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Multivariate Statistical Analysis of Stream Sediments for Mineral Resources from the Craig NTMS Quadrangle, Colorado

By

Michael Beyth, Carlotta McInteer, David E. Broxton,
Stephen L. Bolivar, and Mary E. Luke

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MULTIVARIATE STATISTICAL ANALYSIS OF STREAM SEDIMENTS
FROM THE CRAIG NTMS QUADRANGLE, COLORADO

by

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ABSTRACT

Multivariate statistical analyses were carried out on Hydrogeochemical and Stream Sediment Reconnaissance data from the Craig quadrangle, Colorado, to support the National Uranium Resource Evaluation and to evaluate strategic or other important commercial mineral resources. A few areas for favorable uranium mineralization are suggested for parts of the Wyoming Basin, Park Range, and Gore Range. Six potential source rocks for uranium are postulated based on factor score mapping. Vanadium in stream sediments is suggested as a pathfinder for carnotite-type mineralization. A probable northwest trend of lead-zinc-copper mineralization associated with Tertiary intrusions is suggested. A few locations are mapped where copper is associated with cobalt. Concentrations of placer sands containing rare earth elements, probably of commercial value, are indicated for parts of the Sand Wash Basin.

INTRODUCTION

As part of the National Uranium Resource Evaluation (NURE), the Los Alamos Scientific Laboratory (LASL) is conducting a Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) in the states of Colorado, Montana, New Mexico, Wyoming, and Alaska. All data are reported according to 1° x 2° National Topographic Map Series (NTMS) quadrangle boundaries with each quadrangle normally containing 1500 to 2000 sample locations. Data are reported for uranium and as many as 43 additional elements for each sample location. A typical report includes data listings, sample location and concentration overlays for uranium concentrations in water and sediments, and basic statistical data (mean, median, and standard deviation) for uranium in each sample type. Reports also include a brief evaluation of areas that may have potential for further uranium exploration. The data evaluation sections of these reports are brief by necessity, consisting predominantly of comparisons of uranium concentrations and uranium/thorium (U/Th) ratios with bedrock geology of the quadrangle. Although the data evaluations in LASL HSSR reports represent logical first steps in assessing potential, follow-up areas within NTMS quadrangles, a large amount of multielement data available for each sample location could greatly enhance the interpretation of the uranium data as well as aid in the assessment of other economic or strategic mineral commodities. The goals of this study are twofold:

- . To support evaluations of rational uranium resources through multivariate statistical analysis for sediment samples, and
- . To use the multielement data included in typical HSSR reports to support the evaluation of strategic or other commercially important mineral resources in the US (Van Eeckhout, 1979).

A preliminary study of multivariate statistical methodology for the HSSR at LASL was carried out by Dawson (1979).

Background

The sediment data base of the Craig NTMS quadrangle was selected as a test model. This quadrangle, which comprises about 18 900 km² in northwest Colorado, includes sections of the Wyoming Basin and the Southern Rocky Mountains (Maps 1 and 2). In an HSSR report published by Bolivar and Hill (1979), the quadrangle was further divided into six approximate physiographic and geologic provinces. The data were evaluated both for the whole quadrangle and for each province. The boundaries of these provinces are shown on Map 3.

Sediment samples for the quadrangle as a whole have uranium concentrations that range from 1.53 parts per million (ppm) to 385.60 ppm. A recalculated mean of 6.23 ppm was obtained after dropping 13 samples with concentrations greater than 50.00 ppm. Eight areas containing clusters of sediments with anomalous uranium concentrations were delineated (Fig. 5 in Bolivar and Hill, 1979).

Computer Facilities

All data base management was developed to be used on a 6600 CDC, 128K central memory computer. A special program, Statistical Package for the Social Sciences (SPSS; Nie et al, 1975), was used to perform several different types of data analyses including histograms, scatter plots, correlation coefficients, and factor analyses. To transfer data from the data base on a CDC 6600 computer disk to the Nie et al system, it was necessary to use System

2000. Some of the basic statistics were done with System 2000 and some were done with the Nie et al system.

Methods

All elements analyzed in the Craig report of Bolivar and Hill (1979) were examined for potential use in this study. Elements considered favorable were those that are or could be pathfinders for uranium or could be used to study strategic mineral deposits. It was necessary to avoid selecting elements with many reported concentrations below the analytical detection limit. Consequently, 23 elements were chosen for study from a total of 1732 sample locations. The data were then evaluated following these methods:

- (1) The absolute values of the detection limits are used for copper, lead, lithium, aluminum, barium, and calcium. Out of a total of 1732 samples, the number below the detection limit for copper is 46, for lead are 171, and for barium are 47. For aluminum, lithium, and calcium, there are only a few samples with values below the detection limit. Therefore, the statistical parameters for these variables, such as average, calculated by SPSS, are slightly lower than the same parameters calculated directly by system 2000, which ignored concentrations less than zero. As a standard routine for all elements (except the ones mentioned above), only concentrations above the detection limit are entered in SPSS programs. Hence, all values below the detection limit are ignored. Histograms and basic statistics for each element for all cases are shown on Figs. 1-25 and are summarized in Table I.
- (2) Iterations were then carried out for each element eliminating concentrations above the following cutoffs: U >50 ppm, Cu >66 ppm, Pb >50 ppm, Li >70 ppm, Co >25 ppm, Cr >200 ppm, Dy >40 ppm, Eu >5 ppm, Fe >50 000 ppm, Hf >55 ppm, La >400 ppm, Mn >5000 ppm, Sc >26 ppm, Sm >140 ppm, Th >100 ppm, Ti >12 700 ppm, and V >250 ppm. These high values were removed because they significantly skew statistical averages and standard deviations on which anomaly thresholds are based. After iteration, a threshold of two standard deviations above the mean was arbitrarily selected (Table I). Thresholds for five elements (Pb, Li, Ba, U, and Cu) were calculated independently on log-probability paper using a 95.5 percentile cutoff. These results (not listed) differ only slightly from those listed in Table I.
- (3) To identify samples with the most favorable concentrations (i.e., the highest values), a threshold of three standard deviations above the mean was calculated (after iteration). Samples with concentrations above this threshold are listed with the corresponding histogram in Figs. 1-25.
- (4) Scattergram plots (Nie et al, 1975) and correlation coefficients were then calculated for all element combinations. Several of these plots for selected cases are shown in Figs. 26-43.
- (5) R mode factor analyses with varimax orthogonal and oblique rotation (structure matrix and pattern matrix) were calculated for 22 elements (including Mg and Zn, excluding Ce, Figs. 44 and 45). Because Mg and Zn analyses included too many values below the detection limits, another set of factor analyses was run for all

TABLE I
BASIC STATISTICS (IN PPM) FOR 23 ELEMENTS IN SEDIMENTS
FROM THE CRAIG QUADRANGLE, COLORADO

WHOLE AREA (out of 1732 samples calculated, only >0)

Element			After Iteration		(M + 2 SD) [‡]
	Average (ppm)	Standard Deviation	Average (ppm)	Standard Deviation	
U	7.055	13.410	6.726	5.684	17.594
Cu	24.671	9.153	24.376	8.187	40.775
Pb	13.880	8.408	13.514	6.315	26.144
Li	24.067	11.458	23.822	10.674	45.170
Al	58 283.786	11 888.962	--	--	82 061.710
Ba	665.734	216.197	--	--	1098.128
Ca	20 941.576	18 367.267	17 846.815	9932.319	37 711.453
Co	15.457	3.752	10.375	3.561	17.497
Cr	59.690	31.833	58.114	26.518	111.150
Dy	6.741	10.210	5.724	3.897	13.518
Eu	1.352	.872	1.299	.491	2.281
Fe	21 226.568	12 259.302	20 371.452	8554.982	37 431.416
Hf	13.315	15.458	12.282	7.583	27.449
K	16 477.716	3681.857	--	--	23 841.430
La	79.474	164.018	62.078	48.991	160.060
Ce	146.572	322.218	116.265	105.568	327.401
Mn	725.932	680.405	708.310	511.011	1730.332
Na	10 208.062	4777.037	--	--	19 762.136
Sc	9.642	4.902	9.366	4.293	17.952
Sm	11.161	29.388	9.260	12.105	33.470
Th	26.182	61.358	17.821	14.944	47.709
Ti	4471.125	2071.948	4369.655	1750.299	7870.253
V	88.853	42.906	87.015	37.395	161.805

[‡]Mean plus two standard deviation.

elements (excluding Mg and Zn, including Ce), and this set of data appears to provide more satisfactory results (Figs. 46 and 47). The factor analysis and multielement correlation charts are helpful in indicating elemental assemblages and characterizing metallogenic provinces.

- (6) After all the data were analyzed as one data base for the entire quadrangle, data for the individual physiographic-geologic provinces of Bolivar and Hill (1979) were analyzed by the same methods. Basic statistics, described in (2) above, and factor analyses, described in (5) above, were calculated for each province (Table II; Figs. 50-51, 53-56, and 58-63).
- (7) Concentrations greater than two standard deviations above the mean (after iteration) for the whole quadrangle and each element were plotted on 1:250 000-scale maps, which were reduced as overlays for this report. High concentration clusters were delineated and boundaries were generally drawn according to topographic drainage basins rather than just connecting sample locations (Maps 4-24). These clusters were then overlaid on the geology map and correlated with the structure and stratigraphy. The results of this correlation are summarized in Table III.
- (8) Using the above data, an attempt was made to find probable locations of mineralization by following the pattern of elemental concentrations in the drainage basins. In some cases, it was possible to pinpoint the probable source of mineralization, and probable locations are designated by an X on the respective maps (Maps 5, 6, 12, 19, and 20).
- (9) Factor analyses were then calculated for all samples having uranium greater than 20 ppm (anomalous samples of Bolivar and Hill, 1979). These are listed in Table IV. Calculations were done treating all samples as one data base (Figs. 48 and 49) and then for sediment samples in Area A only (Fig. 52) and for sediment samples in Area C only (Fig. 57).
- (10) A factor score contour map was plotted using factor 1 (loaded predominantly with uranium and the lanthanides) for the quadrangle data base. This map (Map 24) is used to look for high residual uranium concentrations and to evaluate potential source rocks for uranium mineralization.

RESULTS

Results of this study are presented in the tables, figures, and maps included in this report. Because of the large volume of data, all results presented are not fully discussed.

The use of the original 1:250 000-scale topographic (US Geological Survey, 1954) and geologic map (Tweto, 1976) is recommended, although reduced copies of these two maps are included in this report (Maps 1 and 2) so that they can be used with the concentration overlays. Map 3 is a sample location overlay. However, concentration overlays, a sample location overlay with sample numbers, and a listing of field data and elemental concentrations for sediment samples from the Craig quadrangle can be found in Bolivar and Hill (1979). Reduced overlays of 1:250 000-scale maps in this report are included for the convenience of the readers. The significance of factor analysis, drainage basin, and source rock for uranium mineralization for the following discussion is explained.

