Title

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ABSTRACT

A radiometric traverse was made across granitic rocks in the Huntington Lake area of the Sierra Nevada, California. Field gamma-ray counting rates were recorded, and samples were taken and subsequently evaluated in the laboratory for U, Th, and K content by gamma-ray spectrographic analyses. These concentrations were converted to heat-generation values, using the factors given by Birch: 1 ppm U = 0.73 cal/g - 10^6y, 1 ppm Th = 0.20 cal/g - 10^6y, 1% K = 0.27 cal/g - 10^6y. Three principal plutons were sampled: a stock of pyroxene quartz diorite on the western border of the Sierra, hornblende-biotite granodiorite of the "Dinkey Creek" type on the western slope of the range, and the Mt. Givens granodiorite occupying the higher elevations east of Huntington Lake. Laboratory results indicate that the Mt. Givens granodiorite averages nearly twice the U and Th content and, therefore, nearly twice the radiogenic heat production of Dinkey Creek-type granodiorite; the pyroxene quartz diorite is quite low in radioisotope content, and consequently heat production, compared to the Mt. Givens and Dinkey Creek plutons. Average values are given below.

	No. of samples	U (ppm)	Th (ppm)	K (%)	Total heat (cal/g-10^6y)
Mt. Givens granodiorite	7	7.61±0.20	23.3±0.30	2.83±0.03	11.0±0.21
Dinkey Creek-type granodiorite	9	3.95±0.12	12.8±0.22	2.05±0.02	6.0±0.14
Pyroxene quartz diorite	2	0.65±0.12	1.1±0.18	0.45±0.01	0.8±0.13

The ratio of thorium to uranium does not vary appreciably between the Mt. Givens and Dinkey Creek plutons, averaging 3.24 in the Dinkey Creek and 3.06 in the Mt. Givens. If the radioactivity of the Mt. Givens granodiorite can be considered to be typical of the younger granitic rocks of the Sierra Nevada, and that of the Dinkey Creek-type granodiorite typical of the older plutonic rocks, a large central portion of the batholith may have considerably higher radioactivity and radiogenic heat production than the older rocks on the western flank of the Sierra.

INTRODUCTION

A knowledge of the abundance and distribution of natural radioactivity in rocks is necessary to properly evaluate the amount of heat generated in the earth. Jacobs et al. [1959] state that "It is practically certain that of the observed heat flow no more than 20 percent can come from the original heat of the earth; the rest must be due to the radioactivity of the rocks." Yet, ocean-floor measurements have shown that the average heat flow above the relatively thin, basaltic sub-oceanic crust is quite similar to that measured on the continents. To explain this it has been suggested (Verhoogen [1956]) that conduction is not the dominant process of heat transfer in the earth; convection may play an important role. Also, the necessity has arisen for a better understanding of the distribution of radioactivity in continental areas, because the assumed distributions of radioactive matter may need to be revised. Therefore, it is evident that an evaluation of the distribution of isotopes responsible for rock radioactivity--uranium-238, thorium-232, their decay products, and potassium-40--is of fundamental importance in establishing the radiogenic basis for earth heat.

The authors with the cooperation of members of the U. S. Geological Survey have undertaken a study of the gamma radioactivity of the granitic rocks of the Sierra Nevada batholith, using gamma-ray spectrographic-analysis techniques employed at the Health Physics Department, Lawrence Radiation Laboratory, Berkeley. In this study we shall attempt to establish the distribution in uranium, thorium, and potassium in several of the batholith's plutonic units as well as the amount of heat generated by radioactivity in each unit.

The reasons for choosing the Sierra Nevada follow:

a. The batholith represents a large volume of fairly homogeneous material;

b. Uranium, thorium, and potassium are in good abundance in granitic rocks;

c. Surface exposures are good, especially in the glaciated higher elevations;

d. The Geological Survey is presently mapping a large area of the batholith, thus offering geologic control for sampling and field radiometric-reading localities.

The initial phase of this study consisted of a radiometric and sampling traverse across part of the Sierra from the eastern edge of the San Joaquin Valley to Florence Lake. This area is referred to hereafter as the Huntington Lake area (see accompanying map). On this traverse field gamma-radiometric readings were taken, and rock specimens were collected at selected intervals in the plutonic units. On return to the laboratory the specimens were analyzed by using a 100-channel gamma-ray spectrometer. Thus we were able to obtain overall field counting rates as well as the concentrations of U, Th, and K in the rocks at various locations in the plutons. The concentration values are based on the assumption that U and Th are in radioactive equilibrium with their decay products. By application of the radiogenic heat factors given by Birch [1954], i.e.

$$1 \text{ ppm U} = 0.73 \text{ cal/g} - 10^6 \text{ y}$$
$$1 \text{ ppm Th} = 0.20 \text{ cal/g} - 10^6 \text{ y}$$
$$1\% \text{ K} = 0.27 \text{ cal/g} - 10^6 \text{ y},$$

radioactive-heat-generation values for the specimens were calculated. At selected localities samples were taken of weathered as well as fresh material from the same outcrop, in an attempt to establish if leaching caused an apparent depletion of uranium in the weathered material.

INSTRUMENTATION

Our field radiometric counting utilizes a 3-in.-diam by 3-in.-thick thallium-activated NaI crystal as a detector coupled through a stable pulse amplifier into a precision count-rate-indicator circuit. This portable count-rate instrument is described by Goldsworthy [1960]. In our laboratory scintillation spectrometer, a 4-in.-diam. by 2-in.-thick NaI(Tl) crystal detector provides the input for a 100-channel differential pulse-height analyser. The crystal detector is located in a low-background environment provided by an 11-by 11-by 22-ft serpentine-concrete room with 4-1/2-to 5-ft-thick walls and roof. Resultant 100-channel gamma-ray spectra are operated upon mathematically to yield quantitative uranium, thorium, and potassium assays. We assume that in the uranium and thorium assays each element is in equilibrium with its respective decay products, and in the potassium assays the ratio K^{40}/K^{39} is a constant in nature. Field and laboratory equipment and techniques are described in detail by the authors in UCRL-10636 (Wollenberg et al. [1963]).

