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Evaluation of stream sediment data for favourability of uranium mineralization in Tertiary granitic plutons of the Alaska Range

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ABSTRACT. Favourability of uranium mineralization in six tertiary granitic plutons of the Alaska Range in the Talkeetna and Mt McKinley quadrangles was studied. The uranium concentrations of drainage sediment samples, which were collected and analysed by the Los Alamos Scientific Laboratory for the National Uranium Resources Evaluation, were statistically evaluated and compared to those of the surrounding area using factor and cluster analyses. The results of this study suggest that five of the six plutons under consideration are likely to contain uranium mineralization. These plutons are probably a potential source rock for uranium in the region.

THE purpose of this study is to evaluate the favourability of uranium mineralization in six granitic plutons (Table I) of the Alaska Range in the Talkeetna and Mt McKinley NTMS quadrangles, Alaska (fig. 1), mapped by Reed and Nelson (1977) and Reed (1961). The evaluation is based mainly on criteria suggested by Simpson *et al.* (1979), using Hydrogeochemical and Stream Sediment Reconnaissance (HSSR) data which was published by Aamodt *et al.* (1979) and Van Eeckhout *et al.* (1979).

Simpson *et al.* (1979) suggest that uranium mineralization is associated with intrusive complexes with a high average content of U, but which also exhibit a high concentration of incompatible elements (e.g. Li, Be, Rb, B, and F), high K concentration, but a low K/Rb ratio, low total Sr, low initial $^{87}Sr/^{86}Sr$ ratio, and high geothermal gradient. The standard deviations for U data are greater where such intrusives are mineralized, but their average values are relatively unaltered. Hence, Simpson *et al.* (1979) suggested that U is enriched in the granitic magma primarily by scavenging from the subcontinental lithosphere, but also by magmatic differentiation. They further suggest that magmatic differentiation results in a redistribution of U in the granitic rock and does not involve further introduction of U.

During mineralization U is released by the dissolution of resistate minerals like zircon, apatite, and monazite by processes of greisenization and tourmalinization, which involve massive interaction with meteoric water. Uraniferous ore minerals are deposited in vein-type mineralization down the *P* and *T* gradient. Simpson *et al.* (1979) suggested that U may be again redistributed by later hydrothermal mineralization during periods of higher than average heat flow from the mantle or during dyke emplacement. An extensive system of channels for heating and circulating water is necessary for this system to function, and faults in granites would be particularly favourable.

Geology. In the area studied the Alaska Range forms a NE-trending arc of mountains. It is separated into two blocks, which were about 38 km right-laterally displaced during the last 38 m.y., by the McKinley segment of the Denali fault system. This fault system trends northeast, parallel to the Alaska Range (Reed *et al.*, 1979). Reed divided the area into four different geological terrains. The northern one, which is composed of sedimentary, metamorphic, and volcanic rocks that range in age from early Palaeozoic through middle Tertiary, is the only terrain north of the McKinley segment of the Denali fault system. The second, which occupies most of the area bordering this fault system on the south, is an allochthonous terrain composed of middle and late Palaeozoic trench, slope, and terrestrial assemblages. It is thrusted southward over the third, which is the oldest and is composed of lower Palaeozoic sedimentary rocks and ultramafic bodies. Most of the plutons discussed in this study were emplaced in lower-to-middle Tertiary time (Table I) in a NE-trending series of stocks, along the fourth and southeastern terrain (Reed *et al.*, 1979).

