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INLAND WATERS BRANCH

DEPARTMENT OF ENERGY, MINES AND RESOURCES

Seasonal Variations, Sulphur Mountain Hot Springs, Banff, Alberta.

R.O.VAN EVERDINGEN

TECHNICAL BULLETIN NO.33



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Abstract

Seasonal variations in the physical and chemical parameters of the sulfurous hot springs on Sulphur Mountain near Banff, Alberta, occur between late April and early August as a result of the influx of varying quantities of water having temperatures and dissolved-solids concentrations lower than the sulfurous thermal water. In the absence of accurate discharge measurements, only a "minimum required" mixing ratio could be calculated, leading to minimum ion concentrations and a minimum temperature for the cooler water.

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INTRODUCTION

Seasonal variations in the temperature and flow of the Upper Hot Spring on Sulphur Mountain near Banff, Alberta, were mentioned by Warren (1927). In one known instance, the spring ceased flowing in the winter and spring of 1923. By January 23 of that year, the discharge rate had dropped to 52 l/min. from its usual value of about 550 l/min., while the water temperature decreased to 40.5°C from the usual winter maximum of about 47°C. By March 11, the flow was only 9 l/min. and the temperature had decreased further, to 32.2°C. By March 12, the spring was dry and it remained dry until May 11 when it began flowing again with an initial flow of about 50 l/min. and a water temperature of 35°C, increasing to 550 l/min. and 46.1°C, respectively, by July 14. The decrease in temperature in late winter can be regarded as a direct result of the low flow rate which brings the water in contact with the cold near-surface rocks for a longer period and allows it to cool quicker than usual. The decrease in flow resulted from temporary exhaustion of the spring "reservoir". No indications were given by Warren about possible variations in the dissolved solids concentration and composition of the spring water during the course of this occurrence.

The flow rate of the Upper Hot Spring always decreases somewhat in late winter, for example, near the end of April 1970 the flow rate was only one third of the normal annual rate; the corresponding water temperature was 45.6°C. About mid-May, a sudden increase in discharge occurs, accompanied by a drop in water temperature. Similar effects of varying magnitude have been noticed at the other spring sites on Sulphur Mountain (van Everdingen, in press); it was found that the dissolved solids concentration increased and decreased with the temperature (Fig. 1).

Between October 1968 and October 1969, a sampling and measurement program was carried out to gather more information on the relationship between the physical and chemical characteristics of the spring water. The Kidney Spring just below the Upper Hot Spring, and the Cave Spring behind the Cave-and-Basin Aquacourt were selected as subjects for this program because of their accessibility and the limited amount of human interference with their free flow. The results of the study are described in this report.

PROCEDURE

Between October 23, 1968 and October 15, 1969, temperature, pH, H₂S content and dissolved-oxygen content were measured on 20 days at the Kidney Spring and on 21 days at the Cave Spring. Results of the field tests are

