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Radium and uranium data for mineral springs in eight Western States

By

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Abstract

Data for 116 mineral springs in eight Western States show a wide range of values. Specific conductance, temperature, and pH were measured at the sites between 1975 and 1977, and samples for radium and uranium analysis were collected. Correlation and regression analyses among the five measured parameters indicate that a positive correlation exists between radium and specific conductance and that negative correlations exist between radium and pH, specific conductance and pH, and uranium and temperature.

Sample localities

Between 1975 and 1977 we collected data and(or) water samples at 116 mineral springs in eight Western States. Sample localities are shown on figure 1 and listed in table 1; two of the sites (one in Idaho and one in Nevada) are not shown on the map because the samples were taken with the permission of the property owners on the condition that the sample locations be considered confidental. Sample distribution by State is as follows:

State	Number of samples
Arizona	10
California	2
Colorado	27
Idaho	6
Nevada	27
New Mexico	5
Utah	28
Wyoming	11

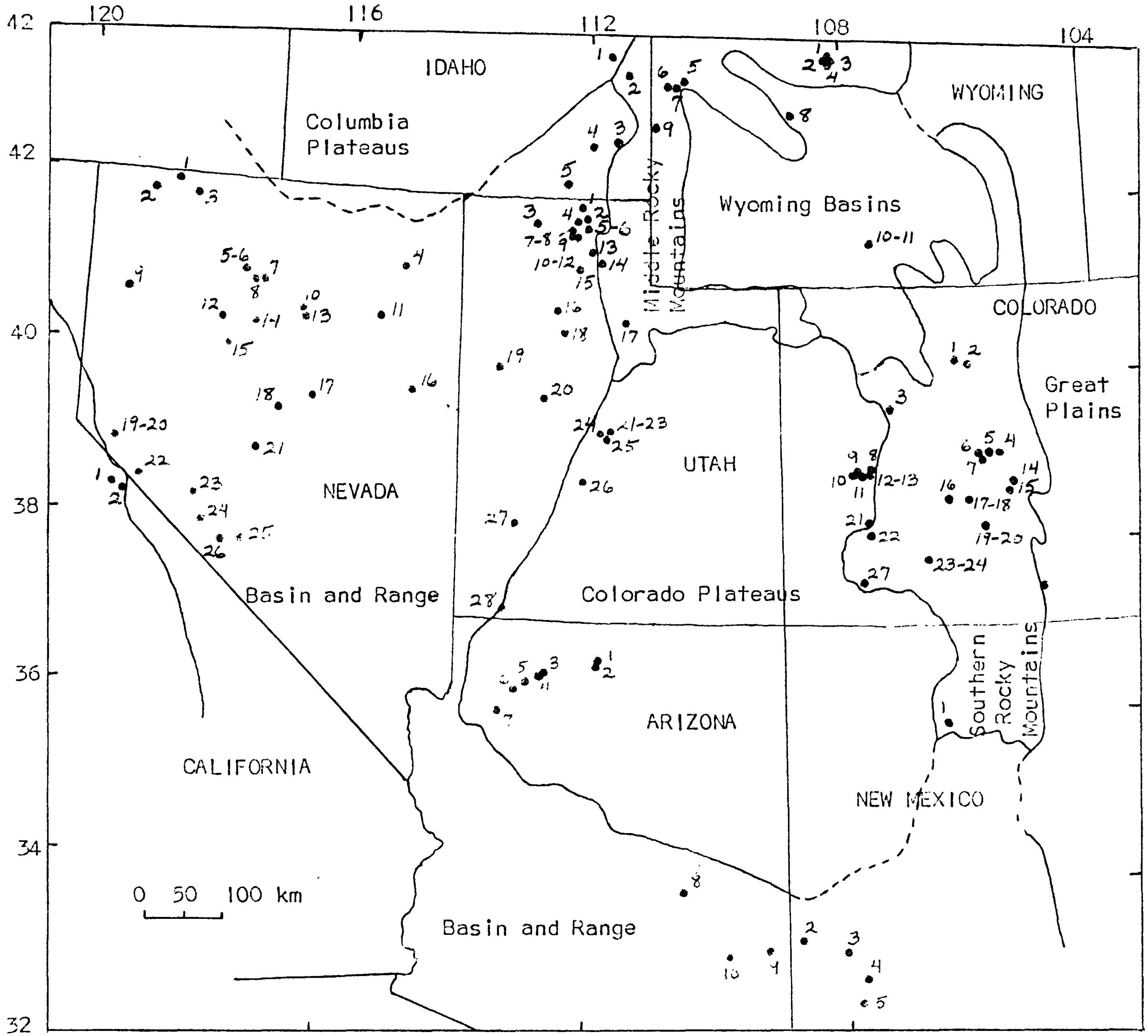

Figure 1. Index map of sample localities and physiographic provinces.

Table 1.--Sample localities

Loc. no.	Locality name	Latitude	Longitude
	Arizona		
1	Vasey's Paradise spring	36°29'57"	111°51'26'
2	Spring	36 28 37	111 50 42
3	Spring	36 20 47	112 43 29
4	Spring	36 20 44	112 40 15
5	Spring at Fern Glen Canyon	36 15 43	112 55 03
6	Lava Warm Springs	36 11 39	113 04 59
7	Pumpkin Spring	35 54 59	113 19 59
8	Salt Banks springs	33 49 56	110 35 49
9	Clifton Hot Spring	33 04 48	109 18 11
10	Indian Hot Springs	32 49 59	109 48 53
	California		
1	Fales Hot Springs	38°21'01"	119°24'00"
2	Travertine Hot Springs at Bridgeport	38 14 47	119 12 12
	Colorado		
1	Sulfur Springs near Kremmling	40°06'01"	106°15'50"
2	Hot Sulfur Springs	40 04 31	106 06 44
3	Glenwood Hot Springs	39 33 01	107 19 15
4	Springs at Sulfur Mountain	39 01 27	105 37 47
5	Hartsel Hot Springs	39 01 07	105 47 41
6	Salt Spring	38 59 42	105 57 30
7	Antero Salt Works spring	38 57 11	105 56 08
8	Colonel Chinn artesian well	38 50 22	107 38 32
9	Sulfur Gulch spring	38 47 21	107 50 32
10	Austin springs	38 46 59	107 56 14
11	Fish hatchery adit spring	38 46 22	107 46 10
12	Doughty springs	38 46 12	107 45 32
13	Doughty springs	38 46 12	107 45 34
14	Yellow Soda Spring near Guffey	38 44 20	105 31 50
15	Taylor Soda Spring	38 36 08	105 33 00
16	Waunita Hot Springs	38 30 53	106 30 26
17	Poncha Hot Springs	38 29 45	106 04 30
18	Poncha Hot Springs	38 29 43	106 04 20
19	Mineral Hot Springs	38 10 07	105 55 05
20	Mineral Hot Springs	38 10 07	105 55 05

Table 1.--Sample localities--continued

Loc. no.	Locality name	Latitude	Longitude
	Colorado--continued		
21	Orvis Hot Spring	38°08'00"	107°44'00"
22	Ouray hot springs	38 01 08	107 40 27
23	Wagon Wheel Gap hot springs	37 45 00	106 49 45
24	Wagon Wheel Gap hot springs	37 45 00	106 49 45
25	Sulfur Springs near La Veta	37 27 41	105 05 55
26	Sulfur Springs near La Veta	37 27 41	105 05 55
27	Baker Bridge hot springs	37 26 58	107 48 23
	Idaho		
1	Heise Hot Springs	43°38'34"	111°41'15"
2	Fall Creek Mineral Springs	43 25 25	111 24 51
3	Geyser at Soda Springs	42 39 25	111 34 46
4	Lava Hot Springs	42 37 11	112 00 18
5	Pleasantview Warm Springs	42 09 18	112 20 53
6	Spring	Confidential.	
	Nevada		
1	Baltazor Hot Spring	41°55'19"	118°42'34"
2	Virgin Valley Warm Spring	41 47 25	119 06 46
3	Howard Hot Spring	41 43 17	118 30 17
4	Threemile Sulfur Spring	41 09 13	114 59 06
5	Golconda Hot Springs	40 57 44	117 29 26
6	Golconda Hot Springs	40 57 41	117 29 35
7	Plank Spring	40 50 34	117 11 58
8	Brooks Spring	40 49 44	117 18 20
9	Great Boiling Spring at Gerlach	40 39 41	119 22 03
10	The Geysers at Beowawe	40 33 59	116 35 20
11	Sulfur Hot Springs in Ruby Valley	40 33 13	115 17 07
12	Kyle Hot Springs	40 24 25	117 52 59
13	Hot Springs Point	40 24 03	116 31 07
14	Buffalo Valley Hot Springs	40 22 02	117 19 46
15	Sou Hot Springs	40 05 14	117 43 28

Table 1.--Sample localities--continued

Loc. no.	Locality name	Latitude	Longitude
	Nevada--continued		
16	Monte Neva Hot Springs	39°39'33"	114°48'17"
17	Bartine Hot Springs	39 33 30	116 21 32
18	Spencer Hot Springs	39 19 27	116 50 58
19	Nevada Hot Springs	38 53 59	119 24 38
20	Nevada Hot Springs	38 53 59	119 24 38
21	Darrough Hot Springs	38 49 18	117 11 00
22	Grant View hot springs	38 29 24	118 58 34
23	Soda Springs at Sodaville	38 20 32	118 06 11
24	Gap Spring	37 58 46	117 59 31
25	Alkali Hot Spring	37 49 29	117 20 13
26	Silverpeak spring	37 45 28	117 37 48
27	Spring		Confidential.
	New Mexico		
1	Soda Dam Hot Springs	35°47'28"	106°41'09"
2	San Francisco Hot Springs	33 14 40	108 52 53
3	Gila Hot Springs	33 11 55	108 12 11
4	Mimbres Hot Springs	32 44 54	107 50 08
5	Faywood Hot Springs	32 33 17	107 59 42
	Utah		
1	Udy Hot Springs	41°51'30"	112°09'25"
2	Garland Springs	41 43 45	112 06 20
3	Locomotive Springs	41 43 05	112 55 37
4	Salt Spring	41 42 42	112 13 40
5	Crystal Springs	41 39 35	112 05 14
6	Crystal Springs	41 39 34	112 05 13
7	Poison Spring	41 37 40	112 16 01
8	Painted Rock Spring	41 37 15	112 16 03
9	Little Mountain hot spring	41 34 49	112 15 11
10	Stinking Hot Springs	41 34 38	112 13 55

Table 1.--Sample localities--continued

Loc. no.	Locality name	Latitude	Longitude
	Utah--continued		
11	Stinking Hot Springs	41°34'38"	112°13'55"
12	Stinking Hot Springs	41 34 38	112 13 55
13	Utah Hot Springs	41 20 20	112 01 44
14	Ogden hot spring	41 14 09	111 55 16
15	Hooper Hot Springs	41 08 13	112 10 33
16	Grantsville Warm Springs	40 38 47	112 31 20
17	Midway Hot Springs	40 31 35	111 29 13
18	Morgan Ranch Warm Spring	40 23 45	112 25 20
19	Wilson Health Springs	39 54 30	113 25 35
20	Baker Hot Springs	39 36 49	112 43 49
21	Stinking springs	39 14 19	111 39 17
22	Stinking springs	39 14 19	111 39 19
23	Stinking springs	39 14 19	111 39 19
24	Fayette Springs	39 13 40	111 50 37
25	Ninemile cold spring	39 10 20	111 42 10
26	Monroe Hot Springs	38 38 26	112 05 53
27	Thermo Hot Springs	38 12 34	113 13 11
28	Dixie Hot Springs	37 11 24	113 16 16
	Wyoming		
1	Taylor artesian well	43°39'55"	108°11'40"
2	Ulcer spring	43 39 19	108 11 52
3	Big Spring at Thermopolis	43 39 16	108 11 36
4	Wedding of the Waters Spring	43 34 55	108 12 45
5	Granite Hot Spring	43 22 11	110 26 42
6	Astoria Mineral Hot Springs	43 18 01	110 46 28
7	Stinking Springs in Hoback Canyon	43 17 20	110 38 06
8	Washakie Warm Springs	43 00 28	108 50 07
9	Auburn Sulfur Springs	42 49 51	110 59 56
10	Sulfur Springs at Doty Mountain	41 29 34	107 33 24
11	Sulfur Springs at Doty Mountain	41 29 34	107 33 24

Specific conductance, temperature, and pH were measured in the field, and radium and uranium concentrations were determined by laboratories of the U.S. Geological Survey.

The sampling was directed toward mineral springs as opposed to ordinary freshwater springs. By definition, a mineral spring is a spring whose water contains enough dissolved minerals or gases to give it a definite taste, "especially if the taste is unpleasant or if the water is regarded as having therapeutic value" (Gary and others, 1974). The minimum amount of mineral matter necessary to impart a taste is not stated, presumably because the amount is variable and depends on the ions or gases involved. According to Hem (1970, p. 219) water containing more than 1,000 mg/l total dissolved solids is saline, and saline water is usually considered undesirable for drinking. Many mineral waters are saline by this definition, but some are not. Thermal springs are commonly used as health spas and are considered to be mineral water even though the total dissolved-solids content may be less than 1,000 mg/l. Therefore, in order to examine all possible mineral springs, we searched the literature and maps for references to hot springs, salt springs, soda springs, or sulfur springs. We visited mineral springs having a wide range of properties--dissolved-solids contents of 130 to 28,000 mg/l (specific conductances of 130 to 55,000 μmhos/cm) and temperatures of 7°C to 94°C.

Measurements and analytical procedures

Temperature and pH were measured in the field. Temperature was measured at the surface as near the source of each spring as possible and was recorded to the nearest degree celsius. The pH was measured at the site by means of a combination glass electrode using a Ag/AgCl solution as reference and was recorded to the nearest tenth of a pH unit.