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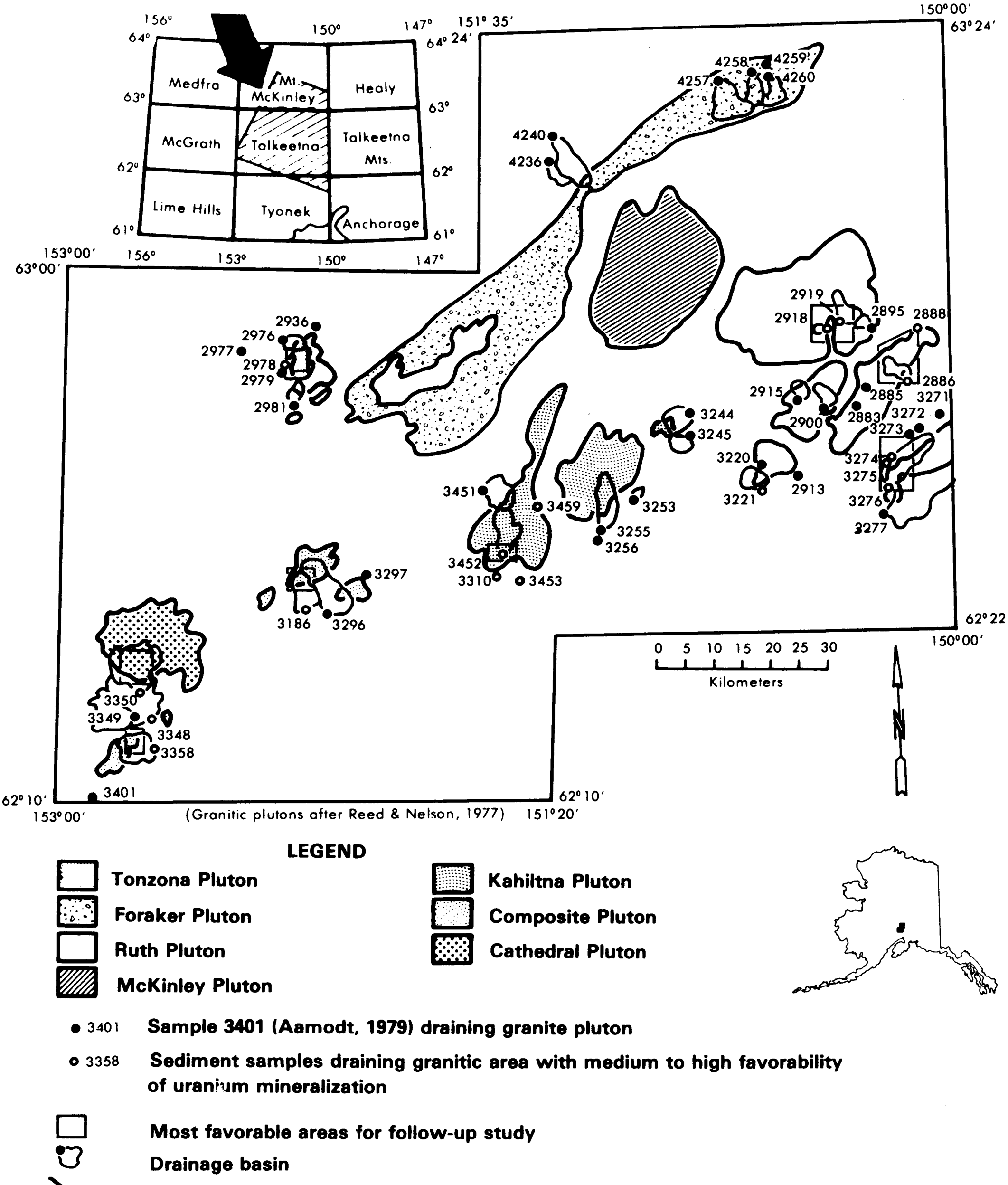


FIG. 1. Relation between HSSR data and granitic plutons in the Alaska Range.

Method. The −100 mesh fraction of the sediment samples are analysed for Be and Li by emission spectrography, and for Si, Bi, Cd, Co, Nb, Ni, Pb, Sn, and W by X-ray fluorescence; the same fraction of the sediment samples are also analysed for U, Al, Ba, Ca, Cl, Dy, K, Mg, Mn, Na, Sr, Ti, and V using neutron activation with a short time delay before analysis; and for Au, Ce, Co, Cr, Cs, Eu, Fe, Hf, La, Lu, Rb, Sb, Sc, Sm, Ta, Tb, Th, Yb, and Zn by using neutron activation with a long time delay before analysis). The information resulting from the HSSR is made public as open-file reports through the DOE, Grand Junction, Colorado. The results are reported by US Geological Survey NTMS quadrangle maps.