GEOLOGIC SETTING

The Huntington Lake area referred to in this report and shown on the accompanying map encompasses two principal plutons of the Sierra Nevada batholith; hornblende-biotite granodiorite of the "Dinkey Creek" type (symbol Kdc on Table 1) on the western slopes of the range, and the younger, more feisic Mt. Givens granodiorite (Kmg on Table 1), occupying the higher elevations from near Huntington Lake eastward to near the crest of the Sierra. The traverse included a stock of pyroxene quartz diorite (symbol Kdg) bordering the valley sediments on the western edge of the Sierra, as well as quartz monzonite intrusives (Kbv) in the vicinity of Huntington Lake. These plutonic units are described in detail by Bateman et al. [1963]. In general the Mt. Givens granodiorite is more felsic than the Dinkey Creek-type granodiorite, which in turn is more felsic than the pyroxene quartz diorite. Kistler et al. give hornblende-based potassium-argon ages of 91 to 92×10^6 y for the Dinkey Creek and 86 to 87×10^6 y for the Mt. Givens. No radiometric ages are available for the quartz monzonite; it is considered younger than the Mt. Givens. The age relationship between the pyroxene quartz diorite and the Dinkey Creek-type granodiorite is unknown.

RESULTS

Field readings and laboratory results are shown in Table 1. From inspection of this table we note a marked difference between the overall gamma radioactivities, the U, Th, and K concentrations, and consequently the radiogenic heat values of the Mt. Givens and Dinkey Creek-type granodiorites. The pyroxene quartz diorite is very much lower than both the Mt. Givens and Dinkey Creek in these parameters. Average values are given at the bottom of Table 1.

The histograms in Figs. 2 through 4 illustrate the frequency distributions of uranium, thorium, and potassium in the samples, and also the grouping of the various plutonic units according to each radioisotope. Here we see that the Dinkey Creek granodiorite is generally lower in U, Th, and K than the Mt. Givens granodiorite. The Dinkey Creek, Mt. Givens, and pyroxene quartz diorite samples fall into fairly definite ranges in all three plots. The four quartz monzonite samples are more scattered; two are in the Dinkey Creek range for Th, while three fall into the Dinkey Creek range for U.

The generally higher activity of the Mt. Givens samples is also illustrated in Figs. 5 through 8. On all graphs the Mt. Givens samples are grouped together, with generally higher values than those from the Dinkey Creek. Values for the pyroxene quartz diorite are appreciably lower than those for the Dinkey Creek in all cases. The good linearity expressed in the plot of U plus Th vs laboratory counting rate (Fig. 5) indicates that combined, these isotopes are primarily responsible for the radioactivity of the rocks. The weaker linearity shown in the graph of %K vs laboratory counting rate (Fig. 6) indicates the subordinate role K plays in contributing to the rocks' radioactivity. As one would suspect, the plot of U plus Th vs K (Fig. 7) indicates that the U plus Th/K ratio is fairly constant, especially where values for K exceed 1%. Thus, rocks high in U and Th are also high in K. Good correlation exists between heat values and the field counting rate (Fig. 8), with the apparent intercept on the abcissa indicating the average contribution of fission-product fallout to the field radioactivity (~ 100 counts/sec).

The ratio of thorium to uranium does not appear to vary appreciably between the Mt. Givens and Dinkey Creek plutons. The average Th/U ratio for the Dinkey Creek samples is 3.24, ranging from 5.58 in fairly weathered granodiorite at site 23 to 2.08 in fresh granodiorite at site 21. The Mt. Givens Th/U average is 3.06, with a range from 4.33 in fresh porphyritic granodiorite at site 10 to 1.93 in fresh granodiorite at site 20 near Florence Lake.

There is no indication of an apparent systematic depletion of uranium from fresh to weathered material, although one cannot make a general conclusion from these limited data. The combined averages of the thorium-uranium ratio are 3.82 for the fresh rock samples, 3.68 for weathered rock. Some discrepancies exist between U and (or) Th contents of weathered and fresh rock from the same outcrops; site 3 in porphyritic quartz monzonite (Kbv), and sites 4, 21, and 22 in Dinkey Creek-type granodiorite are examples. Good agreement is seen in samples from site 12, a Mt. Givens granodiorite outcrop, and from site 1, an outcrop of quartz monzonite.

CONCLUSIONS

When heat-production figures for the Dinkey Creek and Mt. Givens granodiorites are compared with those given by McDonald (1959) for acid igneous rocks and granite (see Table 2) it is seen that the Dinkey Creek values compare closely with McDonald's. (McDonald's values are converted from ergs to calories for comparative purposes in this paper.) U, Th, and total heat values of the Mt. Givens granodiorite are nearly twice those of the Dinkey Creek pluton and McDonald's values.

The Mt. Givens granodiorite is an extensive pluton, and together with the Half Dome granodiorite to the north (with which it may correlate both lithologically and in age as a part of the Tuolumme intrusive series) makes up a substantial part of the Sierra Nevada Batholith. If these radioactivities can be extrapolated to the entire

Mt. Givens-Half Dome pluton, a large central portion of the batholith would have overall radioactivity, and consequently radiogenic heat, considerably higher than the older plutonic rocks on the western flanks of the Sierra.

Planned further studies of the radiogeology of the Sierra Nevada granites include a continuation of the Huntington Lake traverse from Florence Lake eastward over the crest of the range. Also, a traverse will be made across the granitic units in Yosemite National Park. Comparison of the Yosemite and Huntington Lake data should indicate whether any radiometric correlations exist between the Half Dome and Mt. Givens plutons as well as between the older Yosemite plutons and the Dinkey Creek granodiorite. With the aid of U. S. Geological Survey, comparisons will be made of radioisotope concentrations and the abundance and distribution of accessory minerals in the plutons encountered in the Huntington Lake, Yosemite, and Florence Lake traverses. Autoradiographic methods will be used to establish the accessory minerals responsible for radioactivity. Accumulation and evaluation of this information will be an important step toward understanding the sources and distribution of radiogenic heat in the batholith.

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Table 1. Radioactivity and Radiogenic Heat Values of Sierra Nevada plutons.

