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ART. XXX.—*The Radioactive Properties of the Mineral Springs of Colorado;* by O. C. LESTER.

An investigation of the radioactivity of the numerous mineral springs found chiefly in the mountainous region of Colorado was begun in the summer of 1914. The work was under the auspices of the Colorado State Geological Survey, which had undertaken some time previously a study of these springs in relation to the geology of their surroundings and the chemical constituents of their waters. This previous study had provided a list of some 200 springs, giving locations, chemical analyses, and considerable information of a general nature. Most of these springs are highly mineralized, many of them are very hot, and many give off large quantities of gas. The present study was confined chiefly to the springs on this list although not all of them are included. On the other hand some springs not on the list have been included when they appeared to promise results of interest. It was impossible for several reasons to examine all the known springs and there are doubtless many unknown to us that might well be worthy of investigation. A few springs are located in regions where travel was practically impossible except on foot or on horseback. Others, owing to an unusually rainy summer for Colorado, were rendered temporarily inaccessible by damage to roads and bridges or were covered with water or the debris of washouts.

Since most of the springs are situated at distances varying from a mile to more than fifty miles from the

nearest railroad it was decided to do all traveling by automobile. A large box divided into convenient trays and compartments was built firmly into the back part of the machine. This held all the necessary apparatus and supplies for a well-equipped field laboratory and made it possible to use the more accurate boiling-out method described by Boltwood[1] instead of the Fontaktometer. Mr. J. H. V. Finney, an instructor in the department of Physics of the University of Colorado and a skilled automobile driver and mechanic, acted as general assistant not only in the field work but also in the tests made later in the laboratory. Without his efficient services the work would not have gone so smoothly nor could so much have been accomplished in the comparatively brief time of one summer.

The general plan of the work was to visit each spring and to make tests on the spot for the immediate activity of both water and gas. By immediate activity is meant the activity of freshly collected samples. Wherever it was possible the gases were also tested for thorium emanation. Samples of water and mud or sinter (if any) were collected chiefly from springs showing fair to high activity and shipped to the laboratory at the University to be tested later for dissolved or deposited radioactive substances.

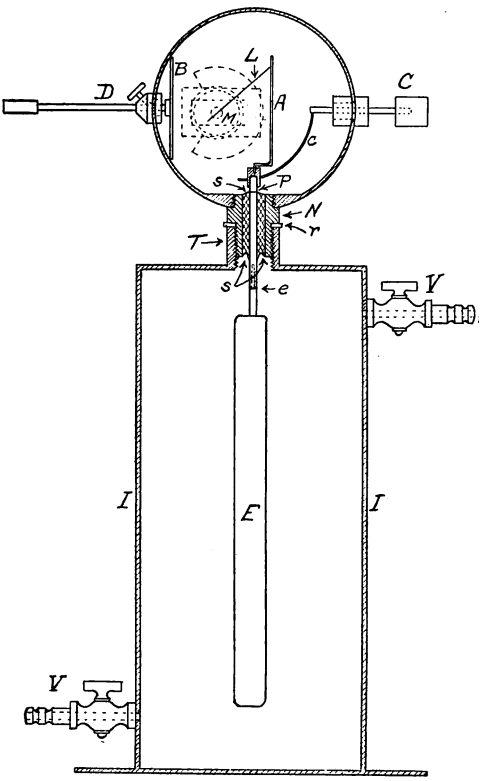
The field tests occupied the whole of the summer of 1914. A few short trips were made in the fall of 1914 and in the summer of 1915. Tests for activity due to salts dissolved in the waters or deposited in muds and sinters continued at various times during the winter of 1914, most of the summer of 1915, and for some time in 1916. During this time tests were made also on the immediate activity of waters shipped in from a number of springs not examined during the work in the field for reasons given above.

To avoid loss of time in waiting for an electroscope contaminated by active deposit to become usable again, several instruments or their equivalent were necessary. On the other hand our carrying capacity though large was not unlimited nor did we wish to have the care of packing, repacking and of keeping in order a number of pieces of apparatus as delicate as the leaf system of an electro-

[1] This Journal, 18, 378, 1904.

scope. The problem was solved by constructing a number of ionization chambers to which could be attached in turn the same electroscope head and leaf. The dimensions, constants, and characteristics of these electroscopes have been fully discussed in a previous paper.[2]

FIG. 1.