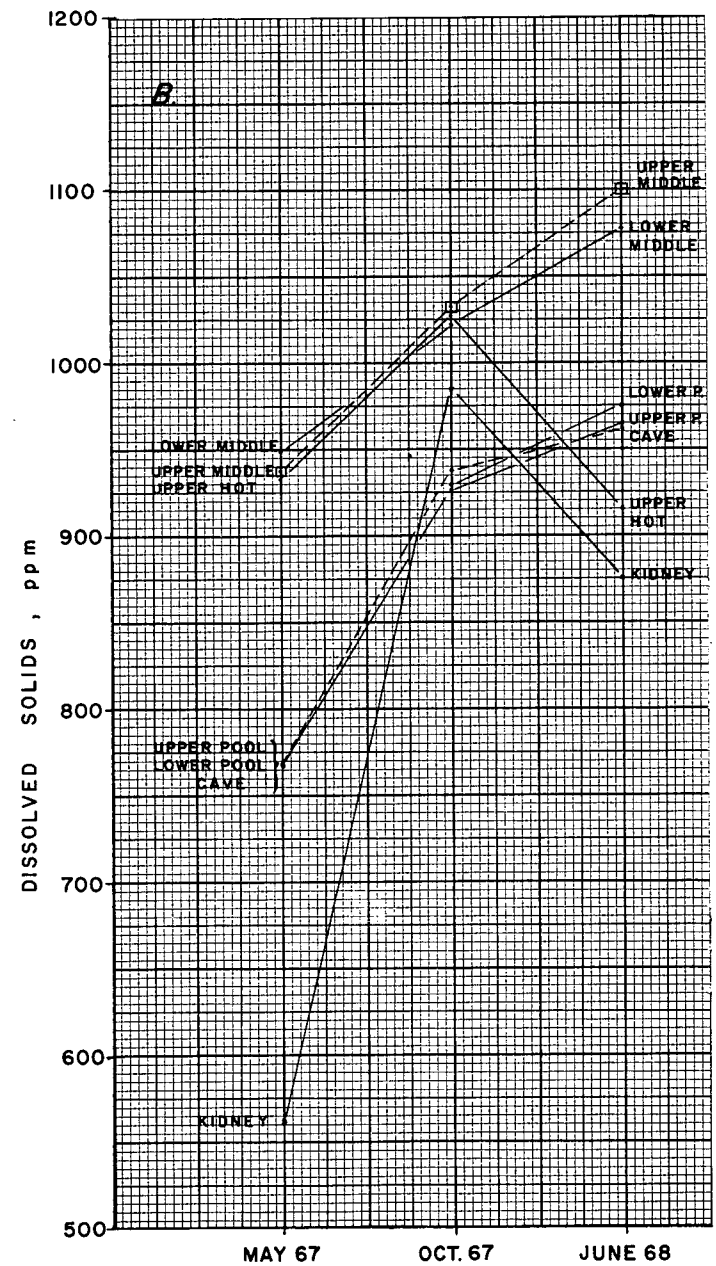
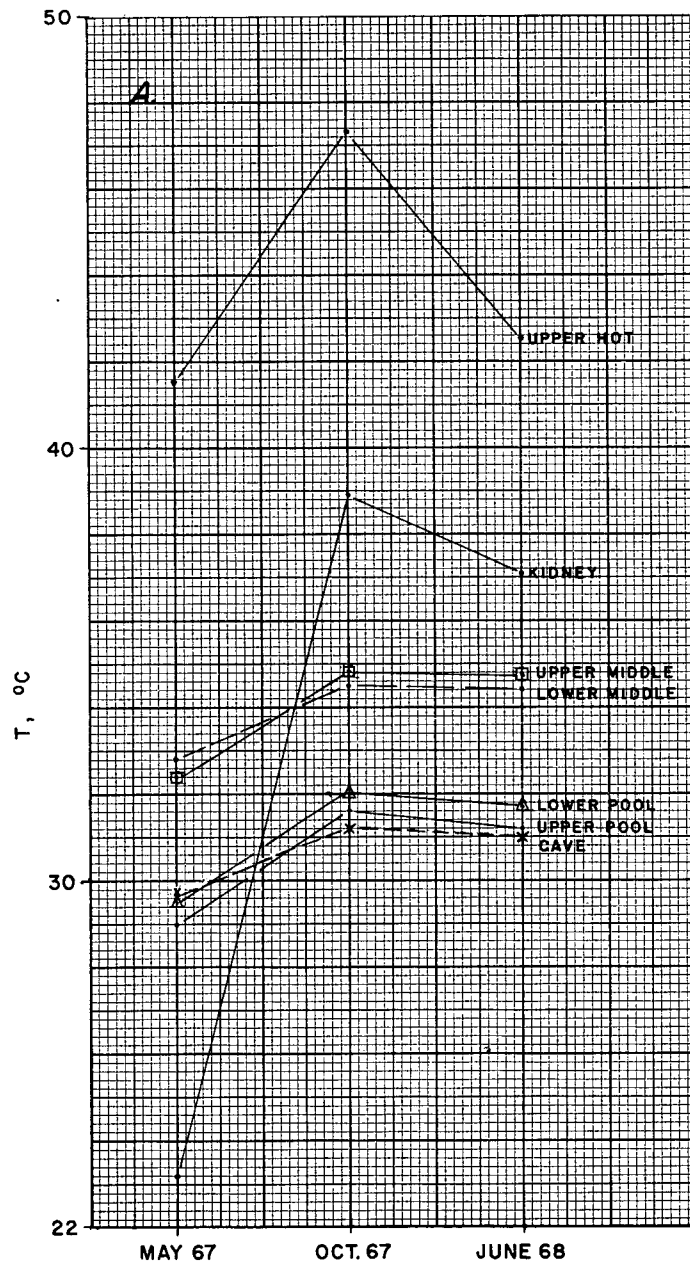


Figure 1. Variation in water temperatures and dissolved-solids concentrations observed at the thermal springs on Sulphur Mountain, near Banff, Alberta.

listed in Table I. The instruments and procedures used for these measurements were described in an earlier report (van Everdingen, 1969). Samples of the spring water were analyzed in the Western Water Quality Laboratory of the Inland Waters Branch in Calgary in accordance with standard methods. Results of the laboratory analyses are given in Table II.

DISCUSSION OF RESULTS

The variations in water temperatures and dissolved-solids concentrations for the Kidney Spring and the Cave Spring are plotted in Figure 2. The widest variation in temperature was again found at the Kidney Spring (cf. Figs. 1 and 2). The variations in water temperature, dissolved-solids, dissolved oxygen, H₂S and redox potential for the Kidney Spring are shown in Figure 3. The low-temperature period was characterized by a drop in the concentration of dissolved solids, the presence of up to 4.8 ppm dissolved oxygen (normally absent), and the near absence of H₂S (normally present in amounts up to 5 ppm). The redox potential increased from about -175 millivolts (reducing conditions) to about +340 millivolts (oxidizing conditions). These observations lead to the conclusion that water, cooler than the normal spring water and containing a lower than normal concentration of dissolved-solids, almost no H₂S, and a higher than normal oxygen content, is contributing to the spring discharge during the low-temperature period. As a result of the lack of H₂S and the presence of oxygen in the spring water, the usually prolific colonies of yellowish and white filament-like algae at the Kidney Spring started disappearing about mid-May. By June 18, the algae had vanished completely and did not become re-established until early August.