Evaluation of such data sets may indicate not only

TABLE I. *Granitic plutons, Alaska Range, Talkeetna quadrangle*

Name of pluton	Age system or probable age (m.y. of emplacement)
Tonzona (Tmt)	Early Tertiary
Foraker (Tf)	38
Ruth (Tmr)	Early Tertiary
McKinley (Tm)	Early Tertiary
Kahiltna (Tmk)	Early Tertiary
Composite (Tcp)	65
Cathedral (Tmc)	Early Tertiary

After Reed and Nelson (1977) and Reed *et al.* (1979).

potential areas of U mineralization but also the probable element association.

In Alaska the samples for the HSSR were collected in remote areas with almost no detailed geological mapping and with a sample density of one sample per 25 km^2. During our work with HSSR data sets we found that most of the well-known uranium mining districts are detectable only by methods such as Kriging (K. Campbell and H. N. Planner, pers. comm.). The absolute U values were too low and the mining districts were detectable only by relatively higher local values. These elevated local values are not always very high compared to other known anomalous values. The main reason for this is most probably the sampling density which does not always enable a direct indication. Therefore, in analysing the HSSR data we try to discuss local anomalous values which may be significant even if they are below known anomalous values in other areas with similar terrain. On the other hand, the results of such a study are only preliminary and require a follow-up field study.

All data base management was developed to be used on a 6600 CDC, 128 K central memory computer. The special program, Statistical Package for the Social Sciences (SPSS; Nie *et al.*, 1975) was used to perform the data analysis except for the cluster Q-mode analysis. The factor R-mode analyses used were PA2 with varimax rotation.

Forty-nine drainage sediment samples out of 683 of the Alaska Project matrix, were used for the granitic matrix of this study. These forty-nine samples are located downstream from the granitic plutons (fig. 1) as mapped by Reed and Nelson (1977) and Reed (1961), except for the McKinley pluton which was not sampled. The 683 drainage samples of the Alaska Project matrix were collected from main parts of Talkeetna, southeastern areas of Mt McKinley and northern corner of the Tyonek quadrangles (fig. 1).

The samples of the granitic matrix also indicate high factor 1 score values compared to the other drainage samples of the Alaska Project matrix. This factor 1 that was used for scoring includes lanthanides, Th, Hf, and U.

In evaluating the granitic matrix during this study, twenty-six elements, including all lanthanides and incompatible elements like Cs and Be, were used (Table II). During the statistic evaluation of the granitic matrix, values below the detection limit were calculated as one-half of the detection limit, and for missing data the average concentrations were used. Basic statistics for the granitic matrix are summarized in Table II.

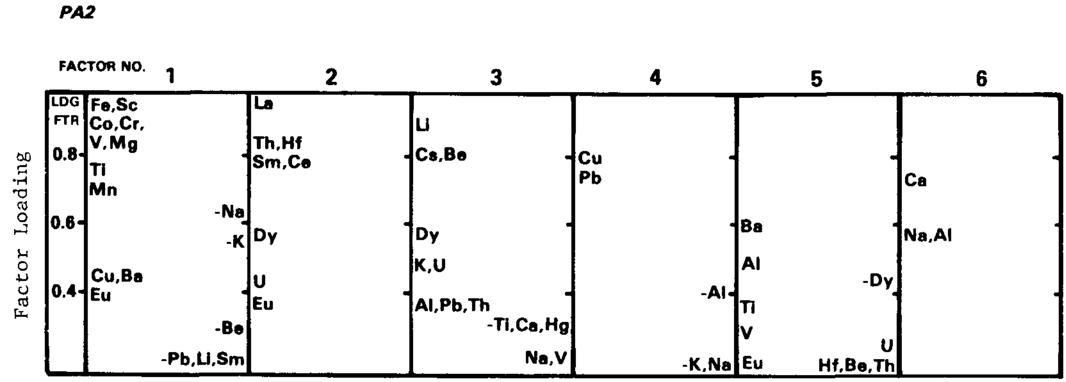
Factor analyses on raw data and on log-transformed data for the granitic matrix were carried out, and the results are presented in figs. 2 and 3. Thirteen samples with U concentrations above the average of U for the granitic matrix are separately discussed. For the final evaluation, a cluster analysis was carried out calculating the distance between the following elements and ratios: U, Be, Li, Ce, Cs, Hf, K, La, Rb, U/Th, and U/Hf. Finally, a contour map showing the concentrations of total uranium in drainage samples of the whole Alaska Project matrix was drafted.

