UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Radium and uranium concentrations and associated hydrogeochemistry in ground water in southwestern Pueblo County, Colorado

By

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Open-File Report 79-974

This report is preliminary and has not
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Abstract

Radium and uranium concentrations in water from 37 wells tapping the aquifer system of the Dakota Sandstone and Purgatoire Formation in southwestern Pueblo County, Colorado, have a wide range of values and define several areas of high radioactivity in the ground water. Radium ranges from 0.3 to 420 picocuries per liter and has a median value of 8.8, and uranium ranges from 0.02 to 180 micrograms per liter and has a median value of 2.4. Radon concentrations, measured in 32 of the 37 wells, range from less than 100 picocuries per liter to as much as 27,000 and have a median value of 580.

Relationships among the radioactive elements and 28 other geochemical parameters were studied by using correlation coefficients and R-mode factor analysis. Five factor groups were determined to represent major influences on water chemistry: (1) short-term solution reactions, (2) oxidation reactions, (3) hydrolysis reactions, (4) uranium distribution, and (5) long-term solution reactions. Uranium concentrations are most strongly influenced by oxidation reactions but also are affected by solution reactions and distribution of uranium in the rocks of the aquifer system. Radon and radium concentrations are mostly controlled by uranium distribution; radium also shows a moderate negative relationship with oxidation.

To explain the statistical and spatial relationships among the parameters, a model was developed involving the selective leaching of uranium-bearing phases and metal sulfides which occur in discontinuous zones in sandstone and shale. When reducing conditions prevail, uranium is immobile, but radium can be taken into solution. When faults and associated fractured rocks allow oxidizing conditions to dominate, uranium can be taken into solution; radium can also be taken into solution, or it may become immobilized by coprecipitation with iron and manganese oxides or with barite. Several areas within the study area are discussed in terms of the model.

Introduction

The purpose of this report is to present and interpret data on radium and uranium concentrations and other hydrogeochemical parameters in the ground water of southwestern Pueblo County, Colo. Locations of the 37 water wells sampled for radium and uranium during this study are shown on figure 1; four of the wells were sampled in 1975, and the other 33 wells, in 1977. The area is located in south-central Colorado on the Great Plains adjacent to the Rocky Mountains. It is drained by tributaries flowing east and northeast to the Arkansas River.

Specific conductance, pH, and temperature were measured in the field at all 37 sites at the time of sampling. In addition, dissolved oxygen and Eh were measured in 1977 at most of the sites and at one of the sites (loc. 24) sampled in 1975.

Sampling and analytical methods

Most of the samples were taken at outdoor faucets after allowing the water to run for several minutes until the temperature stabilized. Some of the faucets tap pressure tanks connected with automatic pumps, and some are fed directly by manually controlled pumps. The use of tanks may have affected the measurements of Eh and of some metals, such as copper and zinc, but we believe that the effects are minimized by the fact that the systems are generally airtight and the water residence time is generally low. A few

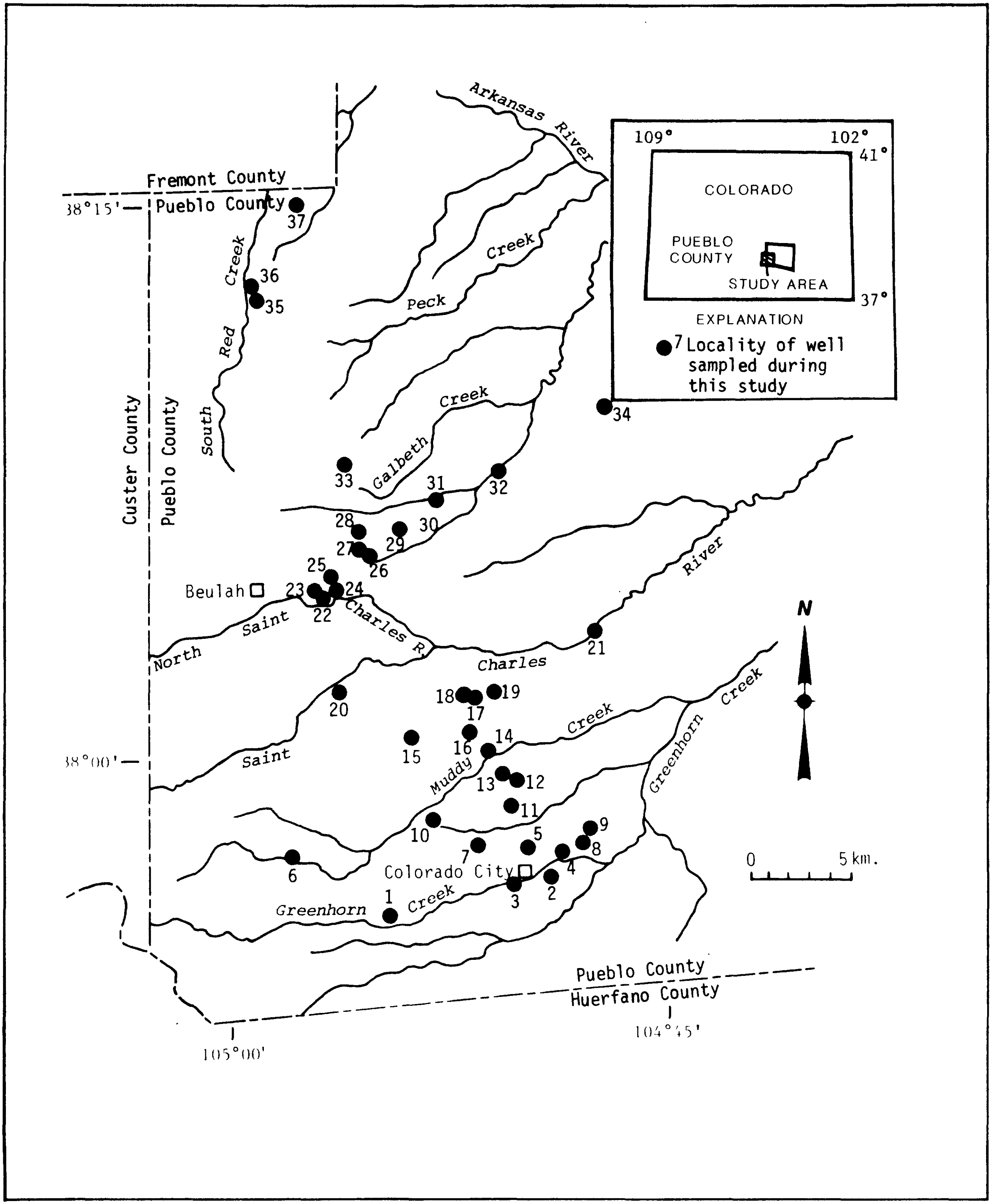

Figure 1.--Index map showing sample localities listed in Table 1.

samples were taken under other circumstances. The samples at localities 8 and 19 were taken directly from a holding tank in the pump house. Sample 10 was taken directly from the well using a downhole thief sampler, and sample 35 was bailed.

Samples for radium and uranium analysis were taken at all 37 sites, and radon determinations were made at 32 of the sites. At 10 of the 37 sites, additional samples were taken to be analyzed for major ions and trace elements. A 1-liter sample, filtered through 0.45-mm filter membrane and acidified with 2 ml of 6 N nitric acid, was collected for analysis of major cations; a 250-ml sample, filtered but not acidified, was collected for major anions; a 250-ml untreated sample was collected for alkalinity and miscellaneous parameters; and a 4-liter sample, filtered and acidified with 4 ml of 6N nitric acid, was collected for analysis of trace elements by emission spectrography. For most of the other 27 sites we used analytical results obtained by Klein and others (1978) for samples collected in 1973. The samples we collected in 1977 and those collected in 1973 at localities 1, 6, and 11 were probably taken from different wells, but field measurements indicate that the waters are similar. Sampling and analytical methods used during the present study and in Klein's study are the same. All analyses were performed by laboratories of the U.S. Geological Survey.

Radium concentrations were determined by radiochemical carrier-precipitation methods. A 1-liter sample of untreated water was collected at each site. The four samples collected in 1975 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 and alpha count is taken on the ingrown radon-222 and the radium-226 is calculated. Because of a change in sample submittal and accounting procedure, the 33 samples collected in 1977 were analyzed by the precipitation 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. Unfortunately, this method determines total radium only. The contribution of radium-228, a thorium daughter product, is assumed to be small in our samples, but resampling would have to be done to verify this assumption. The two highest radium values (from the 1975 samples) were obtained by the radon method for radium-226. Had they been analyzed for total radium by the precipitation method, the values might have been even higher. These two methods are discussed in Thatcher, Janzer, and Edwards (1977).

Uranium concentrations were determined by fluorometric methods. A 1-liter sample of untreated water was taken at the sites sampled in 1975. These samples were analyzed by both direct and 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 ultaviolet light in a reflection-type fluorometer. The extraction method involves preconcentrating the uranium by coprecipitation with aluminum phosphate. The precipitate is then desolved 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 1977 were analyzed by extraction fluorometry only. These 1-liter samples were filtered through

0.45-μm filter membrane and acidified with 2 ml of 6N nitric acid in the field. Analytical results on the two sets of samples are comparable, as determined by duplicate samples taken during another study (Felmlee and Cadigan, 1978).

Radon was measured at the sample sites using a modified alpha spectrometer (Reimer, 1977) which had been calibrated using a U.S. Geological Survey 100-pCi (picocurie) standard. For each determination, a 2-liter sample of water was collected in a 2.8-liter plastic container. The lid was sealed, and the container was shaken vigorously for 1 minute. Using a syringe, a 50-ml sample of the air-gas mixture in the top of the container was taken through a self-sealing valve in the lid. The gas sample was then inserted into a partial vacuum in the alpha-counting chamber of the spectrometer. The sample was counted for 1 minute, recounted after a 2-minute wait, and then recounted after another 2-minute wait. The last count was corrected back to time=1 minute and then adjusted mathematically to obtain the value of radon-222 in picocuries per liter.

Hydrogeology

General Geology

A simplified geologic map of the study area, showing faults and folds and the outcrop areas of Dakota Sandstone and Purgatoire Formation of Early Cretaceous age, is shown on figure 2. Underlying these units and outcropping generally to the west are the Morrison and Ralston Creek Formations and Entrada Sandstone of late Jurassic age, the Fountain Formation of Permian and Pennsylvanian age, and the San Isabel Granite (Boyer, 1962) and migmatitic gneiss of Proterozoic age. Overlying the Dakota and outcropping generally to the east are Graneros Shale, Greenhorn Limestone, Carlile Shale, and Niobrara Formation, all of late Cretaceous age. A diagrammatic stratigraphic section,

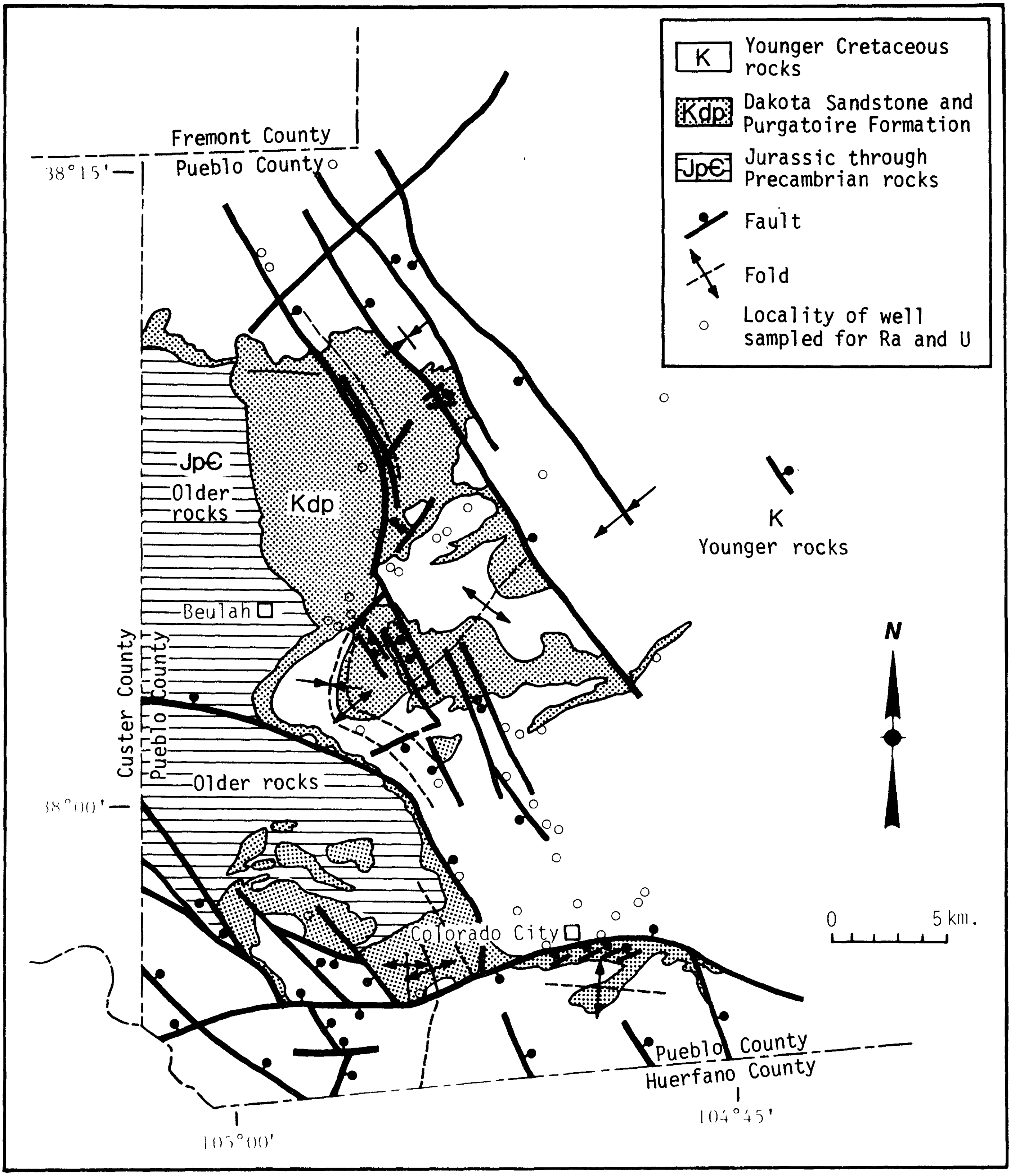

Figure 2.--Simplified geologic map of study area. Modified from Scott and others (1976) and Johnson (1969).