TABLE II

BASIC STATISTICS (IN PPM) FOR 23 ELEMENTS IN SEDIMENTS
FROM SIX PHYSIOGRAPHIC AND GEOLOGIC PROVINCES, CRAIG QUADRANGLE, COLORADO

AREA A (149 cases)				AREA B (754 cases)				AREA C (1280 cases)			
Element	Average	Standard Deviation	No. of Cases (M ± 1 SD)*	Average	Standard Deviation	No. of Cases (M ± 1 SD)*		Average	Standard Deviation	No. of Cases (M ± 1 SD)*	
U	11.470 ^a	18.094 ^a	1	10.000 ^b	10.000 ^b	1		10.000 ^b	10.000 ^b	1	18
Cd	20.797	7.116	1	21.500 ^b	7.116	1		21.500 ^b	7.116	1	8
Pb	17.935 ^a	15.161 ^a	1	11.970 ^b	11.970 ^b	1		11.970 ^b	11.970 ^b	1	3
Li	18.914	8.604	1	24.611	11.062	1		16.442	11.106	1	7
Al	53 847.936	11 970.958	1	54 406.294	4 811.157 ^c	1		62 007.893	9984.192 ^c	1	
Ba	643.646	134.579	1	600.740	11.246 ^a	1		541.079	177.962	1	
Ca	11 689.976 ^b	4568.904	1	11 815.90	18 211.70	1		24 981.704	19 003.960 ^c	1	17
Co	8.696	2.394	1	9.251	1.124	1		13.008 ^c	4.130	1	11
Cr	52.963	25.301	1	58.451	40.077	1		71.332 ^c	41.260 ^c	1	15
Dy	13.476 ^a	23.966 ^a	1	4.040	1.011	1		7.043 ^c	3.241	1	8
Eu	1.740 ^c	1.706 ^a	1	1.380	1.035 ^c	1		1.445	1.548	1	4
Fe	16 969.541	8359.775	1	17 637.608	749.410	1		27 811.704 ^c	11 592.292 ^c	1	19
Hf	18.234 ^a	15.594 ^a	1	10.410	6.275	1		15.971 ^c	20.074 ^a	1	15
K	17 117.008	3731.306	1	16 026.817	268.137 ^c	1		14 764.136	3498.871	1	
La	187.311 ^a	387.426 ^a	1	40.801 ^d	30.274 ^d	1		65.521	47.845	1	5
Ce	37.600 ^a	765.000 ^a	1	74.020	57.177	1		115.941	90.297	1	4
Mn	6.0175	439.128	1	504.888	319.275	1		103.268 ^a	529.044	1	11
Na	6021.472	3104.501	1	6765.012	3 461.18 ^c	1		12 525.111	5090.071	1	
Sc	7.543	1.00	1	7.600	3.101	1		14.360 ^a	6.400 ^a	1	42
Sm	27.576 ^a	601.111 ^a	1	5.066 ^b	4.111 ^c	1		9.641 ^d	8.166 ^d	1	2
Ti	72.007 ^a	144.124 ^a	1	11.702 ^b	12.101 ^c	1		21.767	23.120 ^c	1	12
Tl	46.22386	24.27111	1	3910.515	1623.371	1		5089.783	185.124 ^c	1	13
V	72.024	32.114	1	85.071	43.796	1		109.140 ^c	45.379	1	4

AREA D (237 cases)				AREA E (74 cases)				AREA F (77 cases)			
Element	Average	Standard Deviation	No. of Cases (M ± 1 SD)*	Average	Standard Deviation			Average	Standard Deviation		
U	8.105	11.594 ^c	7	7.925	3.161			4.393	1.705		
Cd	25.878	11.987	11	24.298	8.103			21.818	6.293		
Pb	12.441	5.670	1	20.170 ^a	8.168			12.818	5.228		
Li	23.875	11.904	7	24.221	1.774			24.247	1.753		
Al	64 529.578	11 403.155	1	75 627.553 ^c	6844.771			58 406.364	11 015.871		
Ba	561.540	178.243	1	930.581 ^c	256.049			767.191	283.764		
Ca	19 853.774	8 518.936	9	14 300.862	6891.087 ^c			31 51.7260 ^a	28 425.372 ^a		
Co	11.137	3.091	2	10.862	1.131			9.197	2.289		
Cr	54.118	21.975	3	40.187	14.826			47.435	16.621		
Dy	8.157 ^c	7.215 ^c	15	6.685	1.674			4.416	1.584		
Eu	1.440	1.441	8	1.784 ^c	1.478			1.162	1.296		
Fe	24 745.228	11 063.730 ^c	9	23 914.668	9574.06			18 278.164	1069.137		
Hf	12.668	5.363	10	11.503	5.239			9.996	4.790		
K	17 277.063	3811.684	1	21 409.250 ^c	5131.441			17 203.422	3623.870		
La	89.392 ^c	82.256 ^c	14	120.394 ^c	60.171			51.104	18.334		
Ce	166.616 ^c	150.481 ^c	13	211.436 ^c	160.740			90.078	51.497		
Mn	835.350	403.980	7	349.197	487.107			54.1743	305.214		
Na	13 044.945	4046.869	1	15 853.471 ^c	4300.111			10 306.766	5947.642		
Sc	11.981 ^a	4.151 ^a	5	8.394	2.111			7.588	2.411		
Sm	12.418 ^c	12.630	7	13.534 ^c	8.174			6.169	3.463		
Tb	29.306 ^c	11.816 ^c	13	30.181 ^c	21.113			11.381 ^d	8.736		
Tl	4953.110	1834.129	12	4610.251	1697.737			4116.764	1600.895		
V	87.319	29.533	1	90.660	37.111			91.870	36.617		

^a Concentrations high in relation to Table I (after iteration).

^b Concentrations low in relation to Table I (after iteration).

^c Concentrations medium high in relation to Table I (after iteration).

^d Concentrations medium low in relation to Table I (after iteration).

*M ± 1 SD three standard deviation.

TABLE III

CORRELATION BETWEEN CLUSTERS OF MEAN PLUS TWO STANDARD DEVIATION
FOR ELEMENTS (EXCLUDING Ca, Na, Al)
AND THE GEOLOGY IN SEDIMENT SAMPLES OF THE CRAIG QUADRANGLE, COLORADO

Element Concentration (ppm)	Physiographic Province Cluster ^a	Rock Unit ^b	Main Correlation With Following Elements ^c	Comments
U > 15	A C D E	Tu, Gd, Y, Xg, Tc	Sc, La, Th, Pt Th partly Th partly Th partly	Probably in soil terraces.
<u>Carbonate Assemblage</u>				
Ce > 50	A C D E	Xg, Xg, Qg, Tc	U U U, Fe U	
Pb > 25	A B C D E	Tui Yg Tc, Tm Tm	U	Only partly correlative with U. Main cluster is in tightly folded and faulted area, of Tc intruded by Tertiary intrusive along Trout Creek.
U > 14.5	A C		U U, Fe	Correlation with U not clear; close to old terraces.
La > 150	A C E	Yg, Qg Xg Tc	U Lanthanides, Fe	Only in southern part. Five clusters.
Th > 45	A C D E		U, La, Pb La, Fe La, Pb, Zn	Correlative with U on Yg. Cluster near Trout Creek and north of it. Two south of it correlate with Uranium.
Sm > 5	A B		U U, Fe	High concentrations.
Eu > 1.1	A D E	Tm covered by Tv Tm, Gt		
<u>Basaltic Assemblage</u>				
Sc > 15	C E	Xg, Xfh, Xm Tc	Fe, Co, Cu Cu	Concentrations not high.
Fe > 1500	C D E	Xg, Xfh, Xm Yg, Tc Tc, Tv	Sc, Co, Ti	
Co > 17	A B C D	Tbp	Fe Sc, Fe	
Ti > 700	A B C D E	Twc, Tw Paleozoic-Mesozoic Xfh Tc	Co, Fe, Sc Sc, Fe Fe, Ti	
Cu > 41	C B D	Yg, xfh, Yg Tui Tc	Sc, Pt Zn, Pb Sc	
V > 152	B C	Km, Xm Xfh, Km, Kd	Sc Sc	
Cr > 111	C B D	Pm, Ppwm	Sc, Fe V, Fe, Ti, Co Sc, Fe	
Mn > 1730	A C	Tu, Twc Xfh, Tbp, Xg	Sc, Fe	Almost no correlation with U.
Hf > 27	A B C D	Tu, Tbp Tb Xg, Yg	U U	
Zn > 107	B C D E	Tui Yg Tm	Pb Pb Pb	Trout Creek and Ute Bill Creek anomalies forming a NW trend parallel to dyke direction.
Li > 45	B C F D	Km, Kp, Tui Tc Km, Kp Tm, Tc	V slightly	

^a Physiographic provinces shown in Map 3.

^b Gg = Unconsolidated Pleistocene Deposits - Young Gravels (Bull Lake and younger); Qgo = Old gravels and alluvium (pre-111 La.); Tbp = Browns Park Formation (Miocene); Tui = Upper Tertiary Intrusive Rocks (Pliocene and Miocene - <20 m.y.); Tv = Volcanic Rocks (Pliocene, Miocene, and Oligocene); Twc = Wasatch Formation (Eocene) - Cathedral Bluffs Tongue; Tw = Wasatch Formation (Eocene) - Main body; Tc = Conitmont Formation (Eocene and Paleocene); Tm = Middle Park Formation; Tml = Middle Tertiary Intrusive Rocks (Miocene and Oligocene); Xg = Williams Fork Formation; Kd = Kies Formation; Kp = Pierre Shale (Upper Cretaceous); Km = Mancos Shale (Upper and Lower Cretaceous); Kc = Colorado Group (Upper and Lower Cretaceous); Kd = Dakota Sandstone (Lower Cretaceous); Tr = Chinle and Chugwater Formations; Ppwm = Minturn Formation (Pennsylvanian) or Morgan Formation (Pennsylvanian) in Western Part of Area; Yg = Granitic Rocks (Precambrian Y - =1400-m.y. Age Group); Xg = Rocks of =1700-m.y. Age Group (Precambrian X); Xm = Mafic intrusive rocks; Xfh = Interlayered Felsic and Hornblende Gneisses (Precambrian X).

^c From 1:250 000 scale map of Tweto (1979).