Site No.*	Description	Field Counting Rate, counts/sec	Uranium		Thorium		Potassium		Total Heat $cal/g\text{-}10^6 y$	Th/U	Laboratory Counting Rate, counts/min-g
			ppm	Error‡	ppm	Error‡	%	Error‡			
A	Pyroxene quartz diorite (Kdg)	200	0.93	±0.15	1.66	±0.23	0.64	±0.02	1.2	1.79	0.30
27	Pyroxene quartz diorite (Kdg)	135	0.37	±0.18	0.55	±0.27	0.27	±0.02	0.4	1.49	0.12
4	Weathered granodiorite (Kdc)	580	3.77	±0.36	9.93	±0.53	1.96	±0.05	5.3	2.63	1.29
4	Fresh granodiorite (Kdc)		2.99	±0.43	13.2	±0.63	1.92	±0.05	5.3	4.40	1.35
5†	Granodiorite (Kdc)	440									
21	Weathered granodiorite (Kdc)	680	4.17	±0.29	11.3	±0.43	1.63	±0.04	5.7	2.71	1.36
21	Fresh granodiorite (Kdc)		4.37	±0.44	9.08	±0.69	1.74	±0.05	5.5	2.08	1.25
22	Weathered granodiorite (Kdc)	780	4.30	±0.43	19.9	±0.33	2.64	±0.05	7.8	4.63	1.98
22	Fresh granodiorite (Kdc)		6.45	±0.51	14.2	±0.71	2.26	±0.07	8.1	2.21	1.90
23	Weathered granodiorite (Kdc)	630	2.47	±0.26	13.8	±0.39	2.28	±0.03	5.2	5.58	1.38
24†	Granodiorite (Kdc)	600									
25	Foliated granodiorite (Kdc)	250	1.72	±0.21	4.90	±0.30	1.40	±0.03	2.7	2.84	0.69
26	Biotite granodiorite (Kdc)	380	2.25	±0.22	7.69	±0.33	1.93	±0.03	3.6	3.42	0.98
2	Biotite-hornblende granodiorite (Kkp)	980	7.04	±0.55	24.0	±0.74	2.78	±0.07	10.7	3.40	2.56
6†	Granodiorite (Kkp)	800									
7†	Granodiorite (Kkp)	780									
8†	Light granodiorite (Kmg)	950									

Table 1 (continued).

Site No.*	Description	Field Counting Rate counts/sec	Uranium ppm	Uranium Error	Thorium ppm	Thorium Error	Potassium %	Potassium Error	Total Heat cal/g-10^6y	Th/U	Laboratory Counting Rate, counts/min-g
9	Granodiorite (Kmg)	1000	6.46	±0.44	26.6	±0.65	2.96	±0.06	10.8	4.12	2.64
10	Porphyritic granodiorite (Kmg)	800	4.71	±0.51	20.4	±0.76	2.95	±0.07	8.3	4.33	2.12
11†	Granodiorite (Kmg)	750									
12	Weathered granodiorite (Kmg)	850	8.05	±0.54	24.2	±0.79	2.98	±0.07	11.5	3.01	2.72
12	Fresh granodiorite (Kmg)		8.18	±0.55	29.6	±0.82	3.05	±0.07	12.8	3.62	3.04
13†	Granodiorite (Kmg)	880									
14†	Hornblende granodiorite (Kmg)	880									
15	Mafic ("dark") granodiorite (Kmg)	850	9.48	±0.57	24.3	±0.82	2.46	±0.08	12.5	2.56	2.82
16†	Granodiorite (Kmg)	900									
17	Granodiorite (Kmg)	900	7.77	±0.59	21.3	±0.87	2.86	±0.08	10.8	2.74	2.52
18†	Granodiorite (Kmg)	880									
19†	Granodiorite (Kmg)	880									
20	Granodiorite (Kmg)	1030	8.59	±0.56	16.6	±0.83	2.57	±0.07	10.3	1.93	2.34
1	Weathered biotite-quartz monzonite (Kbv)	480	3.24	±0.49	13.57	±0.68	2.37	±0.07	5.7	4.18	1.48
1	Fresh biotite quartz monzonite (Kbv)		2.72	±0.36	12.52	±0.48	2.39	± 0.05	5.1	4.60	1.36
3	Weathered porphyritic quartz monzonite (Kbv)	850	9.30	±0.53	28.3	±0.79	3.16	±0.07	13.4	3.04	3.00
3	Fresh porphyritic quartz monzonite (Kbv)		4.06	±0.57	24.5	±0.85	3.17	±0.08	8.8	6.04	2.28

Table 1 (continued).

Description	Field Counting Rate, counts/sec	Uranium		Thorium		Potassium		Total Heat cal/g-10^6y	Th/U
		ppm	Error	ppm	Error	%	Error		
Average Values									
Dinkey Creek granodiorite (Kdc)	540	3.95	±0.12	12.8	±0.22	2.05	±0.02	6.0	3.24
Mt. Givens granodiorite (Kmg)	890	7.61	±0.20	23.3	±0.30	2.83	±0.03	11.0	3.06
Pyroxene quartz diorite (Kdg)	170	0.65	±0.12	1.10	±0.18	0.45	±0.01	0.8	2.44

* See location map, Fig. 1.

† No Specimen taken.

‡ The U and Th values are based on New Brunswick Laboratory, U.S.A.E.C. standard samples whose stated accuracy is within 1%. The K standard is chemically pure KCl. The errors listed in this table are only those due to the statistical nature of our gamma-ray spectrometer data.

Table 2. Heat Production in cal/g - 10^6 y

Rock type	by U	by Th	by K	Total
Granites (after McDonald)	2.9	2.0	0.8	5.7
Acidic igneous rocks (after McDonald)	3.0	2.6	0.9	6.5
Dinkey Creek granodiorite	2.9	2.6	0.6	6.1
Mt. Givens granodiorite	5.6	4.7	0.8	11.1

FIGURE LEGENDS

Fig. 1. Location map of the Huntington Lake area, showing site numbers (geology after Bateman et al. [1963].

Fig. 2. Frequency distribution of uranium in the samples.

Fig. 3. Frequency distribution of thorium in the samples.

Fig. 4. Frequency distribution of potassium in the samples.

Fig. 5. Combined thorium and uranium concentration versus laboratory counting rate.

Fig. 6. Potassium concentration versus laboratory counting rate.

Fig. 7. Radiogenic heat versus field counting rate.