The graphical representation of the chemical analyses for the Kidney Spring (Fig. 4) shows that the low-temperature period is further characterized by a decrease in the concentrations of all dissolved components, except HCO₃⁻; the decrease is greatest for Na⁺, K⁺, Sr⁺⁺ and Cl⁻, in the medium range for SO₄⁼, SiO₂ and Ca⁺⁺, and smallest for Mg⁺⁺. On the other hand, the HCO₃⁻ content increased. It is concluded from these observations that the cool water being added to the sulfurous thermal water during the low-temperature period has a much lower Na⁺, K⁺, Sr⁺⁺ and Cl⁻ content; a lower SO₄⁼, SiO₂ and Ca⁺⁺ content; a somewhat lower Mg⁺⁺ content; but a higher HCO₃⁻ content. The analyses for the Cave Spring (Fig. 5) lead to a similar conclusion, except for the fact that the proportion of colder, more dilute water is smaller than in the case of the Kidney Spring.

In order to determine the actual concentration, ionic composition and temperature of the cool water being added to the sulfurous thermal water, the mixing ratio should be known. Since accurate discharge measurements for the various springs are not available, it is impossible to determine the actual mixing ratio. An attempt was made, however, to determine the "minimum-required" mixing ratio, R, for the date on which the lowest temperature was measured, on the basis of the individual ion concentrations in the thermal water in early spring (C_{Hi}) and those in the mixture on the low-temperature date (C_{Mi}), and by assuming zero ion concentrations in the cool water (C_{Ci} = 0). For each constituent in the water, the value of the minimum ratio, expressed as R_i parts of cool water, which have to be added to 1 part of thermal water to produce (1 + R_i) parts of the mixture, is calculated from:

$$R_i = \frac{C_{Hi} - C_{Mi}}{C_{Mi}} \dots\dots\dots(1)$$

Table I. Seasonal variations in temperature, pH, Eh, H₂S content and O₂ content in waters of the Kidney Spring and the Cave Spring, Banff, Alberta.

Kidney Spring					
Date	T, °C	pH	Eh, millivolts	H ₂ S, ppm	O ₂ , ppm
Oct. 23, 1968	39.1	7.05	-162	3	0.0
Nov. 7	39.1	7.25	-177	3.5	0.0
Nov. 21	39.2	7.21	-150	3.5	0.0
Dec. 10	39.0	7.15		3	0.0
Dec. 26	39.1			3	0.0
Jan. 8, 1969	39.0	7.1		3	0.0
Jan. 28	39.2	7.2		3.5	0.0
Feb. 12	39.0	7.1		4	0.0
Mar. 26	39.0	7.2		5	0.0
Apr. 16	38.8	7.05		4.5	0.0
Apr. 30	38.3	7.1	-175	5	0.0
May 14	25.1	7.25	+340	< 0.1	4.8
May 28	26.0	7.15	+332	< 0.1	3.6
June 18	35.2	7.05	+70	0.3	1.0
July 23	33.6	7.20	+317	< 0.1	1.4
Aug. 6	36.7	7.10	-48	2	0.2
Sept. 3	38.2	7.05	-84	3	0.0
Sept. 17	38.4	7.02	-84	3	0.0
Oct. 1	38.6	7.12	-97	4	0.0
Oct. 15	38.7	7.10	-97	3.5	0.0

Cave Spring					
Date	T, °C	pH	Eh, millivolts	H ₂ S, ppm	O ₂ , ppm
Oct. 23, 1968	32.0	7.25	-36	2	1.8
Nov. 7	32.2	7.39	-31	2	2.0
Nov. 21	32.4	7.3	-279	2	2.0
Dec. 10	32.4	7.3		2	1.8
Dec. 26	32.4	7.4			
Jan. 8, 1969	32.6	7.3		2 - 3	
Jan. 28	32.5	7.3		2 - 3	2.2
Feb. 12	32.5	7.3		2	1.6
Mar. 4	32.6	7.3		2	
Mar. 26	32.5	7.3		2 - 3	
Apr. 16	32.8	7.25		2	3.2
Apr. 30	32.8	7.25		2	3.0
May 14	29.9	7.15		1	1.6
May 28	29.1	7.20		2	0.6
June 18	30.5	7.2		2	1.2
July 23	29.8	7.2		1.5	1.8
Aug. 6	30.3	7.2		1	1.4
Sept. 3	30.5	7.15		2	1.4
Sept. 17	31.1	7.15		3	0.8
Oct. 1	31.3	7.2		5	0.8
Oct. 15	31.3	7.2		5	0.8

Table II. Seasonal variations in chemical composition and dissolved solids concentration in waters of the Kidney Spring and the Cave Spring, Banff, Alberta, expressed in ppm.