TABLE IV

CLUSTERS OF SEDIMENT SAMPLES (FROM BOLIVAR AND HILL, 1979)
WITH URANIUM CONCENTRATIONS GREATER THAN 20 PPM
FROM THE CRAIG QUADRANGLE, COLORADO

Sample Number	U	Th	Cu	Pt	Li	Co	Cr	By	Bu	Fe	Hf	La	Ce	Mn	Sc	Sr	Ti	V
S5 (A)																		
CO2030	17.28	273.3	-10	24	12	7.7	141	42	4.4	31700	71.9	692	1226	1240	12.2	105.5	13050	113
CO2829	24.02	190.2	-10	34	5	61.2	62	41	3.0	16910	31.0	412	900	1271	7.9	82.3	9548	63
CO2811	36.16	206.3	11	47	8	6.1	60	44	3.5	15680	31.9	617	1200	1589	8.2	90.6	8987	37
CO2814	27.85	181.2	14	31	42	9.4	42	37	3.1	24630	38.9	422	899	1954	10.7	71.1	9520	65
CO2821	45.09	367.0	11	42	15	7.2	38	62	4.4	17600	36.0	791	1500	1050	1.6	188.0	6187	52
S2 (A)																		
CO2024	54.16	446.8	23	44	21	9.3	69	68	5.8	21500	35.0	1056	2033	907	9.7	165.4	8261	79
CO2041	30.21	275.9	22	28	20	10.7	72	45	3.6	23940	41.9	812	1143	876	10.5	104.6	9038	85
CO2145	28.45	233.7	12	31	16	7.8	60	34	3.2	15260	27.7	512	7062	559	6.4	90.6	5605	62
CO2146	18.61	304.6	-10	35	14	7.1	88	47	4.0	21940	50.0	723	1352	775	9.0	113.1	780	89
CO2150	44.22	507.3	14	5	10	6.9	113	76	6.5	31150	65.2	1115	2411	1165	10.9	185.7	13320	112
CO2603	23.55	181.2	15	22	17	8.5	95	31	2.9	18470	30.7	419	858	665	8.9	68.6	6272	75
CO2804	31.35	226.3	21	35	14	6.4	75	40	3.2	16700	31.0	543	1017	693	7.9	74.5	7260	65
CO2605	20.76	161.8	18	19	17	8.3	46	26	2.6	14130	32.8	357	743	736	7.3	60.7	6124	47
CO2607	21.94	153.9	11	26	16	7.4	40	24	2.8	13520	25.9	363	720	1057	6.8	61.7	7098	48
S3 (A)																		
CO2163	11.0	220.9	10	44	16	6.3	45	41	3.2	169	45.2	544	590	606	7.3	61.8	5981	66
CO2167	85.98	789.3	15	100	20	14.7	81	101	9.0	45810	72.4	1746	3676	1895	14.0	242.5	12070	168
CO2064	12.21	444.8	-10	69	13	5.9	62	69	5.5	10810	34.7	1047	2348	436	5.2	151.1	3655	44
CO2070	167.30	1546.0	-10	147	9	5.5	206	209	16.6	26490	145.6	3486	7038	1061	13.6	469.0	9561	89
CO2173	34.04	275.7	-10	41	16	6.8	61	47	3.7	14690	39.5	619	1360	641	6.7	104.0	6368	49
CO2175	14.96	307.8	15	40	14	9.8	79	47	4.0	17670	40.1	679	1362	1276	9.0	111.1	7890	86
CO2177	87.50	610.0	14	64	13	10.1	132	82	9.3	23470	62.5	1745	2747	2739	9.6	311.9	5275	62
CO2178	29.48	213.3	23	33	21	7.3	55	37	3.2	14720	21.2	533	942	683	6.9	82.2	5425	53
CO2181	84.68	746.0	-10	44	3	8.6	92	105	8.4	24360	50.7	1700	3130	871	8.5	270.0	11050	82
CO2187	65.49	444.7	-10	31	3	8.0	63	89	6.9	27690	64.4	1342	2114	1345	10.1	166.6	14550	85
CO2189	35.44	261.7	-10	40	7	9.1	96	46	4.2	34030	48.4	730	1334	1577	10.1	115.3	12950	101
S4 (B)																		
CO2051	26.46	14.3	15	16	59	7.6	11	2	0.9	12500	6.4	57	95	1276	4.4	6.7	-1501	-16
CO2052	37.13	64.3	11	11	28	7.7	102	9	3.0	21110	76.4	379	515	1164	10.2	30.7	9465	97
CO2053	39.72	300.0	-15	45	41	10.7	68	41	4.2	28000	35.5	687	1360	745	10.1	110.0	6819	111
S5 (C)																		
CO2499	24.73	24.6	25	41	31	11.4	44	10	3.1	19590	11.0	130	160	350	10.4	23.6	5097	47
CO2567	52.25	270.2	-10	45	5	15	73	42	7.3	121100	491.3	154	1086	1462	26.6	122.4	9239	356
CO3367	24.60	73.1	29	39	20	17.6	103	12	7.7	51930	77.9	140	280	151	19.6	22.9	6721	181
S6 (C)																		
CO2189	54.78	51.5	45	49	38	13.5	54	14	1.7	24490	30.2	159	247	1605	5.4	25.8	3416	69
CO2190	48.96	41.4	45	25	46	21.4	55	14	2.7	28370	15.0	145	227	2215	15.9	24.6	2504	54
CO2510	25.38	571.2	20	47	47	6.8	28	7	1.4	20880	26.4	123	140	708	7.9	13.3	4961	57
CO2571	21.15	471.0	40	37	52	11.1	34	8	1.4	25390	34.9	114	105	784	5.3	16.0	4566	61
CO2636	24.46	72.9	26	9	31	3.6	28	9	1.5	40530	35.2	119	161	1077	14.9	10.2	6511	98
CO2637	31.77	112.7	29	30	17	7.8	34	10	1.6	31400	26.6	119	146	1720	6.2	25.2	8453	54
CO2639	29.24	56.1	20	23	33	7.3	24	8	1.6	18140	18.3	136	154	579	6.5	19.1	3452	39
CO2643	29.21	27.9	28	24	31	13.7	97	7	1.4	29780	15.3	75	149	1520	37.8	6.0	6733	197
CO2650	26.09	58.4	14	17	39	8.0	28	10	1.7	1700	36.2	101	125	652	6.7	13.6	4814	33
CO2654	26.12	10.4	22	15	35	13.7	64	5	1.3	29500	41	66	68	648	15.2	8.4	5306	120
CO2655	35.39	8.7	22	12	30	13.8	66	5	1.4	31500	41	71	71	1151	15.9	8.9	5663	104
CO2656	20.99	16.0	35	5	31	16.7	90	8	1.5	37130	22.0	17	114	1262	17.8	14.5	4782	101
CO2658	20.86	59.7	43	17	36	9.4	35	8	1.3	29940	32.9	31	169	730	10.1	14.7	6012	76
S7 (C)																		
CO2187	40.15	112.9	17	37	29	12.5	58	16	1.2	37200	34.9	158	190	1018	14.7	17.6	5102	81
CO2468	44.72	311.0	20	24	45	8.1	24	8	1.2	13440	19.4	85	110	457	8.9	13.0	3684	54
CO2463	24.53	27.6	16	30	58	9.0	26	8	1.3	15500	17.1	21690	115	537	7.6	10.2	2562	49
CO2339	21.42	18.7	30	9	23	8.4	71	9	1.4	23690	6.0	94	120	417	15.9	11.9	5135	127
CO3317	22.27	44.6	17	29	20	10.7	20	10	1.3	20260	11.3	90	148	1360	7.7	10.3	2155	38
CO3319	23.02	46.1	29	16	20	12.0	66	7	1.2	29730	17.0	77	106	1717	15.3	10.4	6653	73
CO3320	34.14	34.3	30	1	25	10.9	34	13	1.6	18420	15.2	21750	155	549	8.7	19.8	2732	43
S8 (D)																		
CO3329	36.12	293.5	21	15	17	17.1	162	74	1.3	52340	61.8	766	1505	1713	20.2	114.3	11840	145
CO3330	34.10	29	53	14	14	12.4	117	88	1.1	29090	39.3	1242	2478	1074	13.8	653.8	11210	101
CO3334	37.35	21	273.4	14	-1	18.3	172	71	1.9	61240	55.6	760	1196	1083	19.8	120.9	11340	192
Average	42.6	238.8	19.1	33.7	23.0	10.1	75.1	40.2	3.8	27561.5	45.6	590.4	1143.9	1104.1	11.1	93.3	7411.8	85.0
Standard Deviation	29.1	250.0	9.2	26.3	13.9	3.7	53.0	41.6	3.2	16969.0	59.4	703.4	1402.9	534.5	4.3	107.1	3461.1	51.1

* Cluster designation and physiographic province of Bolivar and Hill (1979).

Factor Analysis

The single most distinctive characteristic of factor analysis is its data reduction capability. Given an array of correlation coefficients for a set of variables, factor-analysis techniques enable one to see whether some underlying pattern of relationships exists so that the data may be reduced to a smaller set of factors (Nie et al, 1975). Each factor could be defined as the best linear combination of the variables.

There are three main steps to factor analysis: (1) the preparation of the correlation matrix, (2) the extraction of the initial factors, and (3) the rotation to the terminal solution.

There are five different methods of factoring available in the subprogram used for extracting the initial factors, and three orthogonal rotation and one oblique rotation method. In the present study, PA1 (principal factoring without iteration) and PA2 (principal factoring with iteration) with varimax orthogonal rotation were used. Oblique rotation was used in one case only (Fig. 45). Because the factors are almost the same using the different methods, the discussion is primarily based on factor analysis using PA2 as recommended by Nie et al (1975).

The results of the factor analysis after varimax rotation are the factor matrix or factor loadings. These loadings are the correlation coefficients with the given elements. The factor loadings for this study are summarized in the rectangular diagrams that describe the factor matrixes for the different data sets. By calculating the square of the factor loadings, it is possible to find out how much of the total information for the respective element is accounted for in each of the factors. The communality, which is defined as the total variance or total information of a variable, accounts for a combination of all common factors and is calculated by the sum of squares of the respective factor loadings.

The loadings and communality aid in the recognition of the mineral associations and the understanding of the mineralogy of respective elements. For example, if the communality value for uranium in a given factor analysis is low and the factor loading in the lanthanide and hafnium factor (factor 1 in the present study) is low, it may indicate that the residual part of the uranium information is high and that uranium is not only in refractory minerals, but also in ore-forming minerals.

The program used enables a factor score matrix (composite indices) to be built from the factor-score coefficient matrix. By mapping the factor scores, the assemblages of the elements as described by the respective factor and their standardized values are mapped, which may help to increase the sensitivity of the interpretation. In the present study, it is used to identify source rocks for uranium mineralization.