Fig. 8. Combined thorium and uranium versus potassium concentration.

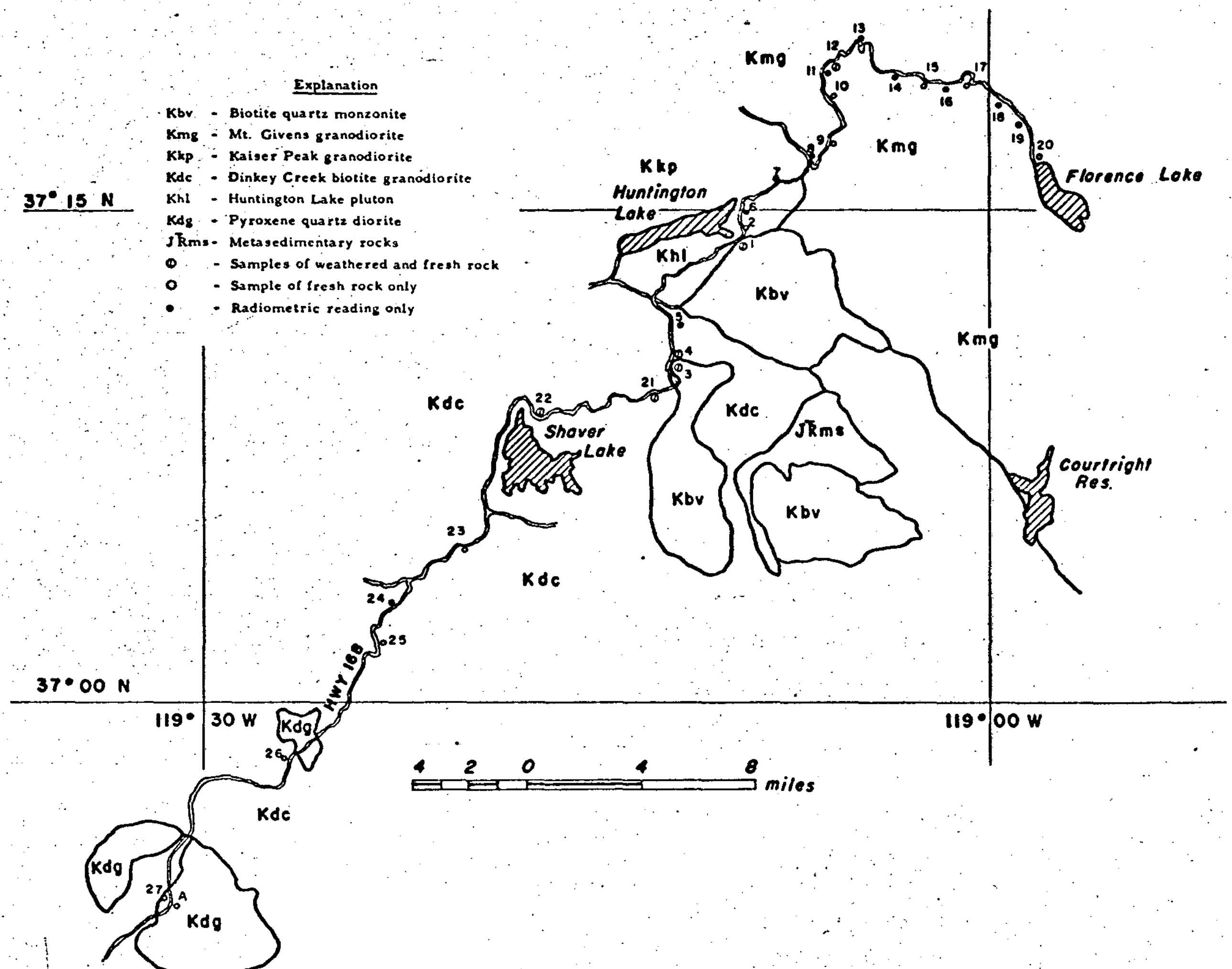

Fig. 1

MUB-2388