The essential features are shown in fig. 1. I is an air-tight cylindrical brass ionization chamber having stop cocks V near the top and bottom. Altogether four such chambers were used, all taking the same electroscope head but each having its own electrode E.

The head screws on at T and is made air-tight by the rubber gasket *r*. S is an insulation made of banker's specie sealing wax. Through this passes a brass rod

[2] This Journal, 44, 225, 1917.

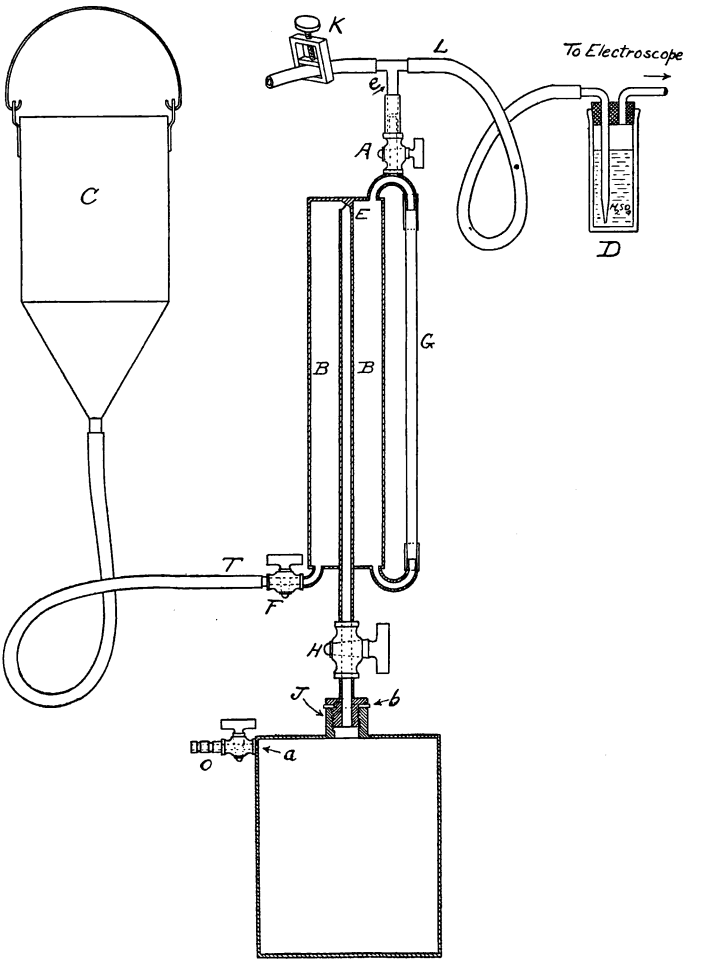
P, threaded at *e* for the attachment of the electrode and carrying on its upper end the leaf support A, which is firmly attached to the rod by means of a four-jawed friction clamp. The heavy front and back plates of the head, which carry small windows, are not shown in the figure. They are easily removed by taking out a few screws when it is necessary to get at the leaf system. A Pye telemicroscope serves to read the deflections of the leaf. The microscope is rigidly attached to the head in such a way that it can not change its focusing position on the leaf. C is a charging device and DB is merely an arrangement for protecting the leaf when traveling.

The electroscope head inclosing the insulated leaf system was so carefully made that it formed an almost air-tight chamber. This enabled the instrument to be used in the open with little or no disturbance to the leaf even when a considerable breeze was blowing. To cut down the natural leak due to ionization produced by sunlight a strong corrugated pasteboard box with suitable openings was fitted over and around the electroscope when in use in the open. This box also served as a protection in bad weather. In the field the leaf system was charged negatively by means of a metal tipped celluloid "charging rod."

The behavior of the electroscope, often under very trying field conditions, was practically perfect. Even in rainy weather the only trouble experienced was in keeping the charging rod dry. After standing charged for about half an hour the natural leak was usually between 0·05 and 0·15 division per minute although there were a few occasions when it amounted to nearly 0·4 division per minute.

The boiling-out apparatus for the field tests of water samples is shown in fig. 2. The water to be tested was carefully introduced into a vessel I containing caustic soda when necessary. This vessel has a stop cock O and communicates through the cock H and a three-eighths inch brass tube with the collecting chamber BB made of brass tubing two inches in diameter and ten inches long. The neck J is made air-tight by the rubber gasket B. G is a glass tube serving as a water gauge. The vessel I was made in three sizes with capacities of 0·5 liter, 1 liter, and 2 liters respectively. The two-liter vessel was used in most cases although there were some springs for which

FIG. 2.



the one-liter was convenient and a few for which the half-liter had to be used. The entire apparatus except the drying tube D was supported on a tall, heavy, ring stand with suitable clamps. Two gasoline torches served as sources of heat.