Drainage Basin Delineation and Anomaly Threshold

A stream sediment can be regarded as nature's closest approximation to a composite sample of the rock and soil upstream from the sampling point. Consequently, the source of a sample with an anomalous value must be located by the drainage basin of the sample. By mapping the drainage basin of a cluster of samples with high values, the potential source area of mineralization can be located much more accurately (Map 5). The correlation of high values for different elements among themselves and with the geology will also be more accurate. However, if the location of the sample is inaccurate, this approach could be misleading.

By selecting a single anomaly threshold and identifying only samples above it, significant information could be ignored because of local changes in background. In a few cases (Areas A, C, and D; Maps 5, 19, and 21), values below the threshold of mean plus two standard deviations were mapped because they contained elemental concentrations above local background values and were significant in describing a mineralized area. Also, if only one significant high value for a specific element was mapped, its reliability could be checked by comparing it with a high value of associated elements such as uranium with vanadium in Areas B and C and uranium with copper in Area D (Maps 5, 19, and 21). Some of the above-mentioned problems can be overcome by the use of a rolling average analysis (Nichol et al, 1969; Webb et al, 1978). However, this technique was not used in this study.

Source Rock

Some recent data summarized by Morton (1980) and by Simpson et al (1979) suggest that even refractory minerals could be a source for uranium ore bodies. Uranium can probably go into solution in nature after disintegration of monazite and zircon under favorable Eh, pH, salinity, and temperature conditions. Granitic rocks with high concentrations of uranium in refractory minerals (e.g., monazite and zircon) suggest that the granitic magma itself was high in uranium. Uranium could also be enriched in other mineral phases such as feldspar, biotite, and epidote (Stuckless and Nkomo, 1980) as well as in intergranular sites in these uraniferous granites. This uranium could later be mobilized and enriched by hydrothermal activity and redeposited in ore bodies along the shear zones. Hence, a good indication for uranium source rocks could be gained by high score values of a factor that is loaded by uranium, lanthanides, hafnium, and thorium.

It is interesting to note that in the Craig quadrangle, the Maybell (Map 4), which is the main mining district, is adjacent to the Sand Wash Basin where monazite was reported (Nelson-Moore et al, 1978). The host rocks for the uranium mines in this district are Miocene, whereas the monazite placers of the Sand Wash Basin are Eocene. Uranium mineralization is associated with shear zones (Nelson-Moore et al, 1978) in Precambrian Y granitic rocks in the Park Range, which is probably a uraniferous granite (Phair and Gottfried, 1964).

DISCUSSION

In discussing the results of this work, certain aspects concerning the methods of sampling, chemical analysis, and statistical evaluation must be considered.

- (1) The average sampling density is one sample location per 10 km². Certain types of deposits, for example, vein types, may not be detected using this sampling density (Bramlett, 1979).
- (2) The total concentrations for each of the elements in the -100 mesh fraction of sediment samples were analyzed. No separation of heavy minerals or analyses of extractable metals were carried out.
- (3) No transformation on raw data as suggested by Garret (1979) was carried out. However, the statistical results were plotted on point maps, and clusters of samples with high elemental concentrations were examined with respect to geology.
- (4) No separate calculation of threshold values was carried out for the physiographic-geologic provinces.

(5) The original field sample locations were taken from 1:24 000- and 1:62 500-scale maps and transferred to a 1:250 000-scale map. The boundaries of drainage basins for samples with high elemental concentrations were plotted as accurately as possible on the 1:250 000-scale map.

(6) This report utilizes stream sediment data only. The hydrogeochemical information was not used in the present study.

Whole Craig Quadrangle

The data base used in this study consists of the 1732 sediment samples collected in the Craig quadrangle as part of the NURE program. By comparing the basic statistics of Table I with element abundances in major rock types (Table V; Raukama and Saharna, 1968; Wedepohl et al, 1978), it is apparent that the average values of uranium, thorium, and lanthanides are moderately high, copper and lead are less so, whereas concentrations for cobalt and chromium are relatively low.

The scattergram plots for all sediments of the Craig quadrangle (Figs. 26-29) show that for lanthanides and thorium versus uranium there are two trends: one where lanthanides, thorium, and uranium correlate and one where uranium is independent of the lanthanides and thorium. These samples, where uranium is independent, are characterized by low U/Th ratios. There is a very high correlation between thorium and lanthanides and among the lanthanides themselves.

Therefore, sediment samples with high U/Th ratios may be good indicators of the most promising potential uranium occurrences. These high ratios probably reflect the fact that part of the uranium is not in monazite, xenotime, zircon, or other thorium and lanthanide-bearing refractory minerals, but is in minerals such as uraninite (Carpenter and Koch, 1979), which contains soluble uranium and is the principal ore-forming mineral in economic deposits.

Two major regional mineral assemblages were identified (Figs. 44-47). These assemblages account for more than 60% of the total information in the factor analysis. One assemblage is the lanthanide group, which includes uranium, lanthanides, thorium, and in places lead, hafnium, and titanium. The other assemblage is a group with mafic affinities, which includes scandium, vanadium, iron, cobalt, chromium, titanium, and manganese. The highest clustering of high concentrations of the lanthanides are in physiographic Areas A, C, D, and E (Maps 6-12, 24) accompanied with some lead, especially in Areas A and E (Map 13), and some hafnium (Map 17). The main elements in the basic assemblage, especially scandium (Map 19), are primarily clustered in Area C and the northern part of Area D (Map 18).

Area A

The Sand Wash basin in the northern part of Moffat County comprises Area A (Map 3). No major uranium mines are reported from this area by Nelson-Moore et al (1978). However, several radioactive mineral occurrences, mainly placers of black sands of ilmenite-monazite type associated with gold and tungsten in one location, were reported. In addition, carnotite and tyuyamunite were described from a shallow open pit mine in the southeastern part of Area A at Doc Armor (Map 4). These occurrences are mainly concentrated in the Wasatch and Tipton Green River formations of Eocene age. This region is underlain by Tertiary nonmarine sedimentary formations (Map 2).

In the Craig quadrangle, background values for total uranium concentrations are the highest in the Sand Wash basin (11.5 ppm and 18.9 ppm respectively, Table I), whereas the U/Th ratios are generally low (Map 7). Uranium

TABLE V
ELEMENT ABUNDANCE (EXCLUDING Ca, Na, Al) (IN PPM)^a

Element	Acidic Rocks	Basic Rocks
U	1 - 10	0.1 - 1
Cu	15 - 20	40 - 80
Pb	20 - 50	2.7 - 4.3
Li	70 - 700 ^b	75 ^b
Ba	730 - 880	14.5 oceanic basalt 246 Tholeitic basalt 613 Alkali basalt
Co	1 - 2	40 - 50 (ultrabasic 70 - 120)
Cr	16 - 22	200 - 300 (ultrabasic 2000 - 3000)
Dy	6.1	5.9
Eu	1.1	1.5
Fe	2.5% ^b	8.8% ^b
Hf	<10	2.8 - 3.3
K	38	6.1
La	55	16
Mn	500 ^b	1500 ^b
Sc	3 - 10	23 - 92
Sm	6.2	4.3
Th	10 - 20	0.5 - 2
Ti	2600 - 5000	22 000
V	17 - 30 ^b	56 - 320 ^b
Zn	30 - 70	80 - 120

^a Average after Wedepohl et al (1978).

^b Rankama and Sahama (1968).

correlates extremely well with heavy and light lanthanides, with lead, hafnium, titanium, and thorium (Fig. 50). The average concentrations in sediments of these elements are also very high (Table V; Dy = 13.5 ppm, Eu = 1.7 ppm, Hf = 18.2 ppm, La = 187 ppm, Ce = 359 ppm, and Th = 27 ppm). The strong correlation of uranium with the lanthanides and thorium suggests the presence of rare earth-bearing resistate minerals such as monazite and xenotime (Nelson-Moore et al, 1978, Bolivar and Hill, 1979). The high correlation of uranium with hafnium and titanium also indicates the abundance of zircon, sphene, and/or ilmenite (Fig. 50) and supports the idea that the lanthanides in Area A are mainly concentrated in the heavy mineral fraction and not as much in clay minerals. Brookins (1975) used correlations between the same element in the Grants Mineral Belt to prove the occurrence of uranium and lanthanides in clays versus resistant minerals.

Factor analysis (PA2, Fig. 51) further confirms this general interpretation. In the Sand Wash basin, 98% of the uranium information is loaded on factor 1 together with lanthanides, thorium, lead, and to a lesser extent hafnium and titanium. Factor 1 in Area A is loaded with 58% of the total information, which is a high loading compared to loadings of uranium in other physiographic areas.

Maps 5-13, 16, and 17 of total uranium, lanthanides, thorium, lead, hafnium, and titanium above the average plus two standard deviations show the strong correlation between the high values of these elements. A factor 1 score map for samples with the strongest intercorrelation in factor 1 (Map 24) indicates that probable heavy mineral placers occur in the Wasatch formation and Tipton Tongue of the Green River formation, and at the northern edge of the Browns Park formation and the Fort Union formation.

In order to confirm the presence of heavy resistate minerals in samples from the Sand Wash basin, a preliminary examination of the heavy mineral fraction of sample CO2070, was undertaken by x-ray diffraction (John O'Rourke, LASL, personal communication, 1980), and by microprobe techniques. Both methods substantiate the existence of monazite, zircon, ilmenite, and sphene. A microprobe semiquantitative analysis of one monazite grain yielded the following results: Al_2O_3 0-1.3%, P_2O_5 32.8-36.5%, CaO 0.9-2.3%, La_2O_3 12.4-16.2%, Ce_2O_3 26.3-27.2%, PbO 1.0-1.3%, ThO 5.4-10.3%, and UO_2 negligible-1.3% (Roland Hagen, LASL, personal communication, 1980). In the same sample, a zircon grain with an inclusion has the following composition: Inclusion-- ZrO_2 31.5-42.3%, HfO_2 0.5-0.9%, UO_2 0.9-1.3%, and SiO_2 19.3-19.7%; crystal surrounding the inclusion-- ZrO_2 59.6-65.1%, HfO_2 2.1-2.6%, UO_2 negligible-0.2%, and SiO_2 30.6-33.4%; while the total for the inclusion reaches only $\approx 60\%$ and is enriched in uranium, the total for the surrounding crystal is $\approx 100\%$ with much less uranium.