Kidney Spring										
Date	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ⁼	Cl ⁻	SiO ₂	Sr ⁺⁺	Total
Oct. 23, 1968	224	40.8	7.0	4.8	144	672	6.2	32.0	1.9	1133
Nov. 7	228	42.2	7.0	4.9	144	639	6.5	33.0		1105
Nov. 21	220	41.0	6.7	5.2	143	639	6.9	32.0		1094
Dec. 10	228	40.8	6.5	4.5	139	661	7.0	32.0	1.8	1121
Dec. 26	229	41.4	7.0	4.7	146	627	6.0	33.0		1094
Jan. 8, 1969	229	38.4	7.0	4.5	143	636	5.5	32.0		1095
Jan. 28	243	44.0	7.0	4.8	140	635	6.0	33.0		1113
Feb. 12	245	41.2	7.0	4.0	144	628	7.0	33.0	1.8	1111
Mar. 26	250	41.6	6.6	4.7	138	634	6.4	30.0	1.9	1113
Apr. 16	238	40.8	6.2	4.5	145	622	6.0	28.0	1.8	1092
Apr. 30	234	34.6	5.7	4.2	146	574	6.1	25.0	1.7	1031
May 14	118	24.1	2.7	2.0	166	245	2.6	14.5	0.7	576
May 28	122	26.8	3.0	2.2	158	275	3.0	15.9	0.8	607
June 18	191	38.6	5.3	3.8	151	495	5.0	26.0	1.4	917
July 23	194	33.2	4.8	3.8	165	461	4.6	25.5	1.3	893
Aug. 6	216	37.6	5.4	3.6	152	543	5.4	29.0	1.2	993
Sept. 3	229	32.6	6.1	3.7	148	582	4.9	30.9	1.7	1039
Sept. 17	230	31.7	5.4	3.9	145	587	5.6	27.3	1.7	1038
Oct. 1	230	36.8	5.8	4.1	145	579	5.4	27.3	1.4	1035
Oct. 15	231	38.4	6.0	4.1	146	587	5.8	27.3	1.8	1047

Cave Spring										
Date	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ⁼	Cl ⁻	SiO ₂	Sr ⁺⁺	Total
Oct. 23, 1968	224	43.6	7.0	4.1	146	633	5.4	26.8	1.9	1092
Nov. 7	226	44.2	6.2	4.7	147	632	5.7	29.0		1095
Nov. 21	230	43.0	6.1	4.8	146	641	6.1	22.0		1099
Dec. 10	226	42.8	6.8	4.3	144	654	7.3	28.0	1.9	1115
Dec. 26	232	44.0	7.0	5.3	149	628	6.0	29.0		1100
Jan. 8, 1969	229	40.8	6.0	4.0	145	641	5.0	26.6		1097
Jan. 28	229	43.0	6.0	4.0	144	642	5.0	29.0		1102
Feb. 12	256	44.4	8.0	4.5	144	644	7.0	30.0		1138
Mar. 4	244	42.8	5.8	4.3	144	640	6.8	26.0	1.9	1116
Mar. 26	241	44.4	6.0	4.4	145	632	5.5	27.0	1.9	1107
Apr. 16	244	43.6	6.1	4.5	145	642	5.3	30.0	1.9	1122
Apr. 30	244	35.4	5.5	4.2	145	609	5.4	24.0	1.8	1074
May 14	194	35.3	4.6	3.4	155	482	4.9	23.0	1.3	904
May 28	194	31.0	4.4	3.2	155	469	4.6	22.5	1.4	885
June 18	215	41.6	5.7	4.2	150	552	5.1	27.0	1.7	1002
July 23	182	38.3	5.0	4.0	161	455	4.7	23.5	1.3	875
Aug. 6	192	32.2	4.9	3.4	163	455	4.6	24.0	1.1	880
Sept. 3	195	36.9	4.3	3.1	161	494	3.5	22.9	1.5	922
Sept. 17	204	34.9	4.3	3.5	156	522	4.3	21.7	1.6	952
Oct. 1	202	42.9	5.0	3.5	154	522	4.2	21.7	1.2	957
Oct. 15	205	42.8	5.2	5.0	155	545	4.8	22.7	1.6	987