The method of operation is the same as that for any boiling-out apparatus. Boiling hot water is poured into the vessel C which is then raised until BB is filled to the top. Next the cock A is closed, H opened and the torches applied to I. The water in I will boil ten minutes or more before enough live steam begins to collect in BB to force the water toward the bottom of the gauge. The steam passing up through the central tube serves to keep the water in BB hot. After the temperature of the whole apparatus has risen nearly to the boiling point a touch of the flame on I causes the water in the gauge to descend quickly. With care, however, boiling can be continued as long as it is desirable. After the boiling is completed F is closed, the tube T is connected to O, and the gases in BB are transferred to the electroscope in the usual manner.

The results on the activity of both waters and gases are given in Table I.[3] The individual springs are designated by numbers. Those marked with an asterisk (*) were tested by means of samples shipped to the laboratory and although allowance has been made for the decay of the emanation from the time of collection our experience shows that such results are always too low. The gases were collected over water in glass vessels graduated in cubic centimeters. The apparent volumes of the gas samples were corrected for the pressure due to water vapor and reduced to standard conditions of temperature and barometric pressure.

Columns 3-6 inclusive give the activity per liter of freshly collected samples. Column 7 gives the results of a number of tests on the permanent activity of spring waters. These were made at the laboratory after the

[3] For the locations, chemical analyses and general descriptions of these springs see Bulletin No. 11, Colorado State Geological Survey, in press.

All the measurements in this table are on springs located in Colorado. Tests were also made on samples sent from Bajada Hot Springs, New Mexico, from Saratoga Springs, Wyoming, and from a spring in the Cañon of the Colorado River near Hite, Utah. The sample from the latter spring had the color of a strong solution of copper sulphate and showed the remarkably high radium content of $12{\cdot}12 \times 10^{-10}$ gram per liter.

samples had been acidified and sealed for over a month. Several of the samples were lost during shipment and some were accidentally destroyed where they were stored but it is scarcely to be expected that a greater number of tests would change the general character of the results.

In the column headed "Remarks" the letter S indicates results due to Schlundt.[4] The letter *a* means that the sample has been taken from a pipe or other outlet removed from the source, while *b* indicates thorium emanation.

Tests for thorium emanation were made in a great many places where there was a sufficient flow of gas. No indication of thorium was found anywhere except in spring No. 186 in Gunnison Co. near Powderhorn post-office. A roughly quantitative determination, made from the activity curve of the combined radium and thorium emanation and from the activity curve of the radium emanation alone, gave practically the same amount of activity for each. This scarcity of thorium emanation was somewhat unexpected as monazite is found in the sand of most of the creek and river beds so far examined along the whole eastern slope of the Continental Divide. Similar information for the western slope is lacking but the probabilities are that monazite exists there also. Thorium-bearing ores in place are unknown anywhere in the region in which the springs are located.

For testing the activity of spring deposits in the solid form a sensitive electroscope of the usual type was constructed. The ionization chamber is a cubical brass box having a volume of one liter. The narrow leaf is 4 cm. long and with its support, insulated by a piece of amber, projects downward into the ionization chamber at the bottom of which is a closely fitting drawer for the introduction of the active material.

The instrument has a measured electrical capacity of 1·06 cm. and was standardized by means of thin films of U_3O_8 made up according to the method of McCoy[5] but following the specifications of Boltwood.[6] Ten standard films were made from some very pure uranium oxide kindly furnished by Professor Boltwood. In no case did

[4] Jour. Phys. Chem., 18, 662, 1914.
[5] Phil. Mag., 11, 176, 1906; Jour. Amer. Chem. Soc., 27, 391, 1905.
[6] This Journal, 21, 418, 1906.

TABLE I.