Although minor uranium and vanadium mineralization (e.g., carnotite) is reported from the southern part of the Sand Wash basin (Doc Armor mine; Nelson-Moore et al, 1978), there is no significant correlation between these two elements in sediment samples collected in the Sand Wash basin (Fig. 50). However, a significant, but low, correlation of 0.42 was found for sediments in which uranium concentrations were higher than 20 ppm (Fig. 52). This may indicate that although most of the uranium in the Sand Wash basin is associated with heavy minerals, at least some may be associated with vanadium-bearing minerals. The drainage basin of samples with probable carnotite-type mineralization is indicated by high vanadium values (Map 19) but not by uranium values above the selected threshold.

Samples with high concentrations of manganese (Map 15) form a cluster in Area A where radioactive mineralization is reported (Map 4). This may partly be related to areas of suspected placer sands and in part related to soluble uranium. A low but significant correlation between uranium and manganese of 0.47 for the total matrix and 0.40 for sediments with uranium concentrations greater than 20 ppm is indicated in Figs. 51 and 52.

Area B

Area B consists of the southern part of the Wyoming Basin (Map 4). Carboniferous to Jurassic rocks, consisting mainly of sandstones, conglomerates, and limestones, are exposed along the Axial Basin uplift on Flat Top Dome (Map 2). Other parts of Area B are covered by Cretaceous sandstones, silts, and shales that are intruded in the northern parts by Tertiary intrusive rocks. These intrusions are clustered along a belt trending northwest crossing the Craig quadrangle and associated with northwest-trending faults. Parts of the southeastern corner of Area B are covered by Pliocene to Miocene basaltic rocks. This whole sedimentary complex is broadly folded with the fold axis trending northwest and north-south. In the northern corner of Area B and along the western boundary of the Park uplift, the Browns Park formation of Miocene age overlies all older formations, except in the northeastern corner of Area B where Precambrian mafic intrusions and metamorphic rocks of the Park Range are exposed.

Most of the important uranium-producing mines and occurrences in Area B are found in the Maybell District, Coal Creek Anticline District, and Sleepy Cat Mountain District (Map 4). The uranium mineralization reported from the Maybell District is associated with the tuffaceous sandstones of the Browns Park formation. The main uranium minerals are meta-autunite ($\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 2-6 \text{H}_2\text{O}$), uranophane ($\text{Ca}(\text{UO}_2)_2\text{Si}_2\text{O}_7 \cdot 6 \text{H}_2\text{O}$), coffinite ($\text{U}(\text{SiO}_4)_{1-x}(\text{OH})_{4x}$), and uraninite (UO_2). In the Coal Creek Anticline District and Sleepy Cat Mountain District, the uranium mineralization is found mainly as carnotite ($\text{K}(\text{VO}_2)(\text{VO}_4)_2 \cdot 1-3\text{H}_2\text{O}$), in the Morrison formation around the nose of the Coal Creek anticline (Nelson-Moore et al, 1978). Some minor uraniumiferous pegmatitic vein types were reported from Routt County mainly along the boundary with the Park Range.

Base metal production and occurrences are not very extensive in Area B. Most occurrences are reported from Flat Top, at the southern part of Area B, and a galena sphalerite mine has had minor production near Hahns Peak (Dowsett, 1980).

The background and standard deviation values for uranium in Area B are the lowest for all physiographic provinces in the Craig quadrangle (average 3.6 ppm and standard deviation 2.7 ppm, Table I). Concentrations for the lanthanides, lead, hafnium, and thorium are also relatively low. The average U/Th ratios for sediments from this area are 0.31, much higher than the average for Area A.

The correlation of uranium with the lanthanides, hafnium, thorium, and lead is much less significant than in Area A (Fig. 53). Only around 60% of the total uranium information is loaded on factor 1 (Fig. 54), which is loaded by around 48% of the total information. In Area B, the basic assemblage of iron, cobalt, scandium, chromium, titanium, and vanadium contain around 26% of the total information compared to about 20% for Area A.

Using the threshold of 18 ppm for uranium, three samples (Map 5) indicate the mining area of the Maybell District. Two of these samples have high concentrations of lanthanides (Maps 8-12), lead (Map 13), and thorium (Map 6).

One of these three samples, as well as two other samples in the same area, has a high U/Th ratio (Map 7). Some uranium values in sediments from the Maybell District also show strong association with hafnium (Map 17). The factor 1 score map (Map 24) indicates high and median score values overlay this district.

The Coal Creek Anticline District and Sleepy Cat Mountain District are not drained by samples with high uranium values (Map 6). However, this carnotite-type mineralization is indicated by high vanadium concentrations (Map 19). The Coal Creek Anticline District was detected by three samples draining the area to the north and to the east. Two samples draining the core of the district to the west show relatively low uranium values (3.71 ppm and 3.23 ppm) and low vanadium values (50 ppm and 52 ppm). Similarly, no high vanadium values were found in sediments collected from streams which drain the core of the Sleepy Cat Mountain District (samples C03272 and C03271). However, one tributary farther north has a sample with a high vanadium value. This sample also indicates a moderate factor 1 score value (Map 24). It is most likely that vanadium could be used as a pathfinder for carnotite-type mineralization in this area. Six additional drainage basins with samples with high vanadium content, which could account for the same type of mineralization, were mapped in the same area.

The statistical analysis suggests that there might be a base metal potential in Area B. Multielement correlation matrix for Area B (Fig. 53) shows a low significant correlation of copper with lead (0.29) and with cobalt (0.50). Factor analysis indicates the assemblage of lead and copper in factor 3 (PA2; Fig. 54) and copper with cobalt in factor 2.

Three "small" clusters of samples in the northern part of Area B have associations of high lead (29-56 ppm, Map 13), copper (48-81 ppm, Map 21), and zinc (233-572 ppm, Map 20). The northernmost cluster surrounds the Hahns Peak mine. These base metal clusters are mainly associated with the Tertiary intrusive rocks and are concentrated along a belt crossing the Craig quadrangle in a northwest direction. There is an association of high cobalt values (Map 22) with high copper values (Map 21). Lastly, there is a slight association of cobalt and high copper values at the northern edge of the Flat Top Dome.

Area C

Area C consists predominantly of the Park and Gore Ranges. These ranges are a north-south trending structure, bordered by faults and separated from each other by the Rabbit Ear Range (Map 2). The dominant rocks composing the Gore Range are Precambrian granites (Xg); the dominant rocks composing the Park Range are Precambrian granite (Yg) and migmatites (Xfh) (Map 2).

No intensive mineralization or mining activity for uranium and base metals is reported in the crystalline rocks of this area. There is, however, carnotite and autunite ($\text{Ca}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 10-12 \text{ H}_2\text{O}$), associated in carbonaceous layers of the Dakota sandstone in the vicinity of Rabbit Ears Pass (Map 4). Uranium, accompanied by hematite, magnetite, fluorite, galena, pyrite, chalcopyrite, and sphalerite, is also reported from veins along shear zones in Precambrian granites and pegmatites of the Park Range (Nelson-Moore et al, 1978). The main uranium minerals in these shear zones are uraninite (UO_2), euxenite $(\text{Y, Er, La, Ce, V, Th})(\text{Nb, Ta, Ti})_2(\text{U, OH})_6$, and gummite (fine-grained secondary uranium mineral). Even stream sediments with uranium concentrations as low as 9 ppm accompanied by niobium and thorium were reported and documented.

The background (10 ppm; Table V) and standard deviation (9.1 ppm) values for uranium in Area C are relatively high. Moderate background values were also observed for dysprosium, hafnium, vanadium, copper, cobalt, and chromium and high values for scandium (Map 18) and manganese (Map 15). Moderate-to-low background values were observed for samarium. The average U/Th ratio for Area C is 0.46; for samples with uranium greater than 20 ppm U/Th ratios are 0.58.

The correlation of uranium with lanthanides is less significant in Area C (Figs. 55 and 57) than in the previously discussed areas. High uranium concentrations in sediments, greater than 20 ppm, have a significant correlation with manganese (0.43), iron (0.32), chromium (0.36), cobalt (0.36), and vanadium (0.29) (Fig. 57). A low, but significant, correlation also exists between uranium and copper (0.25), uranium and lead (0.41), and lead and copper (0.27). In the factor analysis for all sediments (Fig. 56), uranium is loaded on factor 1 ($\approx 30\%$), factor 3 ($\approx 17\%$), and factor 5 ($\approx 13\%$). Altogether only 60% of uranium is loaded in a complex way on three different factors. This suggests that part of the uranium is in vein-type uranium-base metal mineralization, part with lanthanides and zircon in resistant minerals, and some with certain vanadium minerals such as carnotite.

Careful observation of the various maps supports this hypothesis. Four main clusters of samples with high uranium values are observed in Area C; three overlay Xg, Yg, Xfh, and Xb of the Park Range and one overlays Xg of the Gore Range (Map 5). Samples in the three northern clusters also have high U/Th ratios (Map 7). High U/Th ratios are almost always associated with samples with high uranium values in Area C. These samples with high U/Th ratios are not correlative with samarium (Map 8), lanthanum (Map 9), and cerium (Map 11). Only two europium (Map 12) and a few high dysprosium (Map 10) values are associated with these three clusters.

Of the four main clusters, the southernmost is partly associated with thorium (Map 6) and hafnium (Map 17). High concentrations of hafnium are also associated with the northernmost cluster. Lanthanides, thorium, and hafnium are associated better with the cluster overlaying the Gore Range (Map 5). Medium-to-high factor 1 scores values (Map 24) are associated with the two main clusters of samples with high uranium values in Area C.

A few clusters of samples with high concentrations of lead (Map 13), zinc (Map 20), copper (Map 21), and cobalt (Map 22) correspond to the areal extent of the uranium cluster of the Park Range. These clusters are part of the northwest mineralization trend associated with the young Tertiary intrusions.

The Yg granites and, to a lesser extent, the Xfh migmatites and Xg granites of the Park Range are the most favorable areas for uranium vein-type mineralization. A few probable locations of mineralization are shown on Map 5. In the Front Range, according to Phair and Gottfried (1964), the most uraniumiferous granites are the ones intruded during the interval of 1000-1500 Myr, which is equivalent in age with the Yg granites of the Park Range. According to our data analysis, uranium will appear in places as an independent leachable mineral such as uraninite and will be associated with copper, lead, zinc sulfide mineralization in veins along shear zones. The most favorable area for this type of mineralization is located on the junction between the northwest trend of Tertiary intrusions and base metal mineralization and Yg granite of the Park Range. By comparison, the cluster of sample with high uranium concentrations in the Gore Range is mainly associated with rare earth and zircon minerals.

The carnotite-type mine mineralization of the Rabbit Ears Pass was not indicated by samples with high uranium values (Map 5). But, similar to the Coal Creek Anticline District and Sleepy Cat Mountain District in Area B, there is a close association with high vanadium values in sediments in this area. Clusters of high vanadium values, which trend north-south along the strike of Mesozoic sandstones, were mapped (Map 19) and the probable location of mineralization was marked. Only one high uranium value (18.33 ppm) is associated with this cluster, though several samples have uranium concentrations above the background.