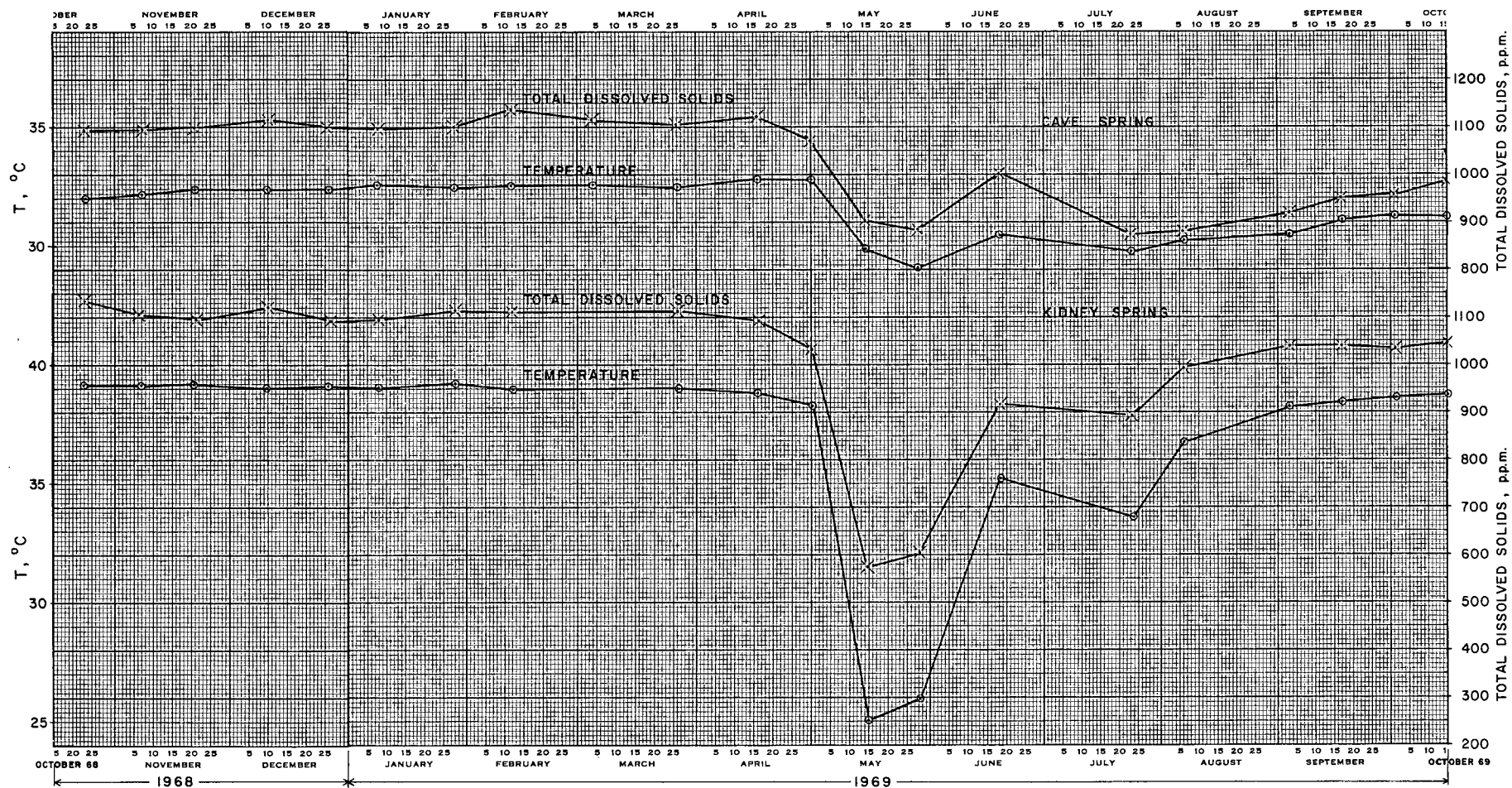


Figure 2. Seasonal variations in water temperatures and dissolved-solids concentrations for the Kidney Spring and the Cave Spring, near Banff, between October 23, 1968 and October 15, 1969.