No.	Temp.	Curies Ra Em. per liter × 10^{-10}		Mache units per liter		Permanent activity of water	Remarks[a]
	°C	Water	Gas	Water	Gas	Gram Ra per liter × 10^{-10}	
1	11·0	2·15	.....	0·58			
3	15·5	1·53	.....	0·41			
5	44·5	6·70	.....	1·81			
7	48·0	.....	27·84	.....	7·52		
11	20·5	trace	.....	trace			
12	13·5	26·75	.....	7·22			
13	12·0	41·44	.....	11·19	.....	none	
14	10·0	4·33	.....	1·17			
15	15·0	6·08	.....	1·64			
15	12·3	14·7	.....	2·49	.....	.....	S
16	....	12·61	.....	3·40			
17	10·0	0·92	.....	0·25			
17	12·5	2·7	.....	0·43	.....	.....	S
18	42·5	10·35	.....	2·80			
21	34·6	3·58	.....	0·97	.....	.....	*a*
22	19·5	.....	none	.....	none	.....	*a*
23	15·6	2·05	.....	0·55			
*25	14·0	1·04	.....	0·28			
26	8·5	5·85	.....	1·58			
27	18·5	16·80	78·0	4·54	21·05	0·074	
28	14·5	21·02	.....	5·68			
*31	6·7	2·38	.....	0·64			
*32	6·7	0·91	.....	0·25			
34	8·0	23·63	.....	6·38			
35	14·3	10·73	.....	2·90			
35	14·5	22·4	.....	3·74	.....	.....	S
36	29·4	.....	23·2	.....	6·26		
38	26·8	none	.....	none			
39	12·8	trace	.....	trace			
*42	9·4	1·87	.....	0·51			
43	13·0	6·41	.....	1·73			
45	28·3	15·04	129·5	4·06	34·98		
*47	....	0·73	.....	0·20			
*48	....	0·27	.....	0·07			
*49	....	10·10	.....	2·73			
52	26·0	8·35	101·6	2·25	27·42	none	
52	21·0	19·6	.....	3·25	.....	.....	S
53	25·0	4·73	.....	1·28			
54	51·5	.....	13·74	.....	3·71		
55	51·0	.....	19·68	.....	5·32		
58	51·5	0·87	.....	0·24			
63	50·0	.....	27·30	.....	7·37	0·197	
64	....	.....	0·44	.....	0·12		
67	9·5	none	.....	none			
69	....	none	.....	none			
71	56·5	15·14	414·0	4·09	111·8	0·180	
72	8·5	11·30	.....	3·05			
73	16·0	18·40	.....	4·97			

a Letters given in this column are explained in the text.

TABLE I (continued).

No.	Temp.	Curies Ra Em. per liter × 10^{-10}		Mache units per liter		Permanent activity of water	Remarks[a]
	°C	Water	Gas	Water	Gas	Gram Ra per liter × 10^{-10}	
76	16·1	.....	229·0	.....	61·85	none	
77	20·5	24·55	.....	6·63	.....	none	
78	35·0	5·99	.....	1·62			
80	44·5	.....	60·32	.....	16·29	none	
81	....	.....	.....	.....	.....	trace	
82	45·0	3·60	.....	0·97	.....	none	
83	43·0	3·27	.....	0·88			
84	17·0	4·92	.....	1·33			
85	....	.....	.....	.....	.....	none	
86	13·7	4·54	.....	1·23	.....	none	
87	13·0	6·58	.....	1·78	.....	none	
88–1	43·0	7·53	117·0	2·03	31·6		
88–2	43·0	11·49	.....	3·10			
89	40·0	15·51	.....	4·19			
90	41·6	2·20	.....	0·69			
91	35·5	2·78	146·10	0·75	39·45		
92	32·5	9·24	.....	2·50			
93–1	40·0	6·81	180·15	1·84	48·63		
93–2	....	6·58	.....	1·78			
94	....	.....	100·10	.....	27·02		
95	38·7	9·42	.....	2·54			
102	18·5	1·87	.....	0·51			
107	10·0	47·23	164·0	12·75	44·3	none	
108	10·0	50·20	.....	13·56	.....	none	
109	9·3	11·09	.....	2·99			
111	8·5	42·38	.....	11·44			
112	9·5	28·37	.....	7·66	.....	none	
113	8·5	38·07	131·6	10·28	35·52	trace	
*114	....	0·95	.....	0·26			
115	16·3	4·57	.....	1·23			
117	10·5	16·42	.....	4·44	.....	.....	*a*
117	10·2	20·0	.....	3·25	.....	.....	S
118	10·0	3·24	.....	0·88	.....	.....	*a*
118	15·1	8·45	.....	1·41	.....	.....	S
119	16·0	3·56	.....	0·96			
120	13·5	none	trace	none	trace		
120	13·7	8·2	.....	1·35	.....	.....	S
121	14·2	.....	11·94	.....	3·23		
124	14·0	2·35	11·49	0·63	3·10		
124	14·7	22·4	15·4	3·74	2·6	.....	S
125	12·0	7·30	.....	1·97	.....	none	
125	12·8	11·5	.....	1·98	.....	.....	S
126	18·0	15·35	77·6	4·14	20·95	none	
126	13·0	26·7	47·0	4·49	8·0	.....	S
127	22·3	12·07	73·15	3·26	19·75	none	*a*
127	....	20·1	48·1	3·36	8·03	.....	S
128	15·5	8·89	.....	2·40	.....	none	
128	12·7	13·1	.....	2·32	.....	.....	S
129	14·5	2·68	16·22	0·72	4·38	none	*a*

