.0	.0	.09	.0	5	5.8
705	38 mi. northeast of Sonora, Calif., Calif. 108	.8	1.9	.3	.2	0	4	-	.9	.1	.00	.0	.2	.02	10	11	5.7
707	38 mi. northeast of Sonora, Calif., Calif. 108	.0	.0	.3	.2	0	2	.3	.1	.2	.05	.00	.0	.07	.0	3.0	5.6
708	38 mi. northeast of Sonora, Calif., Calif. 108	.0	.0	.9	.5	0	4	.8	.4	.2	.16	.0	.0	.15	.0	7	6.0
709	36 mi. east of Sonora, Calif., Calif. 108	.0	.0	.3	.1	0	3	.3	.2	.5	.09	.0	.0	.07	.0	2	5.8
711	1 mi. southwest of Strawberry, Calif.,Calif.108	.0	.5	.4	.1	0	3	1.8	.2	.0	.02	.0	.0	.10	2.0	4	5.6
712	Peddlers Hill Ski 300 ft. U.S. 88 Calif.	.0	.0	.4	.1	0	3	1.8	.2	.0	.02	.0	.0	.02	.0	5	5.7
714	4.2 mi. west of Peddlers Hill, Calif.	.0	.5	.2	.3	0	3	1.8	.2	.0	.04	.0	.10	.00	2.0	3	5.6
716	¼ mi. east of Camp Connell, Calif., Calif. 88	.0	.5	.1	.1	.0	3	1.6	.1	.0	.00	.0	.0	.03	2.0	4	5.6
718	5 mi. west of Camp Connell, Calif., Calif. 88	.0	.5	.1	.1	0	3	1.7	.0	.0	.02	.0	.0	.03	2	5	5.5
721	Shore of Mirror Lake, Yosemite National Park, Calif.	.4	.0	.9	.8	1.9	6	.4	.9	.1	.10	.0	.0	.04	1.0	10	6.0
742	Spooner Grade, 9.5 mi. east of Junct. U.S. 50 and U.S. 395	.0	.2	.9	.7	-	4	.6	.3	-	.01	-	.1	.00	1.0	7	5.7
747	Donner Grade, bottom U.S. 40	.4	.0	.3	.3	0	4	.3	.7	.1	.10	0	.0	.00	1.0	7	5.9
749	1 mi. west of Soda Springs, Calif., U.S. 40	.4	.0	.3	.3	1.0	4	.5	.8	.0	.00	.0	.0	.02	1.0	6	8.3
752	Echo Summit, Calif., U.S. 50	-	-	.4	.3	-	2	.2	.3	-	-	-	-	-	.5	4	6.0
753	Echo Lake (Needle Point), Calif.	-	-	.2	.1	-	1	.3	.2	-	-	-	-	-	1.5	3	5.8

a/ Dash indicates determination not made.

b/ Hardness as $CaCO_3$.

c/ Specific conductance (micromhos at 25°C)

Table 1.- Mineral constituents and related physical measurements of snow samples after melting.- Continued.

[Analytical results in parts per million except as indicated.]