In the lower southern part of Area C, there is a cluster of samples with high copper values (Map 21) associated with high cobalt values (Map 22). These samples overlay faulted Precambrian Xg granite that is intruded by Tertiary intrusions (Tmi). This association could be an indication of copper mineralization as was the case for a similar elemental association near Hahn's Peak.

Area D

Area D is comprised of North Park, a large intermontane basin underlain by the Tertiary Coalmont and North Park formations and with lesser amounts of volcanics. This basin is bounded on the northeast, north, and west by Precambrian Xg and Yg granites and Xfh migmatites. Paleozoic to Mesozoic sediments flank those Precambrian rocks outcropping along the margins of the basin.

The background and standard deviation values for uranium, lanthanides, hafnium, and thorium are moderately high compared to concentrations in samples from the rest of the quadrangle (Tables I and II). Values for copper are also high. The average U/Th ratio for Area D is 0.28.

For the sediments in Area D, uranium is slightly correlative with the heavy and light lanthanides and with thorium; however, there is no significant correlation with lead and hafnium (Fig. 58). There is a significant correlation of uranium with iron. Uranium is mainly loaded (≈ 0.90) on factor 4 together with iron and some copper. Because only a small amount of the total uranium information is loaded on factor 1 with the lanthanides, much of the uranium may be located in leachable minerals (Fig. 59).

There are few high uranium values in Area D (Map 5). Except for a few samples along the western edge of the area, most uranium-rich samples are associated with moderate-to-high factor 1 score values (Map 24). The main uranium cluster overlying the Precambrian Xg granite on the northeastern edge of the area is associated with thorium (Map 6), low U/Th ratios (Map 7), iron (Map 14), cobalt (Map 22), and one copper value of 61 ppm (Map 21).

The most favorable areas for uranium mineralization in Area D are the ones accompanied by high U/Th ratios and adjacent to Area C where a few uranium occurrences were reported (Map 4).

Another interesting area is the drainage basin of sample C03118, which drains Pinkham Mountain and contains a sample with a uranium value of 19.66 ppm and U/Th ratio of 0.52. Sample C03114, which drains the same area, indicates an elevated uranium value of 8.99 ppm. These samples drain the faulted Yg Precambrian granite of Pinkham Mountain, which is covered by tuffs of the White River formation. Here, a few mines are mapped and sediment samples also have high copper values (Map 21). The Yg granite in this area contains uranium refractory minerals as indicated by samples C02224 and C02223, which drain the central part of a Yg stock at the northeastern corner of Area D. The uranium values for these two samples are 27.98 ppm and 10.34 ppm. These samples are also associated with a value of 83 ppm and 29.6 ppm thorium, U/Th ratios of 0.35 and 0.34, and cerium concentrations of 480 ppm and 233 ppm.

The Pinkham mines area has an average copper concentration of 35.41 ppm (Map 21), which is significantly above the background of 25.9 ppm for sediments of Area D. The average for uranium in the same area is only 7.18 ppm which is below the background of 8.11 ppm uranium for Area D. There are, however, a few isolated high uranium samples, such as C02652 (11.48 ppm uranium) in this area. These data may be an indication for uranium vein-type mineralization associated with copper in Pinkham Mountain.

Along the western edge of Area D, three clusters of samples with high cobalt, copper, and zinc concentrations (Maps 20-22) were mapped. The southernmost cluster is part of the northwest base metal trend associated with Tertiary plutons and is close to a mine between Pitchpine Mountain and Mount Ethel. This cluster overlays faulted Precambrian Yg granite. The two northern clusters are along the Independence Mountain range, in a faulted Precambrian area (Map 2). All of these clusters are potential areas for base metal mineralization.

Areas E and F

Area E consists of the Rabbit Ears Range and eastern Middle Park (Map 3); Area F consists of the western Middle Park. Both areas are the southern continuation of the North Park basin. Middle Park is an intermontane basin underlain by the Coalmont formation and contains several intermediate Tertiary intrusive rocks. These intrusions cluster along the northwest trending mineral belt previously mentioned. Central sections of the basin are overlain by young volcanic rocks. Precambrian Xg granites and Xb migmatites, which comprise the core of this basin, are overlain by the Miocene Troublesome formation. Mesozoic sediments flank the Precambrian rocks of the Gore Range.

Uranium production from this area has been limited (Nelson-Moore et al, 1978) to peneconcordant carnotite type mineralization in the Troublesome Creek District and uraniferous pegmatites from the Beaver Creek District (Map 4). The greatest potential for sandstone-type uranium mineralization is in the Troublesome formation (Nelson-Moore et al, 1978).

In Area E, background values for uranium are moderate (7.9 ppm), whereas in Area F background concentrations are low (4.4 ppm). Thorium, lead, hafnium, and lanthanides have high to very high average concentrations in samples in Area E and moderately low concentrations in samples in Area F (Table II). The average U/Th ratios for Area E are 0.22 and for Area F, 0.31.

In Area E, uranium correlates significantly with lanthanides, lead, thorium, scandium, potassium, and to a lesser extent with hafnium. Uranium is negatively correlative with calcium (Fig. 60). The lanthanides among themselves are less significantly correlative. Uranium is loaded (≈ 0.65) on factor 1, associated with lanthanides, thorium, and hafnium, and negatively loaded (≈ 0.65) on factor 2 with lithium and lead (Fig. 61).

The multielement correlation matrix for the elements in sediments from Area F is similar to the correlation matrix of Area C for samples in which uranium is greater than 20 ppm (Fig. 57). Cobalt and chromium show a significant correlation with each other as well as with uranium (0.49, Fig. 62). Both correlation matrixes suggest a possibility of uranium being associated with base metals and vanadium. A low, but significant, correlation exists between uranium and copper (0.30, Fig. 62), between lead and copper (0.22, Fig. 62), and between uranium and vanadium (0.34, Fig. 62). The lanthanides, hafnium, and thorium show less significant correlation among themselves in both Areas E and F.

In the factor analysis for Area F, about 40% of the total uranium information is loaded in factor 1 along with the lanthanides, thorium, and hafnium. In factor 3 (Fig. 63), about 10% of the uranium values are loaded together with cobalt, vanadium, copper, and iron.

Two vanadium-uranium clusters, which may be indicative of carnotite-type mineralization, are found in the western edge of Area F and in the northcentral part of Area E (Maps 5 and 19). The westernmost cluster is associated with high copper values and is the southern continuation of the mineral trend of the carnotite-autunite of the Rabbit Ears Pass mining district (Map 4). Both clusters have high U/Th ratios.

A cluster of samples with high uranium concentrations in the western edge of Area E (Map 5) also have high thorium (Map 6), lead (Map 13), and lanthanides, except europium (Maps 8-11). Samples in this area also have low U/Th ratios (Map 7). This suggests that the uranium present is tied up in rare earth minerals such as monazite.

Both main uranium mineralization districts, the Beaver Creek and the Troublesome Creek (Map 4), are only indicated by factor 1 score values between 0.1 and 1.0 (Map 24).

A few clusters of base metals, predominantly lead (Map 13) and zinc (Map 20), are associated with the Tertiary intrusive rocks at the northern part of Areas E and F.

CONCLUSIONS

(1) Precambrian rocks of the Park Range are favorable for uranium vein-type mineralization. Uranium-rich sediment samples in this area are associated with copper, zinc, lead, and cobalt.

(2) Six new potential locations for carnotite-type mineralization are located in the southern part of the Wyoming Basin. Seven are located in a belt trending north-south in the Gore Range, and one is in eastern Middle Park.

(3) Six potential source rocks for uranium were identified by factor 1 score values greater than one: the Wasatch formation and Tipton Tongue of the Green River formation in the Sand Wash Basin; the Browns Park formation in the Wyoming basin; the Precambrian Yg and, to a lesser extent, Xg granites in the Park and Gore Ranges; and the Coalmont formation in eastern Middle Park where it is intruded by intermediate Tertiary intrusions.

(4) Vanadium in sediments could probably be used as a pathfinder for carnotite-type mineralization in the Craig quadrangle. In some igneous terranes in the eastern Park Range, copper could be used as a pathfinder for uranium vein-type mineralization.

(5) Most of the mineral occurrences described by Nelson-Moore et al (1978) for the Craig quadrangle were detected by high factor 1 score values greater than zero; by mapping the drainage basins for values above the threshold for uranium, vanadium, and copper; and by high U/Th ratios. However, using only values greater than the regional threshold, several significant values below the threshold are not used. Use of values below regional threshold could be critical in discovering new ore bodies.

(6) A probable northwest trend of lead-zinc mineralization associated with Tertiary intrusions crosses the Craig quadrangle from eastern Middle Park to the northern part of the Wyoming basin.

(7) At the northeasternmost part of the Park Range, clusters of samples around the Independence Mountain and Pinkham mines have high copper and cobalt values and, to a lesser extent, high uranium. Clusters of samples with high copper concentrations, also associated with high cobalt, exist at the northern margin of the Flat Top Dome.

(8) Concentration of placer sands containing rare earth elements, probably of commercial value, are found in the Sand Wash basin.

(9) This type of statistical approach in evaluation of NURE HSSR data may be a tremendous aid using HSSR data for mineral resources evaluation.

RECOMMENDATIONS

(1) The results of this study should be verified by follow-up field studies and supplemented with chemical analyses of sediment-size fractions. Additional aids might include analyzing the leachable or the extractable uranium in the sediments with high uranium concentrations and the separation and identification of heavy minerals by microprobe analyses, x-ray diffraction, and optical methods.

(2) Rolling average or spatial moving average techniques should be used to identify regional trends in the elemental data, local and regional background values, and anomalous areas.

(3) HSSR data should be used as a regional reconnaissance data base for the exploration of strategic or commercial commodities, such as base metals and precious metals.

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List of 58 samples with values above the mean and three standard deviations (23 ppm), after iteration..

CO 2024	CO 2478	CO 3037
CO 2030	CO 2483	CO 3039
CO 2041	CO 2499	CO 3043
CO 2043	CO 2567	CO 3132
CO 2051	CO 2570	CO 3230
CO 2052	CO 2571	CO 3234
CO 2065	CO 2796	CO 3235
CO 2067	CO 2800	CO 3302
CO 2067	CO 2803	CO 3304
CO 2071	CO 2804	CO 3319
CO 2073	CO 2808	CO 3320
CO 2075	CO 2809	CO 3329
CO 2077	CO 2811	CO 3330
CO 2078	CO 2814	CO 3334
CO 2187	CO 2821	CO 3367
CO 2189	CO 2833	CO 3428
CO 2190	CO 2855	CO 3433
CO 2224	CO 2857	CO 3448
CO 2468	CO 2859	CO 3480
	CO 3036	

Fig. 1. Histogram of uranium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 24 samples with values above the mean and three standard deviations (49 ppm), after iteration.

