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RADIOELEMENT AND RADIOGENIC HEAT DISTRIBUTION IN DRILL HOLES MAHOGANY 5-4-1 AND MURPHY 7-4-1, IDAHO

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Two exploratory drill holes, Mahogany 5-4-1 and Murphy 7-4-1, were drilled at lat 42°48.3'N., long 116°24.3'W. and lat 43°11.3'N., long 116°41.1'W., respectively, to provide geologic and geophysical data for an investigation of geothermal energy sites. Samples were selected for radioelement analyses at intervals of about 6.1 m from both drill holes; sampled depths were 42.4-247.8 m (40 samples) in Mahogany 5-4-1 and 33.8-252.7 m (32 samples) in Murphy 7-4-1.

Reported here are analyses of the radioelements uranium, thorium, and potassium. Radiogenic heat production was calculated from these analyses to determine its contribution to in-hole temperatures and heat flow.

ANALYTICAL METHOD

The radioelement contents of the samples were measured by gamma-ray spectrometry. Approximately 600 g of drill cuttings were sealed in 15-cm-diameter plastic containers. A delay of 3 weeks between sealing and analysis permits sort-lived daughters of uranium and thorium to attain equilibrium with the parent radioisotopes. The containers were placed on a 12.5-cm-diameter by 10-cm-thick sodium iodide crystal. The radiation penetrating the crystal was sorted by the spectrometer into gamma-ray energy levels, and the resulting spectra were stored in a 100-channel spectrometer memory. The spectra were interpreted with the aid of a linear least-squares computer method which matches the spectrum from a sample to a library of radioelement standards; the computer method for determining radioelement contents is a modification of a program written by Schonfeld (1966). The basic operational procedures and calibration techniques have been described in more detail by Bunker and Bush (1966, 1967). Standards used to quantify the interpretations include the USGS standard rocks, New Brunswick Laboratory standards, potassium salts, and several samples for which U and Th contents had been determined by isotope dilution and mass or alpha spectrometry.

Uranium contents were measured indirectly by measuring the ^{26}Ra daughters (^{214}Bi and ^{214}Pb) to obtain radium-equivalent uranium (RaeU) values. Radium-equivalent uranium is the amount of uranium required to support secular isotopic equilibrium between the ^{226}Ra and its daughters measured in a sample. All uranium contents referred to in this paper are radium-equivalent values.

Although thorium is also measured from daughter products (^{212}Bi, ^{212}Pb, and ^{208}Tl), isotopic disequilibrium is improbable because of the short halflives of the daughter products of ^{232}Th. Therefore, the daughter products measured are considered to be a direct measurement of thorium. Potassium is determined from the ^{40}K constituent, which is directly proportional to the total potassium.

All the radioelement data reported here (tables 1 and 2) are based on replicate analyses. The coefficient of variation for the accuracy of these data, when compared to isotope-dilution and flame-photometer analyses, is about 3 percent for RaeU and Th and about 1 percent for K. The percentages are in addition to minimum standard deviations of about 0.05 ppm for RaeU and Th and 0.03 percent for K.

Table 1.--Radioelement contents and ratios, and calculated radiogenic heat, drill hole Mahogany 5-4-1, Idaho