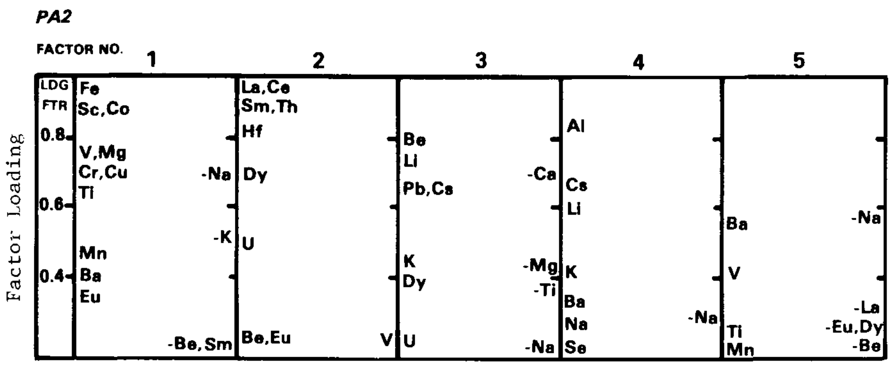
TABLE II. *Average and standard deviation, in ppm, for Granitic Matrix and Alaska Project Matrix, Alaska*

	Granitic Matrix*		Alaska Project Matrix†	
Element	Average	Standard deviation	Average	Standard deviation
U	13.2	15.0	4.1	9.4
Cu	22.8	21.9	28.1	24.4
Pb	12.4	8.8	6.8	7.2
Be	3.3	2.1	—	—
Li	73.2	40.4	30.0	29.7
Al	69339.6	7768.1	54847.5	32262.5
Ba	868.6	410.0	772.5	726.6
Ca	15300.1	9427.6	14286.3	13976.9
Ce	138.1	110.6	54.4	65.7
Co	10.3	6.2	14.2	6.6
Cr	77.5	77.6	74.2	74.9
Cs	6.0	4.6	—	—
Dy	8.3	8.5	3.7	3.9
Eu	1.3	.5	—	—
Fe	19693.0	10183.5	21036.4	18449.1
Hf	11.8	8.8	4.7	5.5
K	19486.5	7207.8	10975.4	9044.7
La	75.3	57.7	—	—
Mg	13869.1	10823.2	14324.6	11535.8
Mn	712.5	650.8	622.0	912.7
Na	19262.2	5107.4	—	—
Sc	11.3	5.4	10.0	5.2
Sm	10.8	10.4	—	—
Th	22.6	22.3	7.9	11.6
Ti	3149.0	1849.6	3223.6	2176.2
V	69.8	51.5	89.3	69.2
Rb	56.3	35.6	—	
U/Th	0.58		0.5	
U/Hf	1.12		0.7	
K/Rb	346.18		122.9	
K/Cs	3258.62		—	

* Granitic Matrix—composed of forty-nine sediment samples, draining granitic plutons in the Alaska Range of Talkeetna and Mt McKinley quadrangles (twenty-six elements).

† Alaska Project Matrix—composed of 683 sediment samples from main parts of Talkeetna quadrangle, southeastern areas of Mt McKinley and northern corner of Tyonek quadrangles (twenty elements).





FIGS. 2 and 3. Factor analyses. FIG. 2 (*top*). Alaska Project—granitic matrix raw data (forty-nine cases). FIG. 3 (*bottom*). Alaska Project—granitic matrix log-transformed data (forty-nine cases).

Discussion. The average and standard deviations for U, Pb, Li, Ce, Dy, Hf, Th, Al, and K are significantly higher in the granitic matrix than in the Alaska Project matrix (Table II), while the averages for some elements of basic rock assemblage (e.g. V, Ti, Fe, and Mg) are a little lower. This supports the assumption that the granitic matrix really represents drainage sediment samples derived from granitic plutons. The cumulative frequency curves, especially for U, but also for Li, Ce, Cr, Hf, La, Mn, Sm, and Th, do not indicate log normal distributions, but more polymodal situations. Therefore, they suggest: U mineralization; the presence of refractory and resistate minerals like zircon and monazite; and the enrichment of Li in pegmatitic granites.