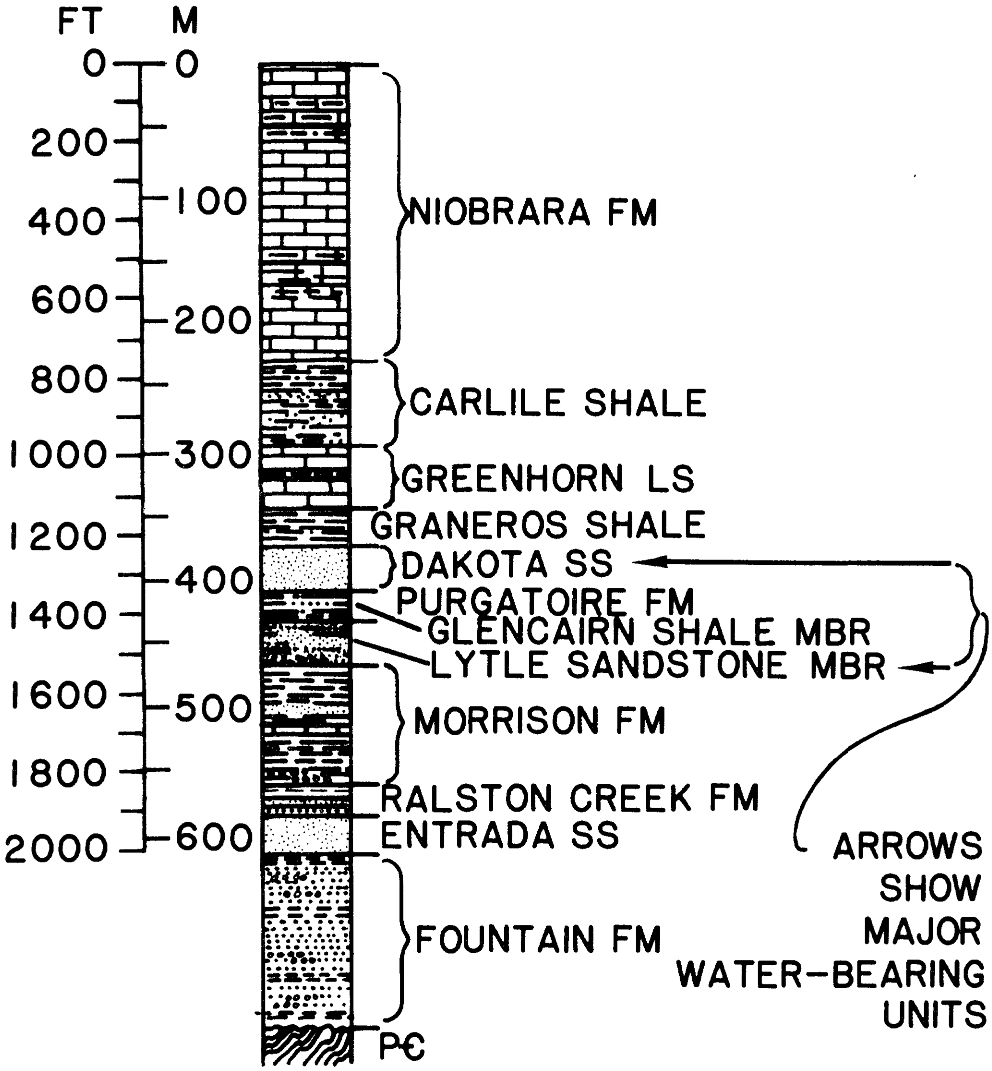

Figure 3.--Diagrammatic stratigraphic section for study area. Compiled from Scott and others (1976) and Scott and Taylor (1973).

showing approximate thicknesses of units penetrated by wells in the study area, is shown on figure 3.

Most of the faults, which are probably Tertiary in age, are northwest trending, but several have a northeast or east trend. Some faults are paired to form grabens, and some translate into folds at one end. The most complex area of intermixed folding and faulting is in the area east and southeast of Beulah.

Water-bearing units

All of the sampled wells are believed to be tapping the Dakota Sandstone and (or) Purgatoire Formation (fig. 3), as recorded in unpublished information of the U.S. Geological Survey, the Office of the State Engineer, and the Colorado Department of Health. Three of the wells, 3, 26, and 28, are believed to be drawing some water from the Morrison Formation as well. With reference to figure 3, terminology of the major water-bearing units has been variable. The term "first Dakota" has been used to refer to the Dakota Sandstone, and "second Dakota" has been used for the Lytle Sandstone Member of the Purgatoire Formation. Simply "Dakota" may thus refer to either one where the specific unit is not known.

Information about well depths, cased intervals, and penetrated rock units is not complete. Many of the wells were sampled by the U.S. Geological Survey in 1973 (Klein and others, 1978), and well depths were recorded at that time. Major formation names were also recorded, and notes were made for several samples on what specific rock units are being tapped by those wells. Other sources of well information are the Colorado Department of Public Health, which has studied a number of wells believed to be tapping the "Dakota," and the Office of the State Engineer, which has driller's logs for a few of the wells.

Ground-water flow patterns

Water levels are known for 77 wells tapping the Dakota in the study area. A potentiometric map of the wells (fig. 4), showing contour lines for the altitude of the water levels, indicates that the subsurface water flow is generally eastward, as one would expect from the topography and the direction of surface flow. Many water levels were reported at the time the wells were drilled, mostly in the 1960's, and approximately half were measured in the spring of 1973. Where large differences (>15 m) exist between measured and reported values for the same well, the measured values were used on the map. Where differences are smaller (<10 m), either value was considered usable. Reported values were used where no other values were available and where they seem to fit in with measured 1973 values on nearby wells. Because of the possible errors involved, the map is thought to approximate the potentiometric surface but not to be correct in every detail. Interpolations between data points were made by taking into account the altitude of surface flow, the possible influence of faults, and the patterns of geochemical data.

The effect of the faults on water flow is not fully known. Locally the faults may impede or enhance the rate of flow, thereby causing a change in the direction of flow for short distances. An area of complex faulting, such as the area a few kilometers east of Beulah, may be causing local changes in flow direction which are too detailed to decipher with the available data.

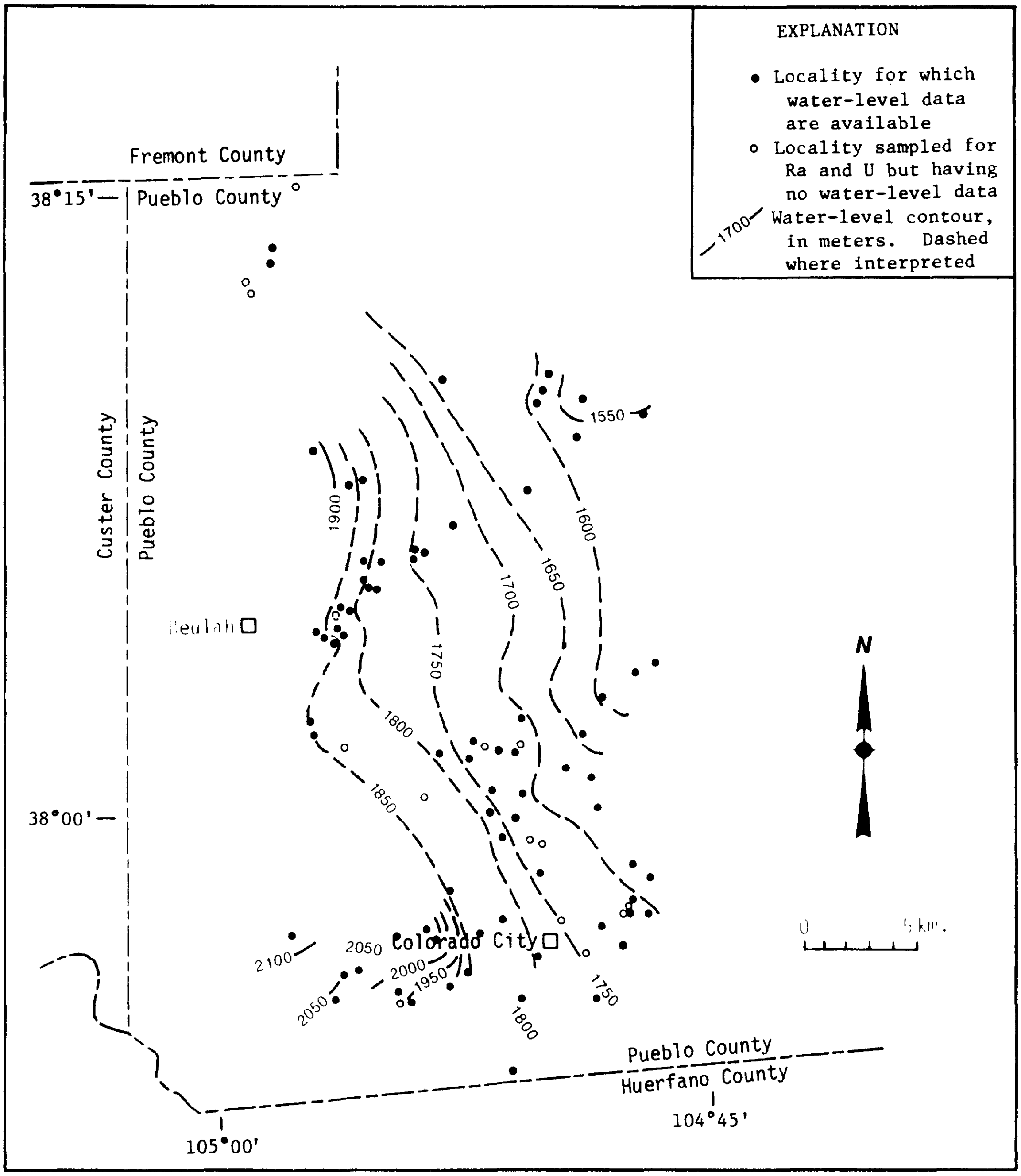

Figure 4.--Potentiometric map of 77 water wells tapping the aquifer system in the Dakota Sandstone and Purgatoire Formation.

Hydrogeochemistry

Radioelement concentrations

Radium, uranium, and radon concentrations for the 37 sites are listed in table 1 and are shown diagrammatically on figures 5-7. Histograms and statistical parameters are shown on figure 8. For data listed as below the detection limit in table 1, a value one-half the lower detection limit was substituted for use in statistical analyses and graphs.

All of the radioelements show a wide range of values. Log values show a normal distribution for radium and radon and a near-normal distribution for uranium, so log values were used in statistical analyses. Anomaly thresholds were not determined because the entire study area is considered to be unusual; the area was chosen for study because of known radioactivity in the ground water. As a result, our sampling was biased toward wells reportedly high in radium content. Radioelement concentrations do show a normal distribution of values (fig. 8), but the median values are higher than average, as compared with median values for radium (0.4 pCi/L) and uranium (0.5 μg/l) in 141 samples of ground water from throughout Colorado (Scott and Voegeli, 1961).

The relationship between radium and uranium concentrations is shown graphically on figure 9. The correlation coefficient (0.03) is not significant, indicating that the values for the two elements vary independently. Radium, like radon, is derived from uranium by natural radioactive decay: uranium-238, thorium-234, protactinium-234, uranium-234, thorium-230, radium-226, radon-222, and so on. The chemically distinct behavior of radium as well as of the intermediate daughters commonly serves to separate it from uranium as water comes in contact with uranium-bearing rocks; some of the waters contain excess radium relative to the equilibrium amount expected from the uranium in the water, and some contain excess uranium. The

Table 1.--Hydrogeochemical data for 37 wells in study area

[Sample localities are shown on fig. 1. Quarter sections: 1, NE; 2, NW; 3, SW; 4, SE. Tapped aquifer: Kd, Dakota; Kpg, Purgatoire (Glencairn); Kpl, Purgatoire (Lytle); Kdp, Dakota-Purgatoire system (exact units unknown); Jm, Morrison. Water type: See text for discussion. *, probably different wells on same property; L, less than detection limit shown; ---, not analyzed for]

Sample	Latitude	Longitude	Township S Range W	Section; successively smaller quarter sections	Date (yr-mo-dy)	Specific conductance (umhos per cm at 25C)	Temperature (C)	pH	Tapped aquifer	Water type
1*------	37.9239	104.9052	24.67	32.111	77-07-08	540	14	7.1	Kdp	CaHCO3
					73-04-12	440	13.0	6.9		
2-------	37.9411	104.8214	24.66	19.341	77-07-29	580	20	7.3	Kdp	CaHCO3
					73-03-13	551	14.5	7.6		
3-------	37.9422	104.8369	24.67	24.423	77-07-29	930	17	7.3	Kdp-Jm	CaSO4
4-------	37.9514	104.8086	24.66	20.222	77-07-26	550	17	7.5	Kd	CaHCO3
					73-03-10	526	---	7.3		
5-------	37.9528	104.8261	24.66	18.333	75-06-20	570	20	7.1	---	---
6*------	37.9542	104.9667	24.68	23.211	77-07-26	530	10	7.2	Kdp	CaHCO3
					73-05-05	540	9.0	6.9		
7-------	37.9581	104.8536	24.67	14.314	77-07-08	1040	17	7.0	---	---
8-------	37.9583	104.7978	24.66	17.421	77-07-26	580	18	7.2	---	---
9-------	37.9614	104.7936	24.66	17.144	77-07-26	1160	18	7.2	Kdp	CaNaHCO3ClSO4
10------	37.9686	104.8839	24.67	10.333	77-11-03	860	12	7.2	Kdp	CaHCO3.
11*-----	37.9750	104.8369	24.67	12.133	77-07-26	530	18	7.1	Kd	CaHCO3
					73-03-16	531	16.0	6.8		
12------	37.9858	104.8367	24.67	1.423	77-07-26	480	19	7.4	Kdp	CaHCO3
					73-03-16	520	15.0	7.4		
13------	37.9881	104.8417	24.67	1.311	77-07-27	480	16	7.3	Kd	CaHCO3
14------	37.9997	104.8500	23.67	35.443	77-07-27	490	18	7.1	Kd	CaHCO3
					73-04-19	500	13.5	7.3		
15------	38.0056	104.8972	23.67	33.243	77-07-28	650	16	7.1	Kdp	CaNaHCO3
16------	38.0078	104.8661	23.67	34.114	77-07-27	470	19	7.5	Kd	CaHCO3
					73-03-16	444	14.0	7.1		
17------	38.0250	104.8617	23.67	26.221	77-07-08	2500	14	7.1	Kpl	MgSO4
					73-03-15	4500	11.0	6.6		
18------	38.0258	104.8644	23.67	22.444	77-07-08	550	19	7.1	Kdp	CaHCO3
19------	38.0261	104.8361	23.67	24.333	77-07-27	2650	15	7.3	Kdp	CaMgSO4
20------	38.0300	104.9389	23.68	24.414	77-07-08	400	19	7.2	Kdp	CaHCO3SO4
					73-04-16	1300	12.0	7.6		

21------	38.0578	104.7847	23.66	9.342	77-07-27	850	13	6.8	Kdp	CaSO4
22------	38.0714	104.9478	23.68	1.432	77-07-07	335	15	7.4	Kdp	CaHCO3
					73-04-16	430	14.5	7.6		
23------	38.0717	104.9514	23.68	1.342	77-07-07	530	19	7.5	Kd-Kpl	CaHCO3
					73-04-10	560	11.0	7.2		
24------	38.0764	104.9392	23.68	1.411	75-06-20	440	15	6.8	Kdp	CaHCO3
					73-04-14	440	13.0	6.7		
25------	38.0811	104.9394	23.68	1.141	77-07-06	680	17	7.7	Kd	CaHCO3
					73-04-09	682	6.0	7.2		
26------	38.0911	104.9194	22.67	32.322	77-07-06	1200	17	7.3	Kdp-Jm	CaMgSO4
					73-04-09	1300	5.5	7.6		
27------	38.0922	104.9211	22.67	31.144	77-07-06	1140	16	7.2	Kpl	CaMgSO4
					73-04-10	1125	12.5	7.2		
28------	38.1022	104.9211	22.67	30.431	77-07-28	600	18	7.0	Kpl-Jm	CaHCO3
					73-03-19	500	11.0	6.8		
29------	38.1025	104.8969	22.67	28.313	77-07-07	830	13	7.5	Kpl	CaHCO3
					73-04-19	650	13.5	6.8		
30------	38.1047	104.8928	22.67	28.311	77-07-06	940	15	7.1	Kd-Kpg	CaSO4
					73-04-09	975	13.0	7.6		
31------	38.1158	104.8825	22.67	22.333	77-07-07	1180	14	5.3	Kdp	MgSO4
					73-04-13	1230	14.5	5.2		
32------	38.1297	104.8450	22.67	13.332	77-07-07	660	16	6.3	Kdp	CaSO4
					73-03-12	589	8.0	6.1		
33------	38.1347	104.9417	22.68	13.412	77-07-28	780	18	7.7	Kdp	NaCaHCO3
					73-04-24	825	13.0	7.9		
34------	38.1628	104.7806	22.66	4.422	77-07-29	1830	16	7.3	Kdp	CaMgNaSO4
35------	38.2097	104.9822	21.68	22.133	75-06-18	2400	21	7.3	---	---
36------	38.2169	104.9878	21.68	15.343	75-06-19	2800	20	6.5	Kdp	NaHCO3
					72-09-12	2650	22.0	6.3		
37------	38.2556	104.9494	21.68	1.242	77-07-28	3000	21	6.2	Kdp	NaHCO3