Sample depth (meters)	RaeU (ppm)	Th (ppm)	K (wt %)	Heat (µcal/g-yr)	Th/RaeU	RaeU/$Kx10^{-4}$	Th/$Kx10^{-4}$	Rock description 1/
42.4	1.54	6.78	1.89	2.99	4.40	0.81	3.59	Qtz. diorite
49.7	1.03	9.95	2.75	3.48	9.66	0.37	3.62	biotite granoblast
55.2	1.90	7.85	2.03	3.51	4.13	0.94	3.87	Qtz. diorite
64.0	1.12	5.16	4.30	3.01	4.61	0.26	1.20	Qtz. diorite
80.5	8.11	8.06	1.46	7.93	0.99	5.55	5.32	Biotite gneiss
85.0	4.88	50.99	4.48	14.97	10.45	1.09	11.38	Qtz. diorite
93.0	5.67	4.20	3.59	5.95	0.74	1.58	1.17	do.
99.7	3.08	46.01	5.12	12.83	14.94	0.60	8.99	do.
105.8	9.00	8.59	1.48	8.69	0.95	6.08	5.80	Interlayered
112.5	1.93	4.18	0.83	2.47	2.17	2.33	5.04	Qtz. diorite
116.1	1.73	16.62	1.77	5.06	9.61	0.98	9.39	and schistose
120.7	2.62	4.62	4.49	4.05	1.76	0.58	1.03	rock
128.5	1.91	7.70	4.97	4.28	4.03	0.38	1.55	Qtz. diorite
139.1	2.45	8.45	4.54	4.70	3.45	0.54	1.86	do.
141.9	2.95	2.24	2.08	3.16	0.76	1.42	1.08	do.
145.4	5.31	1.66	0.11	4.24	0.31	48.27	15.09	Interlayered qtz.
150.6	3.40	1.40	3.48	3.70	0.41	0.98	0.40	diorite and
156.8	1.14	1.13	3.14	1.91	0.99	0.36	0.36	schistose rock
158.2	3.07	4.58	2.56	3.85	1.49	1.20	1.79	Massive qtz.
162.2	1.32	1.38	1.64	1.68	1.05	0.80	0.84	diorite, some
165.2	1.50	7.36	3.30	3.46	4.91	0.45	2.23	diorite, minor
171.1	1.35	10.53	3.77	4.11	7.80	0.36	2.79	biotite
178.9	1.13	6.24	3.86	3.12	5.52	0.29	1.62	do.
183.8	0.87	5.30	2.83	2.46	6.09	0.31	1.87	do.
186.1	0.95	2.37	3.53	2.12	2.49	0.27	0.67	do.
197.2	1.58	11.11	3.14	4.22	7.03	0.50	3.54	do.
202.1	1.33	7.90	1.88	3.06	5.94	0.71	4.20	do.
205.4	4.84	8.13	1.44	5.55	1.68	3.36	5.65	Gradation zone
209.1	2.80	16.08	1.88	5.77	5.74	1.49	8.55	Massive qtz.
212.4	1.25	1.41	5.26	2.61	1.13	0.24	0.27	diorite, 5-25
214.3	1.73	6.41	2.23	3.15	3.71	0.78	2.87	percent biotite
217.9	1.79	7.43	2.11	3.36	4.15	0.85	3.52	do.
227.4	2.28	7.61	5.55	4.68	3.34	0.41	1.37	do.
228.9	1.76	31.01	5.30	8.92	17.62	0.33	5.85	do.
231.6	3.27	5.95	1.64	4.02	1.82	1.99	3.63	do.
235.9	1.02	4.94	3.17	2.59	4.84	0.32	1.56	do.
238.0	0.92	4.62	3.15	2.45	5.02	0.29	1.47	do.
241.2	5.71	8.35	1.48	6.24	1.46	3.83	5.60	do.
245.1	1.50	19.65	2.72	5.76	13.10	0.55	7.22	do.
247.8	1.19	0.73	0.59	1.17	0.61	2.02	1.24	do.

1/ Wm. H. Diment, written communication. 1975.

Table 2.--Radioelement contents and ratios, and calculated radiogenic heat, drill hole Murphy 7-4-1, Idaho.