Specific conductance is a measure of the ability of a water to conduct an electrical current. It was measured in the field using standard instrumentation of the U.S. Geological Survey that compensates for temperature and standardizes the reading to 25°C. The conductance is directly related to the total ion concentration, and approximate dissolved-solids contents can be calculated from conductance values by the relationship:

$$KA = S,$$

where K is specific conductance in micromhos per centimeter, S is dissolved solids in milligrams per liter, and A is the conversion factor (Hem, 1970, p. 96-102). The value of A can range from 0.54 to 0.96, but for most waters, A is between 0.55 and 0.75, making the dissolved solids roughly two thirds the conductance. The relationship between conductance and a single dissolved salt is a simple linear one, but the occurrence of many salts in varying proportions in natural waters causes the relationship to be less straightforward.

Radium analyses were done by radiochemical carrier-precipitation methods. A 1-liter sample of untreated water was collected at each site, and most of these were analyzed by the radon emanation method. The radium is coprecipitated with barium sulfate, the precipitate is then dissolved, and the solution is bubbled with helium to flush out existing radon. The bubbler is allowed to equilibrate for 2-20 days before an alpha count is taken on the ingrown radon-22 and the radium-226 is calculated.

Because the U.S. Geological Survey changed its sample submittal and accounting procedure while this study was in progress, some of the samples were analyzed by the precipitation method. In this method the radium is coprecipitated with barium sulfate, and the precipitate is collected on a filter, or planchet. The planchet is allowed to equilibrate for at least 15 days before an alpha count is taken. Both of the above methods are discussed in Thatcher, Janzer, and Edwards (1977).

Uranium analyses were done by fluorometric methods. A 1-liter sample of untreated water was taken at all sites except those in Nevada and part of Utah, where filtered and acidified samples were taken, as discussed below. The untreated samples were analyzed by direct fluorometry and then, if necessary, by extraction fluorometry; those samples showing less than 30 percent quenching or those having uranium contents above 0.3 μg/l by the direct method did not require further analysis by the extraction method. The direct method involves evaporating a water sample to dryness and then fusing the residue with a fluoride-carbonate flux. The fluorescence of the fused disk is determined under ultraviolet light in a reflection-type fluorometer. The extraction method involves preconcentrating the uranium by coprecipitation with aluminum phosphate. The precipitate is then dissolved in dilute nitric acid, the uranium is extracted with ethyl acetate or ethyl ether, and the solution is then evaporated, fused, and fluoresced. Both the direct and the extraction methods are discussed in Thatcher, Janzer, and Edwards (1977). Samples collected in Nevada and part of Utah were analyzed by extraction fluorometry only. These 1-liter samples were filtered through 0.45-μm filter paper and acidified with 2 ml of 6N nitric acid in the field. Duplicate samples were taken at seven sites for comparison of analytical results from the two sample sets. The results are the same magnitude and have a correlation coefficient of 0.97, which is significant at the 99-percent level; they are therefore comparable (fig. 2 and table 2).

Presentation of data

Values of radium, uranium, specific conductance, pH, and temperature for the 116 sample localities are listed in table 3 and shown diagrammatically on figures 3-7. We did not take samples at every site, choosing to rely on data already available for some sites in Colorado, New Mexico, and Utah. References are given for these data in table 3. A few measurements were inadvertently not made; data from references were used to fill these holes where possible.

Frequency distributions and chi square tests indicate that the best fit to a normal distribution is achieved by using log values for radium, uranium, conductance, and temperature and nonlog values for pH. Frequency diagrams (fig. 8) show that values for most parameters have multimodal distributions. This implies that in some sense we are dealing with more than one population of

Table 2.--Comparison of uranium data on duplicate samples for two methods of sample treatment and analysis

Locality	Uranium (µg/L)	
	Direct and(or) extraction fluorometry on untreated samples	Extraction fluorometry on filtered-acidified samples
Gap Spring, Nev-------------------	4.5	6.8
Fales Hot Springs, Cal------------	1.9	2.2
Wilson Health Springs, Utah-------	.13	.09
Golconda Hot Springs, Nev---------	.09	.11
Buffalo Valley Hot Springs, Nev---	.04	<.01
Monte Neva Hot Springs, Nev-------	.03	.02
Golconda Hot Springs, Nev---------	.02	.03

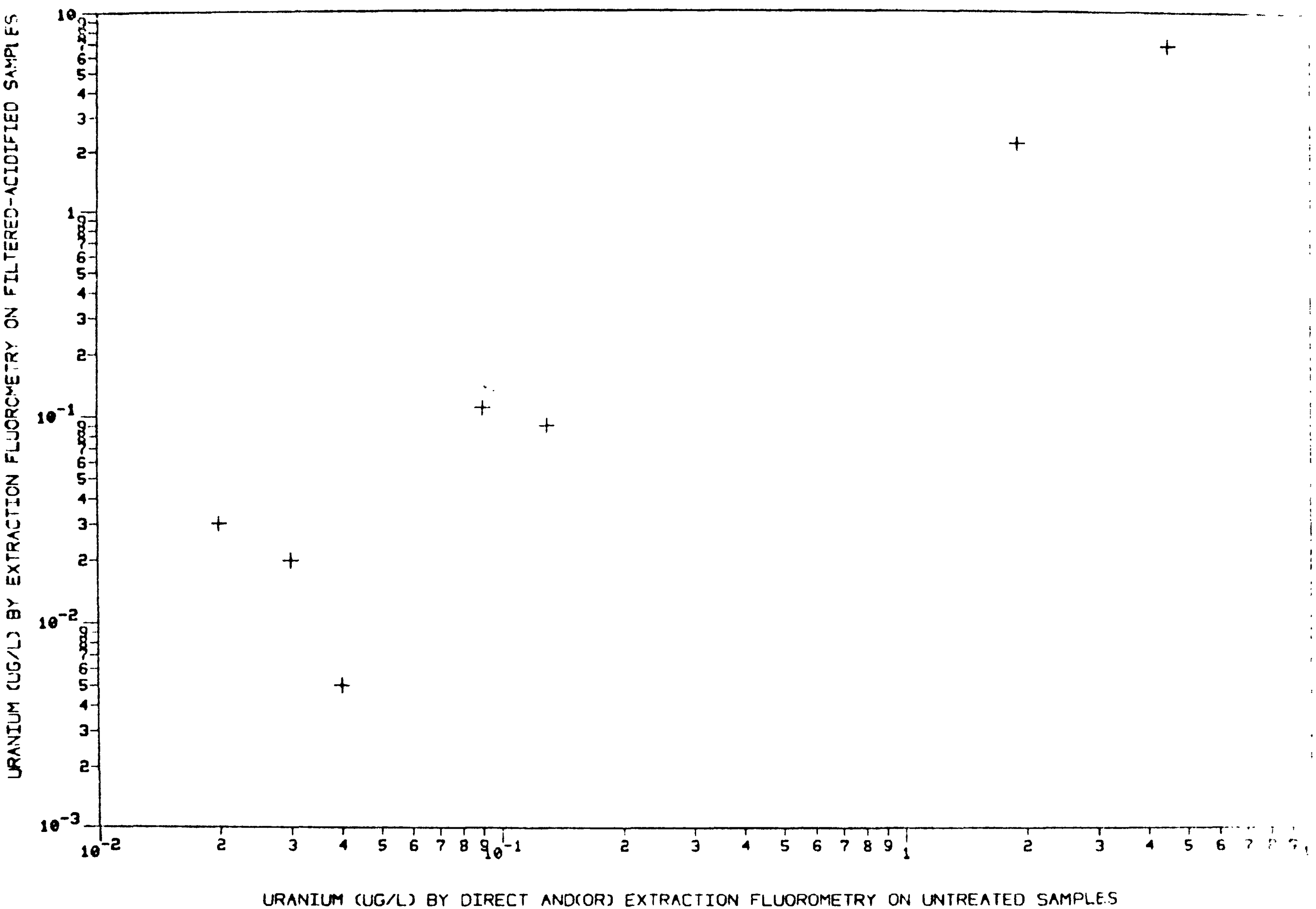

Figure 2. Comparison of uranium data on duplicate samples for two methods of sample treatment and analysis.

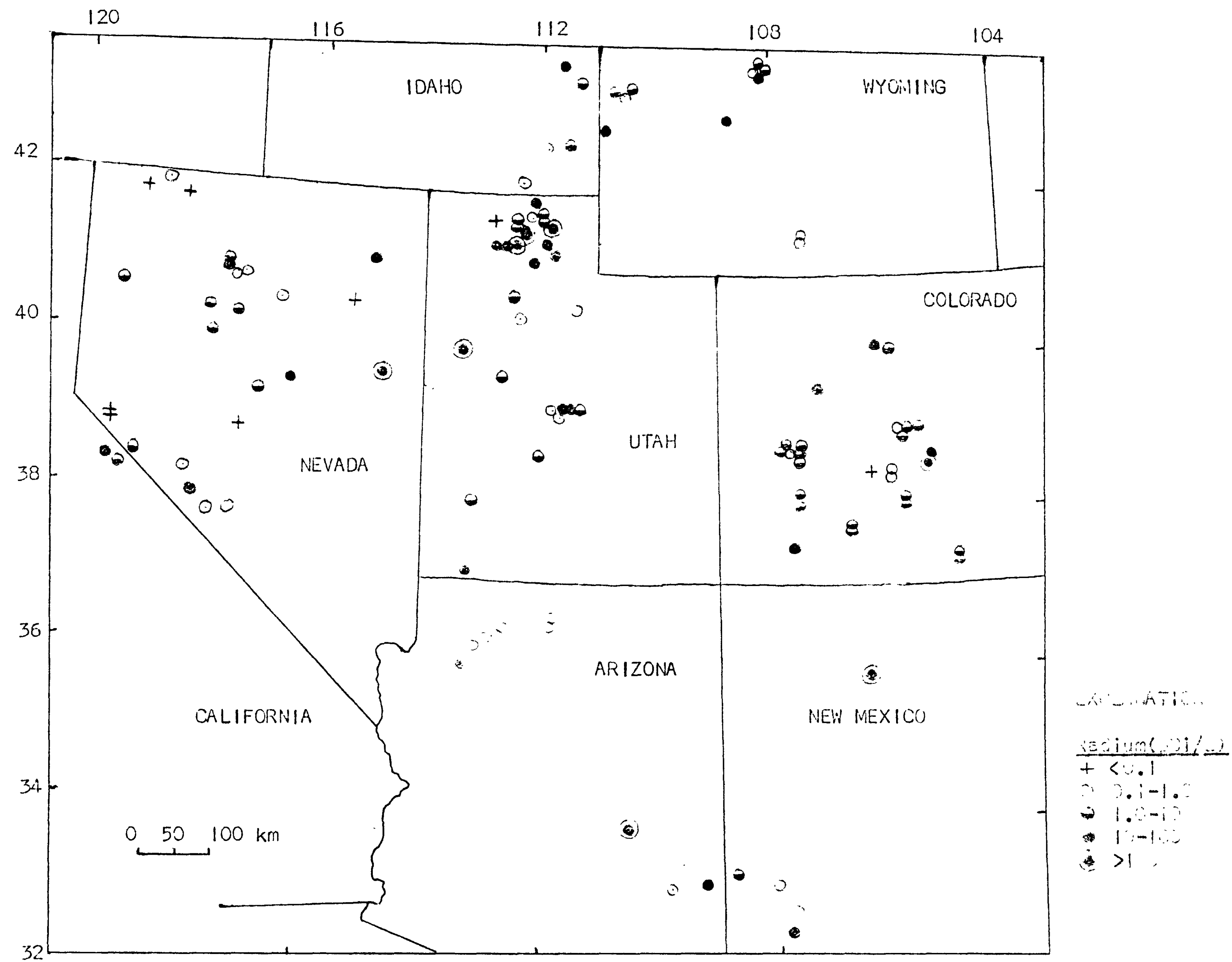

Figure 3. Radium values.

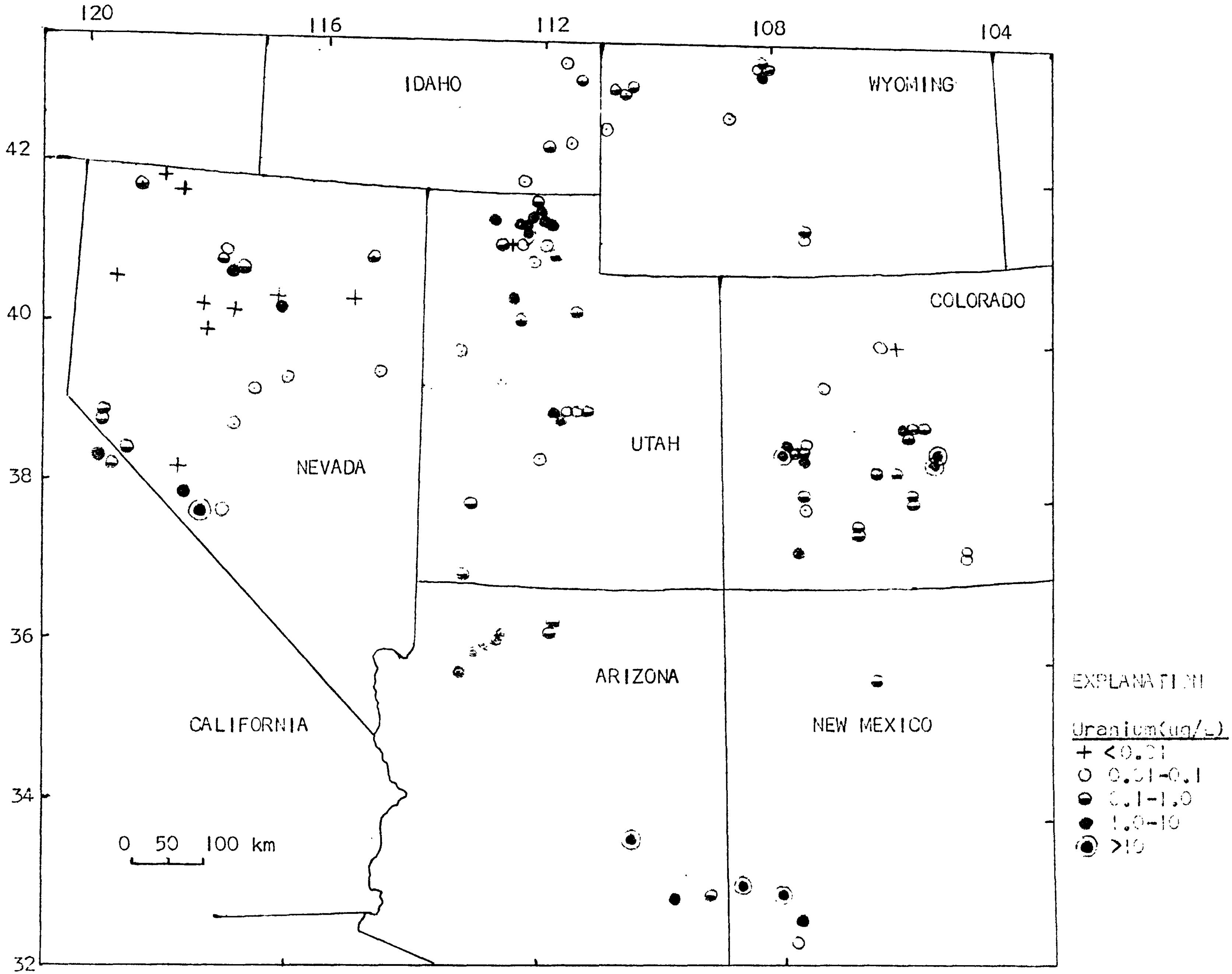

Figure 4. Uranium values.