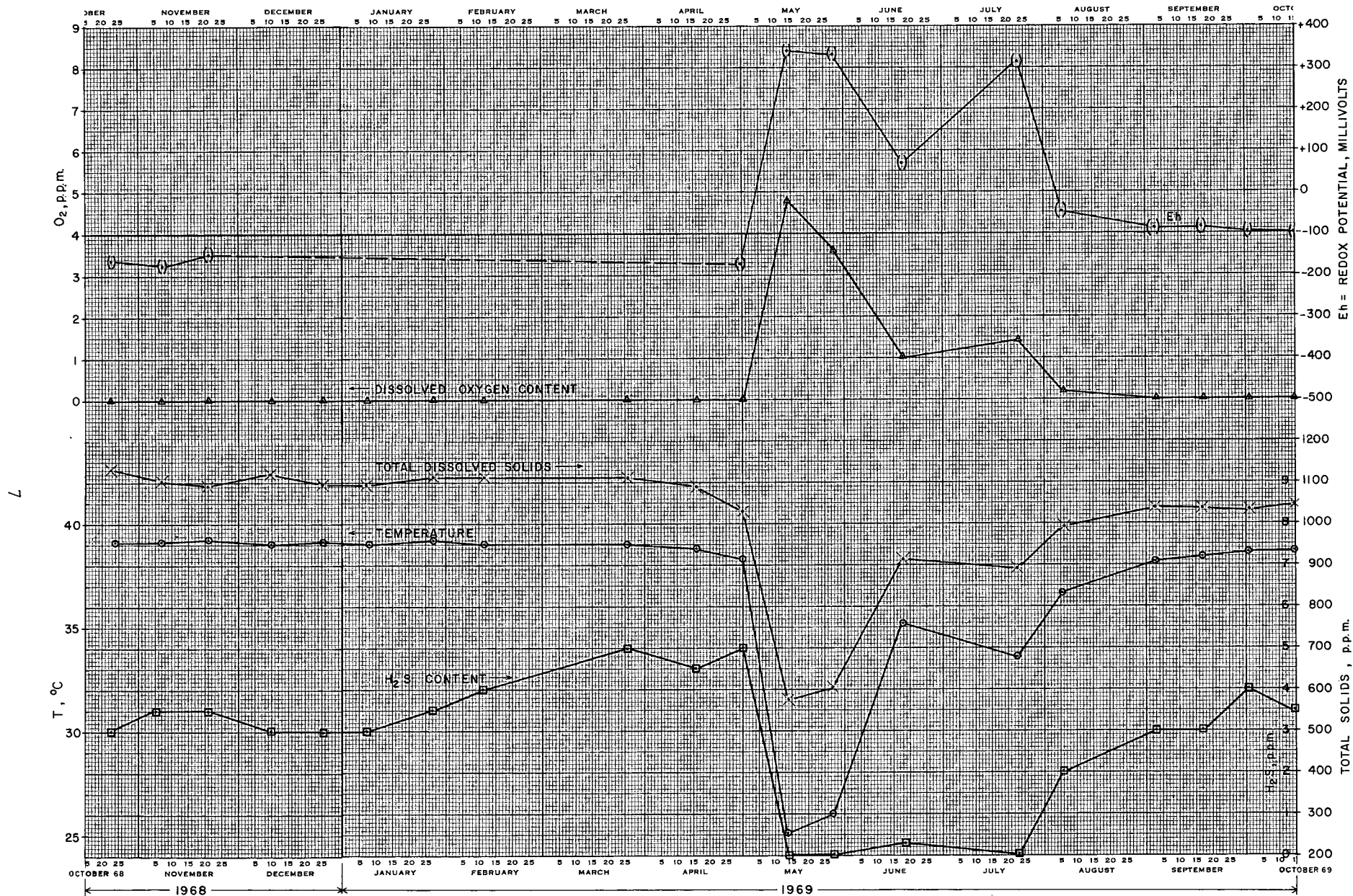


Figure 3. Seasonal variations in water temperature, dissolved-solids concentrations, redox potential, and H₂S and dissolved-oxygen contents of the water from the Kidney Spring between October 23, 1968 and October 15, 1969.

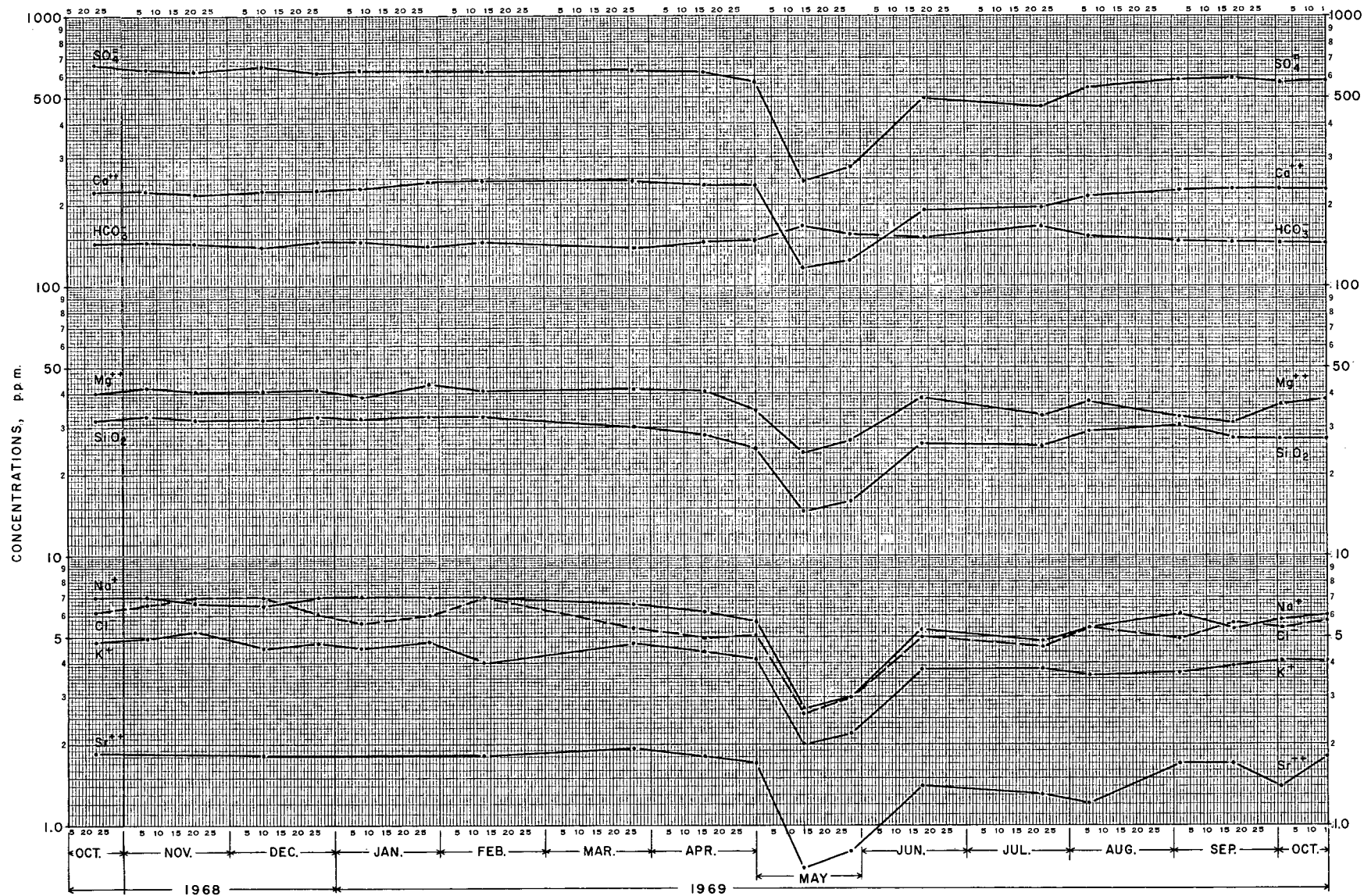


Figure 4. Seasonal variations in ionic concentrations in water of the Kidney Spring between October 23, 1968 and October 15, 1969.