TABLE I (continued).

No.	Temp.	Curies Ra Em. per liter × 10^{-10}		Mache units per liter		Permanent activity of water	Remarks[a]
	°C	Water	Gas	Water	Gas	Gram Ra per liter × 10^{-10}	
129	14·5	17·6	.....	3·04	.....	.....	S
130	15·5	16·60	155·2	4·48	41·92	none	
130	14·9	47·3	205·0	8·25	31·2	.....	S
131	11·0	4·62	21·93	1·25	5·92		
131	11·2	14·0	28·8	2·34	4·77	.....	S
132	....	.....	19·65	.....	5·31		
133	9·5	16·84	.....	4·55	.....	0·08	
133	17·2	19·5	.....	3·16	.....	.....	S
136	47·0	4·93	262·0	1·33	70·75	trace	
139	51·0	.....	391·5	.....	105·7		
141	22·0	trace	.....	trace	.....	.....	*a*
142	83·8	.....	656·0	.....	177·15	none	
144	46·0	9·41	.....	2·54			
145	....	.....	202·2	.....	54·6	none	
146	9·5	13·35	.....	3·61	.....	none	
147	12·0	69·40	.....	18·74	.....	trace	
148	13·5	2·47	.....	0·67			
150	10·0	273·0	.....	73·7			
151	11·5	.....	334·5	.....	90·34		
152	34·7	10·38	.....	2·80	.....	none	
153	36·1	.....	152·35	.....	41·14		
155	18·5	27·2	.....	7·34	.....	none	
156	34·0	36·9	.....	9·99	.....	none	
157	51·5	6·38	.....	1·72			
158	47·5	11·53	.....	3·11	.....	0·096	
*159	....	none	.....	none			
160	50·0	.....	6·63	.....	1·79		
161	12·5	2·30	.....	0·62			
162	65·0	.....	12·36	.....	3·34		
164	15·0	none	.....	none			
*165	....	0·83	.....	0·22	.....	trace	
167	15·5	1·42	.....	0·38			
170	14·5	none	.....	none			
175	71·5	18·62	760·0	5·03	205·2	0·091	
*176	....	13·58	.....	3·67	.....	0·121	
177	64·5	263·9	.....	71·25	.....	0·063	
178	....	.....	.....	.....	.....	0·186	
179	33·5	8·31	.....	2·24			
182	40·5	.....	128·5	.....	34·7		
183	26·4	.....	229·7	.....	62·0	trace	
184	9·9	41·10	112·5	11·10	30·38	none	
186	10·3	79·25	375·6	21·4	101·41	none	*b*
189	24·0	2·05	.....	0·55			
190	26·5	trace	.....	trace			*a*
191	27·5	2·54	.....	0·69			
192	11·3	.....	4·97	.....	1·34		
194	13·0	.....	1·90	.....	0·51		
196	53·5	8·75	36·2	2·36	9·78		
199	22·5	.....	5·66	.....	1·53		

TABLE I (continued).