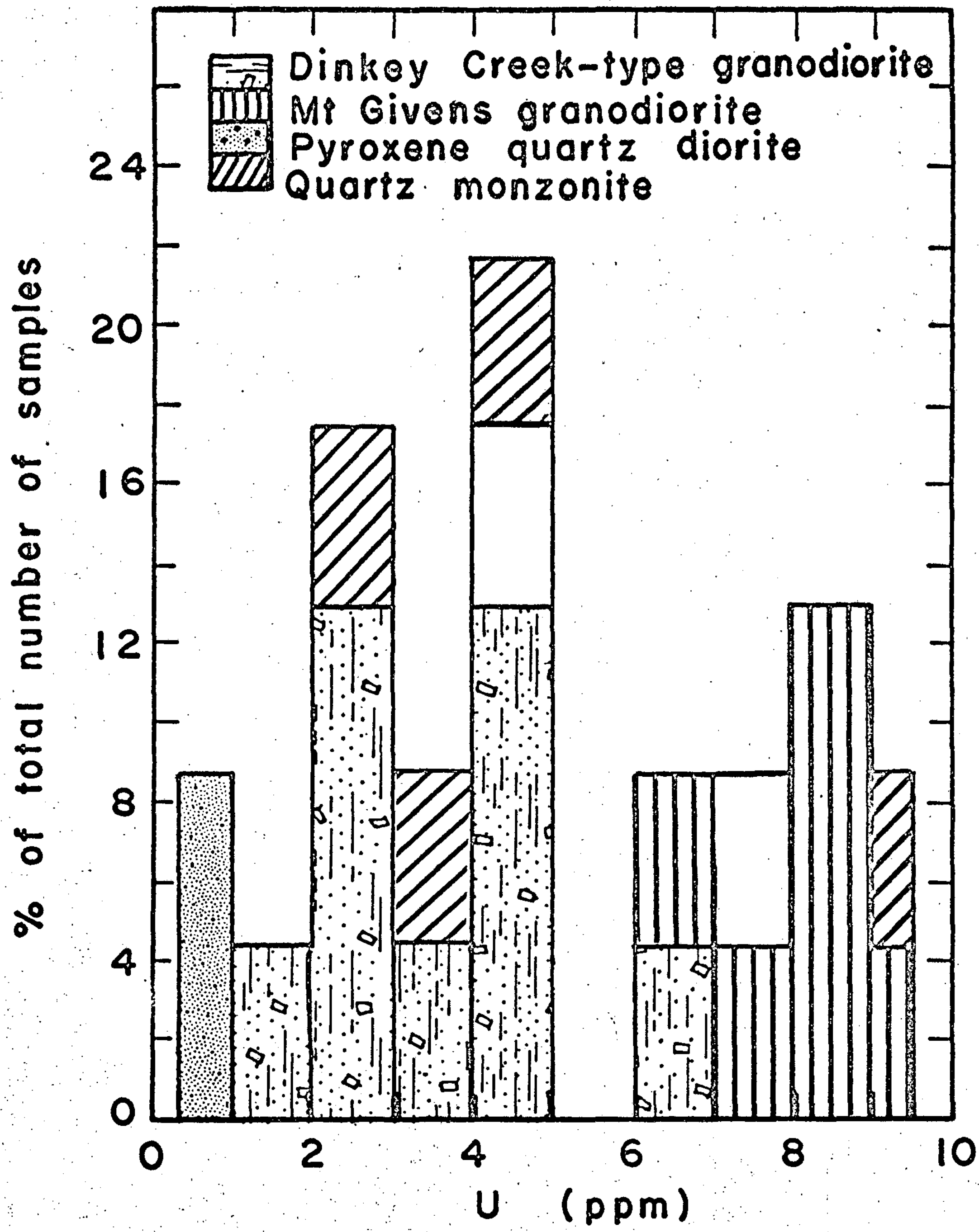

Fig. 2

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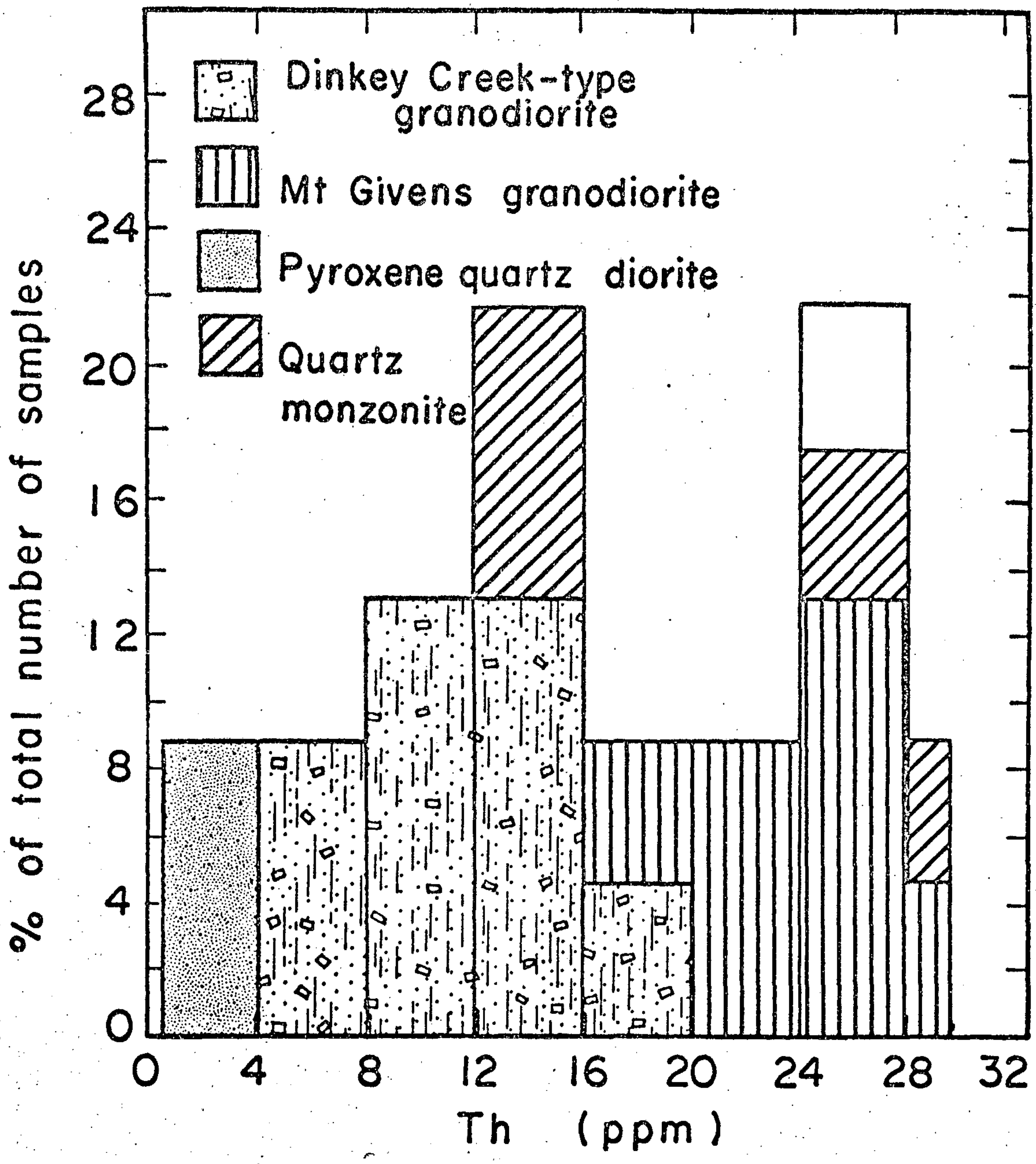