CO 2095	CO 2643
CO 2196	CO 2644
CO 2200	CO 2996
CO 2259	CO 3123
CO 2274	CO 3128
CO 2280	CO 3171
CO 2288	CO 3302
CO 2290	CO 3335
CO 2434	CO 3360
CO 2481	CO 3400
CO 2487	CO 3542
CO 2562	CO 3697

Fig. 2. Histogram of copper concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 35 samples with values above the mean and three standard deviations (32 ppm), after iteration.

CO 3743	CO 2307	CO 2804
CO 2024	CO 2562	CO 2808
CO 2065	CO 2571	CO 2809
CO 2067	CO 2664	CO 2811
CO 2069	CO 2665	CO 2821
CO 2070	CO 2668	CO 2855
CO 2073	CO 2671	CO 2859
CO 2077	CO 2673	CO 3330
CO 2078	CO 2774	CO 3448
CO 2189	CO 2775	CO 3697
CO 2247	CO 2796	CO 3698
CO 2294	CO 2800	

Fig. 3. Histogram of lead concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 31 samples with values above the mean and three standard deviations (56 ppm), after iteration.

CO 2051	CO 2737	CO 3344
CO 2380	CO 2748	CO 3410
CO 2420	CO 2754	CO 3413
CO 2425	CO 2761	CO 3424
CO 2443	CO 2782	CO 3505
CO 2483	CO 2899	CO 3506
CO 2537	CO 2910	CO 3595
CO 2538	CO 3138	CO 3723
CO 2547	CO 3141	
CO 2556	CO 3151	
CO 2622	CO 3152	
CO 2719		

Fig. 4. Histogram of lithium concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 5. Histogram of aluminum concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 6. Histogram of barium concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 7. Histogram of calcium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 30 samples with values above the mean and three standard deviations (21.058 ppm), after iteration.

CO 2100	CO 3177
CO 2171	CO 3187
CO 2190	CO 3306
CO 2290	CO 3312
CO 2346	CO 3336
CO 2348	CO 3337
CO 2350	CO 3344
CO 2352	CO 3418
CO 2481	CO 3419
CO 2643	CO 3453
CO 2653	CO 3469
CO 2722	CO 3646
CO 2983	CO 3685
CO 3040	CO 3694
CO 3176	CO 3697

Fig. 8. Histogram of cobalt concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 42 samples with values above the mean and three standard deviations (138 ppm), after iteration.

CO 2030	CO 2514	CO 3418
CO 2070	CO 2567	CO 3419
CO 2116	CO 2643	CO 3426
CO 2138	CO 2722	CO 3469
CO 2171	CO 2725	CO 3470
CO 2192	CO 2728	CO 3542
CO 2256	CO 3020	CO 3639
CO 2290	CO 3022	CO 3644
CO 2346	CO 3045	CO 3682
CO 2348	CO 3047	CO 3685
CO 2350	CO 3132	
CO 2352	CO 3227	
CO 2434	CO 3312	
CO 2435	CO 3329	
CO 2457	CO 3334	
CO 2482	CO 3400	

Fig. 9. Histogram of chromium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 63 samples with values above the mean and three standard deviations (17.415 ppm), after iteration.

CO 2024	CO 2224	CO 2859
CO 2025	CO 2326	CO 3020
CO 2030	CO 2392	CO 3022
CO 2031	CO 2412	CO 3132
CO 2041	CO 2567	CO 3145
CO 2042	CO 2796	CO 3146
CO 2043	CO 2800	CO 3151
CO 2048	CO 2803	CO 3233
CO 2049	CO 2804	CO 3327
CO 2061	CO 2805	CO 3329
CO 2065	CO 2807	CO 3330
CO 2067	CO 2808	CO 3331
CO 2069	CO 2809	CO 3332
CO 2070	CO 2811	CO 3334
CO 2073	CO 2814	CO 3343
CO 2074	CO 2817	CO 3397
CO 2075	CO 2821	CO 3428
CO 2077	CO 2833	CO 3433
CO 2078	CO 2855	CO 3448
CO 2223	CO 2857	CO 3465
	CO 2858	CO 3466
		CO 3480

Fig. 10. Histogram of dysprosium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 47 samples with values above the mean and three standard deviations (2.778 ppm), after iteration.

CO 3728	CO 2224	CO 2833
CO 3739	CO 2315	CO 2855
CO 2024	CO 2338	CO 2857
CO 2030	CO 2499	CO 2859
CO 2041	CO 2567	CO 3132
CO 2043	CO 2677	CO 3145
CO 2052	CO 2796	CO 3146
CO 2065	CO 2800	CO 3233
CO 2066	CO 2803	CO 3329
CO 2067	CO 2804	CO 3330
CO 2069	CO 2807	CO 3334
CO 2070	CO 2808	CO 3380
CO 2073	CO 2809	CO 3428
CO 2075	CO 2811	CO 344R
CO 2077	CO 2814	CO 3470
CO 2078	CO 2821	

Fig. 11. Histogram of europium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 42 samples with values above the mean and three standard deviations (46036.0 ppm), after iteration.

CO 3739	CO 2565	CO 3313
CO 2057	CO 2567	CO 3329
CO 2174	CO 2644	CO 3331
CO 2224	CO 2677	CO 3335
CO 2326	CO 2983	CO 3344
CO 2346	CO 3040	CO 3350
CO 2352	CO 3093	CO 3366
CO 2476	CO 3130	CO 3367
CO 2477	CO 3132	CO 3370
CO 2480	CO 3145	CO 3437
CO 2481	CO 3176	CO 3469
CO 2482	CO 3302	CO 3682
CO 2558	CO 3304	CO 3685
CO 2559	CO 3312	CO 3694

Fig. 12. Histogram of iron concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 68 samples with values above the mean and the standard deviations (35.032 ppm), after iteration.

CO 3739	CO 2224
CO 2019	CO 2326
CO 2020	CO 2474
CO 2030	CO 2476
CO 2041	CO 2559
CO 2052	CO 2567
CO 2057	CO 2569
CO 2061	CO 2796
CO 2063	CO 2800
CO 2065	CO 2808
CO 2067	CO 2814
CO 2070	2821
CO 2073	CO 2833
CO 2075	CO 2855
CO 2077	CO 2857
CO 2111	CO 2859
CO 2174	CO 2866
CO 2210	CO 2900
CO 2219	CO 2958
CO 2220	CO 2960
CO 2223	CO 2984
	CO 3035

Fig. 13. Histogram of hafnium concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 14. Histogram of potassium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 77 samples with values above the mean and three standard deviations (209 ppm), after iteration.

CO 3739	CO 2074	CO 2805	CO 3146
CO 2024	CO 2075	CO 2807	CO 3151
CO 2025	CO 2077	CO 2808	CO 3233
CO 2030	CO 2078	CO 2809	CO 3304
CO 2031	CO 2224	CO 2810	CO 3327
CO 2041	CO 2315	CO 2811	CO 3329
CO 2042	CO 2319	CO 2814	CO 3330
CO 2043	CO 2326	CO 2817	CO 3331
CO 2048	CO 2328	CO 2821	CO 3332
CO 2049	CO 2338	CO 2833	CO 3334
CO 2052	CO 2392	CO 2855	CO 3376
CO 2061	CO 2412	CO 2857	CO 3397
CO 2065	CO 2567	CO 2858	CO 3428
CO 2066	CO 2675	CO 2859	CO 3433
CO 2067	CO 2676	CO 2866	CO 3448
CO 2069	CO 2796	CO 3020	CO 3465
CO 2070	CO 2800	CO 3022	CO 3466
CO 2071	CO 2803	CO 3132	CO 3469
CO 2073	CO 2804	CO 3137	CO 3480
		CO 3145	

Fig. 15. Histogram of lanthanum concentrations in sediments from the Craig quadrangle, Colorado.

List of 69 samples with values above the mean and three standard deviations (43 ppm), after iteration.

CO 3739	CO 2074	CO 2810	CO 3233
CO 2024	CO 2075	CO 2811	CO 3327
CO 2025	CO 2077	CO 2814	CO 3329
CO 2030	CO 2078	CO 2817	CO 3330
CO 2031	CO 2224	CO 2821	CO 3331
CO 2041	CO 2315	CO 2833	CO 3332
CO 2042	CO 2412	CO 2855	CO 3334
CO 2043	CO 2567	CO 2857	CO 3397
CO 2048	CO 2675	CO 2858	CO 3428
CO 2049	CO 2676	CO 2859	CO 3433
CO 2052	CO 2796	CO 2866	CO 3448
CO 2061	CO 2800	CO 3020	CO 3465
CO 2065	CO 2803	CO 3022	CO 3466
CO 2066	CO 2804	CO 3132	CO 3469
CO 2067	CO 2805	CO 3137	CO 3480
CO 2069	CO 2807	CO 3145	
CO 2070	CO 2808	CO 3146	
CO 2073	CO 2809	CO 3151	

Fig. 16. Histogram of cerium concentrations in sediments from the Craig quadrangle, Colorado.

List of 34 samples with values above the mean and three standard deviations (2241 ppm), after iteration.

CO 2002	CO 2393	CO 3313
CO 2066	CO 2482	CO 3314
CO 2077	CO 2559	CO 3335
CO 2100	CO 2856	CO 3336
CO 2190	CO 2976	CO 3337
CO 2200	CO 3080	CO 3361
CO 2224	CO 3114	CO 3385
CO 2290	CO 3124	CO 3414
CO 2330	CO 3153	CO 3453
CO 2376	CO 3156	CO 3457
CO 2388	CO 3312	CO 3467
		CO 3470

Fig. 17. Histogram of manganese concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 18. Histogram of sodium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 54 samples with values above the mean and three standard deviations (22.266 ppm), after iteration.

CO 3728	CO 2559	CO 3040	CO 3314
CO 2188	CO 2564	CO 3047	CO 3338
CO 2264	CO 2565	CO 3126	CO 3341
CO 2277	CO 2566	CO 3176	CO 3344
CO 2279	CO 2567	CO 3177	CO 3347
CO 2434	CO 2582	CO 3178	CO 3366
CO 2457	CO 2585	CO 3179	CO 3437
CO 2476	CO 2607	CO 3180	CO 3684
CO 2477	CO 2643	CO 3187	CO 3685
CO 2480	CO 2644	CO 3243	CO 3694
CO 2482	CO 2777	CO 3299	
CO 2539	CO 2983	CO 3311	
CO 2555	CO 2984	CO 3312	
CO 2556	CO 2992	CO 3313	
CO 2558	CO 3028		

Fig. 19. Histogram of scandium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 47 samples with values above the mean and three standard deviations (45.575 ppm), after iteration.