No.	Temp.	Curles Ra Em. per liter × 10^{-10}		Mache units per liter		Permanent activity of water	Remarks[a]
	°C	Water	Gas	Water	Gas	Gram Ra per liter × 10^{-10}	
*200	14·0	1·03	.....	0·29	.....	trace	
203	20·5	11·86	.....	3·20	.....	none	
206	20·0	2·64	.....	0·71			
207	14·5	305·5	2725·0	82·5	735·8	trace	
208	12·5	108·3	.....	29·25	.....	0·28	
209	14·0	138·4	.....	37·37	.....	0·283	
210	15·5	97·03	614·8	26·2	166·0	0·233	
211	24·0	trace	trace	trace	trace		
211	....	.....	10·9	.....	1·79	.....	S
212	39·5	.....	13·35	.....	3·61		
212	39·5	1·2	7·9	0·21	1·31	.....	S
213	24·0	9·05	35·0	2·44	9·45	none	
213	23·8	14·3	51·5	2·39	9·05	.....	S
214	23·5	.....	63·25	.....	17·08		
216	....	.....	2·39	.....	0·65		
218	15·0	13·58	60·30	3·67	16·28	none	
218	14·8	2·55	20·5	0·43	3·46	.....	S
222	24·5	.....	3·29	.....	0·89		
223	13·5	1·64	.....	0·44			
223	13·0	1·9	.....	0·32	.....	.....	S
224	....	.....	25·58	.....	6·91		
225	21·0	2·62	.....	0·71			
229	30·5	3·75	.....	1·01			
230	49·5	5·14	10·11	1·39	2·73		
231	49·5	.....	12·03	.....	3·25		
*232	6·7	0·78	.....	0·21			
*233	10·0	0·68	.....	0·18			
234	52·0	.....	15·76	.....	4·26		
235	42.5	2·28	136·6	0·62	36·88		
236	39·5	.....	19·97	.....	5·39		
237	52·0	.....	111·8	.....	30·20		
238	64.0	10·69	562·0	2·89	151·7	none	
239	70·0	19·80	956·8	5·35	258·35	trace	
240	68·5	19·54	1155·0	5·29	311·8		
241	70·0	21·51	1280·0	5·81	345·6	trace	
242	71·0	27·94	1147·0	7·54	309·7		
243	59·5	12·66	690·9	3·42	186·5		
244	43·0	16·56	.....	4·47			
245	64·0	28·57	687·5	7·71	185·6	0·083	
246	68·0	18·66	1243·5	5·04	335·5		
247	66·3	12·62	555·0	3·41	149·85		
248	5·5	13·85	.....	3·74	.....	0·085	
249	72·0	1·18	.....	0·32			
250	....	.....	36·2	.....	9·77		
251	55·5	.....	58·3	.....	15·74		
252	35·5	4·40	.....	1·19			
*253	....	5·84	.....	1·58	.....	none	
*254	....	13·63	.....	3·68	.....	none	

TABLE II.

No.	Material	Equiv. Act. grams U per gram × 10^{-10}	Grams Ra × 10^{-10}	Per gram
			Fusion	Solution
12	Quartz sand and orthoclase	0·474		
12	Sand	0·423		
13	Mud and organic matter	1·865		
27	Limonite and calcareous sinter	0·299		
27	Limonite and calcareous clay	0.141		
27	Calcareous clay	0·588		
27	Calcareous clay	0·907	none	
28	Mud and limonite	1·328		
71	Mud and muscovite	0·251		
73–1b	Clay	16·88	8·67	
73–2b	Clay	15·11	3·62	
76b	Sulphura	8·74	1·88	
77b	Clay	0·732		
77b	Clay	0·265		
108	Sand	0·349		
142	Clay	0·444		
147	Carbonaceous clay	1·245		
147	Carbonaceous clay	1·54	0·291	
150	Limonite and calcareous sinter	20·73	.....	3·21
150	Limonite and calcareous sinter	9·36	.....	2·07
152	Calcareous clay	0·007		
153	Calcareous clay	0·263		
153–1	Calcareous tufa	0·527		
154	Limonite and clay	0·321		
158	Calcareous sinter	1·72	.....	1·14
175	Calcareous sinter and clay	1·14	trace	
175	Calcareous sinter and clay	0·485		
177	Tufa	1·345		
182	Limonite and clay	0·639		
182	Limonite and clay	0·855		
183	Limey clay	0·724		
183	Calcareous clay	0·449		
184	Calcareous clay	0·603		
200	Porous sinter and sulphur	0·161		
203	Yellow sinter	0·233		
203–1	Tufa	0·604	0·085	
207	Limonite and sand	0·073	trace	
207	Limonite and sand	0·273	0·125	
235		0·216		
238	Calcareous clay	0·123		
238	Calcareous clay	0·397		
238	Mud	0·057		
165	Cave incrustation, sulphura	trace		
165	Rusty clay	none		

a Sulphur pure enough to burn.

b The springs 73–77 are peculiar. In addition to practically pure sulphur, Schlundt (*l. c.*) finds that part of the sinter deposited by them is about 87 per cent barium sulphate. He also finds a sample of tufa from one of these springs showing 14·8 × 10^{-10} gram Ra per gram.

these films weigh as much as 5 mgs. and the material was spread uniformly on thin sheet aluminium over a surface of 64 sq. cm. The ten films gave an average activity per milligram of three divisions per minute. One division per minute corresponds to $2{\cdot}82 \times 10^{-4}$ gram uranium.