Fig. 3

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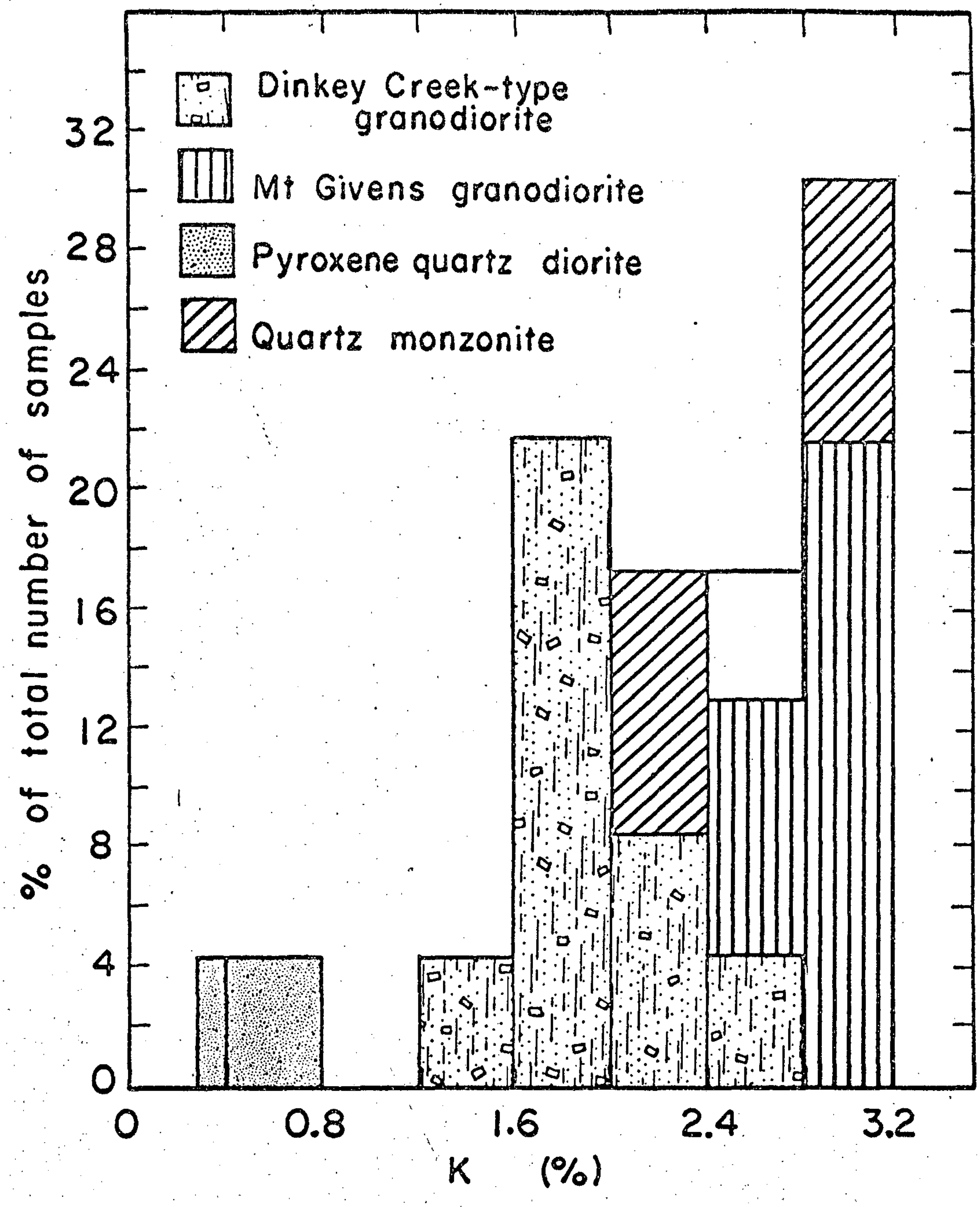

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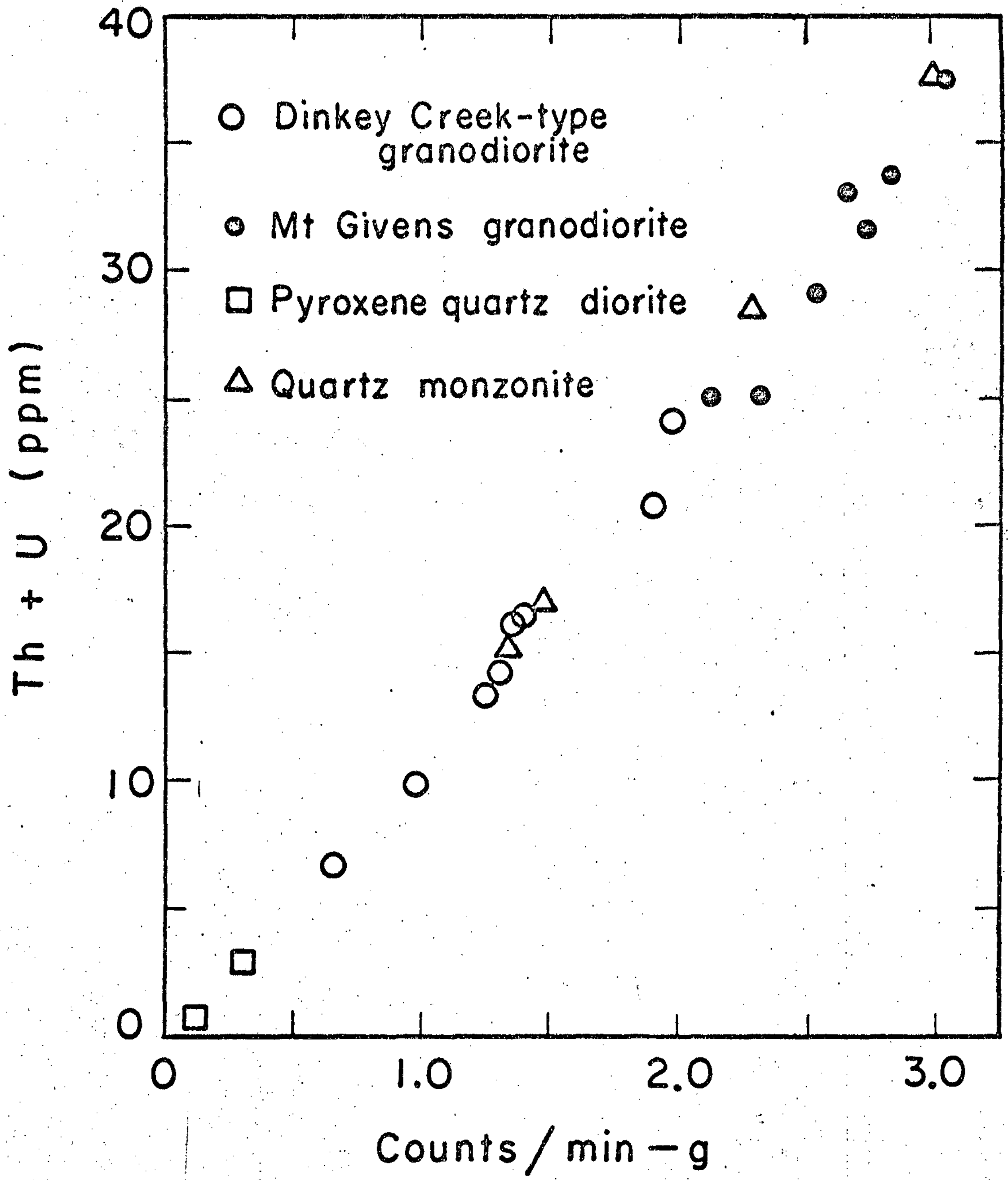