Table 1.--Hydrogeochemical data for 37 wells in study area--Continued

	Radium (Ra) (pCi per L)	Uranium (U) (ug per L)	Radon (Rn) (pCi per L)	Measured Eh (mv)	Dissolved oxygen (ppm)	Dissolved solids (calculated)(mg per L)	Silica (SiO2)(mg per L)	Calcium (Ca)(mg per L)	Magnesium (Mg) (mg per L)	Sodium (Na) (mg per L)
1*------	4.0	0.05	1200	-130	0.3L	---	---	---	---	---
	---	---	---	---	---	248	9.7	45	9.2	22
2-------	180	.52	1300	-130	.4L	---	---	---	---	---
	---	---	---	---	---	324	14	77	13	19
3-------	43	1.3	580	-180	.2L	594	17	130	24	21
4-------	35	.29	900	-180	1.2	---	---	---	---	---
	---	---	---	---	---	315	8.0	60	15	30
5-------	33	.4L	---	---	---	---	---	---	---	---
6*------	5.3	5.7	630	90	8.4	---	---	---	---	---
	---	---	---	---	---	289	21	55	11	34
7-------	18	.4	1400	-80	.3L	---	---	---	---	---
8-------	130	2.4	860	200	4.2	---	---	---	---	---
9-------	90	4.2	---	300	3.0	602	12	110	28	87
10------	.4	2.0	---	210	---	398	25	100	9.9	28
11*-----	1.0	.04	230	-100	.2L	---	---	---	---	---
	---	---	---	---	---	321	8.6	63	14	29
12------	12	.04	100L	-130	.2L	---	---	---	---	---
	---	---	---	---	---	269	9.4	53	13	22
13------	10	.04	160	-160	.1L	271	9.3	55	13	22
14------	4.9	.04	110	-50	.7	---	---	---	---	---
	---	---	---	---	---	289	9.1	56	14	25
15------	8.7	.74	500	-80	.4L	377	14	64	13	54
16------	3.5	.04	120	-230	.2L	---	---	---	---	---
	---	---	---	---	---	269	9.4	54	13	19
17------	.9	19	400	120	8.2	---	---	---	---	---
	---	---	---	---	---	3960	16	390	480	76
18------	110	2.6	3100	-30	.4L	312	12	68	17	16
19------	8.8	70	100L	60	4.7	2240	16	370	200	46
20------	.3	3.8	100L	180	6.5	---	---	---	---	---
	---	---	---	---	---	876	13	180	26	68

21------	2.2	18	380	110	5.7	549	15	120	18	21
22------	16	.34	400	-540	.3L	---	---	---	---	---
	---	---	---	---	---	199	13	37	11	14
23------	3.9	2.2	560	220	9.1	---	---	---	---	---
	---	---	---	---	---	307	26	59	9.6	28
24------	420	9.7	27000	-80	.8	245	11	48	13	15
	---	---	---	---	---	253	12	47	13	14
25------	.8	3.6	830	250	---	---	---	---	---	---
	---	---	---	---	---	427	23	82	13	42
26------	2.8	180	2700	250	.3L	---	---	---	---	---
	---	---	---	---	---	893	9.6	120	62	82
27------	13	77	1800	65	.4L	---	---	---	---	---
	---	---	---	---	---	761	11	120	57	43
28------	1.3	.63	890	110	3.0	---	---	---	---	---
	---	---	---	---	---	290	31	59	8.7	15
29------	31	6.2	5500	-50	.7	---	---	---	---	---
	---	---	---	---	---	460	12	78	26	37
30------	18	3.1	1500	180	5.5	---	---	---	---	---
	---	---	---	---	---	672	12	120	37	40
31------	5.2	8.8	7100	80	.6	---	---	---	---	---
	---	---	---	---	---	927	6.9	71	120	15
32------	5.5	.03	100L	-30	.5	---	---	---	---	---
	---	---	---	---	---	410	12	59	21	19
33------	14	2.5	100L	70	5.0	---	---	---	---	---
	---	---	---	---	---	476	8.8	43	21	93
34------	8.3	.02	270	-300	.2L	1380	6.2	190	73	130
35------	4.3	8.2	---	---	---	---	---	---	---	---
36------	300	2.5	---	---	---	1920	29	140	46	500
	---	---	---	---	---	1950	28	130	46	520
37------	17	2.6	690	-110	.2L	1960	12	150	48	490

Table 1.--Hydrogeochemical data for 37 wells in study area--Continued

Sample	Potassium (K) (mg per L)	Bicarbonate (HCO3) (mg per L)	Sulfate (SO4) (mg per L)	Chloride (Cl) (mg per L)	Fluoride (F) (mg per L)	Nitrate (NO2+NO3 as N) (mg per L)	Phosphate (PO4) (mg per L)	Alkalinity as CaCO3 (mg per L)	Hardness as CaCO3 (mg per L)
1*------	---	---	---	---	---	---	---	---	---
	2.4	166	63	3.3	0.4	0.01	0.03	136	150
2-------	---	---	---	---	---	---	---	---	---
	2.6	266	61	4.0	.6	.04	.03	218	250
3-------	2.8	250	270	3.6	.2	---	---	210	420
4-------	---	---	---	---	---	---	---	---	---
	3.4	282	48	4.3	.7	.52	.03	231	210
5-------	---	---	---	---	---	---	---	---	---
6*------	---	---	---	---	---	---	---	---	---
	.8	291	16	3.8	.2	.63	.15	239	180
7-------	---	---	---	---	---	---	---	---	---
8-------	---	---	---	---	---	---	---	---	---
9-------	3.8	300	120	92	.6	---	---	250	390
10------	1.9	360	50	5.1	.4	---	---	300	290
11*-----	---	---	---	---	---	---	---	---	---
	3.4	278	55	3.7	.6	.06	.03	228	220
12------	---	---	---	---	---	---	---	---	---
	3.2	246	42	2.0	.6	.04	.00	202	190
13------	3.1	240	46	1.9	.6	---	---	200	190
14------	---	---	---	---	---	---	---	---	---
	3.6	248	52	2.6	.6	.01	.00	203	200
15------	3.6	300	69	9.9	.6	---	---	250	210
16------	---	---	---	---	---	---	---	---	---
	3.0	237	48	2.2	.5	.04	.06	194	190
17------	---	---	---	---	---	---	---	---	---
	5.3	421	2700	29	1.0	12	.06	345	3000
18------	2.5	240	76	2.4	.4	---	---	200	240
19------	4.9	370	1400	21	.3	---	---	300	1700
20------	---	---	---	---	---	---	---	---	---
	5.0	397	300	33	.7	12	.03	326	560

21------	3.3	170	280	6.5	.9	---	---	140	370
22------	---	---	---	---	---	---	---	---	---
	3.5	167	33	3.4	.8	.07	.06	137	140
23------	---	---	---	---	---	---	---	---	---
	2.2	223	40	20	.7	2.4	.31	183	190
24------	2.9	161	67	4.0	.6	.04	.00	132	170
	2.9	170	72	5.0	.6	.05	.03	139	170
25------	---	---	---	---	---	---	---	---	---
	1.9	309	65	23	.7	4.9	.06	253	260
26------	---	---	---	---	---	---	---	---	---
	5.9	381	390	25	.6	2.0	.03	313	560
27------	---	---	---	---	---	---	---	---	---
	5.5	376	330	5.6	.5	.04	.03	308	540
28------	---	---	---	---	---	---	---	---	---
	2.4	194	47	9.4	.2	2.9	.09	159	180
29------	---	---	---	---	---	---	---	---	---
	3.9	292	140	12	.5	.03	.00	240	300
30------	---	---	---	---	---	---	---	---	---
	4.4	269	300	20	.7	.94	.03	221	450
31------	---	---	---	---	---	---	---	---	---
	1.3	9	690	3.7	.8	.02	.03	7	670
32------	---	---	---	---	---	---	---	---	---
	3.4	92	220	6.3	.5	.13	.06	75	230
33------	---	---	---	---	---	---	---	---	---
	5.1	319	40	5.5	.7	.03	.00	262	200
34------	11	280	00	10	.9	---	---	230	780
35------	---	---	---	---	---	---	---	---	---
36------	41	1440	230	240	1.8	.02	.09	1180	510
	37	1380	240	240	2.0	.02	.06	1130	540
37------	38	1250	330	270	2.1	---	---	1030	570

Table 1.--Hydrogeochemical data for 37 wells in study area--Continued

Sample	Boron (B) (ug per L)	Barium (Ba) (ug per L)	Copper (Cu) (ug per L)	Iron (Fe) (ug per L)	Lithium (Li) (ug per L)	Manganese (Mn) (ug per L)	Molybdenum (Mo) (ug per L)	Strontium (Sr) (ug per L)	Zinc (Zn) (ug per L)
1*	---	---	---	---	---	---	---	---	---
	---	10L	---	9900	20	310	---	---	380
2	---	---	---	---	---	---	---	---	---
	20	---	5	510	30	170	---	470	60
3	6.6	84	1.7L	990	52L	240	2.4	840	21
4	---	---	---	---	---	---	---	---	---
	---	---	5	3500	50	170	---	550	130
5	---	---	---	---	---	---	---	---	---
6*	---	---	---	---	---	---	---	---	---
	---	200	30	30	---	---	---	400	200
7	---	---	---	---	---	---	---	---	---
8	---	---	---	---	---	---	---	---	---
9	24	100	50	370	75	100	7.8	2000	490
10	---	---	---	---	---	---	---	---	---
11*	---	---	---	---	---	---	---	---	---
	---	---	6	5900	40	200	---	540	20
12	---	---	---	---	---	---	---	---	---
	---	---	---	1900	40	80	---	510	570
13	---	---	---	---	---	---	---	---	---
14	---	---	---	---	---	---	---	---	---
	---	10L	---	2500	20	170	---	540	900
15	75	170	2.4	750	140	130	6.9	980	220
16	---	---	---	---	---	---	---	---	---
	---	---	---	2800	30	90	---	490	290
17	---	---	---	---	---	---	---	---	---
	---	---	20	550	---	2000	---	2000	340
18	20	180	1.5	530	44	330	28	720	820
19	8.7L	30	6.0L	950L	180L	98	13	1700	350
20	---	---	---	---	---	---	---	---	---
	---	10L	---	50	100	---	---	1200	---

21------	12	14	10	240L	47L	4.9	1.5L	960	110.
22------	---	---	---	---	---	---	---	---	---
	---	10L	11	690	30	120	---	---	50
23------	---	---	---	---	---	---	---	---	---
	40	10L	---	40	10	10	---	260	620
24------	14	34	.5	4200	35	.540	2.0	260	80
	---	10L	---	1600	30	510	---	260	200
25------	---	---	---	---	---	---	---	---	---
	40 .	10L	---	40	10	20	---	300	1800
26------	---	---	---	---	---	---	---	---	---
	20	10L	---	30	120	10	---	840	440
27------	---	---	---	---	---	---	---	---	---
	20	10L	---	1600	110	60	---	720	310
28------	---	---	---	---	---	---	---	---	---
	---	---	120	30	60	20	---	250	8300
29------	---	---	---	---	---	---	---	---	---
	---	10L	---	3900	40	110	---	890	1400
30------	---	---	---	---	---	---	---	---	---
	30	10L	---	50	70	110	---	1000.	110
31------	---	---	---	---	---	---	---	---	---
	---	10L	---	11000	50	2400	---	290	150
32------	---	---	---	---	---	---	---	---	---.
	---	---	10	22000	---	670	---	440	50
33------	---	---	---	---	---	---	---	---	---
	---	10L	9	50	200	20	---	1000	450
34------	40	13	3.6L	18000	280	510	3.6L	2500	660
35------	---	---	---	---	---	---	---	---	---
36------	320	160	3.0L	1200	510	90	36	3300	10L
	500	---	---	3100	---	200	---	---	---
37------	120	21	5.4L	860L	670	130	5.4L	2100	54L

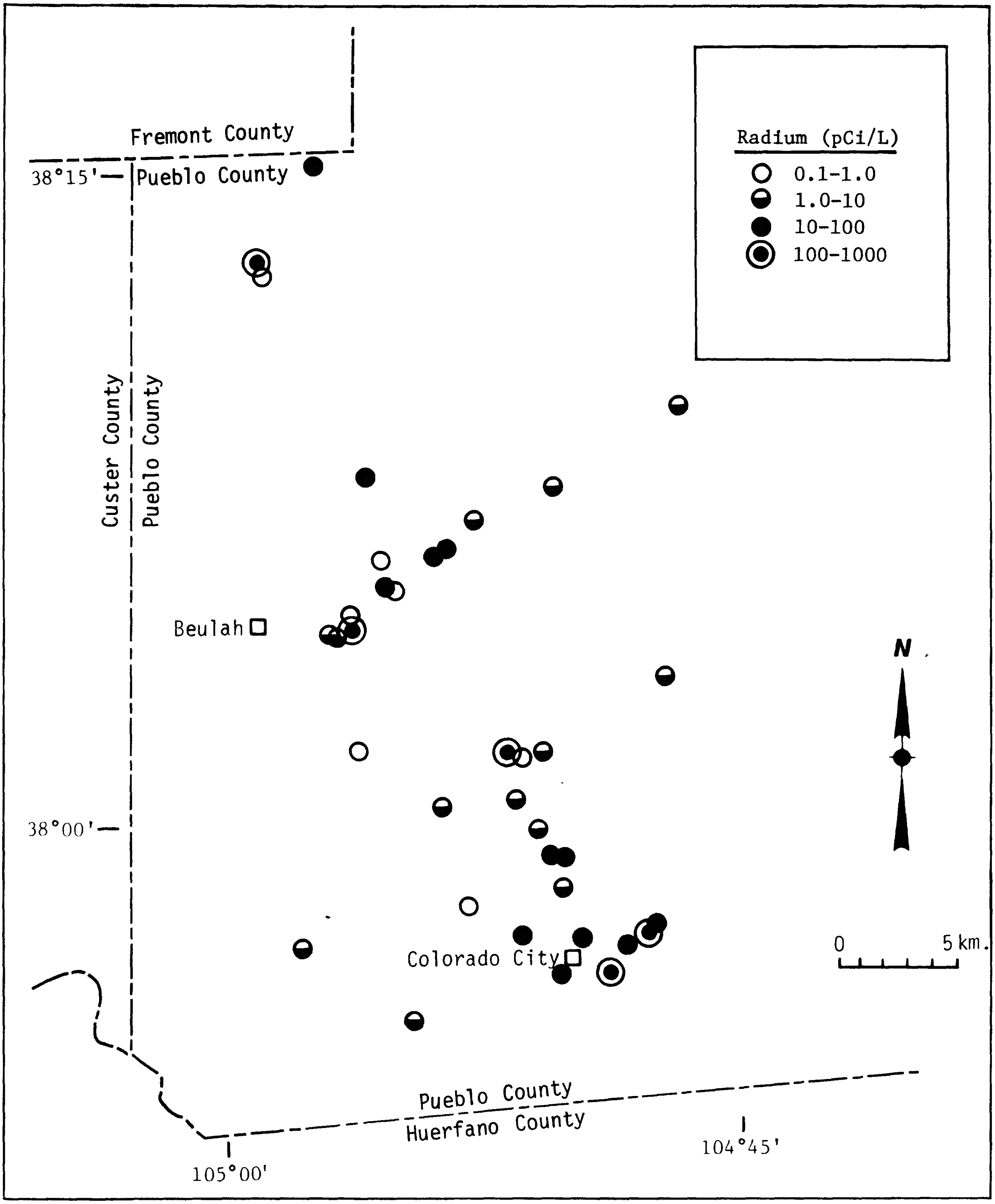

Figure 5.--Areal distribution of Radium concentrations.