Dry samples of the materials to be examined, weighing roughly from 0·5 lb. to 3 lbs., were first pulverized so as to pass through a 100-mesh screen. Small portions of these were further ground with freshly distilled chloroform in an agate mortar and this material was thinly painted with a camel's hair brush over sheet aluminium of the same area as the standard films. These films were made much thicker, however, than the standards so that considerable absorption undoubtedly occurred for which no correction has been made.

The activities of the deposits, muds or sediments from a number of the springs listed in Table I are given in Table II. It was not possible to collect such samples from all the springs. The samples taken were usually from springs which showed at least some activity in the water or gas. From some springs more than one sample was taken when the deposits appeared to differ in nature, color, or age. These are indicated in the table by a repetition of the spring number.

In the column headed "material" will be found a classification made by the Colorado State Geological Survey but no formal analysis has been attempted. Column 3 expresses the activity as equivalent to that of so many grams of uranium per gram. Up to the present it has not been possible to do the work necessary to determine the exact substances to which this activity is due. Small portions only, even of what appeared to be calcareous deposits, were soluble in acids. The deposits contain large amounts of clay and silica and the radioactive salts occur generally in the form of sulphates.

The values given in column 4 were obtained by the method of fusion with mixed carbonates. The samples were sealed for over a month in combustion tubing and care was taken to avoid loss of emanation during fusion. Column 5 contains a few results obtained by the boiling-out method from complete solutions of a few grams of material. This of course is the ideal method for reliable results. However, aside from the fact that lack of time has prevented the use of this method in all cases, it is

very unlikely that results would be obtained commensurate in interest with the labor involved.

Some work has been done on a few of the springs listed in Table I by other observers. Wolcott[7] examined one spring at Glenwood Springs but his method gave qualitative results only. The work of Headden[8] on the Doughty Springs (Nos. 73-77) near Hotchkiss, Colorado, was done by the photographic method and the results given are also qualitative. A few of the springs at Manitou, Colorado, were examined by Shedd[9] and his results show a fair agreement with later observations considering the lack of precision in his apparatus and the fact that he did not use an emanation standard.

The most extensive previous investigation is that of Schlundt[10] who tested a number of springs near Boulder, at Manitou, at Steamboat Springs, and at least one spring at Glenwood Springs. He used a fontactometer having a volume of about 15 liters. His results which can be identified with springs listed in this work are also given in Table I and are indicated by the letter S. The two sets of measurements sometimes agree but often one of them differs by amounts ranging from about one-fourth to five times the other. These differences are due partly to the methods used, to the corrections applied, and partly perhaps to variations in the activity of the sources. An examination of the two sets of temperature readings indicates that changes have occurred in the condition of some of the springs. Likewise the testimony of local observers seems to show that springs in a rather closely associated group sometimes change their character due apparently to connection by means of underground channels. The differences in the measurement of activity, however, appear to have no relation to these indicated changes.

Considered as a whole the results given in Tables I and II indicate a high average activity although there are a few springs which are inactive. The most active waters show the highest radioactivity yet found in the United States and are surpassed by but few foreign springs. The greatest activity found in the spring gases is exceeded in the United States by a few springs in the

[7] Biennial Report Colo. School of Mines, Appendix p. 27, 1904.
[8] This Journal, 19, 297, 1905.
[9] Proc. Colo. Sci. Soc., 10, 233, 1912.
[10] Loc. cit.

Yellowstone National Park and is approached by but two or three European springs.

A careful comparison of the radioactivity measurements with the data obtained from the chemical analyses shows that there is no connection between radioactivity and any chemical property. Neither is there any connection between activity and temperature, nor between the activity in water or gas and that in the deposits. Some springs situated near each other have shown activities of very different magnitude and again the individual springs of a closely associated group have shown quite similar activities. In the first case the waters of the separate springs usually had the appearance of being different in character but not always.