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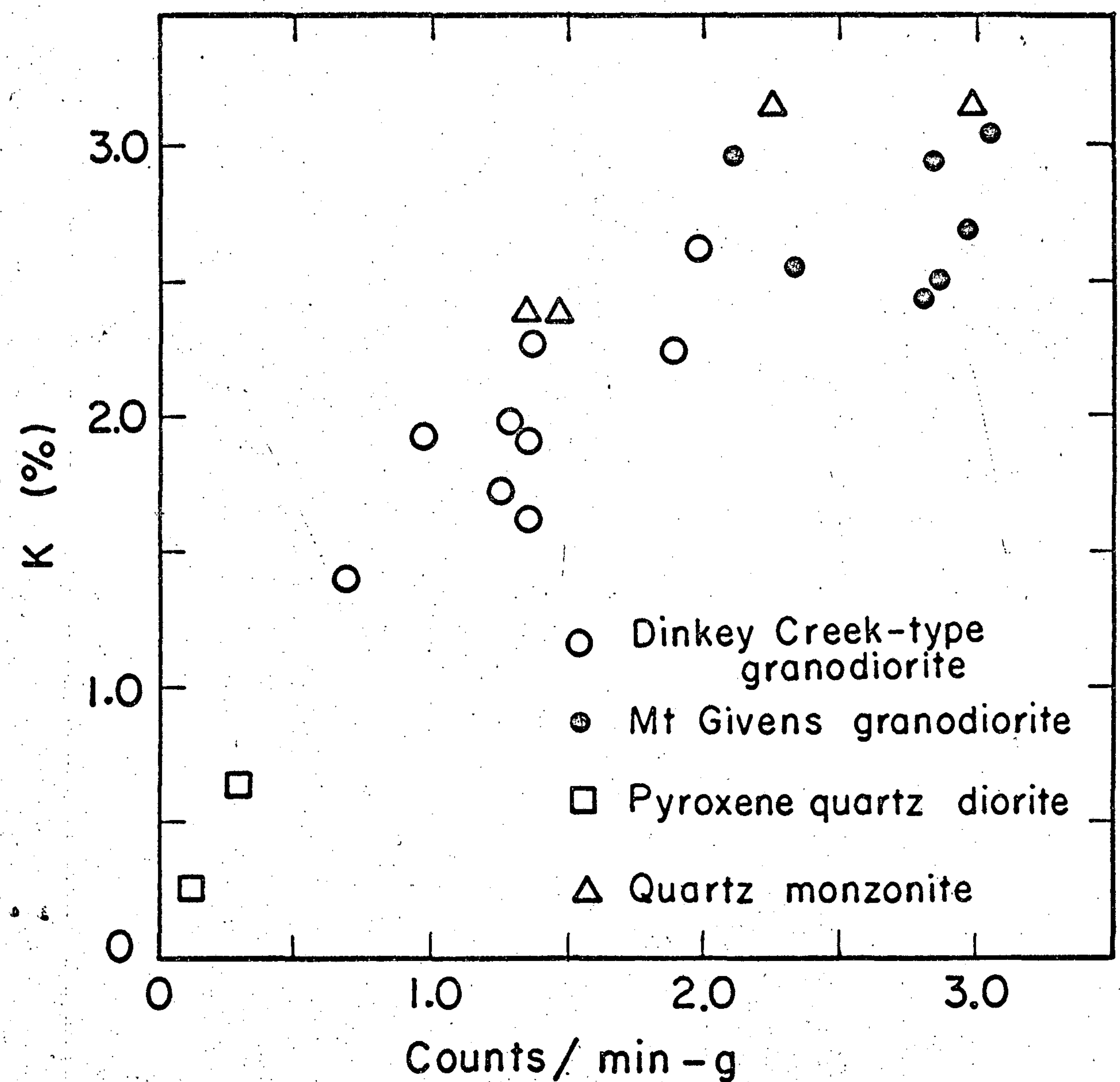