Sample depth (meters)	RaeU (ppm)	Th (ppm)	K (wt %)	(μcal/g-yr)	Th/RaeU	RaeU/Kx10^-4	Th/Kx10^-4
33.8	1.10	10.40	1.87	3.39	9.45	0.59	5.56
42.1	1.04	8.74	1.99	3.04	8.40	0.52	4.39
52.6	1.99	8.36	1.81	3.61	4.20	1.10	4.62
60.0	1.19	9.30	2.06	3.28	7.82	0.58	4.51
68.3	1.52	8.84	2.19	3.47	5.82	0.69	4.04
75.3	0.91	7.60	2.47	2.85	8.35	0.37	3.08
80.2	0.76	8.29	2.48	2.88	10.91	0.31	3.34
86.0	0.86	6.36	2.10	2.47	7.40	0.41	3.03
91.1	0.26	0.46	7.58	2.33	1.77	0.03	0.06
96.9	1.89	4.56	3.43	3.22	2.41	0.55	1.33
101.8	1.15	8.92	1.98	3.16	7.76	0.58	4.51
106.4	1.24	8.64	2.10	3.20	6.97	0.59	4.11
111.6	0.92	8.00	2.32	2.90	8.70	0.40	3.45
120.5	1.02	4.70	2.11	2.25	4.61	0.48	2.23
128.9	0.94	9.50	1.98	3.12	10.11	0.47	4.80
134.7	0.88	7.64	1.96	2.70	8.68	0.45	3.90
138.1	1.14	6.30	1.98	2.63	5.53	0.58	3.18
148.1	1.22	8.98	1.73	3.15	7.36	0.71	5.19
157.9	1.65	10.11	2.10	3.79	6.13	0.79	4.81
163.4	2.08	10.01	1.82	4.01	4.81	1.14	5.50
168.7	1.80	9.92	1.85	3.80	5.51	0.97	5.36
178.6	1.10	8.17	1.79	2.92	7.43	0.61	4.56
187.5	1.09	10.15	3.65	3.81	9.31	0.30	2.78
196.0	1.63	8.67	2.30	3.54	5.32	0.71	3.77
201.5	1.20	5.84	2.37	2.68	4.87	0.51	2.46
208.6	1.34	9.23	2.00	3.36	6.89	0.67	4.62
217.6	2.02	9.84	1.86	3.94	4.87	1.09	5.29
225.6	1.60	7.99	1.95	3.29	4.99	0.82	4.10
234.7	1.41	10.14	2.28	3.67	7.19	0.62	4.45
239.3	1.25	7.61	1.90	2.95	6.09	0.66	4.01
248.4	1.85	8.33	1.73	3.48	4.50	1.07	4.82
252.7	1.95	8.23	1.81	3.56	4.22	1.08	4.55

RESULTS

A comparison of the radioelement contents in these drill holes with averages for various rock types (table 3) indicates that the holes penetrate rocks that have radioelement contents similar to those of intermediate igneous rocks.

A geologic log of core from the Mahogany 5-4-1 drill hole (Wm. H. Diment, written communication, 1975), shows a rock that is essentially a massive quartz diorite with quartz content gradually decreasing from 30-40 percent near the top of the hole to 10-20 percent near the bottom. Schistose or foliated layers as much as 5 m thick intersect the quartz diorite. Metamorphism ranges from schist to biotite gneiss and is usually gradational into the quartz diorite. In addition, most of the rock is badly fractured and weathered. Most of the alteration is related to hydration of the feldspars into kaolinite and montmorillonite along fracture surfaces.

The movement of fluids, particularly hydrothermal fluids, through a rock will often transport uranium and potassium into or from an area. Thorium is relatively insoluble and is less likely to migrate, but may be retained in resistate minerals and concentrated by weathering and sorting or absorbed on clays. Uranium and potassium seem to be highly mobile during metamorphic processes, but thorium is much less mobile during localized metamorphic episodes.