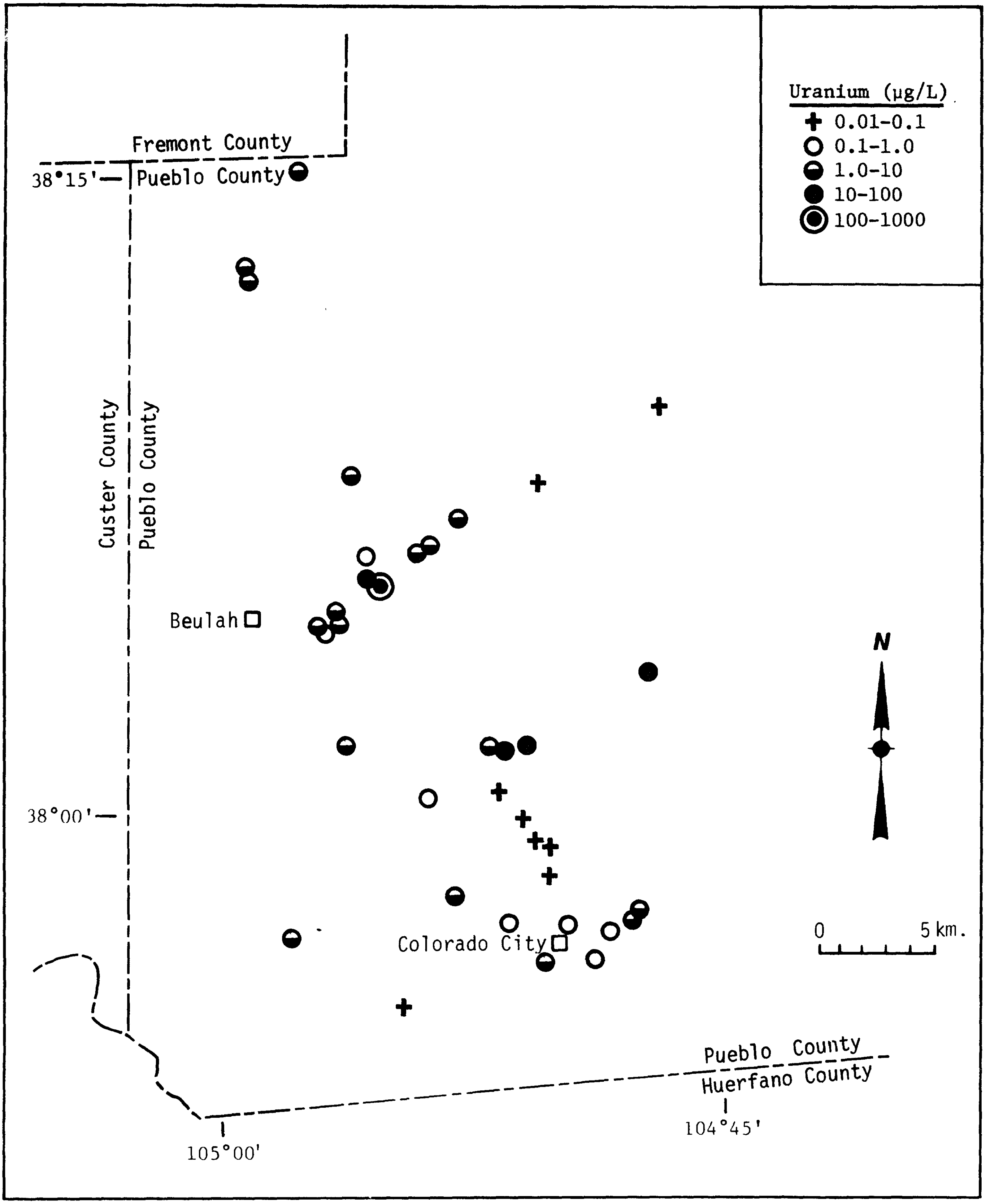

Figure 6.--Areal distribution of Uranium concentrations.

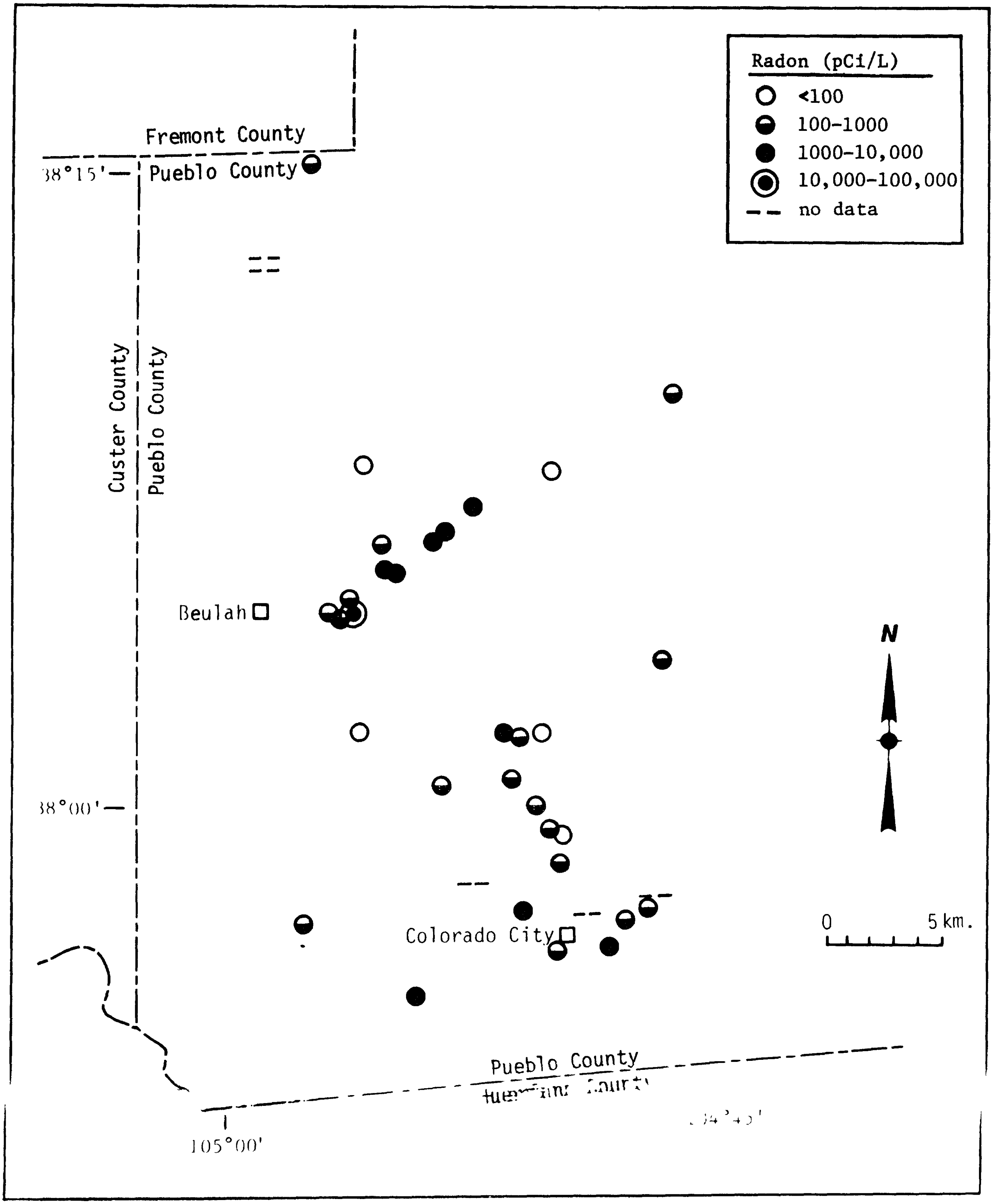

Figure 7.--Areal distribution of Radon concentrations.

STATISTIC	RADIUM (pCi/L)	URANIUM (μg/L)	RADON (pCi/L)
RANGE	0.3–420	0.2–180	100–27,000
MEDIAN	8.8	2.4	580
MEAN	9.9	1.3	550

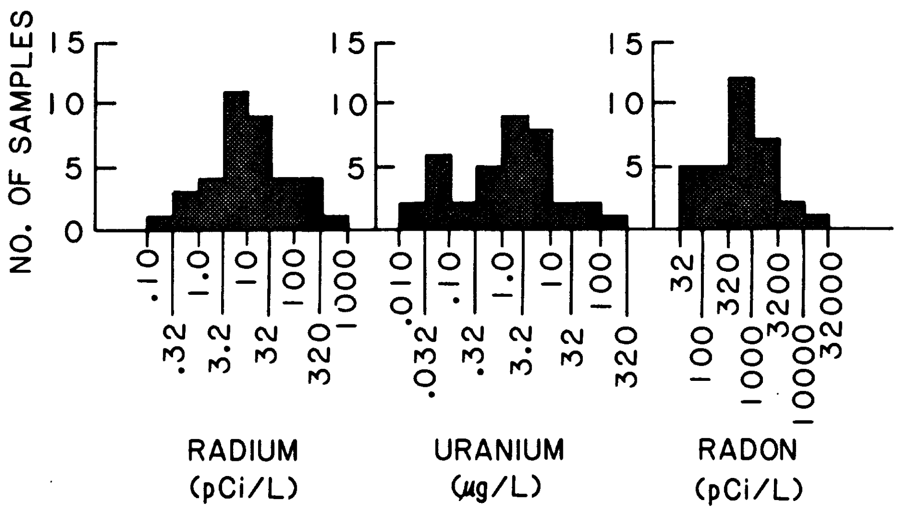

Figure 8.--Histograms and statistical parameters for radium, uranium, and radon.

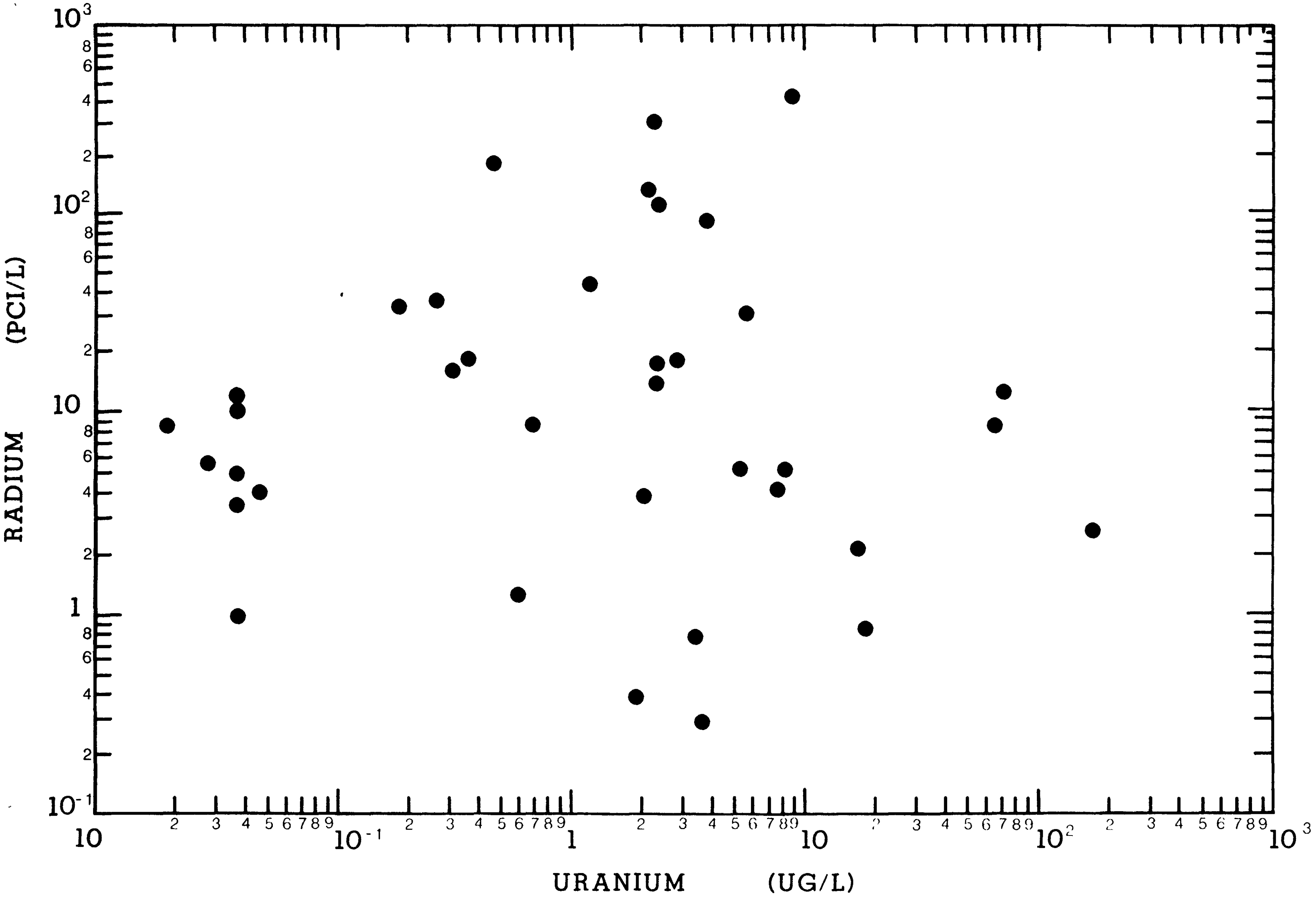

Figure 9.--Relationship between radium and uranium concentrations.

largest area of generally high values of radium is in the southeastern end of the study area, where uranium values are relatively low. Uranium concentrations are highest in the central part of the sampled area, where radium concentrations are low to moderately high.

The relationships between radon and radium and between radon and uranium are shown on figures 10 and 11. Radon has a significant correlation with radium (0.45) at the 99-percent level and with uranium (0.41) at the 95-percent level. Most radon in contact with water is probably taken into solution. In some waters radium is also soluble, but the fact that radon occurs in excess of the equilibrium amount expected from the radium in the water indicates that much of the radium remains in radium- or uranium-bearing minerals elsewhere in the system. Similarly, in other waters radon and uranium are taken into solution while much of the uranium and the intermediate daughter products, radium and probably thorium-230, are left behind.

Other geochemical data

Results of analyses for major ions and trace elements are given in table 1. Normal or near-normal distributions are exhibited by the arithmetic values of temperature, pH, and Eh and by the log values of all other parameters; therefore, these respective values were used in the statistical analyses and graphs. Where more than one analysis is shown for a site, the more recent value was used.

Percentages of the major ions are shown graphically on the trilinear diagram on figure 12. These percentages were used to determine water types, which are listed in table 1 and are shown on figure 13 along with data from Klein and others (1978) for wells not sampled during this study. A cation or anion constituting more than 50 percent of the total cation or anion amount is

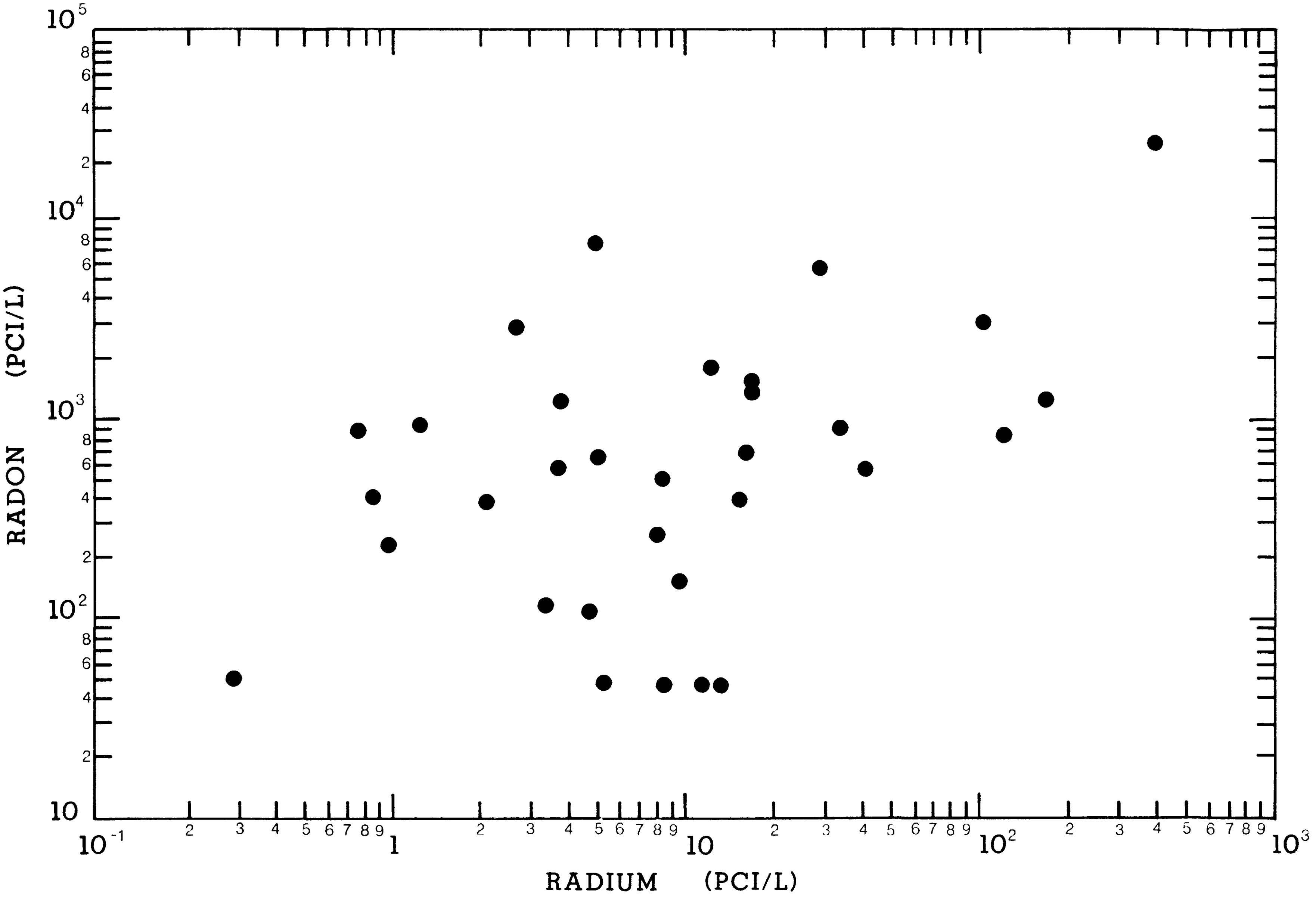

Figure 10.--Relationship between radon and radium concentrations.