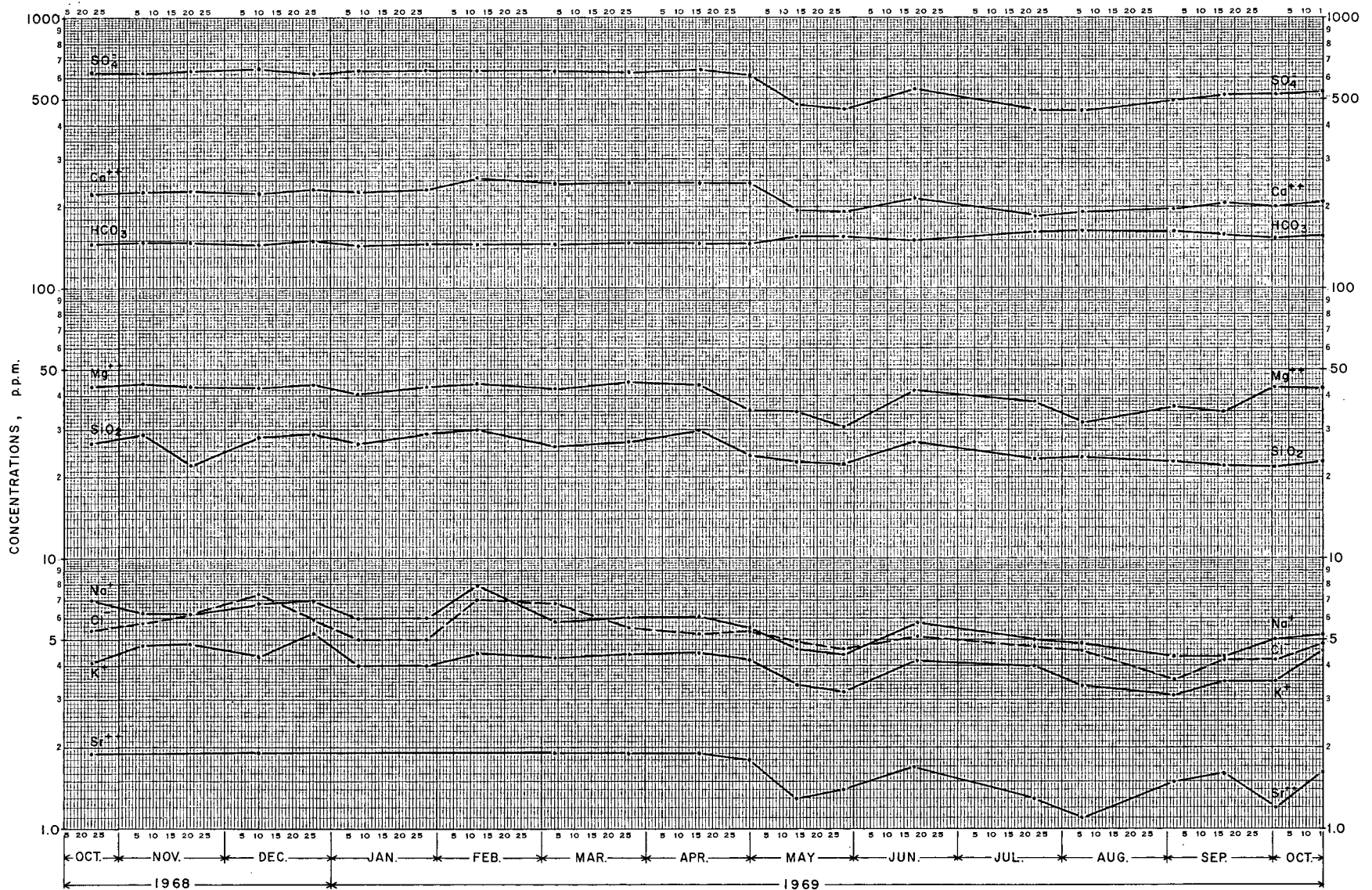


Figure 5. Seasonal variations in ionic concentrations in water of the Cave Spring between October 23, 1968 and October 15, 1969.

The largest of the values of R_i thus obtained is the "minimum required" mixing ratio R.

Using the chemical analyses for March 26 and May 14 for the Kidney Spring, a maximum R_i value of 1.59 was obtained on the basis of the sulfate-ion concentrations. Adopting a mixing ratio of 1.6 : 1, the concentrations of the various ions in the cool water (C_{Ci}) were calculated from the following equation:

$$C_{Ci} = \frac{2.6 C_{Mi} - C_{Hi}}{1.6} \dots\dots\dots(2)$$

The results of these calculations indicated that the cool water should contain at most 183 ppm HCO_3^- , and at least 38.2 ppm Ca^{++} , 13.7 ppm Mg^{++} , 0.01 ppm Sr^{++} , 0.26 ppm Na^+ , 0.31 ppm K^+ , 1.87 ppm SO_4^{--} , 0.23 ppm Cl^- and 4.8 ppm SiO_2 , for a total of 242.4 ppm dissolved solids. Calculation of the corresponding temperature of the cool water gave a value of 16.4°C.