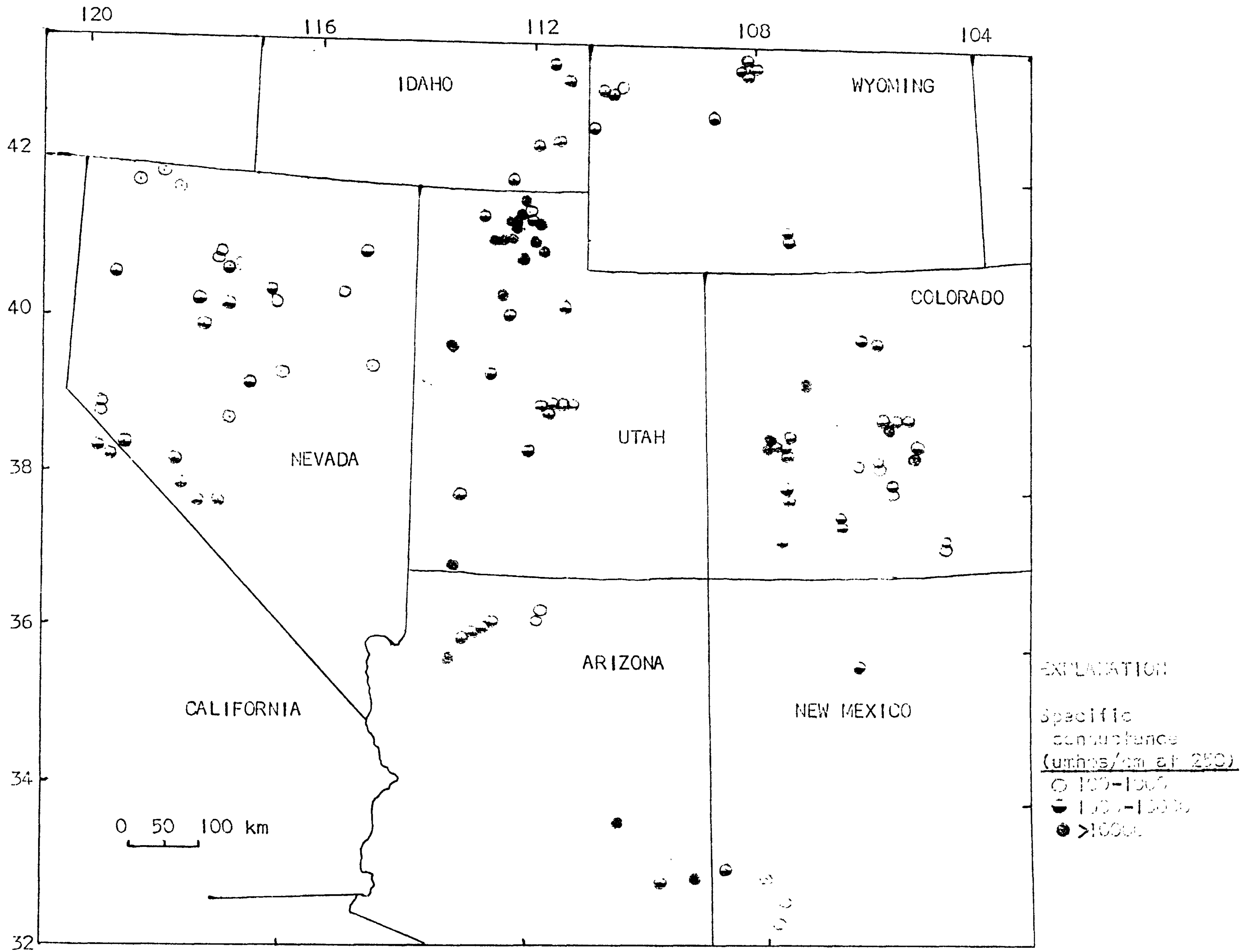

Figure 5. Specific conductance values.

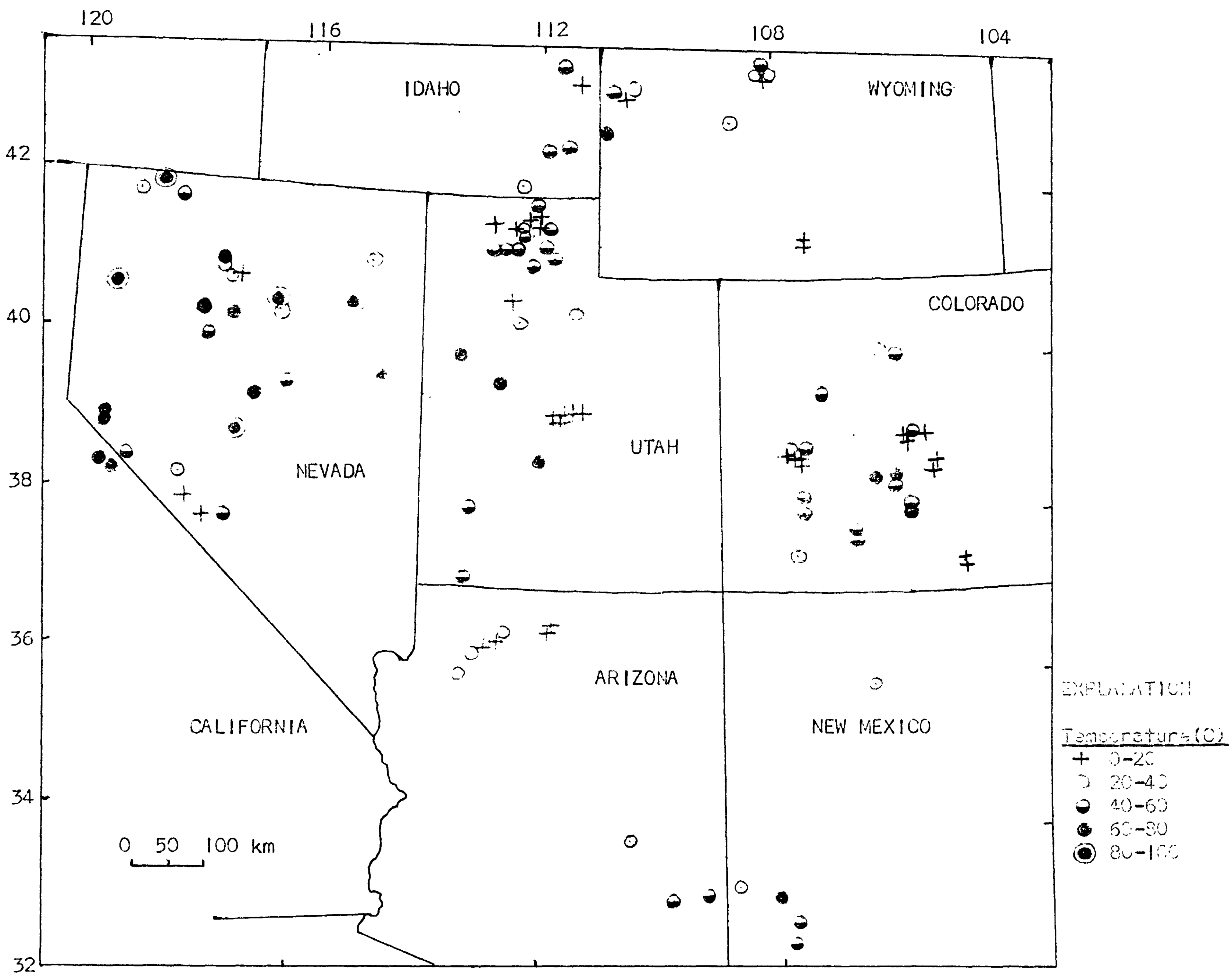

Figure 5. Temperature values.

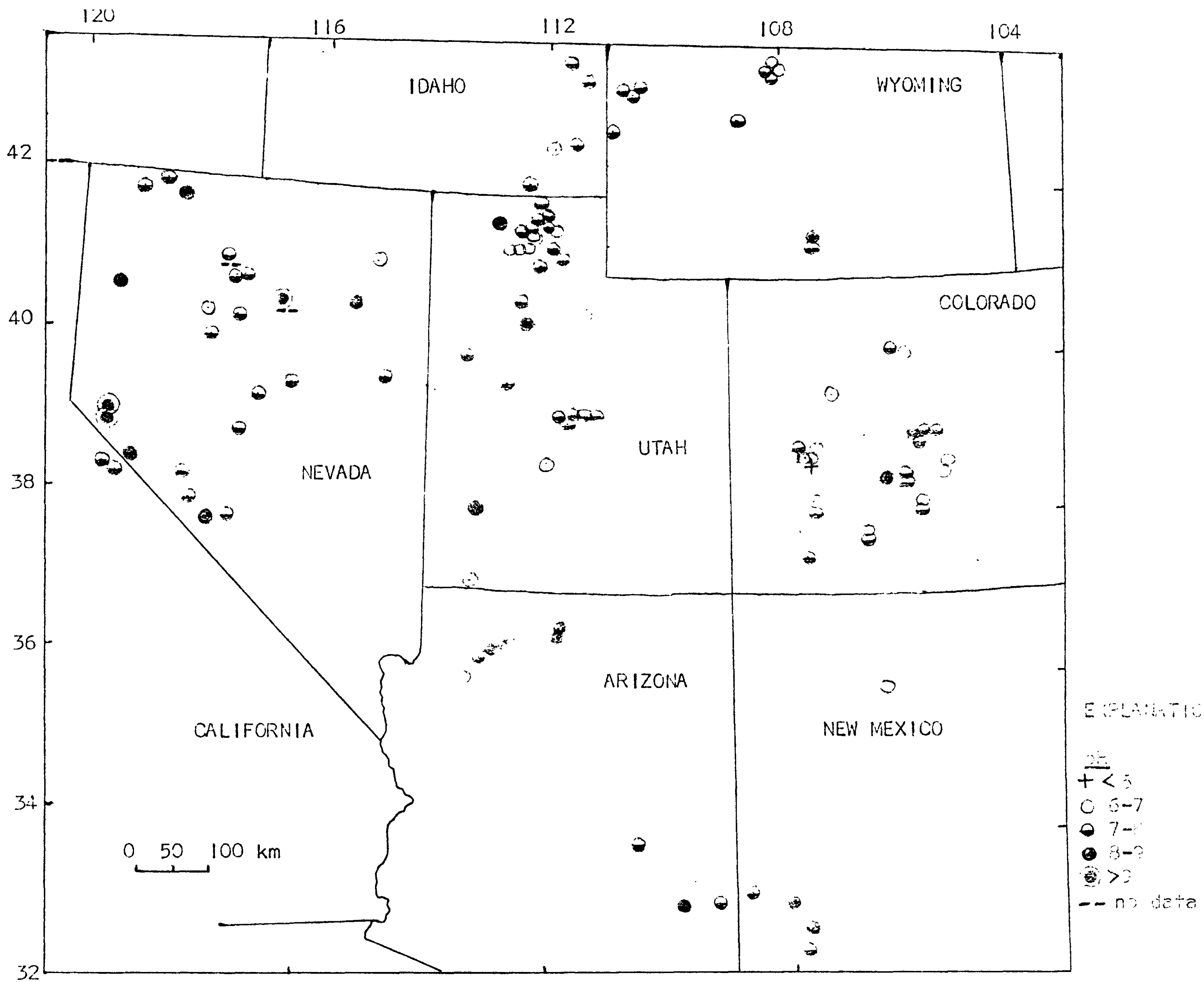

Figure 7. pH values.