Factor analyses carried out on raw data and log-transformed data of the granitic matrix (figs. 2 and 3) suggest five main assemblages:

1. The first factor, using 45–50% of the total information dominated by the Femic elements, includes most of the Cu and Ba and much of the Eu. This assemblage is negatively correlative with the pegmatitic (including Pb) assemblage (factor 3) and with Na and K. Another basic assemblage, without ultrabasic components, like Cr and Mg, is expressed in factor 5 and includes 5–6% of the total information. The first assemblage probably presents ultrabasic rocks associated with the Composite Pluton (Tcp; Reed and Nelson, 1977) and the fifth is probably also basic, related to doleritic dykes that often intrude into granitic plutons.

2. The second factor, which contains around 20% of the total granitic matrix information is an assemblage of lanthanides, Hf, Th, and U. The correlation of U with the other main elements of this assemblage is not very significant and U is only 0.42 loaded on factor 2. There is some Dy and Eu, but both are low loaded and show low correlation with the other lanthanides. V and Ti, both of the basic assemblage, are negatively correlative with this assemblage. This assemblage suggests the presence of resistate minerals like zircon and monazite in the granitic parts of the plutons.

3. The third factor presents the pegmatitic, or

incompatible element assemblage, and includes Be, Li, Cs, Pb, K, Dy, and U. This factor expresses 11-16% of the total granitic matrix information and indicates the existence of pegmatitic rocks in the granite plutons. This U (0.47 on log-transformed data and 0.26 on raw data) is most probably in ore-type mineralization and certainly not in refractory minerals. This assemblage is negatively correlative with the Mg, Ti, and V of the femic assemblage. A similar factor is factor 4 on raw data (fig. 2).

4. Factor 4 on log-transformed data suggests a base metal assemblage (Cu, Pb) that contains around 8% of total granitic matrix information and is negatively correlative with Na, K, and Al.

TABLE III. *Evaluation of tertiary granitic intrusions as described by Reed and Nelson (1977) according to the criteria for uranium-mineralized granites as suggested by Simpson* et al. *(1979)*

	Main composition	Greisen veins	Tin	Indicative mineralogy: Zircon	Apatite	Allanite	Beryllium	Tourmaline	Topaz	Fluorite	Comments
Tf	Granodiorite										
Tmt	Granite	+	+	+	+		+	+	+	+	
Tmc	Granodiorite										
	Granite		+	+	+	+		+		+	
Tmk	Granite										
	Granodiorite	+	+	+	+	+		+			
Tmr	Granite		+	+	+	+		+	+	+	
Tcp	Quartz-monzonite				+						including ultramafic bodies

+ Where criteria suggested by Simpson *et al.* (1979) apply.

TABLE IV. CONCENTRATIONS OF 14 ELEMENTS (IN PPM) AND U/TH U/HF, K/RB, and K/CS RATIOS FOR 13 SEDIMENT SAMPLES DRAINING GRANITIC INTRUSIONS WITH URANIUM CONCENTRATIONS HIGHER THAN 13 PPM[a] IN PARTS OF THE TALKEETNA NTMS QUADRANGLE, ALASKA RANGE