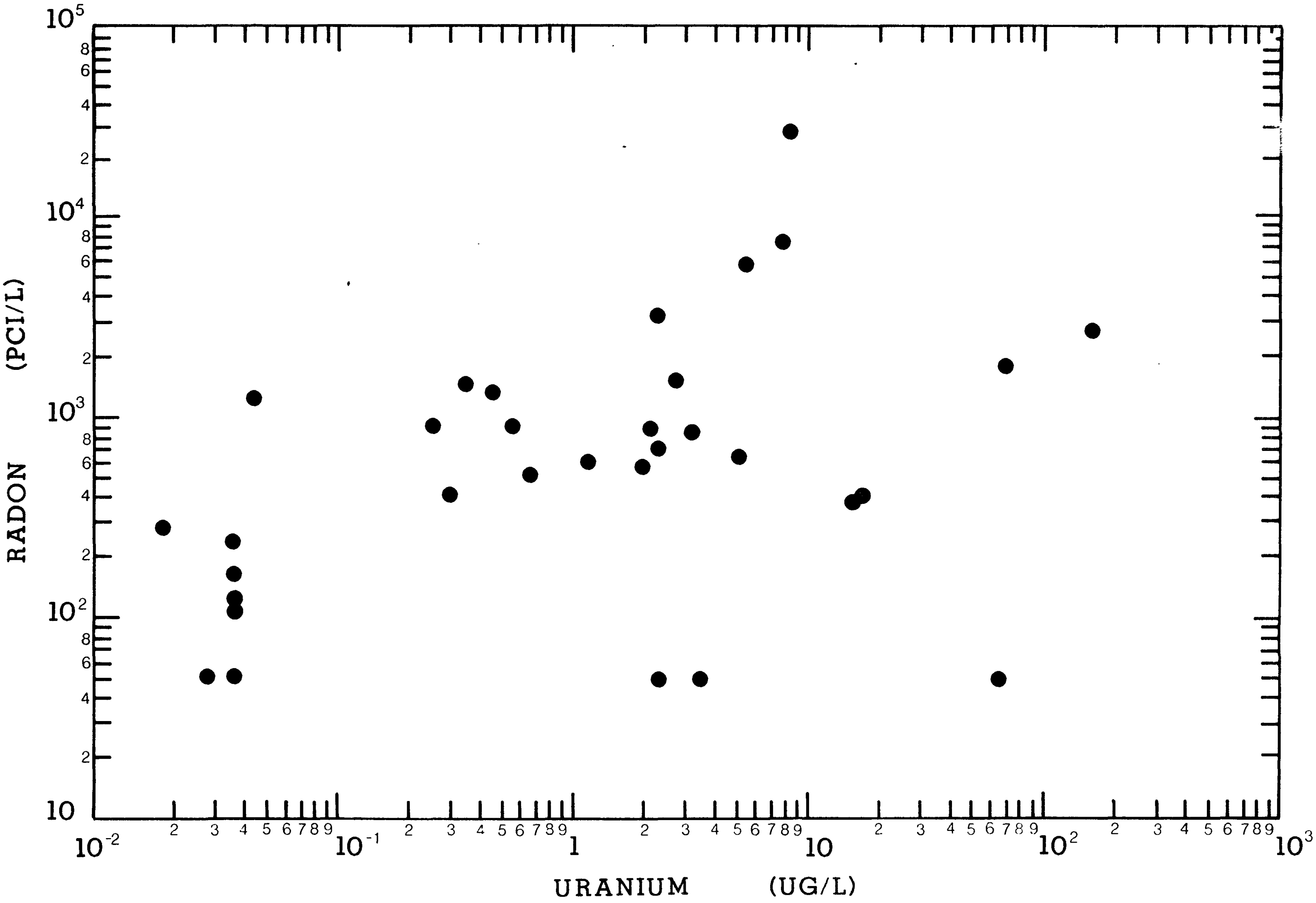

Figure 11.--Relationship between radon and uranium concentrations.

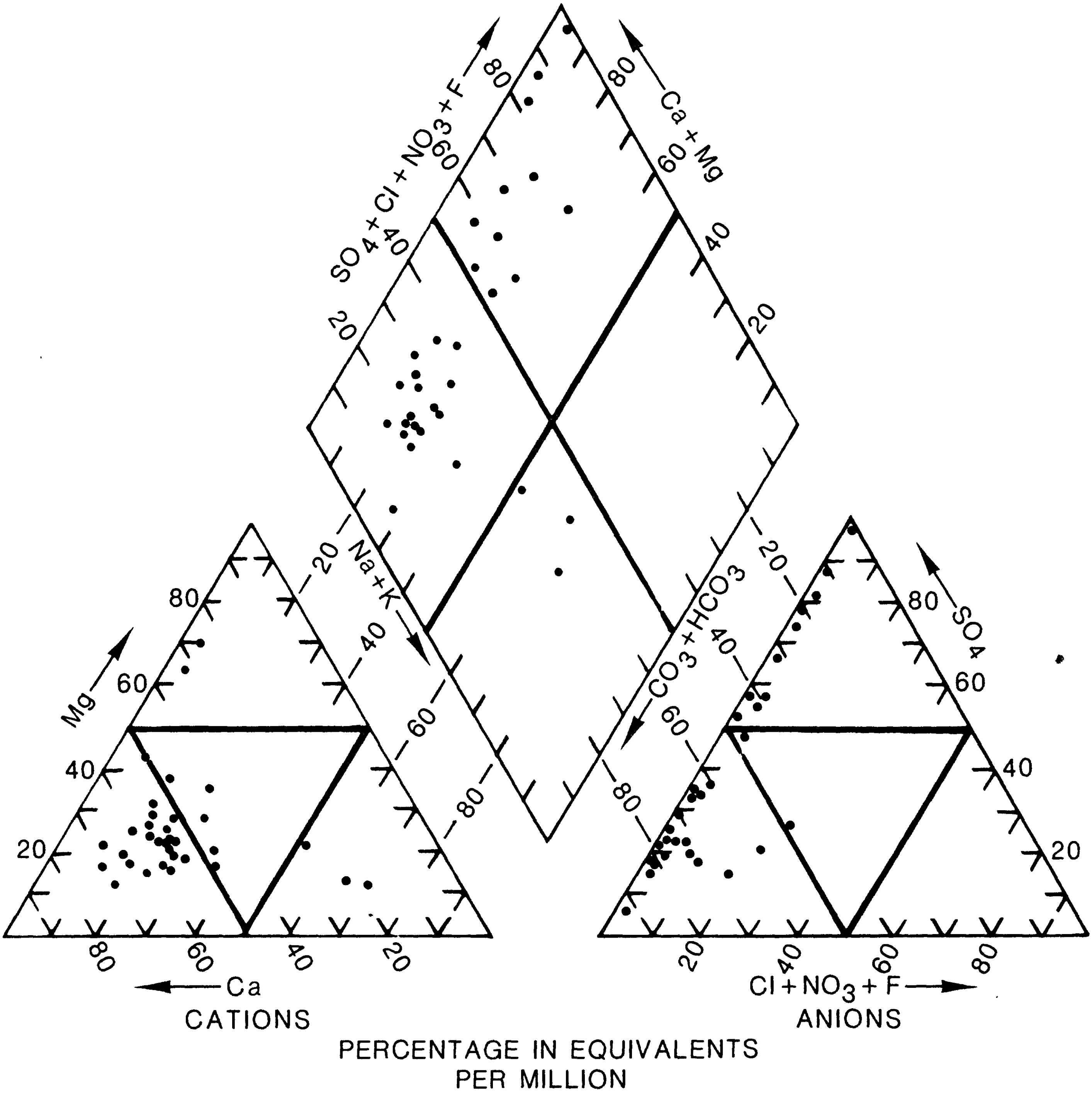

Figure 12.--Water types and percentages of major ions in wells sampled for radium and uranium during this study.

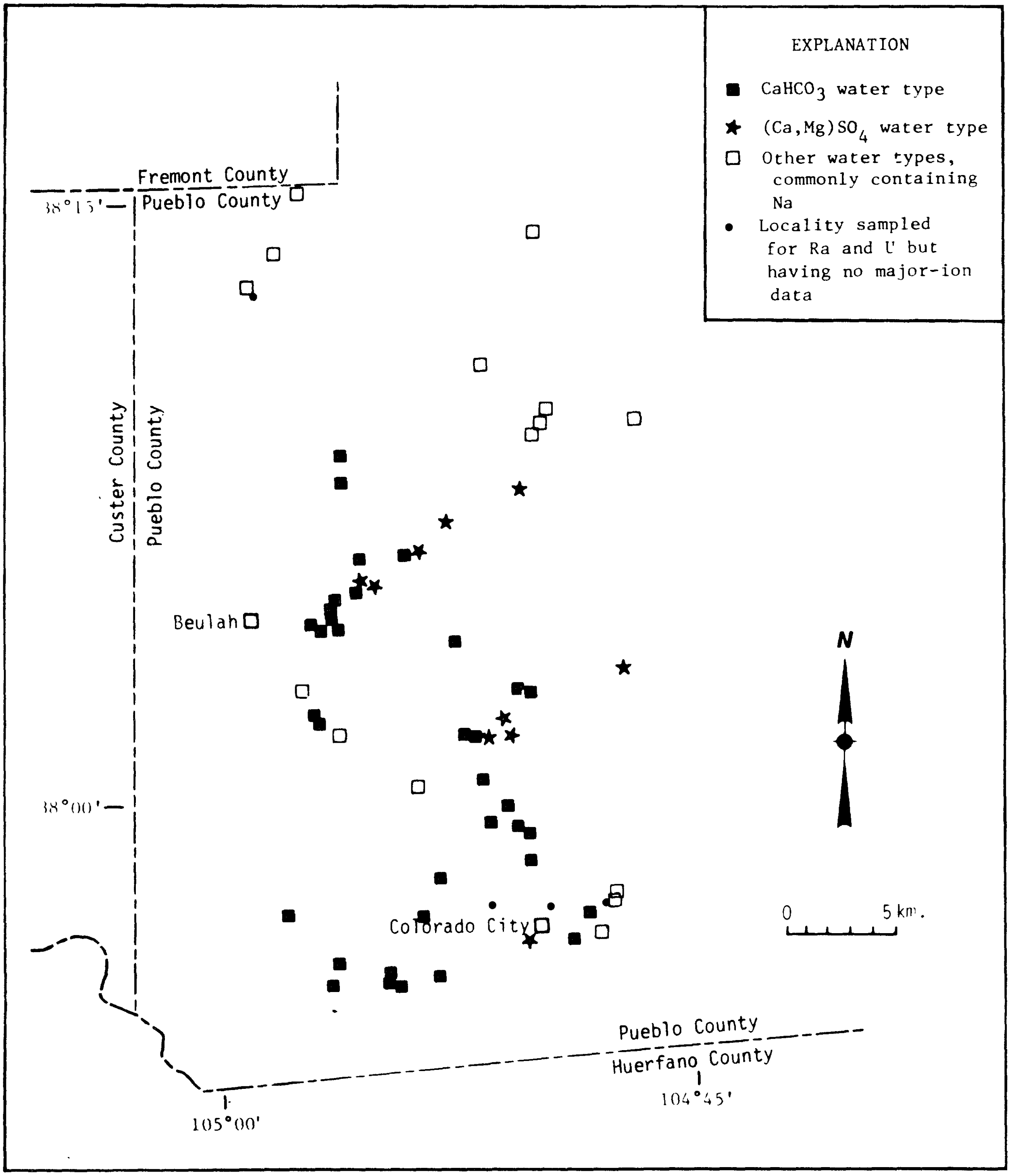

Figure 13.--Areal distribution of water types in wells tapping aquifer systems of Dakota Sandstone and Purgatoire Formation. Map shows sites sampled for radium and uranium during this study as well as sites sampled only for major ions in 1973 (Klein and others, 1978).

used in naming the water type. If no cation or anion exceeds 50 percent, then each one constituting 50-25 percent is named in decreasing order of abundance. (See Hem, 1970, p. 81, 237, 268-269, for further discussion of water classification). These data provide a general picture of hydrogeochemical patterns.

In the study area several types of water are present in wells deriving water from the aquifer system in the Dakota Sandstone and Purgatorie Formation. The Dakota yields calcium bicarbonate or calcium sulfate water; the Dakota and Glencairn Shale Member of the Purgaroire yield calcium-magnesium bicarbonate or calcium sulfate water; and the Lytle Sandstone Member of the Purgatoire yields calcium bicarbonate, calcium sulfate, calcium-magnesium sulfate, or magnesium sulfate water. Wells tapping simply "Dakota," which could mean all or any part of the Dakota-Purgatoire section, have calcium bicarbonate, calcium and (or) magnesium sulfate, or calcium and (or) sodium bicarbonate water. Wells deriving water from the "Dakota" and part of the Morrison yield calcium bicarbonate, calcium sulfate, or calcium-magnesium sulfate water.

Calcium bicarbonate water is most common. Other types of water may be present in the wells for several reasons--leaky well casings, which cause mixing of water from overlying or underlying lithologies with water from the tapped aquifer; different lithologies in the tapped aquifer at different places; or precipitation and dissolution of minerals in interstices or fractures as the water percolates down through the overlying section and then moves through the aquifer. Leaky casings may cause contamination by calcium sulfate water from the Graneros Shale or sodium sulfate water from the Morrison Formation. However, wells yielding sulfate water are similar in age, and hence should have casings similar in condition, to wells yielding the typical calcium bicarbonate water. Also, wells penetrating Purgatoire and Morrison in the study area yield water whose principal cations are calcium and magnesium, not sodium. Therefore, the effect of leaky casings is believed less important than lithologic variations within the aquifer system of the Dakota-Purgatoire section and natural processes involving precipitation and dissolution of minerals.

The distribution of water types (fig. 13) does show some general patterns. Calcium bicarbonate water is dominant in much of the central and southern part of the study area, but sodium-bearing bicarbonate and (or) sulfate water predominates in the northern part. Calcium and (or) magnesium sulfate water is present in an area east-northeast of Beulah, in another area north of Colorado City, and in one well at Colorado City.

The distribution of redox potential, or Eh, measurements is shown on figure 14. Negative values were measured at most of the wells, but positive values were found at the western edge of the sampled area and in some places east of the wells having negative values. Readings were taken using a platinum redox electrode after the electrode and spigot nozzle had both been submerged in a cup or bucket of running water for several minutes. Dissolved oxygen measurements were taken at most of the same sites. The two measurements are comparable and have a correlation coefficient (0.69) significant at the 99-percent level (fig. 15). The plot seems to show two groups of samples--those with relatively high dissolved oxygen and positive Eh and those with low dissolved oxygen and negative Eh. It is essentially the distribution of these two groups that is shown on figure 14.