Table 3.—Radium, uranium, and field data

[O, data from O'Connell and Kaufmann, 1976; M, data from Mallory and Barnett, 1973, and V. J. Janzer, unpub.; S, data from Scott and Voegeli, 1961. REF, radium enrichment factor, or measured radium divided by radium in equilibrium with measured uranium. L, less than; G, greater than; ---, no data]

Loc. no.	Date (mo-dy-yr)	Temperature (C)	pH	Specific conductance (umhos per cm at 25C)	Radium (pCi per liter)	Uranium (ug per liter)	REF (x 1000)	Radium / specific conductance
				Arizona				
1	4-29-76	18	8.2	340	0.15	0.5	0.88	0.44
2	4-29-76	18	8.0	360	.17	.50	1.0	.47
3	5-07-76	20	8.3	2130	.66	8.5	.23	.31
4	5-07-76	19	8.3	1350	.36	6.4	.17	.27
5	5-08-76	17	8.1	1830	.10	3.6	.082	.055
6	5-09-76	26	7.4	1340	.36	3.5	.30	.27
7	5-11-76	25	6.7	11900	23	7.1	9.5	1.9
8	2-07-76	21	7.3	40000	120	13	27	3.0
9	2-06-76	56	7.5	18000	14	.80	51	.78
10	2-06-76	44	8.2	5000	.82	1.0	2.4	.16
				California				
1	5-10-77	63	7.5	2600	15	2.2	20	5.8
2	5-11-77	68	7.3	4600	2.3	.64	11	.50
				Colorado				
1	6-21-76	28	7.7	2650	16	0.06	780	6.0
2	6-21-76	45	---	2020	3.3	.01L	970G	1.6
20	9-16-74	46	6.6	---	3.2	.12	---	---
3	9-21-76	50	6.4	35000	24	.07	1000	.69
4	9-25-76	15	7.1	6300	2.6	.30	25	.41
5	9-25-76	48	7.0	3800	5.1	.20	75	1.3

6	9-25-76	8	8.1	4500	.20	1.9	.31	.044
7	9-25-76	8	7.2	26400	2.4	.20	35	.091
8	5-21-75	41	6.6	3200	9.1	.03	890	2.8
9	7-08-77	22	7.4	11500	9	3.1	8.5	.78
10	9-23-76	16	6.3	13800	2.6	16	.48	.20
11	5-20-75	13	6.3	3300	.55	.45	3.4	.17
12	5-20-75	15	6.5	5000	2.9	.59	14	.58
13	5-20-75	14	2.9	2600	1.5	4.5	.98	.58
14	5-13-75	9	6.5	---	---	---	---	---
14M	9-09-69	10	6.7	7500	16	43	1.1	2.1
15	5-14-75	13	6.7	---	---	---	---	---
15M	9-09-69	9	6.8	14000	260	95	8.1	19
16	5-17-75	69	8.1	750	---	---	---	---
16O	9-19-74	79	7.7	---	.08	.22	1.1	.11
17	5-16-75	64	---	---	---	---	---	---
17M	9-18-68	68	7.5	965	.55	.4L	4G	.57
18M	9-18-68	55	7.7	977	.30	.4L	2.2G	.31
19	5-16-75	59	6.9	1000	---	---	---	---
19M	9-18-68	58	7.2	980	6.4	.4L	47G	6.5
20M	9-18-68	62	7.2	979	6.0	.4L	44G	6.1
21	7-08-77	52	6.8	2900	3.3	.13	75	1.1
22	5-19-75	45	7.9	1920	5.1	.03	500	2.7
23	7-26-75	50	---	2420	---	---	---	---
23M	9-19-68	50	6.7	2290	4.3	.4L	32G	1.9
24	7-26-75	56	---	2440	---	---	---	---
24M	9-19-68	57	7.0	2180	4.6	.4L	34G	2.1
25	7-26-75	---	---	---	---	---	---	---
25M	6-30-69	7	7.5	500	2.7	.01	790	5.4
26	6-30-69	7	7.2	498	2.8	.01	820	5.6
27	7-26-75	30	7.2	6000	---	---	---	---
27S	10-26-59	33	6.7	5930	28	2.4	34	4.7

Table 3.—Radium, uranium, and field data—Continued

Loc. no.	Date (mo-dy-yr)	Temperature (C)	pH	Specific conductance (umhos per cm at 25C)	Radium (pCi per liter)	Uranium (ug per liter)	REF (x 1000)	Radium / specific conductance
				Idaho				
1	6-28-76	45	7.1	9500	28	0.04	2100	2.9
2	6-28-76	17	7.1	4350	2.3	.20	34	.53
3	6-29-76	41	7.0	4100	1.4	.01	410	.34
4	6-29-76	42	6.8	1430	.71	.30	7.0	.50
5	6-30-76	24	7.3	2200	.53	.40	3.9	.24
6	---	75	7.2	3150	8.0	.05	470	2.5
				Nevada				
1	5-06-77	88	7.9	970	0.20	0.01L	59G	.21
2	5-07-77	22	7.9	130	.1L	.90	.33L	.77L
3	5-07-77	54	8.7	420	.1L	.01L	---	.24L
4	5-18-77	35	6.6	1730	14	.13	320	8.1
5	5-05-77	60	7.0	870	3.8	.03	370	4.4
6	5-05-77	33	---	850	13	.11	350	15
7	5-05-77	15	7.0	740	.40	.16	7.4	.54
8	5-05-77	34	7.1	1020	.20	1.2	.49	.20
9	5-08-77	92	8.0	7300	2.3	.01L	680G	.32
10	5-04-77	90	9.4	1170	.10	.01L	29G	.086
11	5-17-77	93	8.4	630	.1L	.01L	---	.16L
12	5-08-77	66	6.9	3500	8.4	.01L	2500G	2.4
13	5-04-77	27	---	570	.1L	[1]3.6	.08L	.18L
14	5-06-77	66	7.1	1480	7.1	.01L	2100G	4.8
15	5-06-77	51	7.8	1430	3.1	.01L	910G	2.2

16	5-16-77	78	7.9	540	110	.02	16000	200
17	5-15-77	42	7.5	600	12	.04	880	20
18	5-14-77	72	7.6	1210	5.6	.04	410	4.6
19	5-10-77	61	9.0	520	.1L	.62	.47L	.19L
20	5-10-77	63	9.0	540	.1L	.18	1.6L	.19L
21	5-14-77	94	7.2	530	.1L	.03	9.8L	.19L
22	5-11-77	53	8.5	1090	7.3	.90	24	6.7
23	5-12-77	33	7.9	1570	.20	.01L	59G	.13
24	5-13-77	14	7.4	4300	11	6.8	4.8	2.6
25	5-14-77	48	7.2	1700	.90	.02	130	.53
26	5-13-77	17	8.0	2900	.20	14	.042	.069
27	---	56	7.7	720	4.5	.04	330	6.3
New Mexico								
1	6-08-75	29	6.7	6000	230	0.60	1100	38
2	2-05-76	20	---	1360	---	---	---	---
20	12-05-74	35	7.3	---	3.4	14	.71	2.5
3	2-05-76	68	8.1	650	---	---	---	---
30	12-05-74	64	8.6	---	.29	15	.057	.45
4	2-05-76	59	8.4	425	---	---	---	---
40	12-05-74	61	8.8	---	.48	3.9	.36	1.1
5	2-05-76	52	---	560	20	.04	1500	36
50	12-05-74	55	7.0	---	16	3L	---	---

[1] Part of sample spilled in transport from field. Analysis believed valid on remaining sample.

Table 3.—Radium, uranium, and field data—Continued

Loc. no.	Date (mo-dy-yr)	Temper-ature (C)	pH	Specific conductance (umhos per cm at 25C)	Radium (pCi per liter)	Uranium (ug per liter)	REF (x 1000)	Radium / specific conductance
Utah								
1	4-29-76	51	7.5	14000	32	0.80	120	2.3
2	4-29-76	13	7.8	990	4.2	1.9	6.5	4.2
3	4-20-76	15	8.1	3500	.09	2.7	.098	.026
4	4-19-76	16	7.6	2150	.30	1.9	.46	.14
5	5-18-77	15	7.7	1730	2	2.3	2.6	1.2
6	4-29-76	56	6.2	52000	220	1.5	430	4.2
7	4-30-76	20	7.8	22000	3.1	1.7	5.4	.14
8	4-30-76	16	7.4	13000	2.9	2.0	4.3	.22
9	4-28-76	43	6.8	45000	53	1.5	100	1.2
10	7-18-75	45	6.7	55000	76	.10	2200	1.4
11	4-28-76	43	6.6	35000	75	.01L	22000G	2.1
12	4-28-76	43	6.6	35000	120	.06	5900	3.4
13	5-01-76	54	7.4	30000	66	.04	4900	2.2
14	7-18-75	56	7.0	15000	21	.28	220	1.4
15	7-19-75	53	7.6	16000	74	.08	2700	4.6
16	5-02-76	17	7.9	30000	5.0	1.4	11	.17
17	7-20-75	33	6.8	2050	.20	.89	.66	.098
18	5-02-76	25	8.0	1430	.26	.50	1.5	.18
19	5-19-77	61	7.5	27000	130	.09	4200	4.8
20	7-20-75	78	7.1	5800	3.5	.05	210	.60
21	7-21-75	14	7.7	6000	36	.05	220	6.2
22	5-03-76	11	7.8	5600	38	.07	1600	6.8
23	5-03-76	14	7.2	3100	4.0	.10	120	1.3
24	5-03-76	18	7.6	1030	.49	1.6	.90	.48
25	5-03-76	12	7.8	1490	.22	4.7	.14	.15

26	7-21-75	74	6.8	3800	6.3	.03	620	1.7
27	7-23-75	59	8.0	2200	---	---	---	---
270	9-18-75	73	7.3	---	7.5	.5L	44G	3.4
28	7-23-75	42	6.6	15000	41	.60	200	2.7
				Wyoming				
1	6-25-76	53	6.4	3050	15	0.10	440	4.9
2	6-25-76	34	7.6	3200	18	.05	1100	5.6
3	6-25-76	30	6.3	3000	15	.10	440	5.0
4	6-15-76	18	7.1	1800	3.5	2.8	3.7	1.9
5	6-27-76	35	7.9	930	1.8	.10	53	1.9
6	6-27-76	41	7.2	1620	3.1	.20	46	1.9
7	6-26-76	8	7.5	1630	.34	.80	1.3	.21
8	6-23-76	38	7.9	1120	61	.03	6000	54
9	6-27-76	62	7.0	7700	31	.04	2300	4.0
10	6-22-76	12	8.0	2080	.47	.10	14	.23
11	6-22-76	10	7.1	1560	.36	.07	15	.23

Parameter	Number of samples	Range	Mode	Median
Radium----------------	116	<0.1-260	3.2	3.3
Uranium---------------	109	<0.01-95	0.15	0.2
Specific conductance--	116	130-55000	1500	2180
Temperature-----------	116	7-94	50	41
pH--------------------	114	2.9-9.4	7.4	7.4

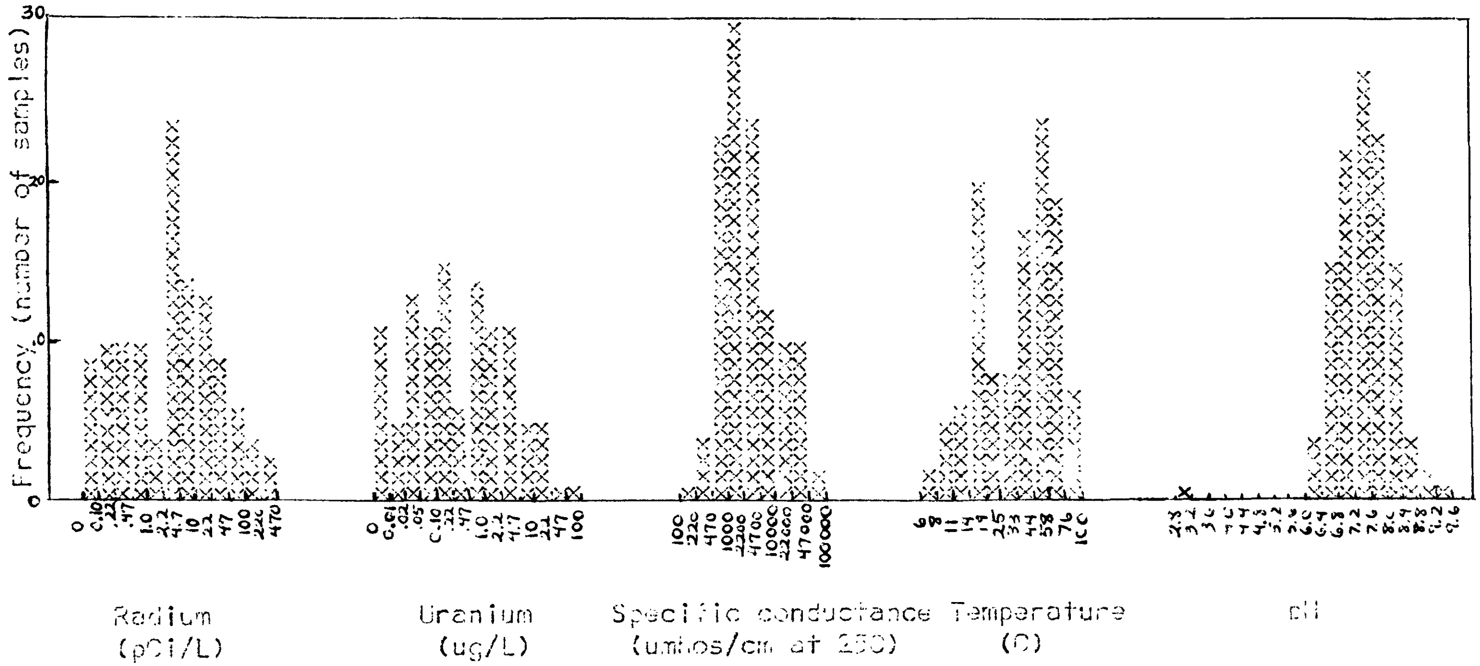

Figure 8. Frequency diagrams for the five measured parameters.

springs--for example, hot ones (>33°C) and cold ones (<33°C) or, possibly, ones showing low contents of radium (<2.2 pCi/l) or uranium (<0.47 μg/l) and ones showing high contents of radium (>2.2 pCi/l) or uranium (>0.47 μg/l). However, a lack of correlation between parameters such as radium and uranium (fig. 9) indicates that a division into two groups of springs would not be a simple one and would involve different sets of springs for each pair of parameters. Therefore, all of the data shall be regarded as coming from one overall population.