The radioelement distribution in drill hole Mahogany 5-4-1 (fig. 1 and table 1) is consistent with the geologic data, indicating an intermediate igneous host rock intersected by many layers having anomalous radioelement content. These layers are located where metamorphism or alteration has occurred. Most movement of radioelements in drill hole Mahogany 5-4-1 is

Table 3. Comparison of radioelement data in drill holes Mahogany 5-4-1, Murphy 7-4-1, and average contents in similar rocks

	RaeU (ppm)	Th (ppm)	K (percent)	Th / RaeU	RaeU / Kx10^{-4}	Th / Kx10^{-4}	Heat (μcal/g-yr)
			(Mean and standard deviation)				
Mahogany 5-4-1	2.25±1.61	6.75±4.33	2.93±1.25	3.90±2.98	1.09±1.16	2.92±2.31	3.76±1.45
Murphy 7-4-1: Above 145 m	1.11±.31	8.11±1.44	2.09±.20	7.65±1.94	0.54±.18	3.92±.86	3.00±.38
Below 145 m	1.58±.33	8.79±1.22	1.96±.22	5.73±1.12	0.82±.21	4.53±.79	3.44±.40
All depths	1.34±.39	8.44±1.36	2.03±.21	6.72±1.85	0.67±.24	4.21±.87	3.21±.44
Averages in igneous rocks							
Continental crust	2.8 (1a,2)	6-10(1b) 10 (2)	2.1,2.5(4) 2.6 (2)	3.5-4(1b) 3.6 (2)	1 (1a)	3.3(1b)	3.7-4.7
Mafic	0.9 (3)	2.7 (3)	.6-.75(4)	≤3(1b) 4.8 (2)	0.6(2)	2.8(2)	1.4
Intermediate	2.0-2.6(3)	8.5-9.3(3)	2.7,3.0(4)	4.1(5)	--	--	3.9-4.6
Silicic	4 (1a) 4.75 (2) 4.7 (3)	18 (1a) 20 (3)	3.6 (1a) 3.79 (2)	4.0 (3) 4.5 (5)	1.29 (2)	4.9 (2) 5.0 (3)	7.5-8.5

Note: Averages recalculated after omitting samples in which any value exceeded 3σ

(1a) Rogers and Adams, 1969b.

(1b) Rogers and Adams, 1969a.

(2) Heier and Rogers, 1963.

(3) Clark, Peterman, and Heier, 1966.

(4) Heier and Billings, 1970.

(5) Z. E. Peterman, written commun., 1963.