It should be stressed that these values represent minimum requirements (maximum in the case of HCO_3^-). It is possible to assume a higher, but not a lower mixing ratio than has been used in obtaining the above results. However, a higher mixing ratio would result in a higher temperature and a higher dissolved-solids concentration in the cool water, both of which appear unlikely; therefore, the figures derived here are regarded as reasonable approximations. Per cent ionic compositions of the thermal water, mixture and cool water are shown as K_1 , K_2 and K_3 on Figure 6.

It is more difficult to apply the above method to the data obtained at the Cave Spring because neither the maxima nor the minima of the individual ion concentrations occur on single dates (Table II). This more complicated behaviour may well result from the addition of varying quantities of a third component to the mixture, in the form of a stream of water that enters the Cave from an opening in its rear wall. Therefore, calculation of the mixing ratio, or of the cool-water composition and concentration has not been attempted for the Cave Spring. The per cent ionic compositions for the thermal water and the mixture for the Cave Spring (February 12, 1969 and August 6, 1969) are shown in Figure 6 as C_1 and C_2 , respectively

In future detailed studies, it is desirable that accurate discharge measurements during periods of low and high discharge be obtained. The difference between these flows can then be taken to represent the rate of addition of the cooler water. This is the only parameter of the cool water that can be readily determined, because the unmixed cool water is usually not accessible for separate sampling and measurement of temperature.

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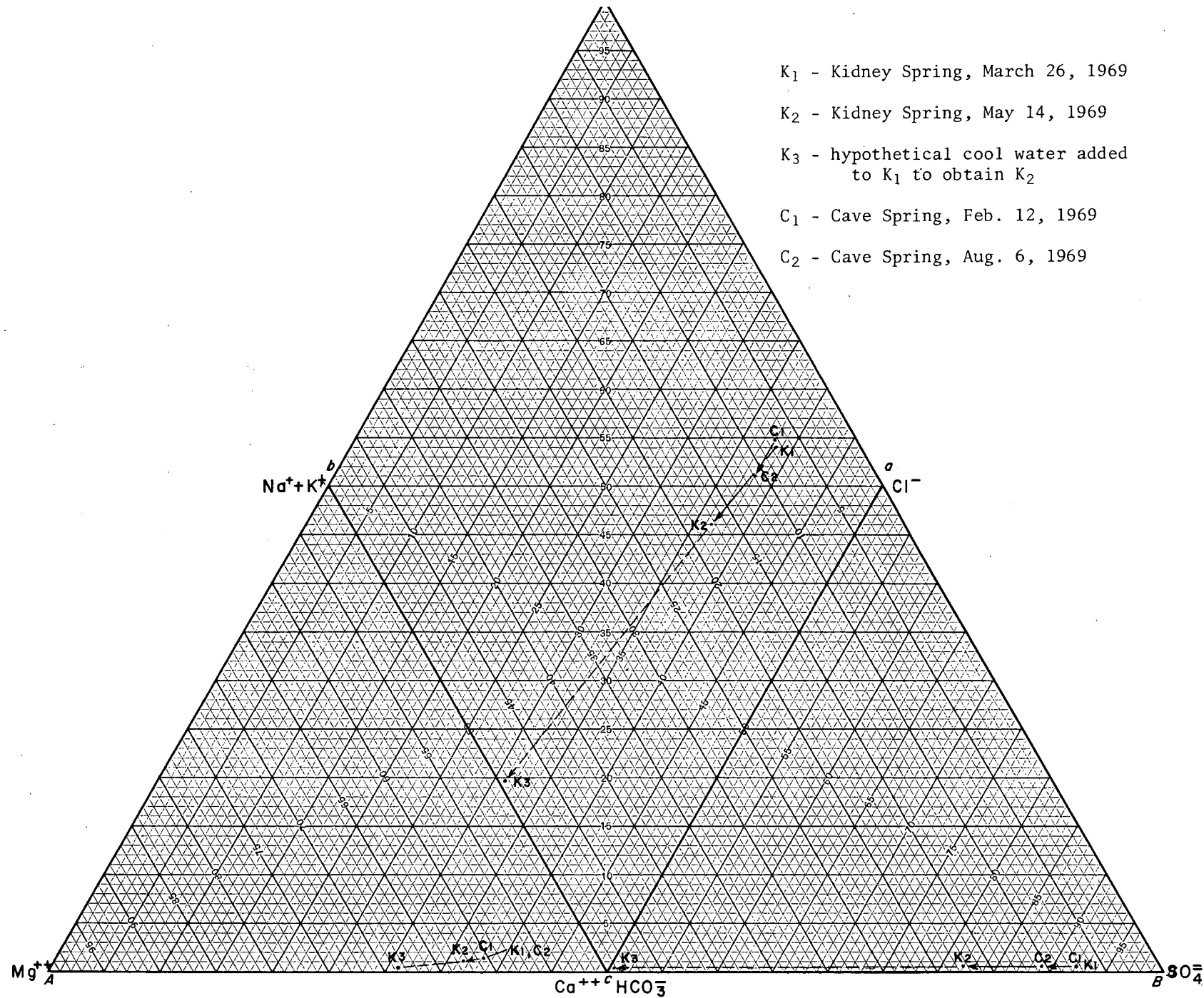


Figure 6. Trilinear plot of per cent equivalent compositions.

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