Analysis and interpretation of data

Linear regression analyses were run to determine the relationships among the five measured parameters--radium, uranium, specific conductance, temperature, and pH. Graphs are shown on figures 9-18, and correlation coefficients are given in table 4. A positive correlation (0.65), significant at the 99-percent level, is apparent between radium and specific conductance. Negative correlations, significant at the 99-percent level, are present for radium and pH (-0.54), specific conductance and pH (-0.48), and uranium and temperature (-0.46). There is no significant correlation between radium and uranium, radium and temperature, uranium and conductance, uranium and pH, conductance and temperature, or temperature and pH. The presence of a correlation does not necessarily indicate a cause-and-effect relationship; it is merely a statistical measure of the degree to which two variables fit a straight line. Why the correlation exists must be reasoned on other grounds. (See Rickmers and Todd, 1967, for

Table 4.--Correlation coefficients for the five measured parameters

	Radium	Uranium	Specific conductance	Temperature	pH
Radium	1.00	0.07	0.65	0.11	-0.54
Uranium		1.00	.18	-.46	-.03
Specific conductance			1.00	-.05	-.48
Temperature				1.00	.14
pH					1.00

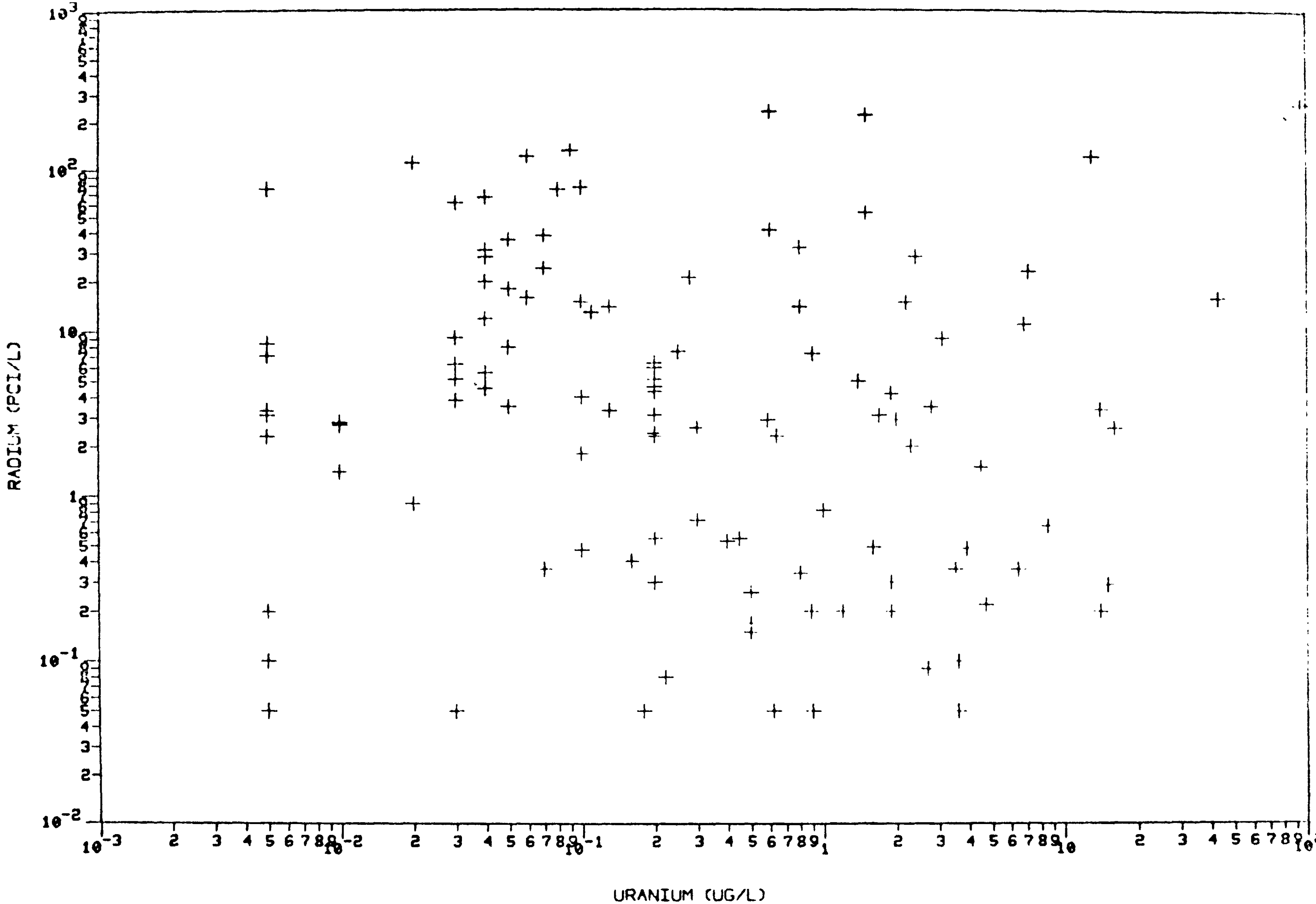

Figure 9. Relationship between radium and uranium concentrations. Correlation coefficient is 0.07.

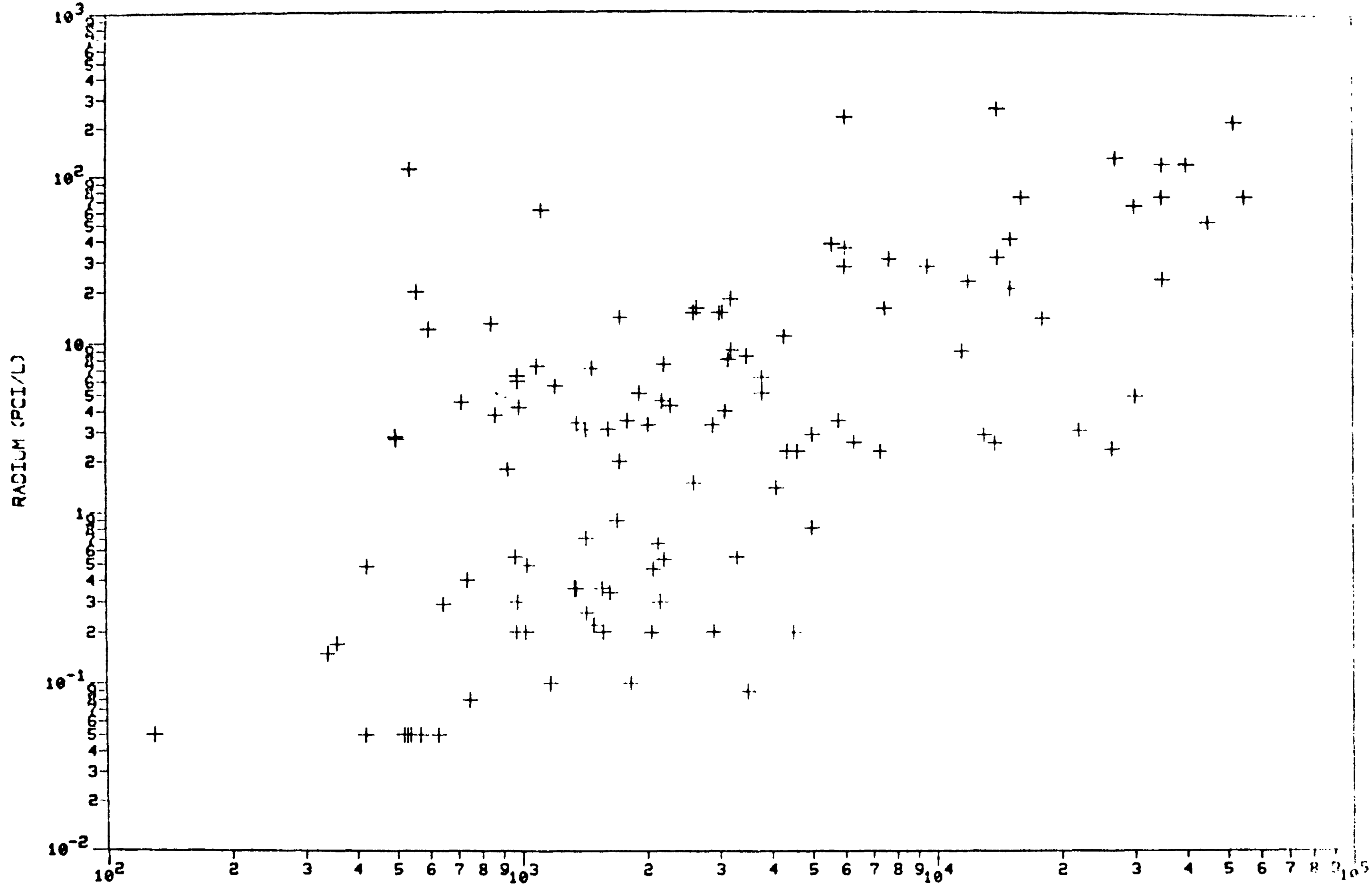

Figure 10. Relationship between radium concentration and specific conductance. Correlation coefficient is 0.65.

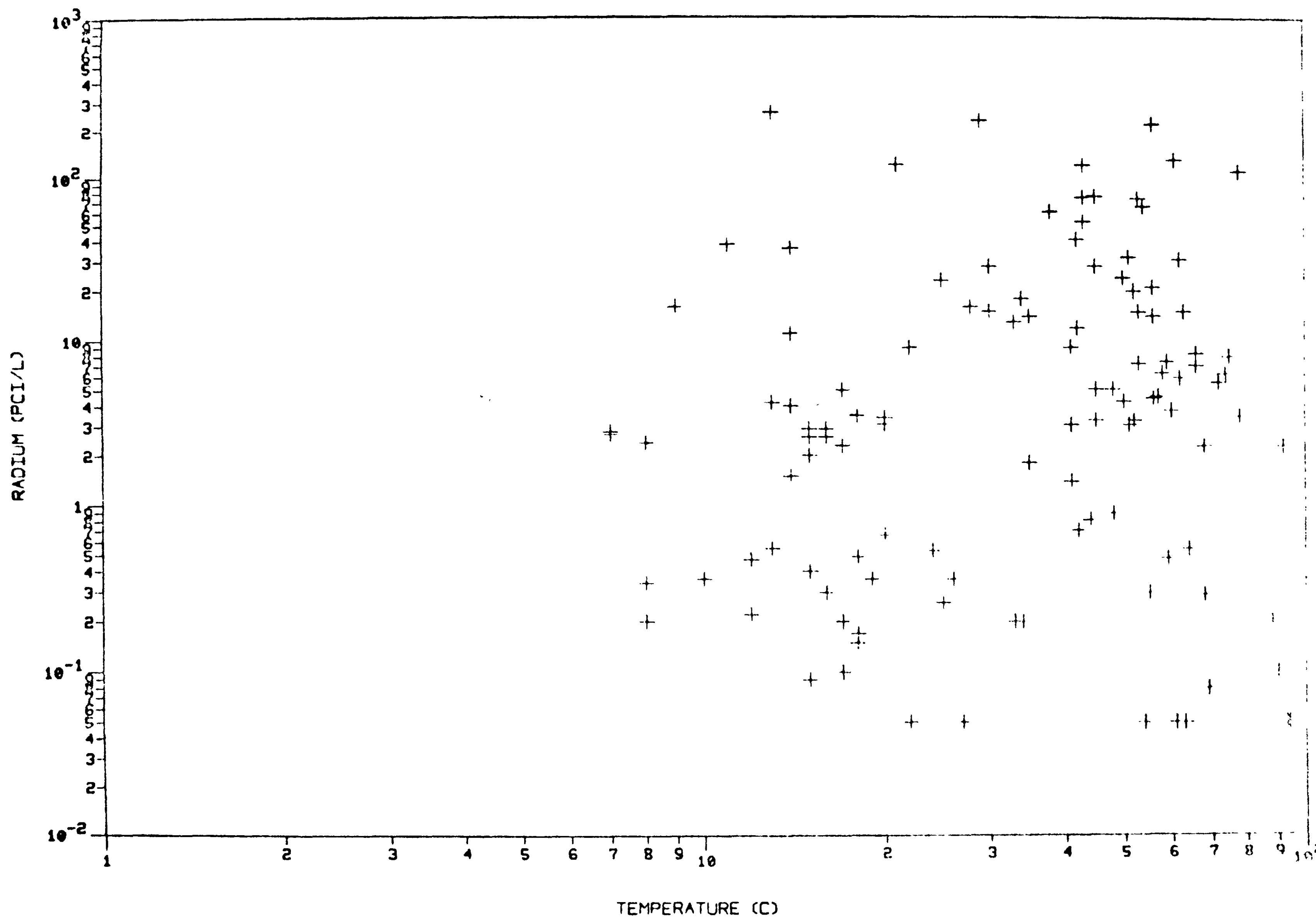

Figure 11. Relationship between radium concentration and temperature. Correlation coefficient is 0.11.

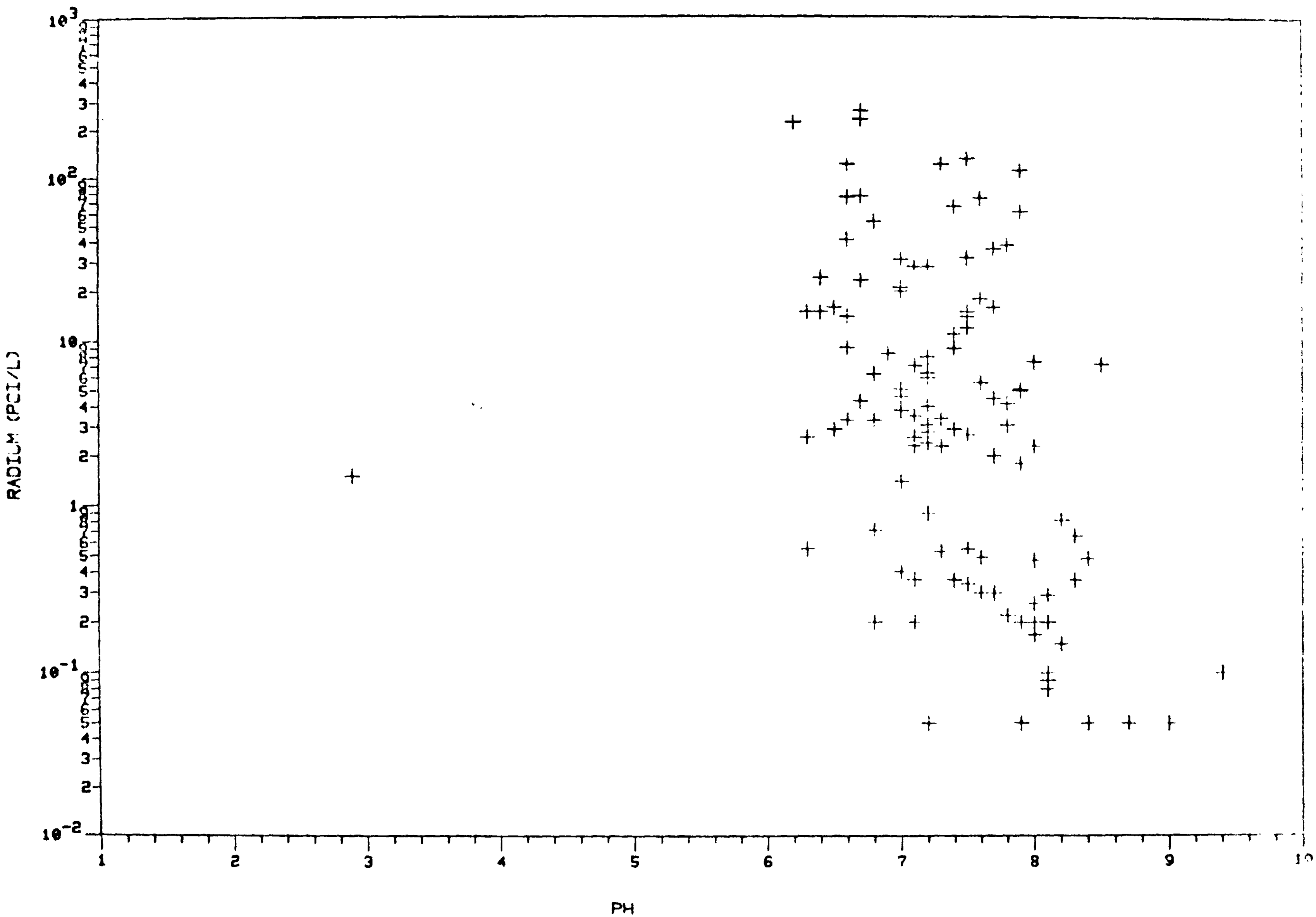

Figure 12. Relationship between radium concentration and pH. Correlation coefficient is -0.54.