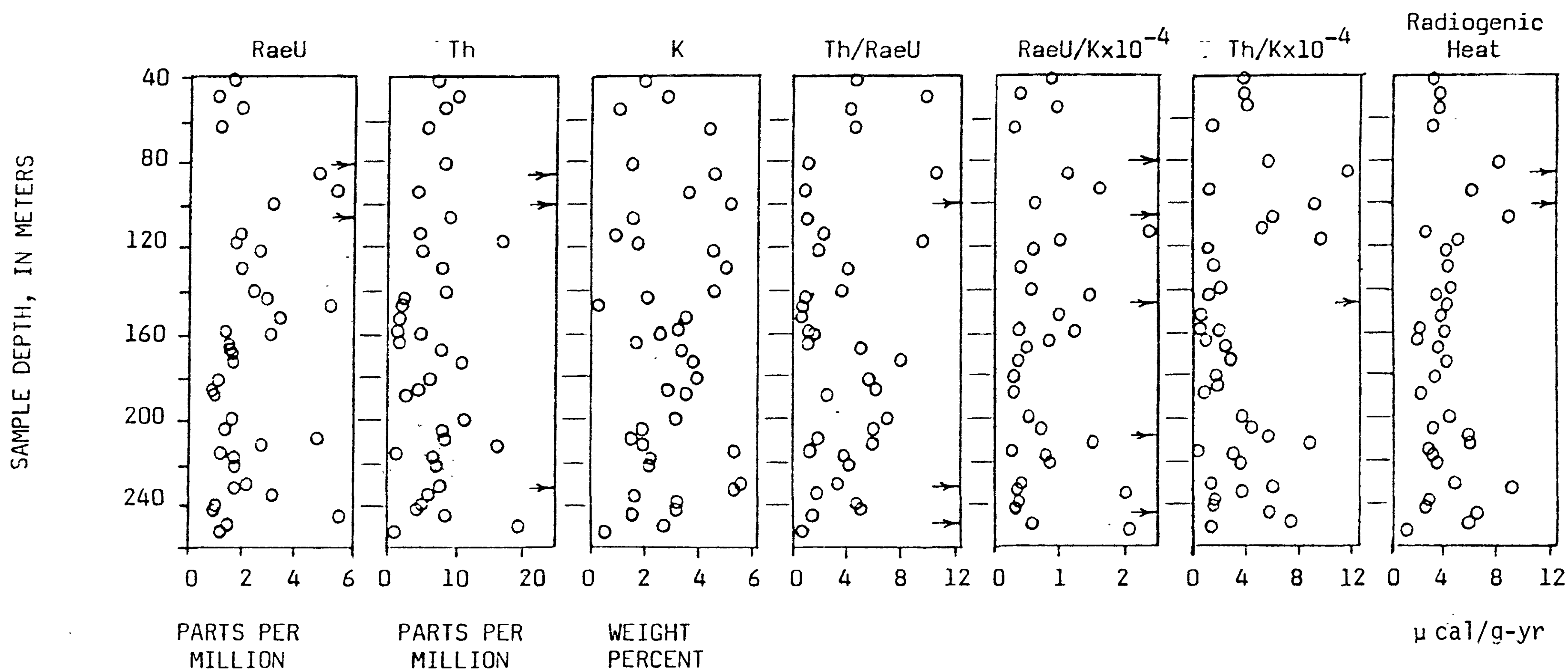

Figure 1.--Radioelement contents and ratios, and radiogenic heat in drill hole Mahogany 5-4-1. Arrows indicate points beyond scale limit.