Results similar to the foregoing have been recorded by many previous observers both in this country and in Europe. There is a general agreement that springs from igneous rocks are more active than those from sedimentary rocks.[11] If we take the ninety-five springs of Table I which show an emanation content equal to or greater than 10×10^{-10} curie per liter we find that 58 or 61 per cent are in pre-Cambrian formations or near a pre-Cambrian contact; 14 or 14·7 per cent are in igneous rock or near igneous and sedimentary contacts; 23 or 24·2 per cent are in sedimentaries of various formations. Approximately 75 per cent of the more active springs are thus in or near metamorphic and igneous formations. Some of the most active springs, however, are found in sedimentaries. Nos. 73-77 in the Cretaceous and Nos. 136-139 in the Miocene are examples.

At the beginning of this investigation it was anticipated that some springs of extraordinarily high radioactivity would be found since Colorado contains quite extensive deposits of radioactive ores. This expectation, however, was not fulfilled. No large mineral springs were found in regions where radioactive ores are most abundant. A number of springs, often highly gaseous, situated not far outside such regions showed in general the least activity of any examined. On the other hand, some quite active springs such as Nos. 107-109 near

[11] Since this article was written there has appeared an extensive investigation on the Radio-activity of Archean Rocks from the Mysore State by Smeeth and Watson (Phil. Mag., 35, 206, 1918). All these rocks, considered to be of igneous origin, contain remarkably little radium. The various igneous magmas not only appear to contain different amounts of radium but the radioactive material seems to be subject to magmatic segregation.

La Veta and No. 71 near Hartsel in South Park are in regions where radioactive ores occur to some extent. Autunite is found in the La Veta region and some Carnotite in South Park. Generally speaking, however, the most active springs are found on both slopes of the Continental Divide and not far from it. So far as is known there are no bodies of radioactive ores near them.

In the course of this work there were found many groups of springs situated just at the foot or within a mile or two of a high mountain range the individual peaks of which reach elevations as high as 12,000 to 14,000 feet. These groups are sometimes arranged in a more or less definite line a mile or more in length as if along an old fault and again are gathered together in an irregular area the opposite sides of which are only a few hundred feet apart. In such areas springs as widely different as a cold soda spring and a hot sulphur spring may be found separated by only a few feet. These areas seem to be merely the common outlets for underground waters draining often from many square miles of high mountainous country which frequently includes formations of widely different age and character.

As to the origin of the radioactivity found in natural waters there seems to be a general agreement that it is picked up little by little during the underground flow from the minute amounts of radioactive matter known to be widely diffused through all rocks and soils. According to Dienert and Guillard[12] the activity arises *exclusively* from this source. They point out further that when water comes from great depths as in Plombières it is possible to find springs very near together, coming from the same geological beds and having very different activity. The work of Schmidt and Kurz[13] indicates that there is no dependency of emanation content on depth, strength of flow, chemical properties or temperature, but only that springs from eruptive rocks are in general much more active than those from sedimentaries.

The question as to whether an underground water or gas collects most of its radioactive material near the outlet or far removed from it, whether by gradual absorption from surrounding rock or by rapid absorption during a brief contact with more active material, does not seem to be answerable without more information than is usually known about the underground course. Mining opera-

[12] Le Radium, 7, 60, 1910.
[13] 1 Phys. Zeitschr., 7, 209, 1906.

tions show that quite extensive open underground water channels are not uncommon and it is quite evident that many of the hot springs flow for long distances in such courses. In a water course which permits free and rapid flow, radium emanation could be absorbed at a great distance and brought to the surface without losing greatly through disintegration. Likewise a rapid flow through a long underground channel could give at the outlet a very active water or gas which need not have encountered any particularly active material. In the case of slow seepage flows which may collect in an open channel extending only a short distance from the outlet or which may empty into the pool which forms the spring itself, most of the emanation is undoubtedly collected not far away. Even though such a spring should show high activity it does not mean necessarily that there is highly active material near by. The slow flow and shorter distance of travel are compensated by the greater area of the underground stream and by its intimate contact with a greater amount of weakly emanating material.

The foregoing argument of course does not exclude the possibility of the underground flow touching very active substances but the presence of such material can not be inferred from the existence of a highly radioactive water or gas without other evidence. If a spring happened to be so situated that its waters came in contact with a material which could be classified as even a low grade radioactive ore, and further if it had the large and rapid flow characteristic of most of the springs examined in this work, it seems fairly certain that it would show an activity of a different order of magnitude from those recorded in the tables above.

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