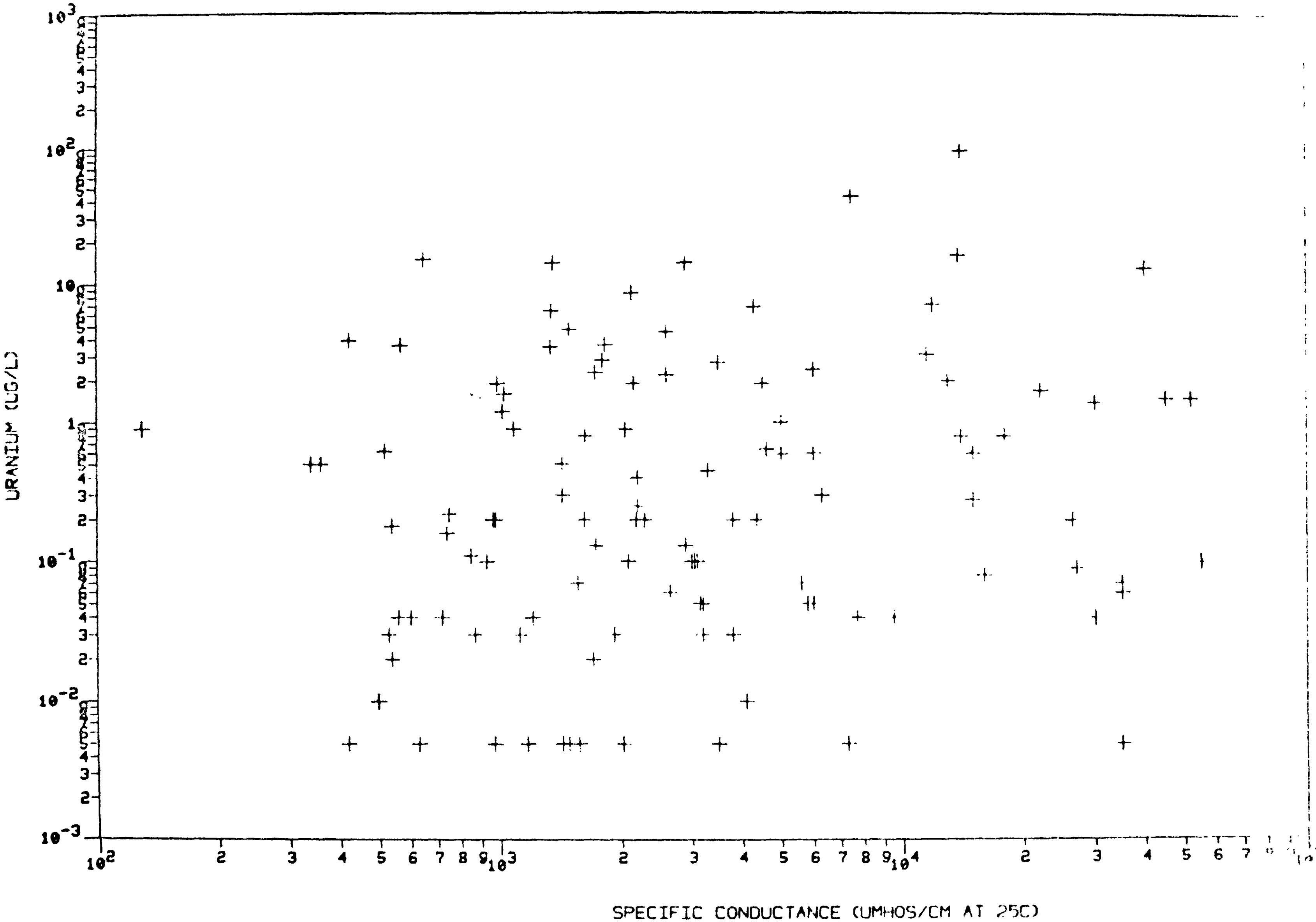

Figure 13. Relationship between uranium concentration and specific conductance. Correlation coefficient is 0.18.

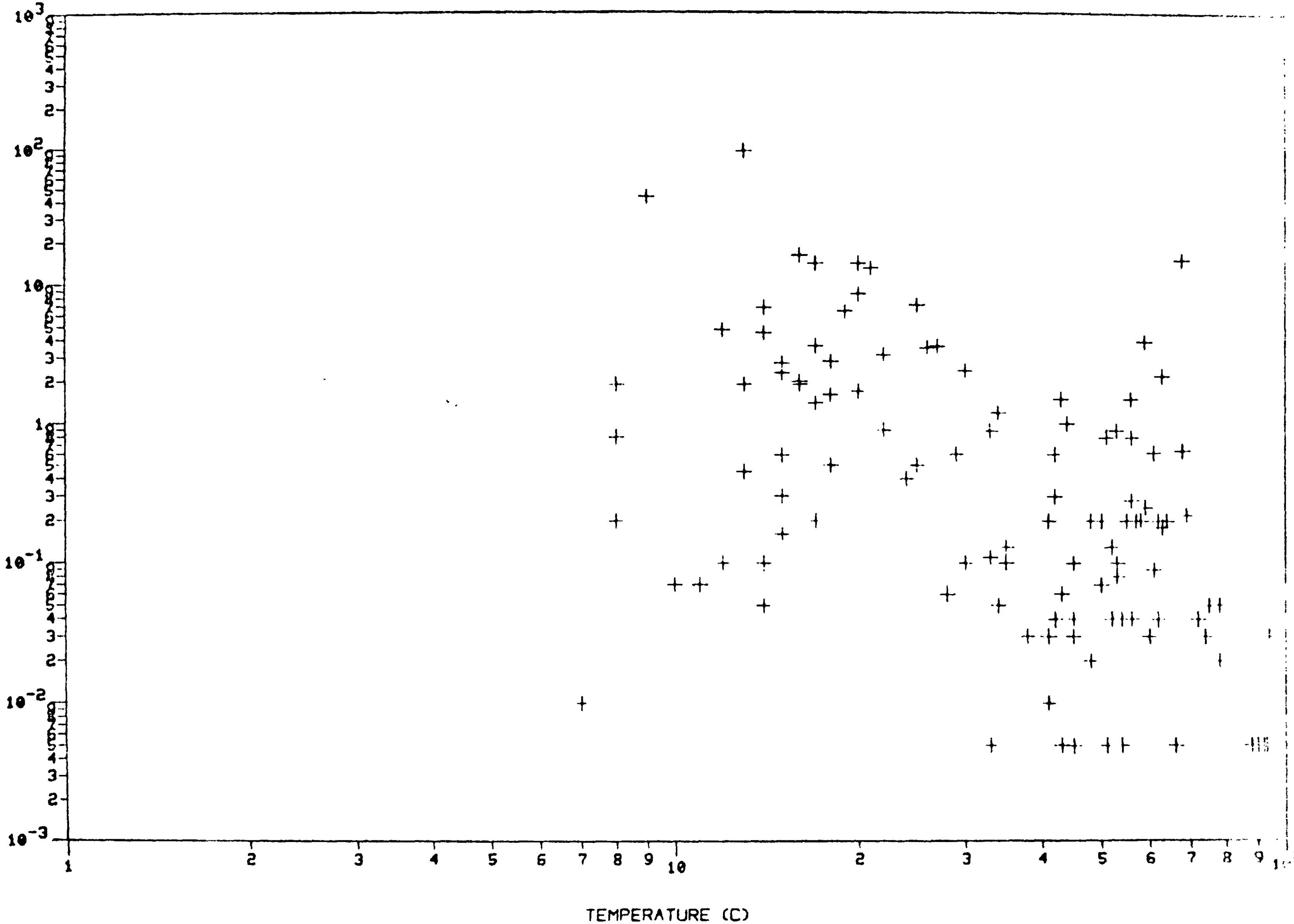

Figure 14. Relationship between uranium concentration and temperature. Correlation coefficient is -0.46.

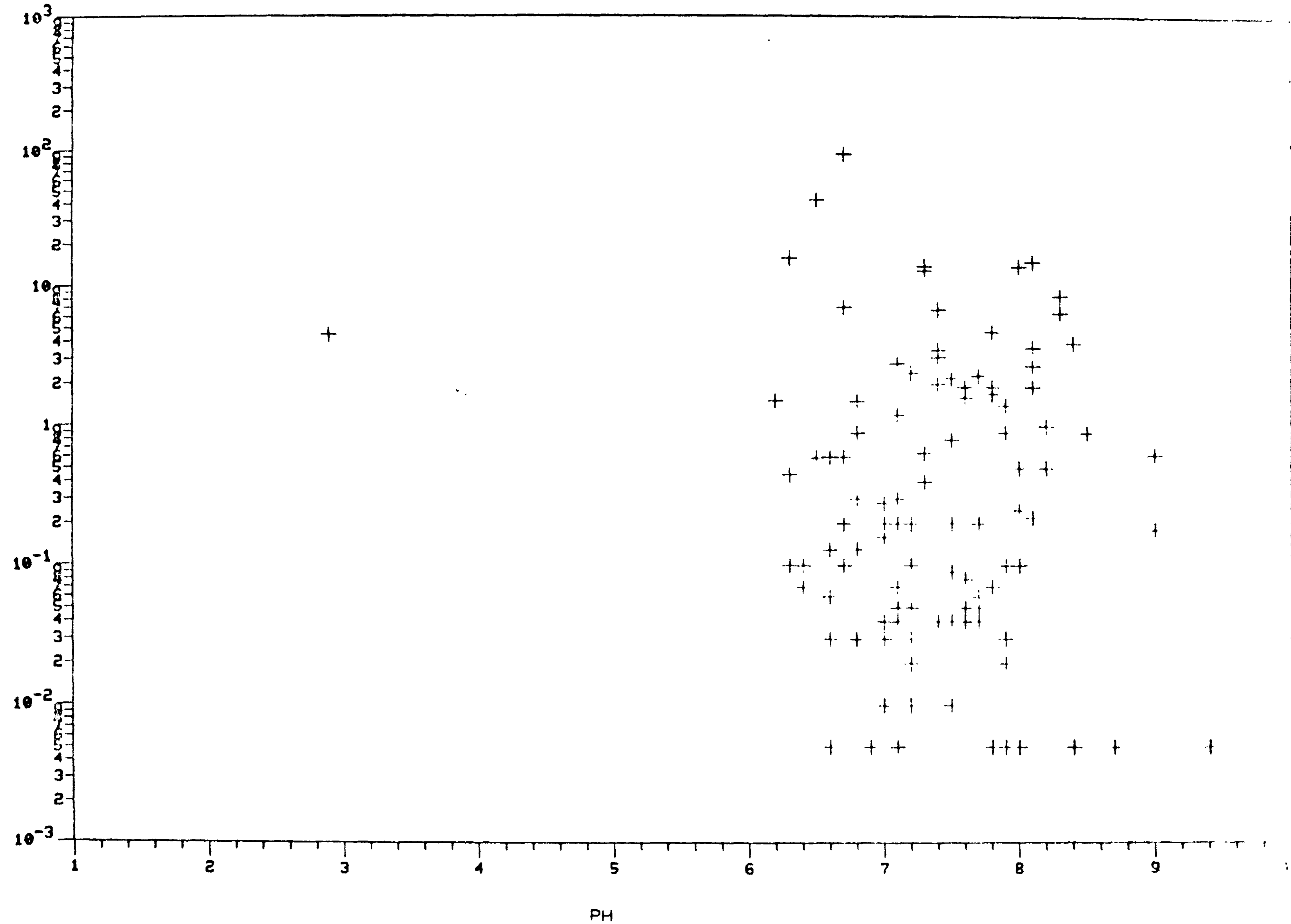

Figure 15. Relationship between uranium concentration and pH. Correlation coefficient is -0.03.