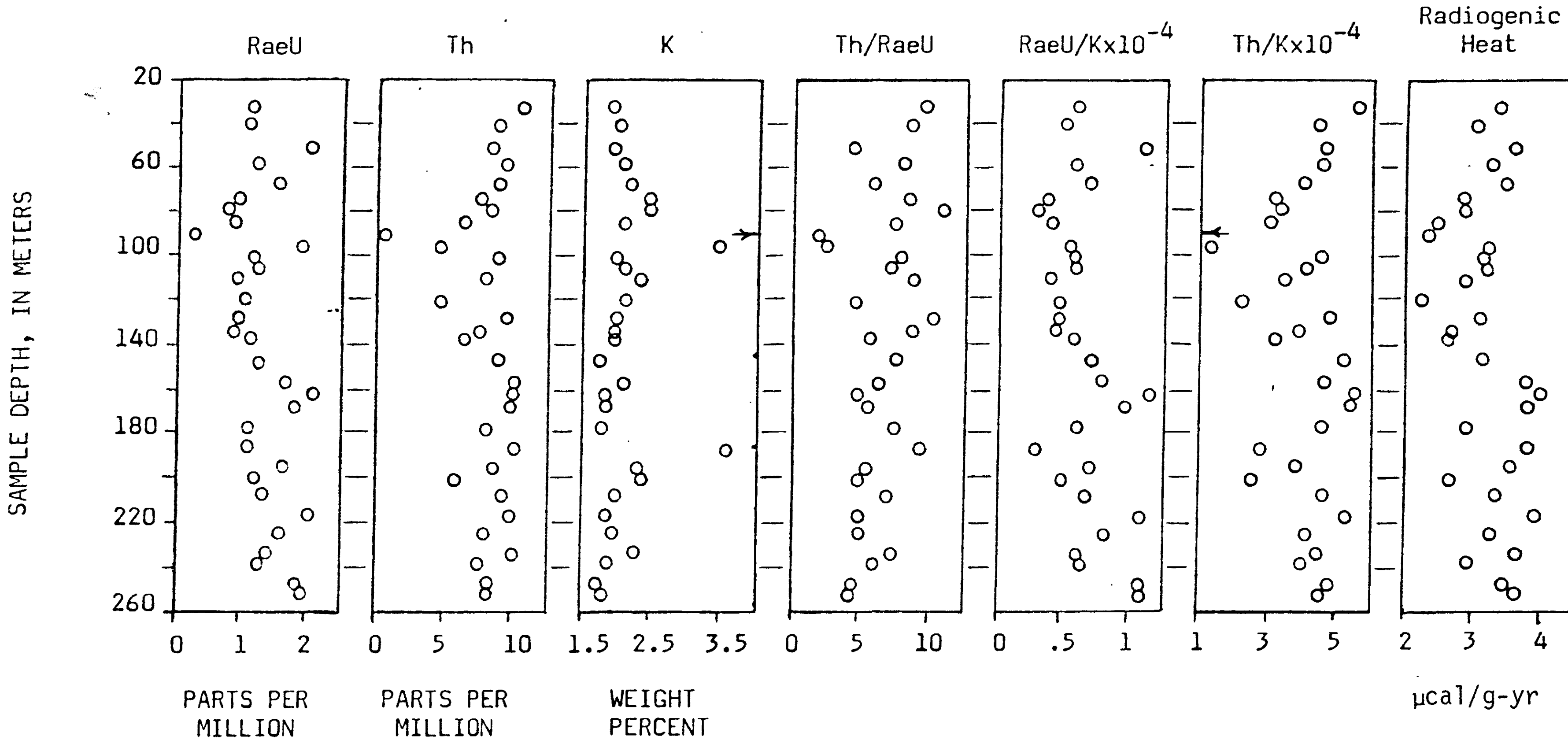

Figure 2.--Radioelement contents and ratios and radiogenic heat in drill hole Murphy 7-4-1. Arrows indicate points beyond scale limit.

probably related to the alteration process. Even though thorium is relatively insoluble, the thorium concentration exhibits wide variability even in zones such as 156.9-202.2 m and 207.7-255.4 m, which are described as massive quartz diorite with no sign of metamorphsm. Histograms of the data (fig. 3) show that about half of the RaeU contents are in a narrow range (1-2 ppm), which probably represents the host rock, but that Th and K range widely. Although the radioelement concentrations are variable and the standard deviations are high, mean values of all three radioelements (table 3) are consistent with those of an intermediate igneous rock.

The radioelement data from the Murphy 7-4-1 drill hole samples (table 2 and fig. 2) indicate that the hole penetrates a very homogeneous section of rock, except for two depth intervals at 91.1-96.9 and 187.5 m. These intervals are indicated by anomalously high potassium contents in both intervals and by low RaeU and Th contents from 91.1-96.9 m. These anomalous intervals probably indicate the presence of small dikes or fractured and altered host rock. Histograms of the data (fig. 3) show that the ranges of the radioelement contents, especially the RaeU and K values, are very narrow, thereby providing further evidence for homogeneity of the rock. The plot of the vertical distribution of the radioelements (fig. 2) suggest an increase in RaeU content below about 145 m; however, no change in the other contents are obvious at that depth. RaeU, RaeU/K, and radiogenic heat values are relatively low in the section above 145 m. One can conclude from these data that the drill hole penetrates, with two exceptions, a virtually homogeneous section of rock from which ^{26}Ra and daughters may have been partly removed from the upper part of the section.

The radiogenic heat, that is, the heat produced by the disintegration of the radionuclides, was determined for each sample and for the averages in