Lab. No.	Location	Ca	Mg	Na	K	NH_4	HCO_3	SO_4	Cl	F	Br+I as Br	I	NO_3	B	Hardness b/	Conductance d/	pH
758	Echo Summit Lodge, Calif.	-	-	.9	.4	-	3	.4	.8	-	-	-	-	-	1.0	7	6.5
759	Summit of Highway, Mt. Rose, Nev.	-	-	.1	.2	-	2	.2	.1	-	-	-	-	-	1.0	3	5.7
760	2.7 mi. west of Mt. Rose Highway Summit, Nev.	-	-	.2	.4	-	2	.5	-	-	-	-	-	-	.4	3	5.7
762	Norden Lake, Calif., U.S. 40	-	-	.4	.2	-	2	.2	.5	-	-	-	-	-	1.0	4	6.0
763	Sugar Bowl Ski area, Calif., U.S. 40	-	-	.2	.1	-	2	.1	.3	-	-	-	-	-	.5	2	5.9
764	Squaw Valley, Calif., just south of ski lodge	-	-	1.4	.7	-	3	.1	1.6	-	-	-	-	-	1.0	10	6.3
765	Rainbow Tavern, Calif., U.S. 40	-	-	.5	.5	-	3	-	.7	-	-	-	-	-	1.5	8	5.9
766	Mt. Rose Highway Summit, Nev.	-	-	-	-	-	4	-	1.4	-	-	-	-	-	-	11	5.9
767	Echo Lake, Calif.	-	-	.2	.1	-	1	.6	.1	-	-	-	-	-	1.0	5	5.3
927	½ mi. east of Kyburz, Calif., U.S. 50	.0	.5	1.1	.7	0	1	.7	1.1	.0	.0	.0	.0	.02	2.0	11	5.5
928	½ mi. west of Twin Bridges, Calif., U.S. 50	.0	.5	.6	.4	0	3	.3	.4	.0	.0	.0	.0	.05	2.0	7	5.6
930	Echo Summit, Calif., U.S. 50	.4	.0	1.2	.5	.0	0	2.8	.6	.05	.1	.0	.1	.04	1.0	7	5.7
932	Spooner Summit, Nev., U.S. 50	.0	.2	.6	.5	.0	3	1.6	.2	.00	.0	.0	.1	.01	1.0	4	5.6
933	1 mi. east of Carson City, Nev.	.1	.5	.6	.4	0	3	1.4	.8	.00	.1	.1	.2	.04	3.0	11	5.7
941	Floristan, Calif., U.S. 40	.8	.9	.3	-	0	3	.5	.8	-	-	-	-	.00	2.0	4	5.7
953	Above Hetch Hetchy Reservoir			.7					.6								
956	Duchesne River area, Indian Canyon, Utah			1.1					1.2							44	
957	Weber River area, Smith and Moorehouse reservoir, Utah			.5					.4							9	
958	Duchesne River area, Trial Lake, Utah			.5					.4							7	
959	Wasatch Mts., main range, Parley's Canyon Summit, Utah			.9					1.6							21	
960	Provo River area, Daniels-Strawberry Summit, Utah			.4					5.0							27	
978	Weber River area, Beaver Creek R.S., Utah			.4					.6							12	
979	Lower Bear River area, Garden City Summit, Utah			.3					2.1								
980	Virgin River area, Midway Valley, Utah			.3					.8								
983	Fremont River area, Farnsworth Lake, Utah			.6					.7							18	

984	Great Salt Lake area, Lower Farmington Canyon, Utah	.6	1.0	18
985	Escalante River area, Widtsoe-Escalante Summit, Utah	.6	.8	
986	Duchesne River area, Julius Park, Utah	1.2	1.3	
988	Provo River area, Timpanogas Divide, Utah	.4	.3	
993	Ogden River area, Lower Ben Lomond, Utah	.7	.7	
994	Ogden River area, Snow Basin, Utah	.5	.2	
1012	Price River area, Gooseberry Reservoir, Utah	.7	.7	
1013	3.1 mi. west of Kyburz, Calif., U.S. 50	.4	.1	
1014	0.6 mi. east of Twin Bridges, Calif., U.S. 50	.1	.1	
1015	Echo Summit, Calif., U.S. 50	.3	.3	
1016	Spooner Summit, Nev., U.S. 50	.4	.1	
1017	Geiger Mountain Summit, Nev., Nev. 17	.3	.6	
1018	Squaw Valley, Calif., at Ski Lift	.3	.5	
1019	Sugar Bowl Ski area, Calif., U.S. 40	.2	.3	
1020	Rainbow Tavern, Calif., U.S. 40	.2	.1	
1022	Price River area, Dry Valley Divide, Utah	.6	.3	
1023	Price River area, Mud Creek, No. 2, Utah	.5	.3	
1025	Spooner Summit, Nev., U.S. 50	.9	1.3	
1026	10 mi. south of Gardnerville, Nev., U.S. 395	.7	.8	
1027	3/4 mi. north of Silver City, Nev.	.2	.4	
1028	3/4 mi. north of Silver City, Nev.	.2	.4	
1029	0.1 mi. north of Virginia City, Nev.	.2	.4	
1030	1.9 mi. north of Virginia City, Nev.	.1	.4	
1031	1 mi. north of Geiger Mountain Summit, Nev.	.2	.3	
1035	Saratoga, Calif., Junct. Hwy 9 and 5 (Skyline)	.3	.7	
1036	Santa Cruz, Calif., Junct. Jamison Creek Road and Empire Grade	.3	.6	

An attempt (fig. 2) to relate chloride content to altitude yielded inconclusive results. The samples from the east slopes of the Sierra Nevada, including those in closely adjacent parts of Nevada, show a general tendency toward increasing chloride concentration with decreasing altitude. The west-slope samples do not show any apparent trend. The scattering of data points for Utah shows an opposing trend to that of the east slope of the Sierra Nevada, but the restricted number and collection period of those samples limit the reliability of the apparent trend.