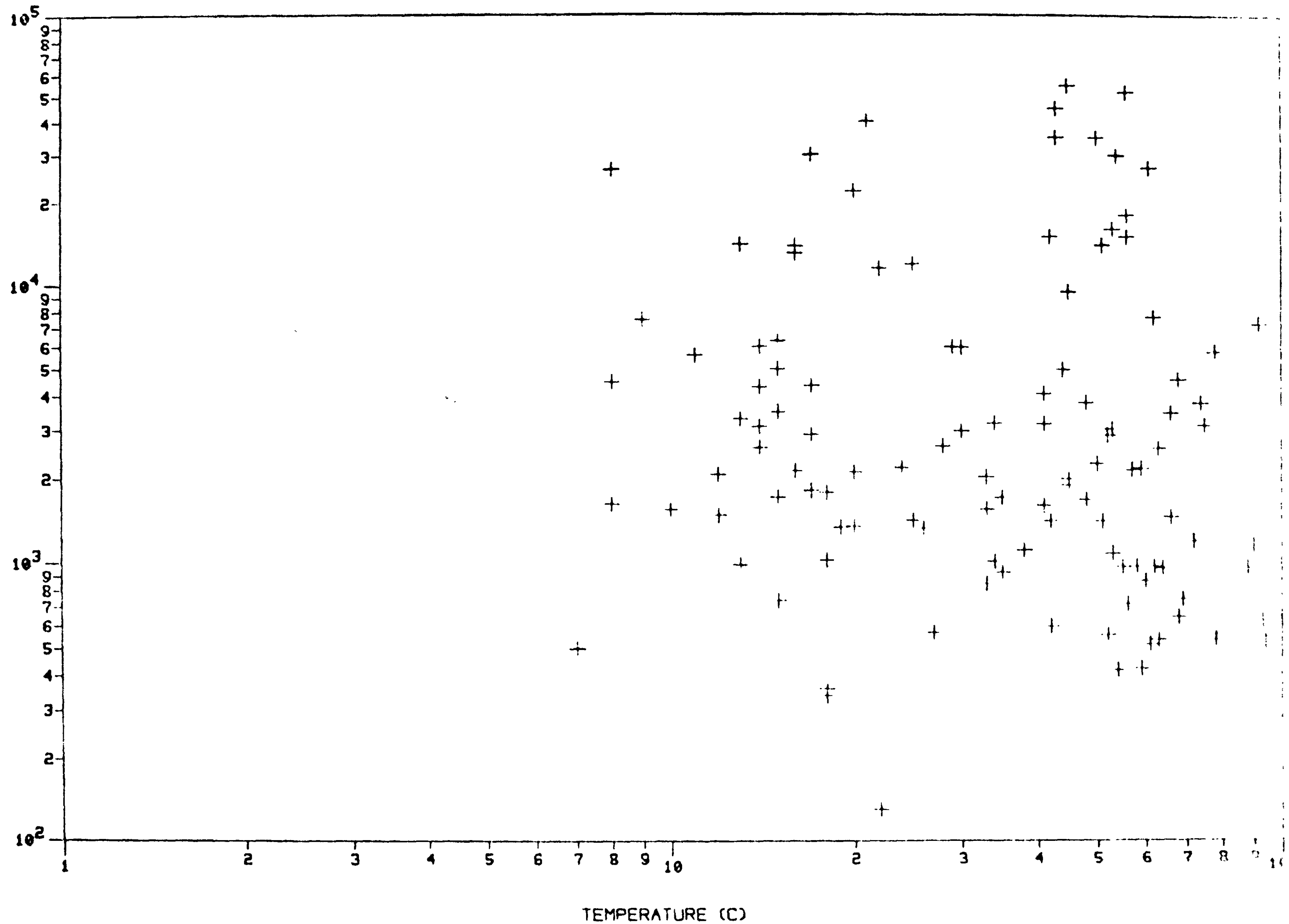

Figure 16. Relationship between specific conductance and temperature. Correlation coefficient is -0.05.

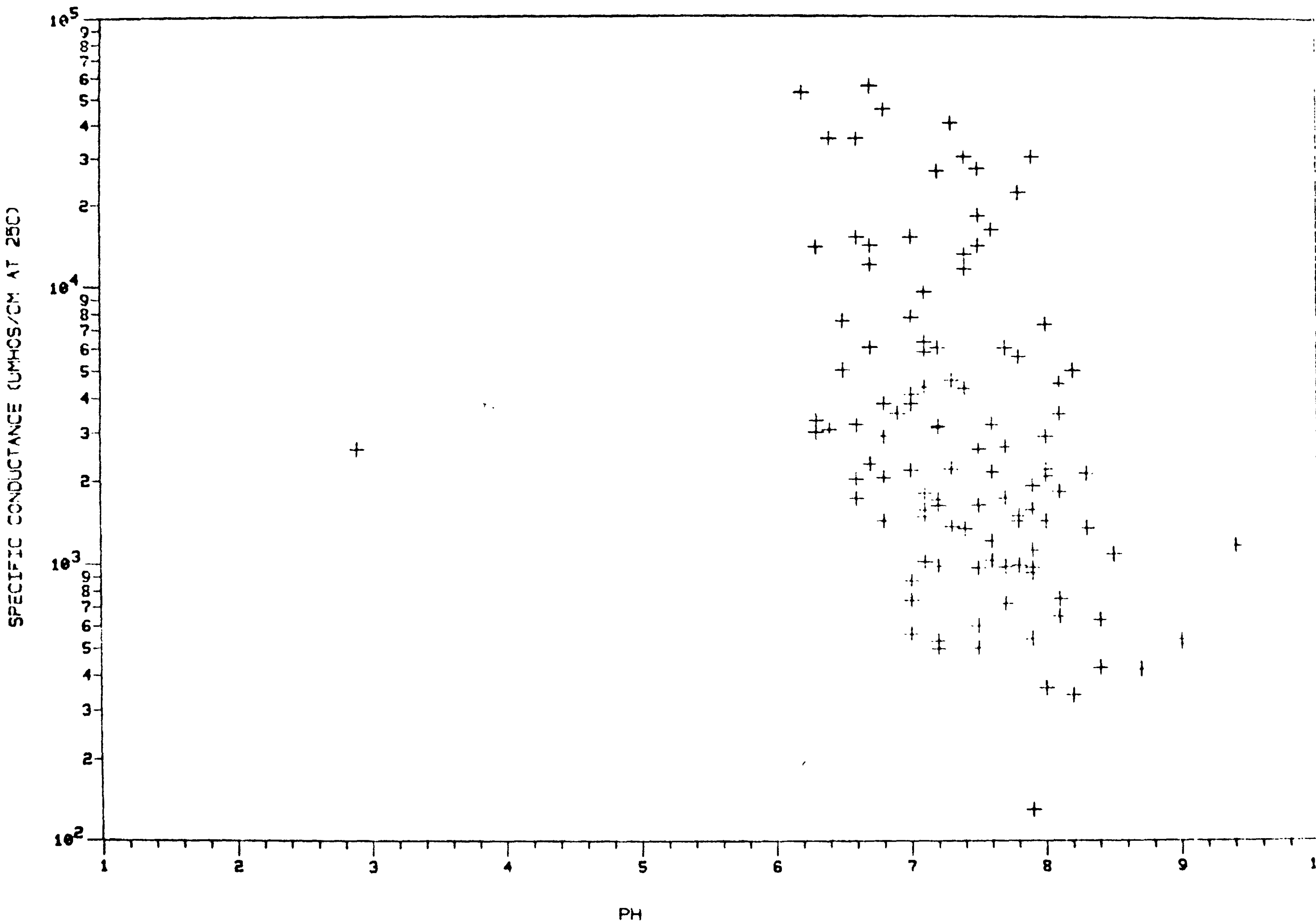

Figure 17. Relationship between specific conductance and pH. Correlation coefficient is -0.48.

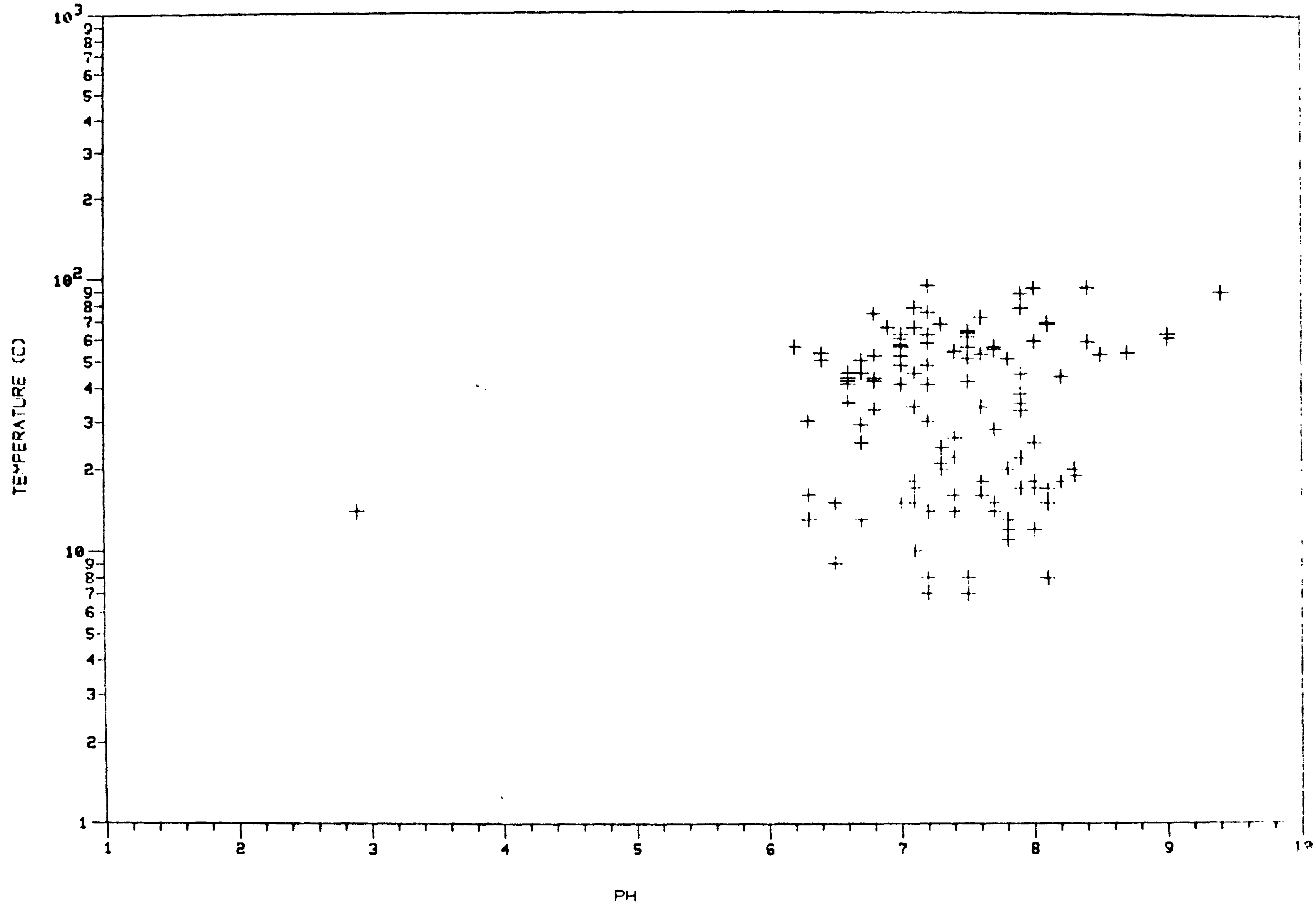

Figure 18. Relationship between temperature and pH. Correlation coefficient is 0.14.

discussion of basic statistics.)

The positive correlation between radium and specific conductance (fig. 10) may reflect the effect that ionic strength has on the solubility of didivalent salts. The ionic strength of a solution increases as the total number and charge of ions present increase, and the greater the ionic strength, the greater will be the solubility of a given salt (Krauskopf, 1967, p. 70-76). The amount of radium in solution may depend in part on the amount of barium and sulfate ions present and on the solubility of barium sulfate (Cadigan and others, 1976; Gilkeson and others, 1977), which in turn depends at least in part on the total ionic strength of the water involved. Therefore, a higher specific conductance indicates a solution having more dissolved solids, more ions, and higher ionic strength, and a higher ionic strength means a greater solubility for barium sulfate and hence more radium that will stay in solution and not be coprecipitated out.

A negative correlation (-0.48) exists between specific conductance and pH (fig. 17). The pH depends on what salts are dissolved in the water; some tend to form basic solutions when dissolved, and others, acidic. Water whose pH is very high (above 8.5) is usually of the sodium-carbonate-bicarbonate type, and water having moderately high pH is commonly bicarbonate rich (Davis and DeWiest, 1966, p. 76). By inference, then, water having a somewhat lower pH, perhaps 5 to 7, is likely to be of the sulfate or chloride type. Like pH, the specific conductance depends on the type and amount of ions present in the water (Davis and DeWiest, 1966, p. 84). Fresh water, which has low conductance, commonly contains dissolved calcium sulfate or bicarbonate as the predominant consituent, whereas more saline water, which has higher conductance, contains a larger amount of dissolved sodium chloride. Therefore, in general, chloride-rich water is likely to have a high specific conductance and a moderately low pH, and bicarbonate-rich water is likely to have a low conductance and a moderately high pH; such relationships lead to an observed negative correlation between conductance and pH.

The negative correlation between radium and pH (fig. 12) is probably a result of the relationships described in the above two paragraphs. Specific conductance is negatively related to pH, and radium is positively related to specific conductance. Therefore, radium appears to have a negative relation to pH, with a correlation coefficient of intermediate value, -0.54.

The only significant correlation (-0.46) that uranium has with any of the other four measured parameters is with temperature (fig. 14). The reasons for this negative correlation may be related to carbonate solubility. Uranium is known to form soluble complexes with carbonate ions, and carbonates, unlike many salts, are more soluble in cold water. Therefore, colder water is likely to have more dissolved carbonate and to contain more complexed uranium than warmer water.

The strongest correlation is between radium and specific conductance (fig. 10). To gain some insight into which springs may have a radium concentration that is most strongly influenced by a factor other than ionic strength (as represented by conductance), we can divide radium by conductance and examine the values (table 3). This shows that Monte Neva Hot Springs, Nev. (no. 16), with a value of 200, is the one most affected by other factors. Other moderately high values (10-100) are shown by Washakie Warm Springs, Wyo. (no. 8), Soda Dam Hot Springs, N. Mex. (no. 1), Faywood Hot Springs, N. Mex. (no. 5), Bartine Hot Springs, Nev. (no. 17), Taylor Soda Springs, Colo. (no. 15), and Golconda Hot Springs, Nev. (no. 6). Uranium concentration in the source rocks is one of the unmeasured parameters which affects the radium concentration observed in a spring. Therefore, it is certainly possible that the Monte Neva Hot Springs system, for example, is related to uranium-rich rocks.