Sample No. and Granite Pluton[b]	Elements[c]: U	Be	Li	Ce	Cs	Dy	Eu	Hf	K	La	Na	Rb	Sm	Th	Ratios: U/Th	U/Hf	K/Rb	K/Cs
Tmr																		
2886	37.23	2	53	139	3.3	8.	1.3	11.4	16990	82	20810	-32	16.0	19.0	1.96	3.27	1061.9	5148.5
2888	25.30	2	36	96	4.3	5.	1.2	9.5	14980	55	14430	-33	8.8	10.1	2.50	2.66	936.3	3483.7
2918	24.12	4	227	113	26.1	9.	1.4	3.4	30050	67	17160	150	10.8	23.6	1.02	7.11	200.3	1134.0
2919	36.96	4	80	364	5.9	21.	1.7	36.4	25990	190	21580	82	32.4	62.5	0.59	1.02	317.0	4405.1
3274	17.97	3	82	293	4.2	29.	0.9	16.8	21660	146	22850	64	35.0	62.9	0.29	1.07	338.44	5157.1
3275	83.34	3	80	115	3.6	4.	1.3	8.1	13200	86	15500	-26	16.3	11.9	7.00	10.29	1015.4	3666.7
3276	28.32	3	56	77	3.1	4.	0.9	6.9	15210	47	18310	38	9.5	8.8	3.22	4.10	400.26	4906.5
Tmk																		
3310	16.22	3	107	287	11.7	9.	2.2	8.8	18680	155	16460	53	19.2	37.3	0.43	1.84	352.45	2075.56
Tcp																		
3186	26.55	3	26	313	2.1	7.	1.6	33.8	20050	179	20880	44	20.8	50.3	0.53	0.79	455.68	9547.62
3358[a]	13.16	3	75	173	11.6	4.	1.4	28.2	20820	80	17250	96	9.5	31.2	0.42	0.46	216.88	1794.83
Tmc																		
2978	31.52	11	107	100	12.2	38.	0.9	4.5	26530	42	24490	123	--	19.6	1.61	7.0	215.69	2174.6
3350	15.10	6	109	177	8.6	11.	0.6	9.5	30050	84	24660	111	17.5	43.4	0.35	1.59	222.16	3491.86
3348	54.97	8	119	583	8.2	46.	0.8	39.8	27520	315	23800	100	54.4	142.0	0.39	1.38	275.20	2902.44

a 13 ppm is the background for uranium in 49 samples which are associated with granites in parts of Talkeetna and Mt. McKinley NTMS quadrangles, Alaska Range, and defined as Granitic Matrix in this study.

b Granitic pluton as mapped by Reed and Nelson, 1977.

c Negative sign for below detection limit. One-half of the detection limit was used for the calculations.

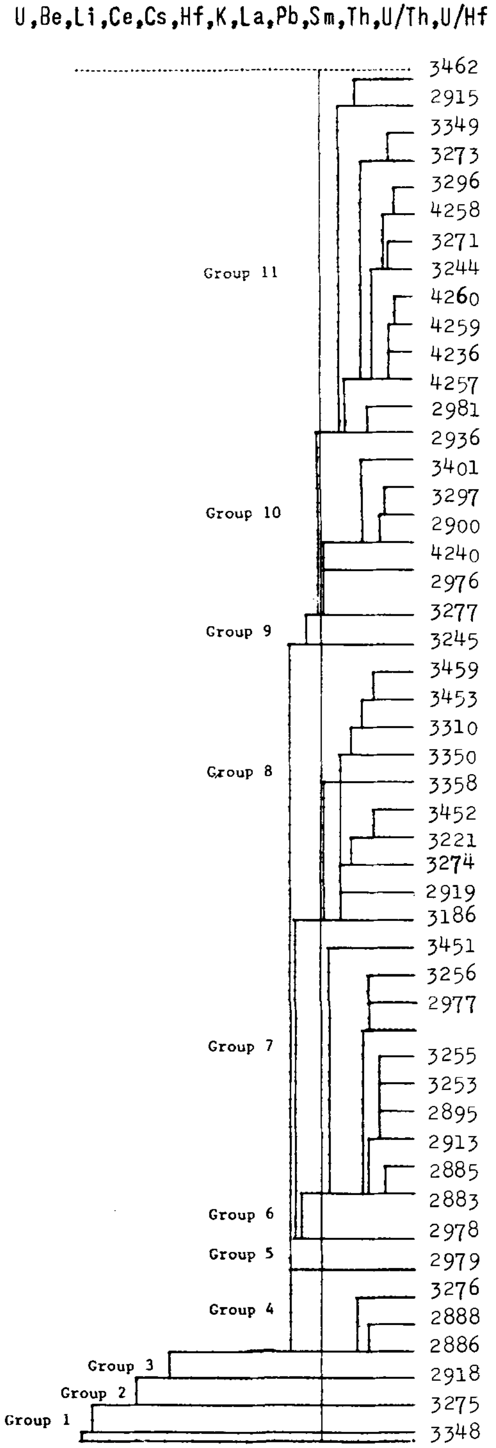


FIG. 4. Cluster analysis—granitic matrix.

5. Factor 6 on log-transformed data presents a positive correlation between Ca and Na. A negative correlation exists between Ca and K in the granitic matrix and, therefore, factor 6 most probably presents a granodioritic assemblage like the Foraker Pluton, which is mainly granodioritic (Reed and Nelson, 1977).