Chloride was determined (table 1) in all 98 samples. Thereafter the extent of the analytical work done was determined principally by the volume of sample remaining. Reasonably detailed analyses were made of about 60 samples.

Results of the analyses show that many of the snows contained a variety of dissolved matter detectable by available methods. Specific conductance, measured in micromhos at 25°C, ranged from 3 to 44. Only a few snow samples exceeded 10 micromhos, and 24 of 63 determinations were in the range of 3 to 5 micromhos. This group of 24 approaches common distilled water in chemical purity.

The bicarbonate and sulfate commonly occurred in concentrations of less than 5 ppm. A few tenths of a part per million of fluoride was found in some samples, and nitrate was found in 15 of the 46 samples analyzed for that constituent. Boron and, a little less often, bromide and iodide are reported in concentrations of a few hundredths of a part per million from a large number of the snows tested.

The concentration of sodium is plotted in relation to chloride concentrations in figure 3, where the scatter of points shows that characteristically the reported sodium content of the snow is higher in relation to chloride than it is in sea water. The evidence available suggests that, during transport of airborne oceanic salts, the sodium and chloride do not occur in molecular proportions. This phenomenon has been noticed by earlier investigators (Emanuelsson, Eriksson, and Egner, 1954, p. 265; Rossby, 1955). Results of the present study tend to confirm the occurrence, although they do not help to explain the mechanism.

Chemical changes occur in nature during melting of the snow and during even the very early stages of runoff, according to data shown in figure 4. The diagram is after Piper (1945). Each point shown represents a sample of snow (dots) or of snowmelt runoff (X's) taken not more than 200 feet from the parent snowbank. The position of each mark on the diagram is in effect a summary statement of the principal chemical characteristics of the water represented. Thus samples plotting in the right-hand quarter of the diagram contain more than 50 percent chloride plus sulfate (total anions = 100 percent) and more than 50 percent sodium plus potassium (total cations = 100 percent), all expressed as chemical equivalents. They are commonly sodium chloride waters. Samples plotting in the lower part of the diagram are characterized by high sodium and bicarbonate content. The left-hand quarter of the diagram illustrates waters in which calcium and magnesium together make up most of the cations, and carbonate and bicarbonate make up most of the anions. In snow waters the "carbonate and bicarbonate" probably is wholly bicarbonate, as none of the pH values of these waters exceeds 8.2, the threshold value for the occurrence of carbonate.

Figure 4 is significant in showing that the chemical character of snows studied varies rather widely, although, like most natural waters, no snow sample analyzed falls in the top (calcium-magnesium-chloride-sulfate) part of the diagram. But of the 6 melt waters sampled near their parent snowbanks, 4 plot near the center of the calcium bicarbonate quarter of the diagram, and two are closely adjacent to the dividing line. The tendency shown probably reflects an actual relationship prevailing in nature. During melting, it is probable that carbon dioxide (CO_2) is dissolved in the water droplets as they form, in quantities sufficient to overbalance the chloride present. In the earliest stages of runoff—almost immediately upon contact with soil or weathered rock—the water acquires enough calcium and magnesium to cause those ions to become dominant on the cation side of the chemical diagram (fig. 4).

CONCLUSIONS

The chloride content of 98 samples of snow, principally from the Sierra Nevada and from the Wasatch Mountains, has been determined. Some 60 melted snow samples were analyzed for other constituents as well. Preliminary results suggest that chloride ranges in concentration from below the limit of detection to 5 ppm but is seldom found in concentrations greater than 2 ppm. Snow samples from Utah tend to contain slightly more chloride than those from the Sierra Nevada, but samples are not numerous enough to provide an assured relationship. The data suggest that the chloride content of snow decreases with altitude on the east slope of the Sierra Nevada, but other areas do not show recognizable trends.

Study of a few samples of melt water in relation to their nearby parent snowbanks suggests that the process of melting and the first few tends of feet of surface flow cause measurable chemical changes, calcium and bicarbonate ions percentages showing increases over percentages of the same ions in the snow. When concentrations are as low as found in these analyses, however, the percentage changes may not be as noteworthy as they appear. Analytical error and sampling procedures can account for part of the values reported.

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