The lack of correlation between radium and uranium (fig. 9) indicates that the factors controlling their concentrations in water are not related. Radium content may be high in a spring where uranium content is low, or vice versa, but if the situation were that simple, a negative correlation would exist. The fact that radium and uranium contents can also both be high or both be low in a given spring, indicates that the situation is more complex. As discussed above, high conductance and low pH tend to favor radium abundance in the water, and low temperature tends to favor uranium abundance; in addition, unmeasured factors, such as Eh or ionic composition of the water, undoubtedly also affect the relative mobility of these two elements and contribute to their fractionation in the hydrogeologic environment.

One way of looking at the relationship between radium and uranium is to calculate the radium enrichment factor (REF) for each spring (table 3). This factor is a measure of the degree of radioactive disequilibrium between radium and uranium and is calculated by dividing the measured radium concentration by the amount of radium that would be in equilibrium with the measured uranium concentration in the spring. In this way we can see which spring systems favor the mobility of radium over uranium. The highest REF values (>10,000) are shown by Stinking Hot Springs, Utah (no. 11), and Monte Neva Hot Springs, Nev. (no. 16). A number of other springs show values over 1,000. Linear regression analyses of REF on conductance, temperature, and pH (figs. 19-21) yield correlation coefficients of 0.33, 0.40, and -0.37, respectively. These coefficients are statistically significant at the 99-percent level and indicate that radium mobility relative to uranium is favored by water with high specific conductance, high temperature, and low pH.

Conclusion

Linear regression analyses indicate that a significant positive correlation exists between radium and specific conductance and that significant negative correlations exist between radium and pH, specific conductance and pH, and uranium and temperature. In other words, radium mobility relative to uranium is favored by water with high specific conductance, high temperature, and low pH.

The strongest correlation is between radium and specific conductance. Examination of the ratio between these two parameters

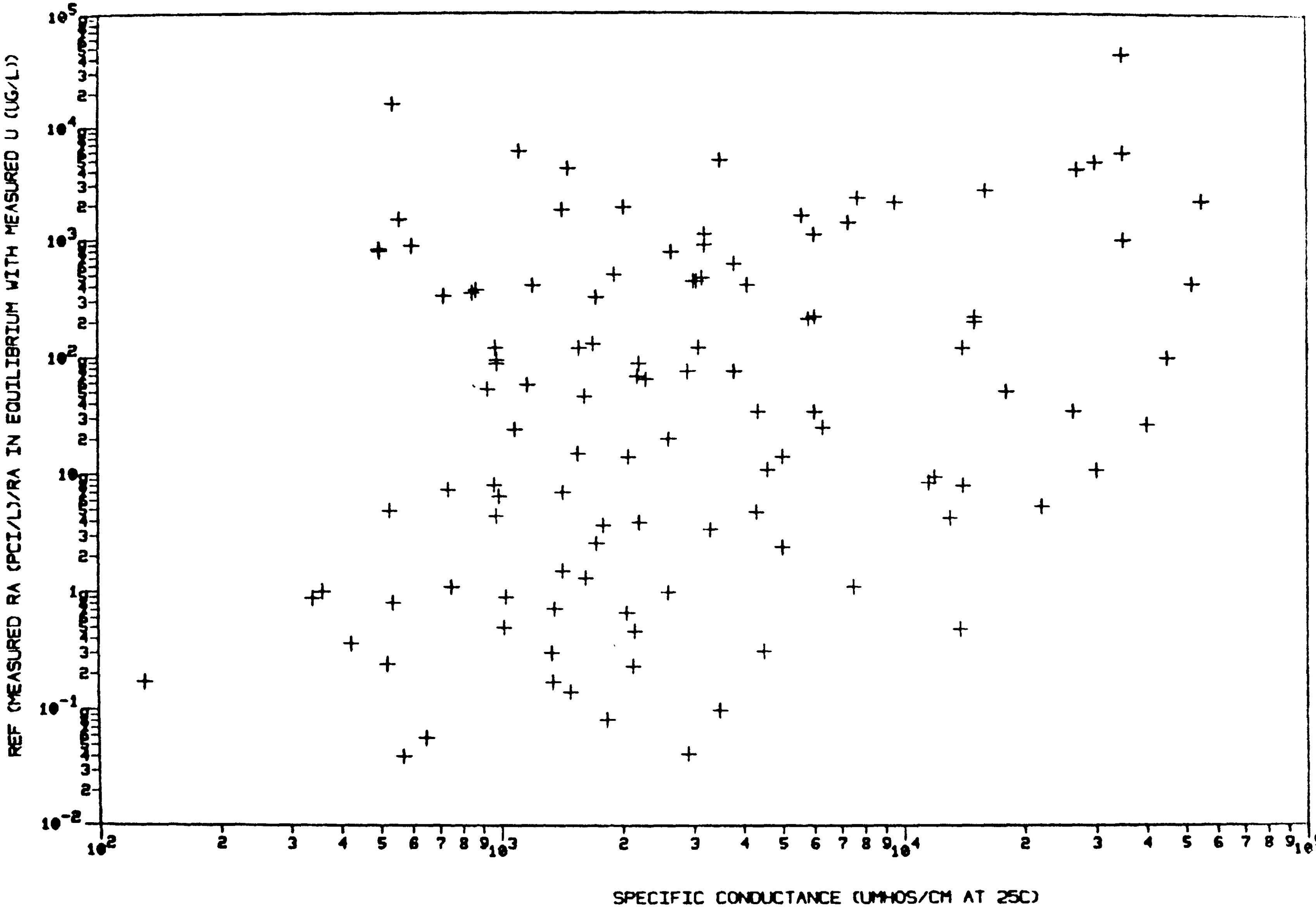

Figure 19. Relationship between REF (radium enrichment factor) and specific conductance. Correlation coefficient is 0.33.

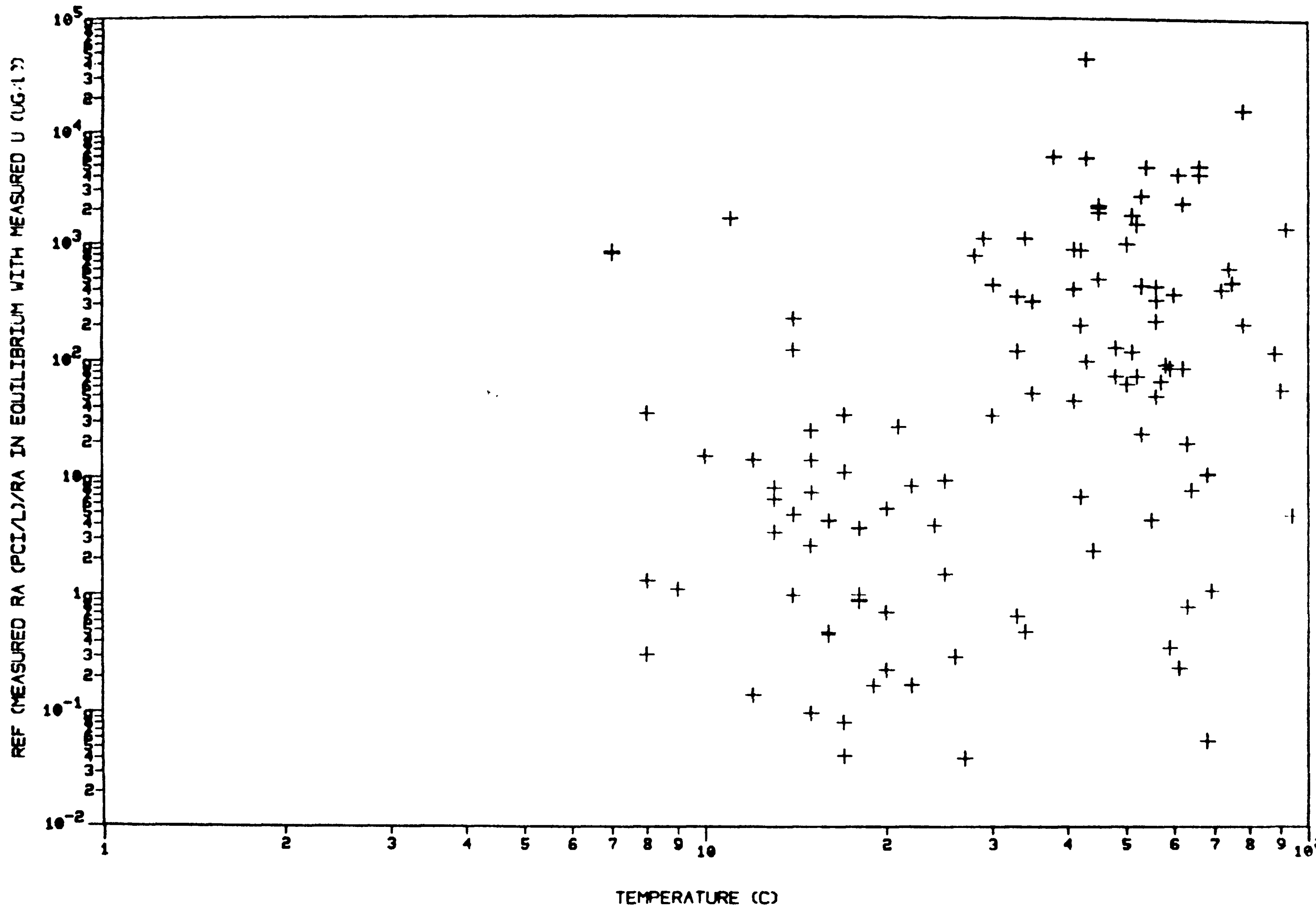

Figure 20. Relationship between REF (radium enrichment factor) and temperature. Correlation coefficient is 0.40.

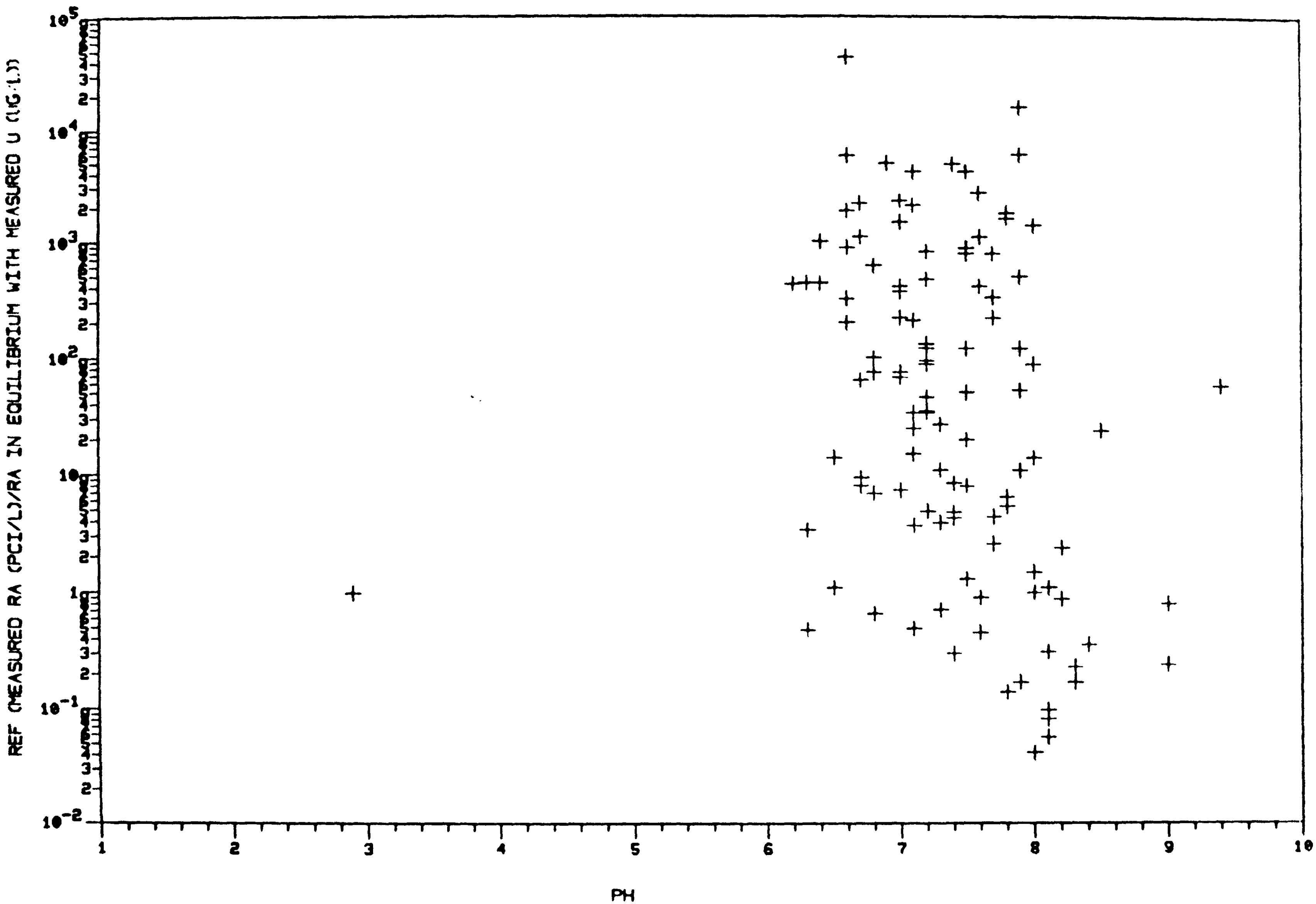

Figure 21. Relationship between REF (radium enrichment factor) and pH. Correlation coefficient is -0.37.

shows that Monte Neva Hot Springs, Nev., has a radium concentration that is affected most by unmeasured parameters, one of which may be the presence of uranium-rich source rocks.

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