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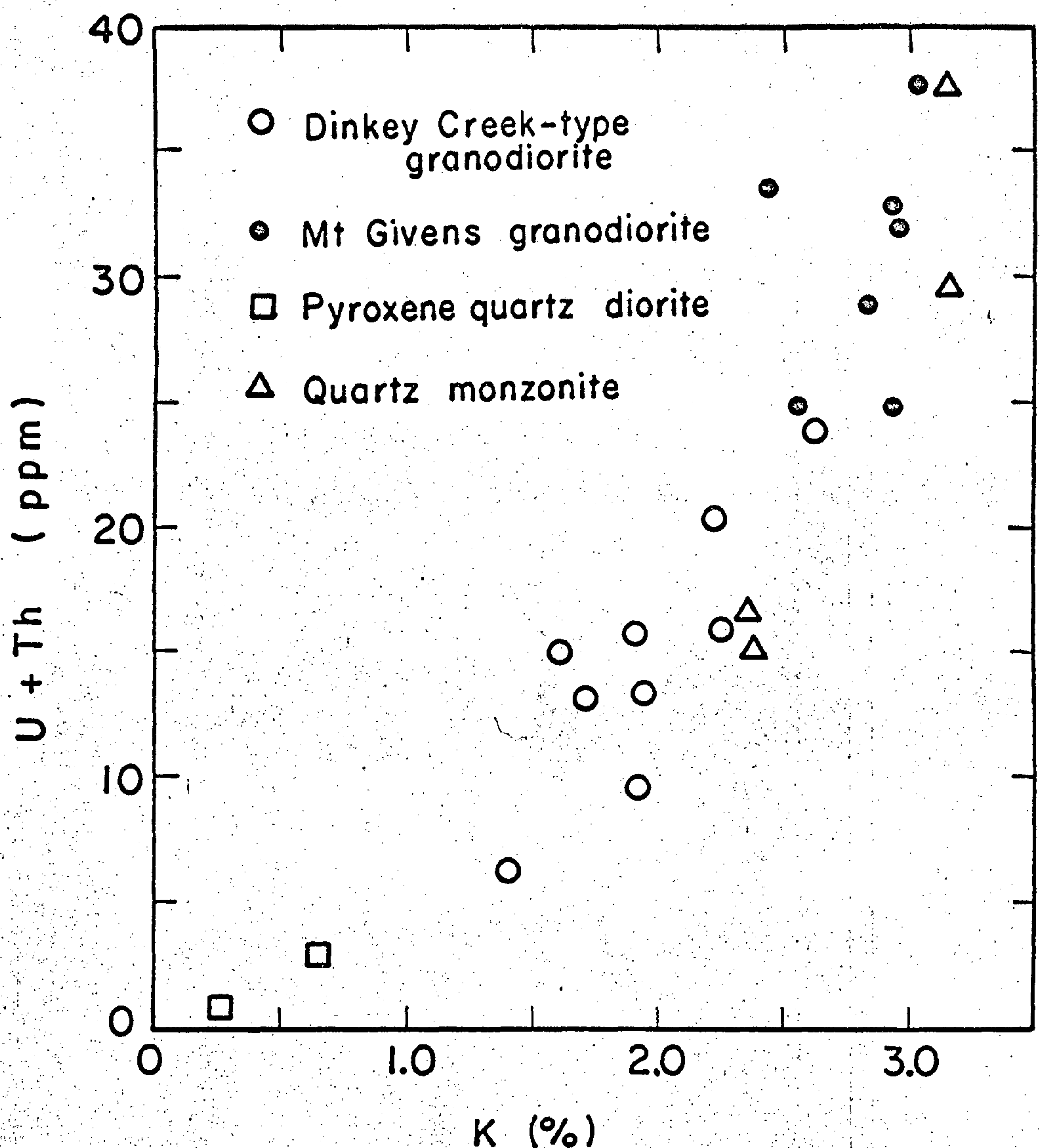

Fig. 7

MU-33359

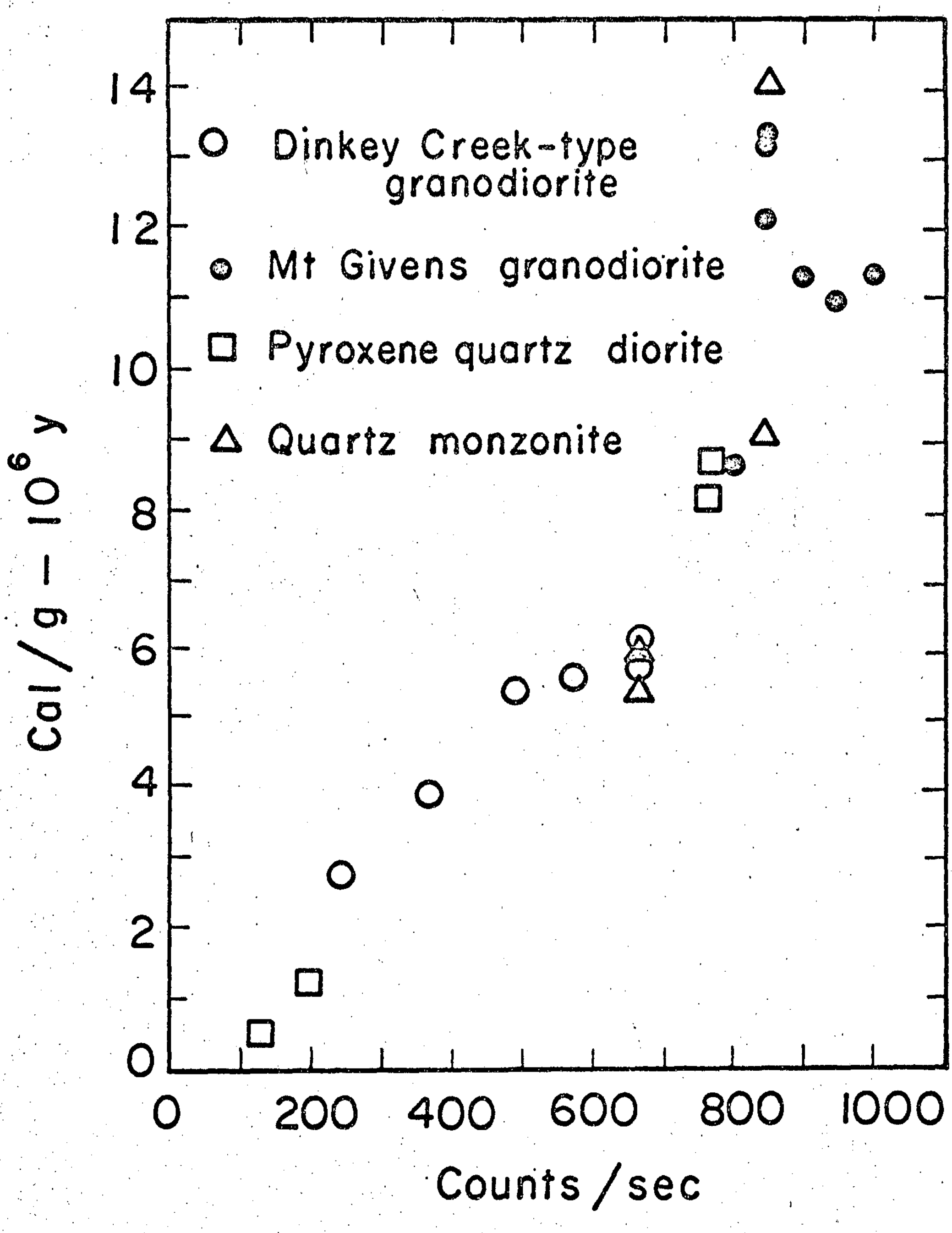

Fig. 8

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