CO 2024	CO 2676	CO 2857
CO 2030	CO 2796	CO 2858
CO 2041	CO 2800	CO 2859
CO 2043	CO 2803	CO 3022
CO 2048	CO 2804	CO 3132
CO 2065	CO 2805	CO 3145
CO 2066	CO 2807	CO 3304
CO 2067	CO 2808	CO 3329
CO 2069	CO 2809	CO 3330
CO 2070	CO 2810	CO 3334
CO 2073	CO 2811	CO 3428
CO 2075	CO 2814	CO 3433
CO 2077	CO 2821	CO 3448
CO 2078	CO 2833	CO 3465
CO 2224	CO 2855	CO 3469
CO 2567		CO 3480

Fig. 20. Histogram of samarium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 108 samples with values above the mean and three standard deviations (62.653 ppm), after iteration.

CO 3739	CO 2075	CO 2804	CO 3150
CO 2023	CO 2076	CO 2805	CO 3151
CO 2024	CO 2077	CO 2807	CO 3229
CO 2025	CO 2078	CO 2808	CO 3233
CO 2026	CO 2187	CO 2809	CO 3327
CO 2030	CO 2191	CO 2810	CO 3329
CO 2031	CO 2224	CO 2811	CO 3331
CO 2038	CO 2315	CO 2814	CO 3332
CO 2041	CO 2326	CO 2817	CO 3334
CO 2042	CO 2392	CO 2821	CO 3349
CO 2043	CO 2412	CO 2833	CO 3366
CO 2044	CO 2490	CO 2855	CO 3367
CO 2047	CO 2567	CO 2857	CO 3376
CO 2048	CO 2615	CO 2858	CO 3397
CO 2049	CO 2623	CO 2859	CO 3398
CO 2052	CO 2625	CO 2866	CO 3428
CO 2061	CO 2635	CO 3020	CO 3429
CO 2063	CO 2665	CO 3022	CO 3431
CO 2065	CO 2673	CO 3035	CO 3433
CO 2066	CO 2675	CO 3036	CO 3445
CO 2067	CO 2676	CO 3037	CO 3446
CO 2069	CO 2708	CO 3041	CO 3448
CO 2070	CO 2774	CO 3130	CO 3460
CO 2071	CO 2775	CO 3132	CO 3465
CO 2072	CO 2796	CO 3137	CO 3466
CO 2073	CO 2800	CO 3145	CO 3469
CO 2074	CO 2803	CO 3146	CO 3480

Fig. 21. Histogram of thorium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 49 samples with values above the mean and three standard deviations (9621 ppm), after iteration.

CO 3728	CO 2480	CO 2970
CO 2030	CO 2482	CO 2986
CO 2041	CO 2544	CO 3093
CO 2052	CO 2558	CO 3130
CO 2057	CO 2559	CO 3132
CO 2067	CO 2560	CO 3145
CO 2174	CO 2565	CO 3311
CO 2208	CO 2581	CO 3329
CO 2223	CO 2585	CO 3330
CO 2224	CO 2722	CO 3332
CO 2273	CO 2800	CO 3334
CO 2283	CO 2808	CO 3344
CO 2326	CO 2814	CO 3418
CO 2346	CO 2855	CO 3419
CO 2352	CO 2857	CO 3469
CO 2476	CO 2859	CO 3679
		CO 3682

Fig. 22. Histogram of titanium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 32 samples with values above the mean and three standard deviations (199 ppm), after iteration.

CO 2057	CO 2540	CO 3132
CO 2111	CO 2558	CO 3285
CO 2118	CO 2559	CO 3403
CO 2120	CO 2565	CO 3410
CO 2173	CO 2567	CO 3421
CO 2174	CO 2644	CO 3424
CO 2326	CO 2759	CO 3469
CO 2346	CO 2768	CO 3542
CO 2352	CO 2782	CO 3595
CO 2470	CO 3001	CO 3697
CO 2498	CO 3082	

Fig. 23. Histogram of vanadium concentrations in sediment samples from the Craig quadrangle, Colorado.

List of 9 samples with values above the mean and three standard deviations (275 ppm), after iteration.

CO 2120	CO 2653
CO 2168	CO 2777
CO 2274	CO 2926
CO 2543	CO 3697
CO 2562	

Fig. 24. Histogram of zinc concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 25. Histogram of magnesium concentrations in sediment samples from the Craig quadrangle, Colorado.

Fig. 26. Scattergram plot showing correlation between dysprosium and uranium from the Craig quadrangle, Colorado.

Fig. 27. Scattergram plot showing correlation between lanthanum and uranium from the Craig quadrangle, Colorado.

Fig. 28. Scattergram plot showing correlation between samarium and uranium from the Craig quadrangle, Colorado.

Fig. 29. Scattergram plot showing correlation between thorium and uranium from the Craig quadrangle, Colorado.

Fig. 32. Scattergram plot showing correlation between hafnium and thorium from the Craig quadrangle, Colorado.

Fig. 33. Scattergram plot showing correlation between samarium and lanthanum from the Craig quadrangle, Colorado.

Fig. 34. Scattergram plot showing correlation between lanthanum and dysprosium from the Craig quadrangle, Colorado.

Fig. 35. Scattergram plot showing correlation between dysprosium and samarium from the Craig quadrangle, Colorado.

Fig. 36. Scattergram plot showing correlation between scandium and manganese from the Craig quadrangle, Colorado.

Fig. 37. Scattergram plot showing correlation between scandium and copper from the Craig quadrangle, Colorado.

Fig. 38. Scattergram plot showing correlation between cobalt and vanadium from the Craig quadrangle, Colorado.

Fig. 39. Scattergram plot showing correlation between scandium and cobalt from the Craig quadrangle, Colorado.

Fig. 40. Scattergram plot showing correlation between cobalt and chromium from the Craig quadrangle, Colorado.

Fig. 41. Scattergram plot showing correlation between cobalt and iron from the Craig quadrangle, Colorado.

Fig. 42. Scattergram plot showing correlation between chromium and titanium from the Craig quadrangle, Colorado.

Fig. 43. Scattergram plot showing correlation between iron and manganese from the Craig quadrangle, Colorado.

Fig. 44. MULTIELEMENT CORRELATION, *Craig, all sediments (including Mg, Zn excluded Co; 1119 cases).*

Fig. 45. FACTOR ANALYSIS, *Craig, all sediments (including Mg, Zn excluded Co; 1119 cases).*

PA1 VARIMAX

PA2 OBLIQUE (structure matrix)

PA2 OBLIQUE (pattern matrix)

HIGH FACTOR LOADING IN EACH FACTOR
MEDIAN FACTOR LOADING

29.8%

OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS

Fig. 46. MULTIELEMENT CORRELATION, Craig, all sediments (1668 cases).

Fig. 47. FACTOR ANALYSIS, Craig, all sediments (1668 cases).

PA1 N FACTOR 9 VARIMAX

PA2 VARIMAX

□ HIGH FACTOR LOADING IN EACH FACTOR

■ MEDIAN FACTOR LOADING

45.1%

OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS

Fig. 48. MULTIELEMENT CORRELATION, Craig; sediments in which uranium > 20 ppm,
from Bolivar and Hill, 1979 (53 cases).

Fig. 49. FACTOR ANALYSIS, *Craig*; sediments in which uranium > 20 ppm,

from Bolivar and Hill, 1979 (53 cases).

PA2 VARIMAX

FACTOR NO.	1	2	3	4	5
LDG FTR	La, Ce, Sm, U, Pb Dy, Eu, Th	Fe, V, Sc			
0.8		Cr Co, Hf	Cu, Al		
0.6		Ca	Na Li Co		
0.4	Ti Mn Cr	Mn Ti	Be K	Ti -Eu, Sm, Dy, Th -Cr, La, Ce, Hf	
	-Na -Ti, Al -Ba, Ca				

Fig. 50. MULTIELEMENT CORRELATION, Craig, Area A; sediments (246 cases).

Fig. 53. MULTIELEMENT CORRELATION, Craig, Area B; sediments (734 cases).

PA1 N FACTOR 9 VARIMAX

34.1% OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS

Fig. 55. MULTIELEMENT CORRELATION. Craig, Area C: sediments (280 cases).

Fig. 55. FACTOR ANALYSIS, Craig, Area C; sediments (280 cases).

PA1 N FACTOR 9 VARIMAX

PA2 VARIMAX

HIGH FACTOR LOADING IN EACH FACTOR

MEDIAN FACTOR LOADING

35.3% OF WHOLE INFORMATION INCLUDED
IN FACTOR ANALYSIS

Fig. 58. MULTIELEMENT CORRELATION, Craig, Area D, sediments (237 cases).

Fig. 59. FACTOR ANALYSIS, Craig, Area D; sediments (237 cases).

PA1 N FACTOR 2 VARIMAX

PA2 VARIMAX

HIGH FACTOR LOADING IN EACH FACTOR

35.9%

OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS

Figure 1 is a triangular diagram illustrating the correlation coefficients between 22 elements: U, CU, PB, LI, AL, BA, CA, CO, CR, DY, EU, FE, HF, K, LA, CE, MN, NA, SC, SM, TH, TI, V. The diagram is a large triangle composed of smaller diamond-shaped cells. Each cell contains a numerical correlation coefficient. The cells are shaded in two ways: white for coefficients greater than 0.80, and stippled for coefficients between 0.50 and 0.80. The legend at the bottom right shows a white box for '> 0.80' and a stippled box for '0.50 - 0.80'.

Fig. 61. FACTOR ANALYSIS, *Craig, Area E; sediments (94 cases).*

PA 2 VAR, MAX

(43.4%)

OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS

Fig. 62. MULTIELEMENT CORRELATION, Craig, Area F, sediments (77 cases).

Fig. 63. FACTOR ANALYSIS. *Craig, Area F; sediments (77 cases).*

PA 2 VARIMAX

FACTOR NO.	1	2	3	4	5
FCTR LDG	Th, Sm, Co La Dy	Ti, Na Ba Mn	Sc Cr Fe, V, Cu Co U	Al Pb K Na Ba Eu	Co V, Li
0.0			16.4%	6.2%	
0.6	Hf, Eu U 49.6%	Co, Eu, Fe Al La, Ce	-Li Al, Ti Dy, Mn	-Hf Co, Ti, Co, La, Th	5.1%
0.4	Fe No, Ti, K				-No, Hf, K

49.6% OF WHOLE INFORMATION INCLUDED IN FACTOR ANALYSIS