Interpretation of the measured Eh and dissolved oxygen values involves some problems. Both measurements may represent the degree of oxygenation in the pressure tank as well as in the aquifer itself. Furthermore, we may not

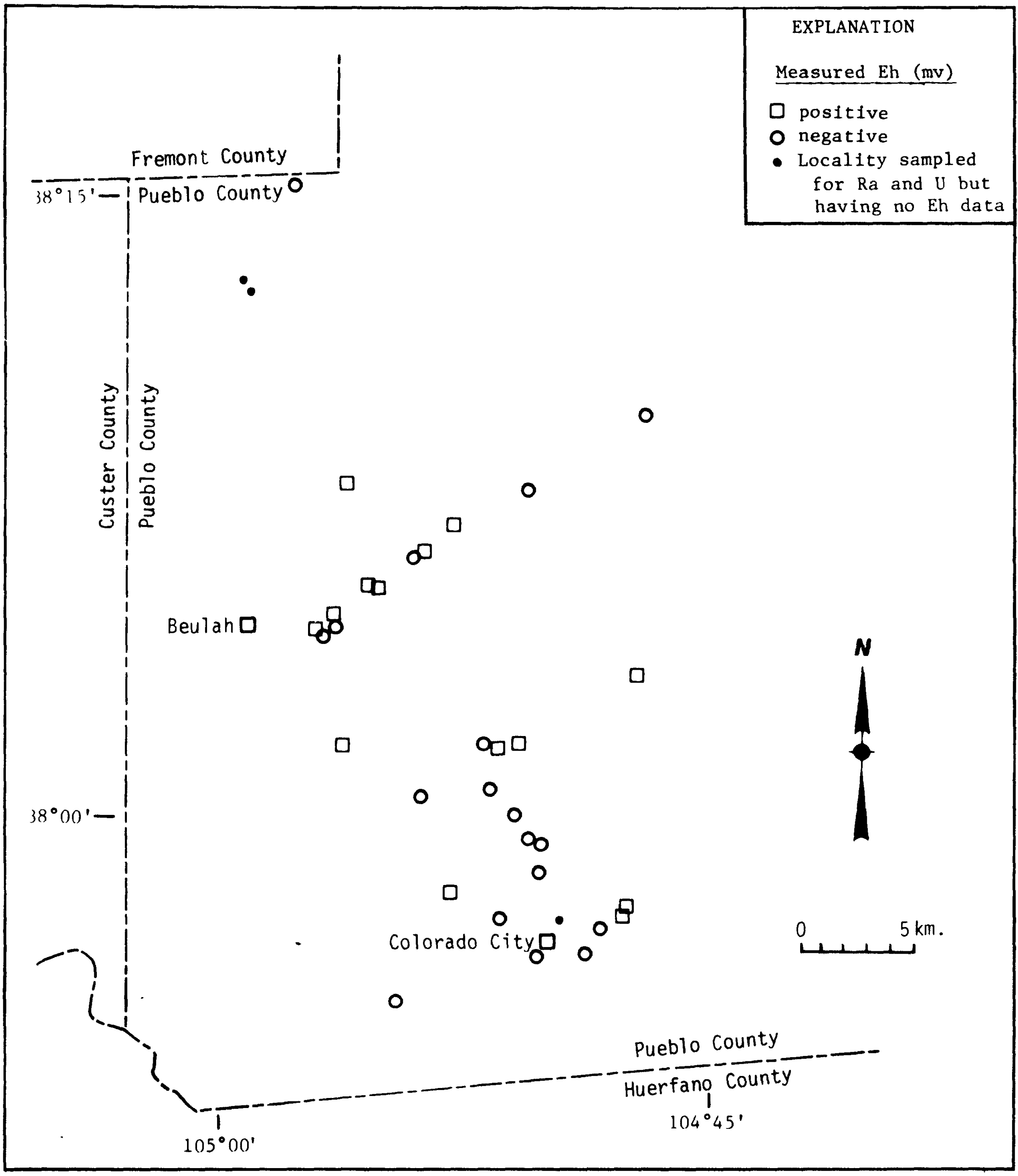

Figure 14.--Areal distribution of redox potential (Eh) measurements.

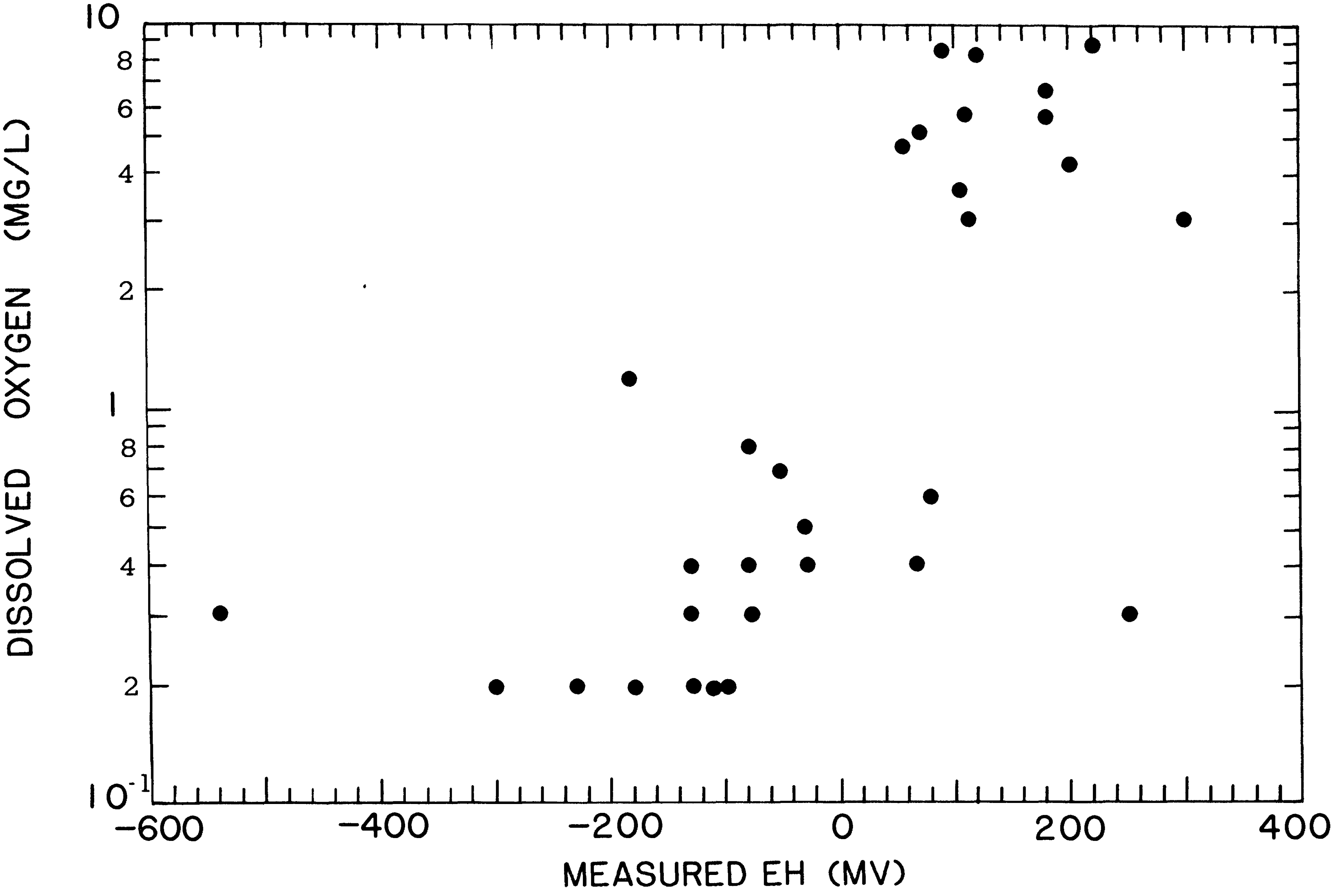

Figure 15.--Comparison of measured Eh and dissolved oxygen values.

have allowed sufficient time for the instruments to equilibrate completely before taking the readings. Therefore, readings of about 0.5 ppm dissolved oxygen or less may actually be zero and may thus corroborate the negative Eh measurements, which probably reflect the presence of reduced iron, sulfur, or other species that affect oxidation-reduction reactions. When measurements indicate several parts per million dissolved oxygen, we really don't know whether this represents conditions in the well system, in the aquifer, or both; but at least we can say that when measurements indicate no oxygen, the well system is probably airtight, and the measurements do represent conditions in the aquifer. All in all, the measurements of Eh and dissolved oxygen were considered adequate for use in the statistical analysis of relationships among the various geochemical parameters. The sensibility of the statistical relationships between these measurements and other ions supports the general validity of the measurements. Uranium, in particular, has a correlation coefficient significant at the 99-percent level with measured Eh (0.60) (fig. 16), as would be expected from the known geochemistry of uranium.

Statistical analysis

Relationships among the various geochemical parameters--major ions, trace elements, and field properties--were studied using linear correlations and R-mode factor analysis. All 37 samples and 31 variables were used initially to produce a matrix of correlation coefficients (table 2). Not all samples were tested for all parameters, so the correlations involve various numbers of samples. As a result, significant values for the correlation coefficients vary according to the number of pairs used in the correlation.

The 31 parameters in table 2 are arranged in groups determined in part by R-mode factor analysis, which is a technique of multivariate analysis designed

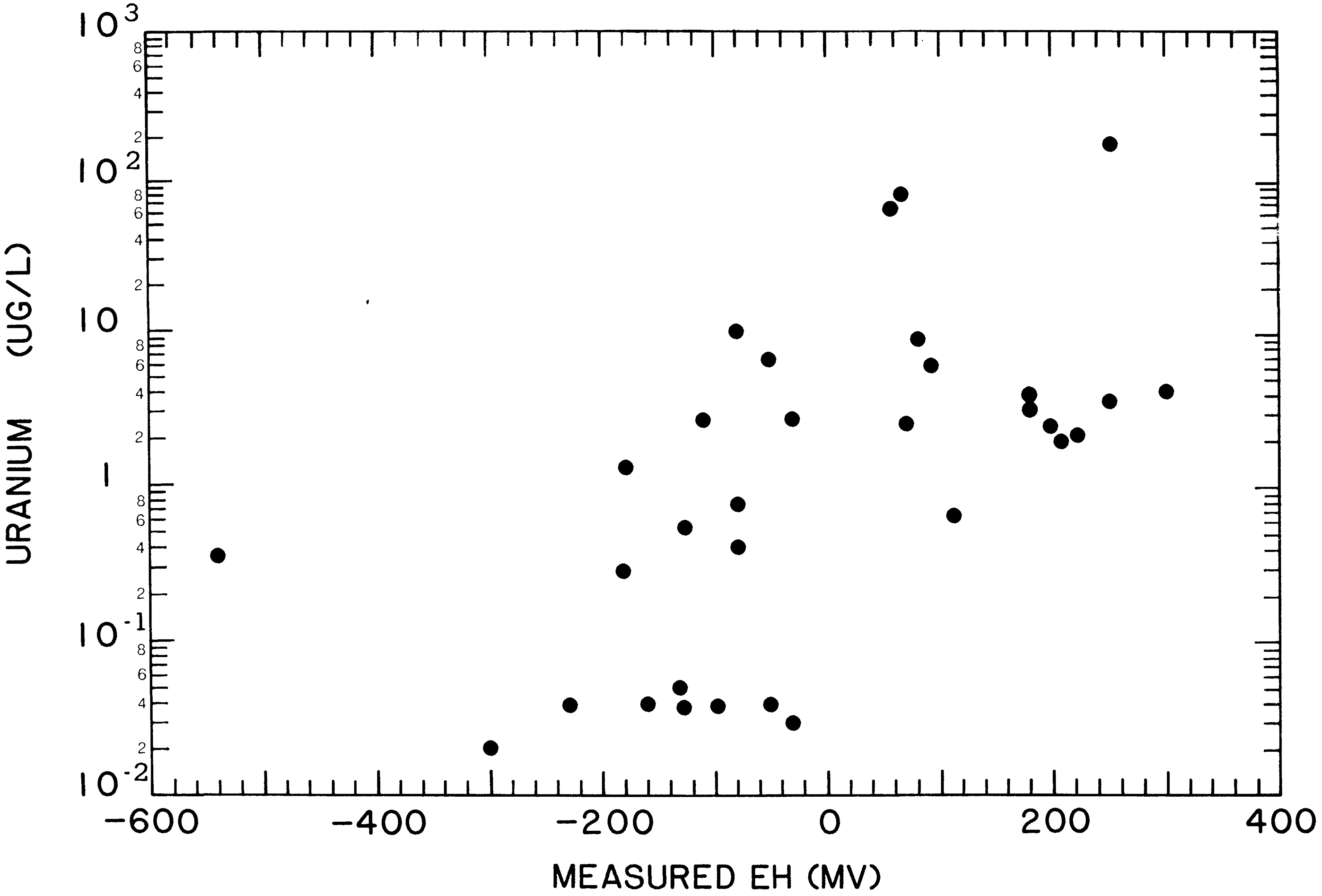

Figure 16.--Relationship between uranium concentrations and measured Eh.

Table 2.--Correlation coefficients for measured geochemical parameters

[Nonelement parameter abbreviations: spc, specific conductance; hrd, hardness; ds, dissolved solids; do, dissolved oxygen; alk, alkalinity; tmp, temperature. *, parameter not used in factor analysis. Numbers below diagonal indicate number of pairs of valid sample values used to determine correlation coefficients shown above diagonal. --, not enough pairs for determination; -, negative correlation; underscored values are significant at 95-percent level or greater]