The results of the correlation and factor analyses suggest the following: (*a*) The granitic plutons of the Alaska Range in the Talkeetna quadrangle contain ultrabasic rocks, probably doleritic dykes, pegmatitic rocks, and probably some base metal mineralization; (*b*) U is present in refractory and resistate minerals such as zircon and monazite and in ore-forming minerals partly associated with the pegmatitic rocks. Hence, mineralization, as suggested by Simpson *et al.* (1979), had already released U from resistate minerals by dissolution, at least in some of the Alaska Range plutons.

Except for the Foraker Pluton (Tf), field evidence presented by Reed and Nelson (1977) and illustrated in Table III, supports these results. Most promising, according to the criteria suggested by Simpson *et al.* (1979), are the Ruth Pluton (Tmr), Kahiltna Pluton (Tmk), Cathedral Pluton (Tmc), and Tonzona Pluton (Tmt).

Further indications of the favourability of U mineralization in the granitic plutons of the Alaska Range were gained by scoring the favourability of thirteen samples of the granitic matrix, which had U concentrations above the average of 13 ppm (Table IV). Since U mineralization in the granites is probably of the vein type and is limited to small areas in the pluton, indications from isolated sediment samples are important. The criteria used for the scoring were the ones suggested by Simpson *et al.* (1979), in addition to high U/Th ratios, which indicate that significant amounts of U are in ore-forming and not resistate mineral phases. K/Cs ratios decrease with differentiation and pegmatitic formation (Wedepohl, 1978) together with U enrichment (Table V). The scoring itself was done by comparing the values of Tables II and IV.

Except for the Foraker Pluton (Tf), which is less favourable for U mineralization, and the McKinley Pluton (Tm), which was not sampled, all plutons of the area studied contain samples that indicate the presence of U mineralization (Table V). The highest scored samples are in the Ruth (Tmr) and Tonzona (Tmt) Plutons. The main clusters of favourable samples are in the Ruth Pluton (Tmr). Although the Composite Pluton (Tcp) does not show good petrographic indications (Table III), it contains two samples with moderate to good score values. The samples draining the Foraker Pluton to the northwest suggest that this pluton contains Th, but probably no U, mineralization. Reed and

TABLE V. *Semiquantitative scoring of sediment samples with uranium concentrations above the background of 13 ppm, granitic matrix, Talkeetna quadrangle, Alaska Range*

Sample no. and granitic pluton	Criteria for scoring: Concentrations: U	Incompatible elements	K	Rb	Ratios: K/Rb	K/Cs	U/Th	U/Hf	Total scoring
Tmr									
2886	++	+	+	−	−	−	++	++	8
2888	++	+	+	−	−	−	++	++	8
2918	++	+++	+++	+++	+++	+++	++	+++	22
2919	++	++	+++	++	++	−	+	+	13
3274	+	++	++	++	++	−	−	+	10
3275	+++	++	+	−	−	−	+++	+++	12
3276		+	+	+	++	−	+++	++	10
Tmk									
3310	+	+++	++	++	++	++	+	+	14
Tmt									
2978	++	+++	+++	+++	+++	++	++	+++	21
Tcp									
3186	++	+	++	+	+	−	+	−	8
3358	+	+++	++	++	+++	+++	+	−	15
Tmc									
3348	+	++	+++	+++	+++	++	−	+	15
3350	+++	+++	+++	++	++	++	−	+	16

− = very low scoring. + = median low. ++ = median high. +++ = very high.

Nelson (1977) describe it as a granodiorite and their petrographic description does not suggest high favourability for U mineralization. Comparing the results of the Q-mode cluster analysis of the forty-nine granitic matrix samples (fig. 4) with the scoring (Table V), it was found that Groups 1 through 4 and Groups 6 and 8 contain sediment samples that indicate the presence of U mineralization. According to these results, four stocks of the Ruth Pluton (Tmr), one stock of the Kahiltna Pluton (Tmk), two stocks of the Composite Pluton (Tcp), one of the Cathedral Pluton, and one of the Tonzona Pluton contain areas favourable for U mineralization. Except for two stocks (in the Tonzona and Cathedral Plutons) each of the remaining seven areas is indicated favourable by multiple adjacent samples. Fig. 5 indicates that indeed the main source rocks for U in the area are these granitic plutons and concentrations of uranium decrease further down stream.