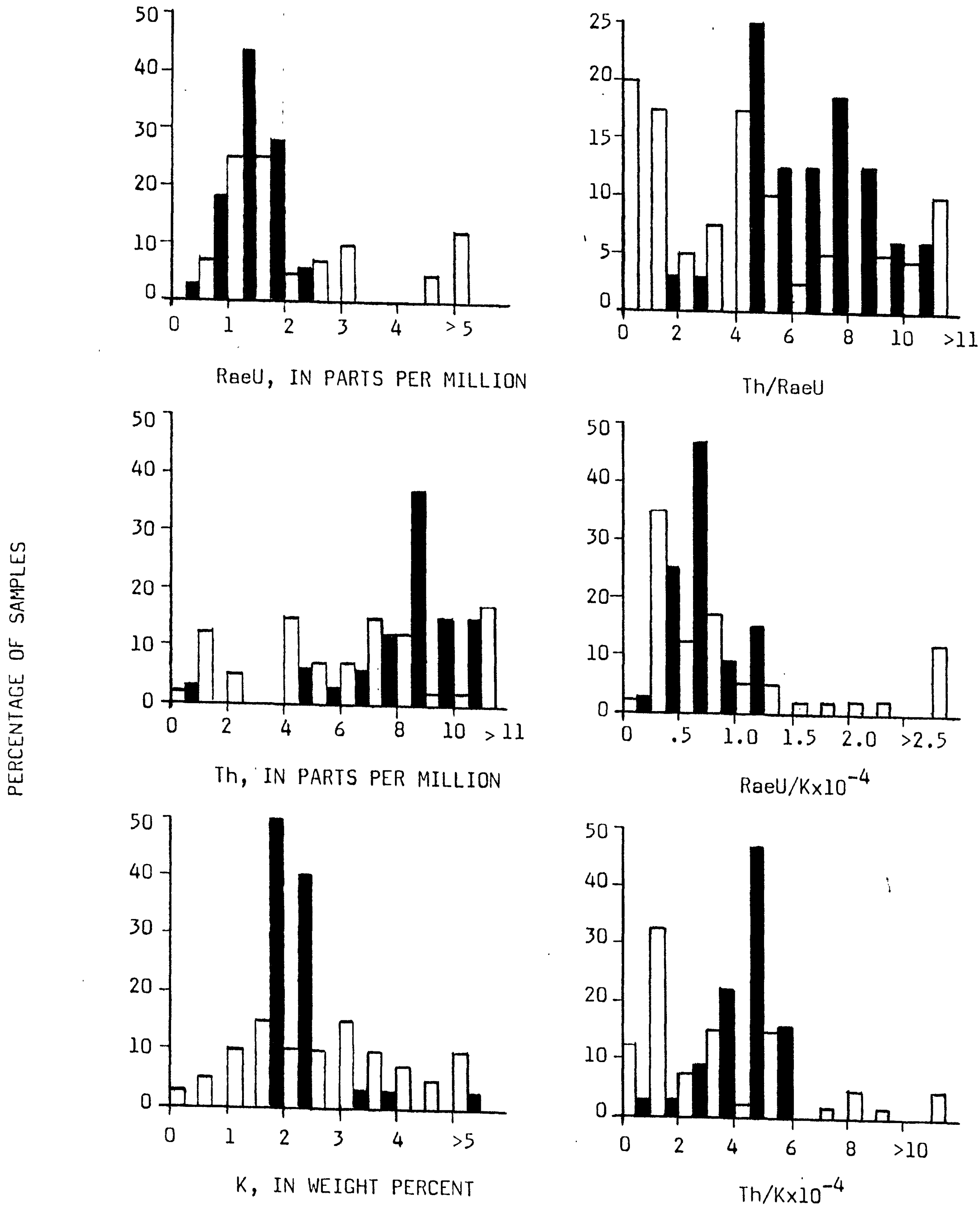

Figure 3.--Frequency distribution of radioelement contents and ratios. Shaded bars are from Murphy 7-4-1 (32 samples); open bars are from Mahogany 5-4-1 (40 samples).

igneous rocks using the constants from Birch (1954). The heat production A, in units of 10^{-6} cal/g-yr, was calculated from

$$A = 0.73\ U + 0.20\ Th + 0.27\ K,$$

where U and Th are in parts per million and K is in percent.

The average heat production in both drill holes is near the lower limit of the range for intermediate rocks (table 3). Neither hole exhibits a vertical gradient in heat production. Higher values below 145 m in Murphy 7-4-1 reflect an increase in RaeU and Th content in that zone.

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