	spc	Ca	SO4	Mg*	hrd*	ds*	Sr*	do	Eh	SiO2	U	Zn	Cu*	NO3*	PO4*	Fe	Mn*	pH	HCO3	alk*	Rn	Ra	Ba*	Mo*	K	tmp	Na	Cl	F	Li*	B*
spc--		.78	.78	.81	.82	.92	.74	.09	.22	.10	.45	-.20	-.14	.11	.12	.03	.13	-.30	.35	.34	.04	.04	.19	.20	.56	.07	.73	.69	.38	.69	.29
Ca---	33		.84	.81	.94	.90	.72	.29	.33	.15	.49	-.09	-.11	.55	.13	-.12	.12	-.09	.37	.37	-.12	-.16	.11	.03	.37	-.03	.52	.59	.20	.47	-.20
SO4--	33	33		.93	.93	.90	.62	.18	.22	-.16	.46	-.12	-.19	.24	-.12	.10	.30	-.35	.02	.02	-.02	-.07	-.16	-.14	.36	-.06	.44	.46	.31	.54	-.22
Mg*--	33	33	33		.95	.91	.59	.19	.20	-.17	.49	-.09	-.10	.22	-.05	.10	.37	-.32	.05	.04	.01	-.02	-.06	.21	.30	-.10	.46	.44	.31	.57	-.12
hrd*-	33	33	33	33		.95	.65	.27	.30	.00	.52	-.08	-.08	.41	.05	-.02	.27	-.24	.17	.16	-.04	-.14	-.00	.10	.31	-.09	.49	.52	.26	.52	-.18
ds*--	33	33	33	33	33		.76	.25	.30	.06	.48	-.20	-.13	.35	.10	-.04	.20	-.32	.32	.31	-.08	-.06	.07	.18	.52	.04	.71	.70	.43	.72	.23
Sr*--	29	29	29	29	29	29		.04	-.05	-.08	.16	-.29	-.17	.06	-.11	.05	.10	-.00	.59	.59	-.30	.16	.27	.30	.57	.11	.79	.63	.46	.75	.32
do---	32	30	30	30	30	30	27		.69	.54	.50	.29	.59	.66	.38	-.64	-.31	.11	.06	.06	-.10	-.19	-.03	.04	-.09	-.25	.11	.37	-.09	-.09	-.24
Eh---	34	32	32	32	32	32	28	32		.44	.60	.39	.47	.60	.21	-.60	-.37	-.05	.06	.06	.11	-.28	-.06	.28	-.09	-.08	.23	.48	-.08	-.03	-.03
SiO2-	33	33	33	33	33	33	29	30	32		.32	.04	.31	.48	.70	-.58	-.41	.10	.34	.34	.03	-.13	.37	.47	.13	-.06	.08	.36	-.22	-.14	.24
U----	37	33	33	33	33	33	29	32	34	33		.06	.01	.36	.07	-.52	-.27	-.08	.12	.12	.41	.02	.03	.15	.03	-.21	.24	.43	.01	.18	-.37
Zn---	30	30	30	30	30	30	28	28	29	30	30		.67	.36	-.08	-.29	-.27	.39	-.16	-.16	.02	-.39	-.37	-.00	-.14	-.12	-.26	-.18	-.38	-.30	-.31
Cu*--	19	19	19	19	19	19	18	18	18	19	19	19		.77	.57	-.53	-.34	.13	-.21	-.21	-.35	-.56	-.10	-.03	-.04	-.23	-.14	.05	-.24	-.13	-.04
NO3*-	23	23	23	23	23	23	21	21	22	23	23	22	11		.51	-.69	-.31	.26	.23	.23	-.14	-.61	-.14	--	.07	.00	.19	.49	-.08	-.08	-.08
PO4*-	23	23	23	23	23	23	21	21	22	23	23	22	11	23		-.36	-.21	-.05	.08	.08	-.06	-.27	.34	--	.03	-.02	.09	.36	-.10	-.15	.57
Fe---	31	31	31	31	31	31	29	29	30	31	31	30	19	23	23		.74	-.27	-.32	-.32	.06	.26	.03	-.11	-.04	-.07	-.16	-.33	.12	.02	.03
Mn*--	29	29	29	29	29	29	27	27	28	29	29	29	18	21	21	29		-.46	-.34	-.34	.16	.21	.23	.22	-.15	-.21	-.10	-.18	.05	.10	.00
pH---	37	33	33	33	33	33	29	32	34	33	37	30	19	23	23	31	29		.43	.43	-.34	-.08	-.12	.03	-.18	.07	-.09	-.20	-.30	-.31	-.46
HCO3-	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33		1.00	-.25	.11	.28	.45	.57	.34	.69	.55	.25	.47	.69
alk*-	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33	33		-.25	.11	.28	.45	.56	.34	.68	.55	.24	.47	.69
Rn---	27	25	25	25	25	25	22	26	27	25	32	24	14	18	18	24	23	27	25	25		.45	.08	-.07	-.13	-.25	-.17	.02	-.01	-.13	.11
Ra---	37	33	33	33	33	33	29	32	34	33	37	30	19	23	23	31	29	37	33	33	32		.55	.48	.15	.25	.10	.05	.13	.22	.10
Ba*--	23	23	23	23	23	23	21	21	22	23	23	22	13	15	15	23	21	23	23	23	18	23		.75	.06	.04	.18	.13	-.22	.30	.14
Mo*--	10	10	10	10	10	10	10	9	9	10	10	10	10	2	2	10	10	10	10	10	7	10	10		.19	.54	.25	.29	-.04	.29	.31
K----	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33	33	33	25	33	23	10		.50	.69	.64	.45	.78	.65
tmp--	37	33	33	33	33	33	29	32	34	33	37	30	19	23	23	31	29	37	33	33	27	37	23	10	33		.31	.29	.35	.26	.55
Na---	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33	33	33	25	33	23	10	33	33		.84	.60	.81	.74
Cl---	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33	33	33	25	33	23	10	33	33	33		.53	.58	.65
F----	33	33	33	33	33	33	29	30	32	33	33	30	19	23	23	31	29	33	33	33	25	33	23	10	33	33	33	33		.46	.83
Li*--	28	28	28	28	28	28	26	26	27	28	28	27	16	20	20	28	27	28	28	28	22	28	22	10	28	28	28	28	28		.53
B*---	16	16	16	16	16	16	16	14	15	16	16	16	11	8	8	16	16	16	16	16	13	16	15	10	16	16	16	16	16	16	

to clarify the structure of a correlation matrix. (See Klovan (1968); Davis (1973), McCammon (1975); or Harman (1976); for discussion of factor analysis.) Two problems were encountered in the selection of a correlation matrix appropriate for factor analysis. First, several pairs of variables having correlation coefficients ≥ 0.90 measure virtually the same thing; inclusion of both variables in the analysis biases the result and may obscure other important relationships. Therefore, alkalinity, hardness, dissolved solids, and magnesium were omitted for factor analysis, while pH, calcium, and specific conductance were left in. Second, factor analysis requires a symmetric matrix of correlation coefficients as input. Therefore, because of the incompleteness of the data, several samples and variables had to be omitted before factor analysis could be done. Several factor analyses were run using various correlation matrices in an effort to maximize the number of samples as well as variables. Slight variations in factor groups were noted as samples were omitted and variables added. A factor analysis based on an 18 by 18 matrix of correlation coefficients for 27 samples (table 3) was chosen for interpretation.

The analysis yielded five factors (table 4) that seem to reflect major influences on water chemistry: (1) short-term solution reactions, (2) oxidation reactions, (3) hydrolysis reactions, (4) uranium distribution, and (5) long-term solution reactions. The highest number (loading) for a given variable in table 4 indicates which factor that variable is most related to. Most variables have only one high loading, but some have more than one, indicating that more than one factor influences that variable.

Factor 1, short-term solution reations, represents chemical reactions involving minerals of relatively low solubility in the near-surface environment. In general, water that has been in contact with the rocks a relatively

Table 3. Matrix of correlation coefficients used in factor analysis

[Nonelement parameter abbreviations: spc, specific conductance; do, dissolved oxygen; tmp, temperature. All coefficients are based on 27 pairs of valid sample values. -, negative correlation; underscored values are significant at 95-percent level or greater]

	spc	Ca	SO4	do	Eh	SiO2	U	Zn	Fe	pH	HCO3	Rn	Ra	K	tmp	Na	Cl	F
spc--	1.00	.89	.89	.13	.30	-.05	.47	-.03	-.05	-.28	.27	-.05	-.19	.51	-.06	.73	.75	.32
Ca---	.89	1.00	.86	.21	.28	.09	.47	-.03	-.08	-.07	.33	-.08	-.18	.37	-.12	.57	.60	.16
SO4--	.89	.86	1.00	.12	.29	-.18	.46	-.06	.11	-.32	-.01	-.01	-.18	.33	-.17	.46	.52	.30
do---	.13	.21	.12	1.00	.64	.54	.45	.28	-.62	.11	.02	-.07	-.24	-.13	-.41	.01	.24	-.12
Eh---	.30	.28	.29	.64	1.00	.35	.61	.33	-.56	-.16	-.03	.15	-.32	-.03	-.16	.14	.36	-.11
SiO2-	-.05	.09	-.18	.54	.35	1.00	.30	.19	-.63	.15	.20	.01	-.13	.05	-.09	-.17	.24	-.45
U----	.47	.47	.46	.45	.61	.30	1.00	.06	-.51	-.10	.09	.45	.09	.01	-.33	.21	.43	-.01
Zn---	-.03	-.03	-.06	.28	.33	.19	.06	1.00	-.24	.28	.01	.00	-.24	.18	-.02	-.05	-.04	-.28
Fe---	-.05	-.08	.11	-.62	-.56	-.63	-.51	-.24	1.00	-.29	-.35	.00	.14	-.13	-.02	-.17	-.34	.16
pH---	-.28	-.07	-.32	.11	-.16	.15	-.10	.28	-.29	1.00	.59	-.28	.09	-.03	.12	.02	-.18	-.27
HCO3-	.27	.33	-.01	.02	-.03	.20	.09	.01	-.35	.59	1.00	-.23	.06	.51	.30	.62	.48	.11
Rn---	-.05	-.08	-.01	-.07	.15	.01	.45	.00	.00	-.28	-.23	1.00	.43	-.12	-.23	-.15	.06	.01
Ra---	-.19	-.18	-.18	-.24	-.32	-.13	.09	-.24	.14	.09	.06	.43	1.00	-.14	.17	-.14	-.17	-.01
K----	.51	.37	.33	-.13	-.03	.05	.01	.18	-.13	-.03	.51	-.12	-.14	1.00	.43	.61	.65	.33
tmp--	-.06	-.12	-.17	-.41	-.16	-.09	-.33	-.02	-.02	.12	.30	-.23	.17	.43	1.00	.16	.10	.24
Na---	.73	.52	.46	.01	.14	-.17	.21	-.05	-.17	.02	.62	-.15	-.14	.61	.16	1.00	.78	.51
Cl---	.75	.60	.52	.24	.36	.24	.43	-.04	-.34	-.18	.48	.06	-.17	.65	.10	.78	1.00	.45
F----	.32	.16	.30	-.12	-.11	-.45	-.01	-.28	.16	-.27	.11	.01	-.01	.33	.24	.51	.45	1.00

Table 4.-- Parameter associations as determined by factor analysis

[Reordered varimax factor matrix is shown. Five factors account for 77 percent of total variance. Communality is percent of variance in each variable accounted for by relationship to these five axes of rotation. Data matrix of 18 variables and 27 samples was used. Underline indicates primary association of variables within factors; parentheses indicate strong secondary association of a variable with another factor]

	Axis of rotation					Communality
	1	2	3	4	5	
Factor 1: Short-term solution reactions						
Specific conductance------	0.93	0.05	-0.08	-0.04	0.27	95
Calcium-------------------	.93	.09	.12	-.05	.06	89
Sulfate-------------------	.92	-.06	-.22	-.05	.03	90
Factor 2: Oxidation reactions						
Dissolved oxygen----------	0.20	0.78	-0.00	-0.11	-0.23	72
Eh------------------------	.27	.78	-.29	-.01	-.02	76
Silica--------------------	-.09	.76	.22	.02	-.05	63
Uranium-------------------	(.52)	.56	-.07	(.50)	-.11	86
Zinc----------------------	-.12	.46	.07	-.31	-.02	33
Iron----------------------	.02	-.86	-.24	-.09	-.19	83
Factor 3: Hydrolysis reactions						
pH------------------------	-0.17	0.12	0.88	-0.11	-0.06	84
Bicarbonate---------------	.23	.13	.76	.03	(.50)	90
Factor 4: Uranium distribution						
Radon---------------------	-0.03	0.12	-0.32	0.80	-0.08	77
Radium--------------------	-.17	-.28	.25	.79	-.02	80
Factor 5: Long-term solution reactions						
Potassium-----------------	0.30	0.04	0.11	-0.14	0.77	72
Temperature---------------	-.31	-.17	.15	-.06	.71	66
Sodium--------------------	(.61)	.00	.17	-.04	.63	81
Chloride------------------	(.61)	.33	-.05	.09	.63	88
Fluoride------------------	.25	-.29	-.32	.07	.60	62

short length of time has a low specific conductance and has calcium and sulfate or bicarbonate as major constituents. As residency time increases, the conductance increases along with these constituents until minerals, such as calcite, begin to precipitate.

Factor 5, long-term solution reactions, is closely related to factor 1. As residency time continues to increase, the conductance increases, and sodium and chloride become the dominant ions because they form minerals of high solubility and therefore, tend to stay in solution. The high loadings of sodium and chloride factor 1 indicate that these ions are seemical parameters--major ions, trace elements, and field properties--were studied using linear correlations and R-mode factor analysis. All 37 samples and 31 variables were used initially to produce a matrix of correlation coefficients (table 2). Not all samples were tested for all parameters, so the correlations involve various numbers of samples. As a result, significant values for the correlation coefficients vary according to the number of pairs used in the correlation.

Factor 2, oxidation reactions, represents changes in oxidation-reduction potential that affect the stability of several ions, iron and uranium, in particular. Iron in solution in a reducing water will precipitate if oxidized, and uranium in solution in an oxidizing water will precipitate if reduced.

Factor 3, hydrolysis reactions, represents changes in hydrogen ion potential that affect the stability of ions such as bicarbonate.

Factor 4, uranium distribution, represents the distribution of uranium in the rocks as it influences the distribution of uranium and its daughter elements in the water. The amount of uranium in the water is primarily influenced by factor 2, oxidation reactions, but it is also strongly influenced by factors 1 and 4, as shown by the high loadings of uranium on these factors. Radon shows a moderate negative loading on factor 3, and radium, on factor 2; but their primary association in factor 4, together with the secondary association of uranium, points to factor 4 as a factor which affects only uranium and its daughter products. This factor is deemed to be the distribution of uranium occurrences in the rocks.

The grouping of elements for presentation in table 2 was done after factor analysis was accomplished. Included in the factor groups in table 2 are elements that were not used in the factor analysis. Addition of an element to a given group was based on an examination of significant correlation coefficients with elements in that group. Therefore, table 2 shows the associations for all measured parameters.

The correlations and the factor analysis indicate that several metal ions are strongly affected by Eh as measured, an observation that agrees well with known chemical phenomena and lends support to interpretation of the Eh measurements. In general, concentrations of uranium, copper, and zinc are all higher in waters which have a higher Eh. Uranium is fixed in minerals such as uraninite when it is in a plus-four state, but it forms soluble uranyl complexes when it is in a plus-six state. In contrast, concentrations of iron and manganese are higher in waters which have a lower Eh. Iron and manganese are more soluble in a reduced state, but in the presence of oxygen they tend to form insoluble oxides and hydroxides. The other metal ions, barium and molybdenum, correlate with radium and may, therefore, be more related to the distribution of radioactive elements in the system than to Eh. Barium would respond to oxidation only if sulfur were present.

A model for interpretation

Several uranium occurrences are known in rocks of the Dakota Sandstone and Purgatoire Formation in the Canyon City embayment area north and northwest of the study area. One occurrence (George Avery mine, sec. 6, T. 18 S., R. 66 W.) involves carnotite in fracture coatings and solution cavities in sandstone where carbonaceous material is abundant. At the Rupp property (sec. 18, T. 17 S., R. 70 W.) carnotite (?) and autunite (?) occur in fractures in sandstone which contains abundant iron oxides and well-developed Leisegang rings; one small isolated nodule with a center of massive pyrite was found by delayed neutron analysis to contain 249 ppm uranium. Another occurrence (D-C claims, sec. 33, T. 17 S., R. 70 W.) has 5-mm thick coatings of radioactive iron and manganese oxides on fracture and joint surfaces in sandstone; whereas one sample was found to be in near secular equilibrium, having 1,550 ppm equivalent uranium and 1,712 ppm uranium, most samples from this occurrence have shown disequilibrium in favor of daughter products, yielding equivalent uranium values of 200-1,500 ppm but uranium values of only 100-300 ppm.

All of these occurrences involve near-surface showings of secondary uranium minerals in fractured rocks. They imply that at least in some places, uranium may have been present in the Dakota-Purgatoire sandstones in association with pyrite or organic material but that subsequent oxidation has locally mobilized the iron and uranium and has probably removed some of the uranium in solution while leaving thorium and radium daughter products behind with the iron and manganese oxides. Radioactive occurrences in the study area may involve similar oxide minerals but may also involve reduced primary uranium minerals that have not been exposed to oxidizing conditions in the near-surface weathering environment.

These occurrences provide the basis for a model of hydrogeochemical conditions in the study area, as shown in figure 17. The model incorporates information from the statistical relationships and spatial distributions of the measured geochemical parameters, as well as information form the known uranium occurrences.

The statistical analyses indicate that the availability of oxygen and the distribution of uranium in the rocks are important influences on the variation in concentrations of uranium, its daughter products, and other metal ions in the ground water. Uranium may occur in discontinuous zones in the units of the aquifer system. Oxygen may be introduced to the system in recharge areas or along faults which are permeable, as indicated by the occurrence of trees along linear fault traces in much of the study area. Where reducing conditions prevail as the ground water encounters an occurrence, radium and iron can be taken into solution along with barium, manganese, or molybdenum, if present; but where oxidizing conditions dominate, uranium becomes soluble along with copper and zinc, if present. Oxidation of pyrite in association with uranium releases sulfate and locally mobilizes the iron. Radium may coprecipitate with iron and manganese oxides and hydroxides or with barite in nearby fractures, or it may stay in solution if not enough iron, manganese, or barium is present to bring about coprecipitation.