Conclusion. The following granitic plutons of the Alaska Range in the Talkeetna quadrangle are considered favourable for U mineralization: Ruth Pluton (Tmr), Tonzona Pluton (Tmt), Cathedral Pluton (Tmc), Kahiltna Pluton (Tmk), and Composite Pluton (Tcp) and are probably a potential source rock for U in the region.

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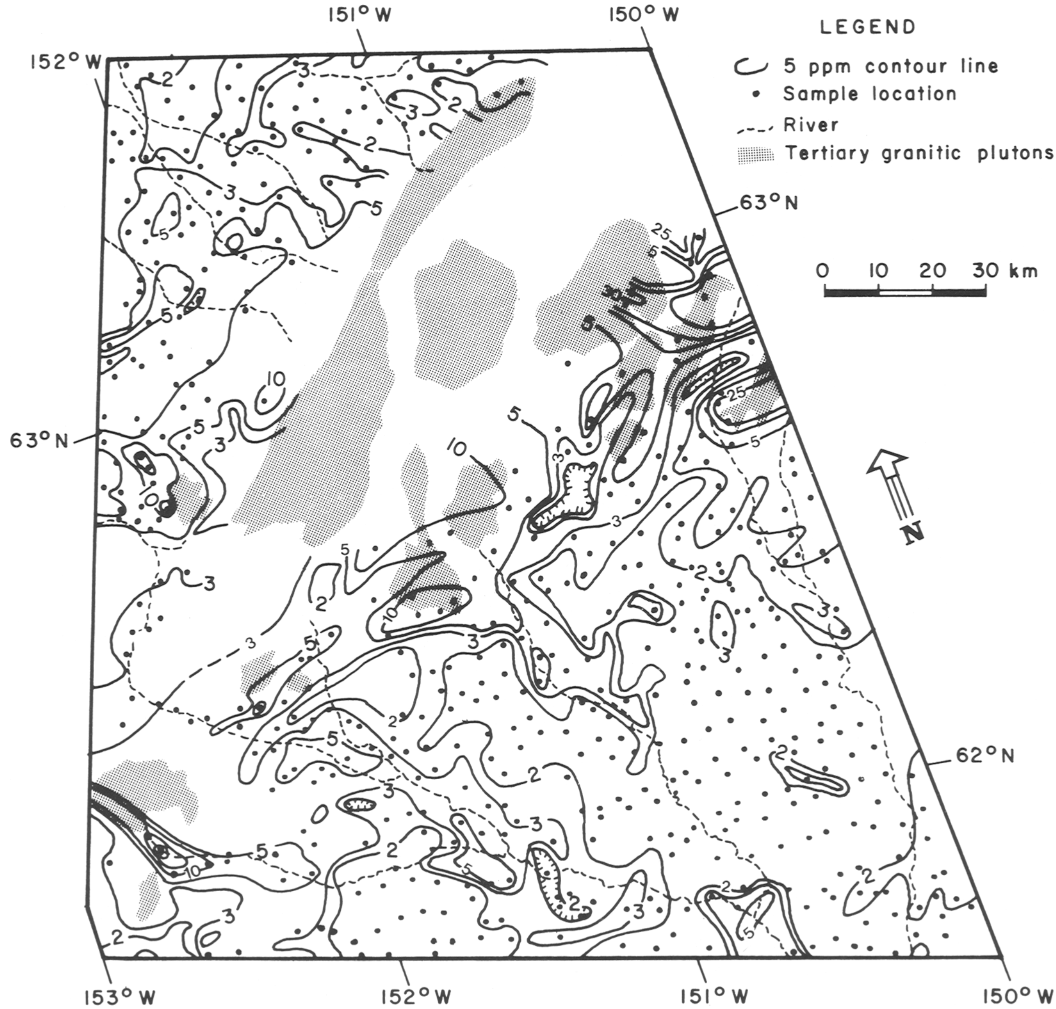

FIG. 5. Concentrations of total uranium (ppm) in sediment samples (−100 mesh) from parts of the Tyonek, Talkeetna, and Mt McKinley quadrangles, Alaska.

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