The spatial distributions of the measured geochemical parameters support the statistical relationships and indicate that uranium occurrences in the area are being leached rather than formed by the present hydrologic system. If occurrences are being formed as ground water flows downdip in an aquifer, one would expect to find high uranium concentrations in the water above the site of precipitation and low concentrations below; and if steady-state conditions exist, uranium concentrations would be similar above and below the

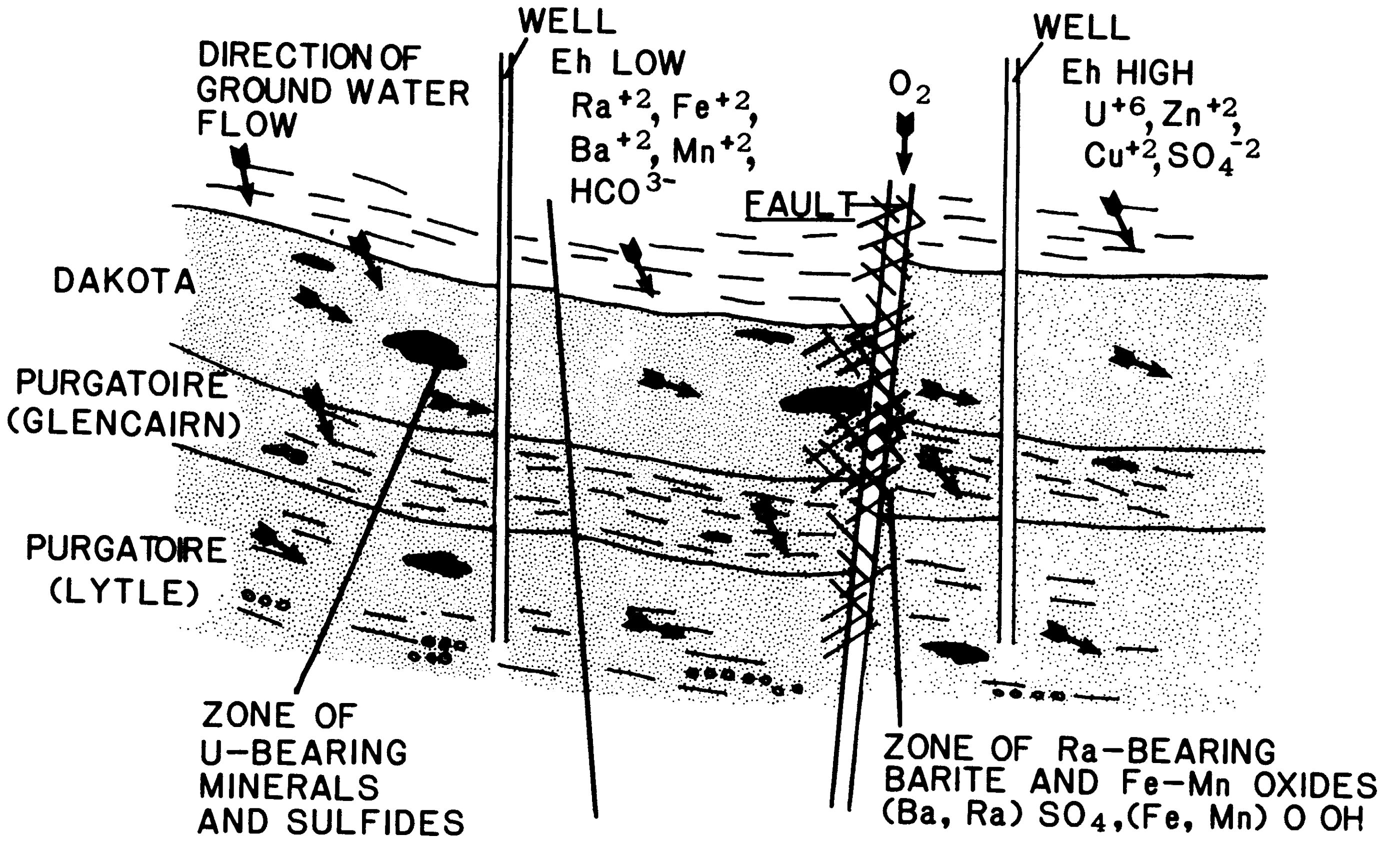

Figure 17.--Hypothetical cross-sectional model of uranium occurrences and hydrogeochemical conditions in the study area.

occurrences. If occurrences are being leached, then uranium concentrations in the water would be higher downdip from the occurrences. In the study area the presence of radium, a daughter product of uranium, in high concentrations in water updip from high uranium concentrations indicates that uranium occurrences giving rise to the radium must also be present updip from the high uranium concentrations; hence, the occurrences are apparently being leached.

Discussion of areas in terms of model

Several areas show promise of being associated with uranium occurrences as depicted in the model. The areas, shown on figure 18, were identified by noting samples with high concentrations of radium, radon, and (or) uranium in the water (as shown on figs. 5-7) and by noting samples with high factor scores on factor 4 (table 5).

The factor scores were determined by multiplying the standardized data matrix by the varimax factor loading matrix. The results are in standardized form, that is, a zero in a column indicates an average amount of that factor at that sample site. Samples with high positive factor scores reflect a high intensity of that factor operating at that site. Therefore, samples with the highest scores on factor 4 are the ones most likely to be associated with uranium occurrences. The map distribution of factor 4 scores is shown on figure 18.

Pertinent data from table 1 for samples in the outlined areas are shown in table 6. Because of the large variance in the data, it is difficult to make comparisons for specific sites; some of the element data do not bear out the correlations as given in table 2, but this lack of fit does not negate the validity of the correlations. The model provides a framework within which the values, relationships, and distributions of several parameters can be

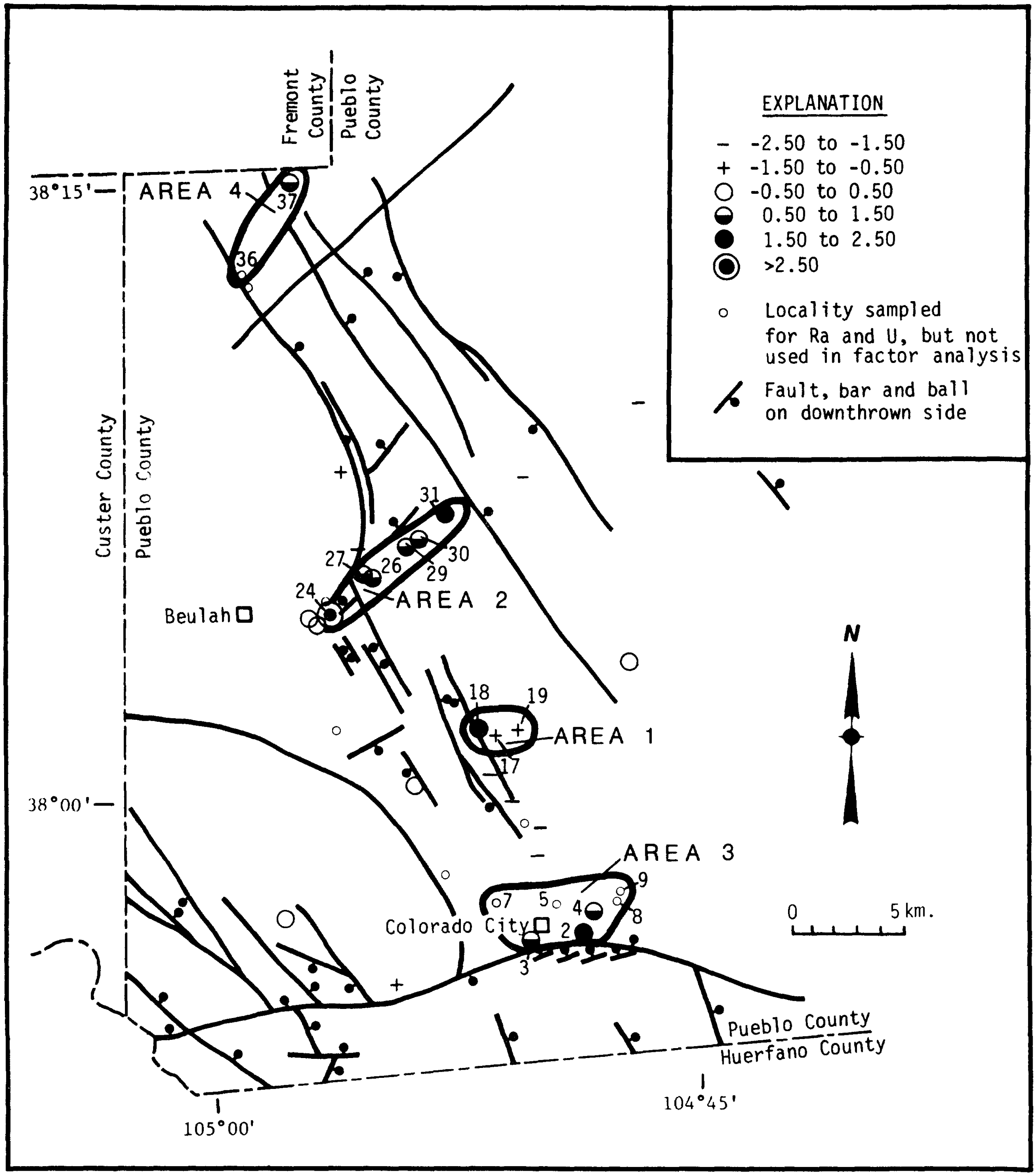

Figure 18.--Areas of possible Uranium occurrences discussed in text. Symbols for ranges of factor 4 scores are shown under Explanation.

Table 5.--Factor scores for samples used in factor analysis

Sample	Factor 1 Short-term solution reactions	Factor 2 Oxidation reactions	Factor 3 Hydrolysis reactions	Factor 4 Uranium distribution	Factor 5 Long-term solution reactions
1-------	-3.75	-2.56	-0.80	-0.75	-2.70
2-------	-3.09	-1.60	1.14	2.17	- .16
3-------	- .41	-1.18	1.38	1.20	-1.74
4-------	-2.64	-2.52	.77	.64	- .29
6-------	-2.64	5.53	1.12	.38	-5.67
11------	-2.69	-3.92	- .22	-1.74	.15
12------	-4.73	-3.06	1.30	-1.98	- .34
14------	-3.64	-1.82	.34	-2.22	- .42
15------	- .76	- .10	.52	- .09	.68
16------	-4.79	-3.38	1.15	-2.07	- .76
17------	9.90	4.24	- .45	-1.36	2.45
18------	-3.44	- .22	.47	2.02	-1.55
19------	7.92	4.10	1.38	-1.09	.72
21------	2.55	3.22	-1.55	- .25	-1.34
22------	-6.12	-5.11	1.38	.47	-1.53
23------	-1.64	5.54	1.10	- .49	.25
24------	-3.13	-1.61	-1.52	4.70	-2.51
26------	4.79	3.20	.21	.92	2.88
27------	2.87	.68	.16	1.26	.55
28------	-2.31	6.54	1.19	-2.10	.27
29------	.71	.80	.32	1.58	- .95
30------	3.13	3.09	- .18	1.11	.84
31------	1.05	-2.77	-8.98	1.78	-4.30
32------	-1.53	-3.29	-2.45	-1.82	-1.35
33------	.09	1.83	1.93	-1.33	1.77
34------	4.61	-4.76	.27	-1.95	3.67
37------	9.71	- .87	.03	1.03	11.38

Table 6. Selected data for samples in areas shown on figure 18

[Data selected from table 1. L, less than detection limit shown]

Sample	Water type	Eh (mv)	U (ug per L)	Cu (ug per L)	Zn (ug per L)	Rn (pCi per L)	Ra (pCi per L)	Fe (ug per L)	Mn (ug per L)	Ba (ug per L)
					Area 1					
18----	CaHCO3	- 30	2.6	1.5	820	3100	110	530	330	180
17----	MgSO4	+120	19	20	340	400	.9	550	2000	---
19----	CaMgSO4	+ 60	70	6.0L	350	100L	8.8	950L	98	30
					Area 2					
24----	CaHCO3	- 80	9.7	0.5	80	27000	420	4200	540	34
26----	CaMgSO4	+250	180	---	440	2700	2.8	30	10	10L
27----	CaMgSO4	+ 65	77	---	310	1800	13	1600	60	10L
29----	CaHCO3	- 50	6.2	---	1400	5500	31	3900	110	10L
30----	CaSO4	+180	3.1	---	110	1500	18	50	110	10L
31----	MgSO4	+ 80	8.8	---	150	7100	5.2	11000	2400	10L
					Area 3					
2-----	CaHCO3	-130	0.52	5	60	1300	180	510	170	---
3-----	CaSO4	-180	1.3	1.7L	21	580	43	990	240	84
4-----	CaHCO3	-180	.29	5	130	900	35	3500	170	---
5-----	---	---	.4L	---	---	---	33	---	---	---
7-----	---	- 80	.4	---	---	1400	18	---	---	---
8-----	---	+200	2.4	---	---	860	130	---	---	---
9-----	CaNaHCO3 ClSO4	+300	4.2	50	490	---	90	370	100	100
					Area 4					
36----	NaHCO3	---	2.5	3.0L	10L	---	300	1200	90	160
37----	NaHCO3	-110	2.6	5.4L	54L	690	17	860L	130	21

explained, but it is not refined enough to account for all of the variations in a specific example. Other factors, such as local structure and lithology, probably play a role.

In area 1, high concentrations of radium and radon in sample 18 contrast with high concentrations of uranium in samples 17 and 19. Slightly reducing conditions in the bicarbonate water within a northwest-trending graben give way to oxidizing conditions in the sulfate water outside the graben, to the east, in the direction of ground-water flow; the fault on the east side of the graben may allow the entry of oxygen-rich water into the system. In agreement with the model shown in figure 17, copper is higher in water down from the fault, and barium is higher up from the fault. However, zinc does not follow copper in this case, and iron and manganese show similar concentrations in all three samples. Nevertheless, the data indicate that uranium occurrences might be associated with sample 18 near the fault. Uranium has travelled in solution eastward, but radium has coprecipitated with barite in the vicinity of the fault.

In area 2, the highest concentrations of radium and radon in the study area (sample 24) contrast with the highest concentrations of uranium in the study area (samples 26 and 27). As in area 1, these values occur on opposite sides of a northwest-trending fault; but the structure is more complex in area 2, and moderately high radium and radon concentrations persist to the northeast beyond the high uranium concentrations. Slightly reducing conditions in the bicarbonate water of sample 24 give way to oxidizing conditions in the sulfate waters across the fault to the northeast. Further northeast, slightly reducing bicarbonate water again appears and again gives way to oxidizing sulfate water, but the radium, radon, and uranium concentrations in these samples (29, 30, and 31) are much lower than in those to the southwest. Iron and manganese concentrations generally follow the changes in measured Eh, but barium concentrations are low in all samples. All these data indicate that uranium occurrences might be associated with sample 24 southwest of one fault and near another. Uranium has travelled in solution to the northeast, but radium has coprecipitated with iron and manganese oxides near the faults. Smaller uranium occurrences near locality 29, possibly reprecipitated from the uranium in solution, have yielded moderately high amounts of radium and radon to the water.

In area 3, radium concentrations are generally high, but radon values are only moderate. There are no contrasting high uranium concentrations, even though some of the waters are oxidizing. Possibly, scattered small uranium occurrences throughout the area yield radium to the ground water flowing through the sytstem. Sample 2, in particular, may be associated with uranium occurrences near an east-west fault, and high uranium concentrations in water not sampled may occur to the south or east.

In area 4, data are sparse, but moderate to high radium concentrations in the sampled water indicate that this area may also be associated with uranium occurrences.

Conclusion

Radium, uranium, and radon concentrations in water from 37 wells in southwestern Pueblo County, Colorado, define several areas of high radioactivity in the ground water that may be associated with uranium occurrences. One of these areas is north of Colorado City, and another is east of Beulah.

Use of correlation coefficients and R-mode factor analysis facilitated the interpretation of the radioelement data along with other data on water chemistry. These results combined with information on known uranium occurrences, water levels, and geologic structure, indicate that the present hydrologic system may be actively leaching uranium-bearing phases in discontinuous zones in sedimentary rocks of the area. Reducing conditions allow the presence of radium in the water, whereas oxidizing conditions near faults and fractured rocks allow the presence of uranium as well as radium.

Acknowledgments

We extend thanks to R. Gamewell of the Colorado Department of Health, G. Hollandsworth of the Pueblo County Environmental Health Office, and L. Hershey of Hershey, Wooderson and Lipp, Inc., for their assistance during the course of this study. We are also grateful to the property owners in Pueblo County who gave us permission to sample their wells.

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