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RADIOGENIC HEAT PRODUCTION IN PREBATHOLITHIC ROCKS OF THE CENTRAL SIERRA NEVADA

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ABSTRACT

Likely source material for the Sierra Nevada batholith is represented by exposures of Paleozoic rocks on the western flanks of the Sierra Nevada, Paleozoic sedimentary rocks in roof pendants east of the Sierran crest, and both Precambrian and Paleozoic rocks in the western portion of the Basin and Range province. The radiogenic heat production of these rocks has been calculated from γ-radiometric determinations of their U, Th, and K contents. The abundances of these radioisotopes in carbonate rocks are roughly an order of magnitude lower than those in adjacent siliceous sedimentary rocks; therefore, the radiogenic heat production in the Paleozoics depends mainly on the relative amounts of carbonate and siliceous material. Heat production varies from east to west, with weighted values (expressed in units of μcal/g-y) of 3.7 in Precambrian rocks of the Death Valley area, 3.5 in Paleozoics of the Inyo and White mountains, 3.8 in Paleozoic pendants, and 2.1 in rocks of the Calaveras formation on the western slope. A difference, similar to that in the Paleozoics, is observed between Mesozoic rocks exposed near the crest (4.4) and the Mesozoics of the western foothills (2.4). The geographic distribution of heat production

matches (though not proportionally) that in the batholithic rocks. This suggests that there was a regional distribution of radioactivity in likely source material for the granitic rocks which now, strongly accentuated by the effects of erosion, is reflected in the batholith.

INTRODUCTION

Sampling and radiometry of Sierra Nevada granitic rocks[1] have disclosed a distribution of U, Th, and K which causes a regional gradient of radioactivity on the western slope of the range, high values in the crestal regions, and moderate values on the east side. Generally, from the western margin eastward to the crest, there is a decrease in age and an increase in acidity and radioactivity. Converting radioactivity to heat production data and combining it with measurements of relatively low heat flow reported by Arthur Lachenbruch,[2] one can suggest for the western slope a layered model of a vertically fractionated batholith with younger rock of higher radioactivity in the upper parts. The low-radioactivity granitic rocks presently exposed on the western margin then would represent older, more deeply eroded material than rocks exposed closer to the crest. Lachenbruch[2] explains that the relatively high radioactivities found in the older plutons east of the present crest may be attributed to less erosion of these rocks than in the old granitic rocks of the western slope.

However, there is also the possibility that the general west-to-east increase in the granitic rocks' radioactivity reflects a similar regional change in composition in the batholith's parent material, most likely represented by the pregranitic rocks exposed on the flanks of the Sierra Nevada. A more basic consideration is whether there was enough radioactivity in the pregranitic rocks to furnish adequate heat (with help of heat from the mantle) to melt and mobilize them for batholithic work. In these respects we have sampled and analyzed for U, Th, and K some Precambrian, Paleozoic, and Mesozoic rocks that may

represent the parent material,[3] and have sampled and analyzed Mesozoic rocks that may represent a thermal blanket present during intrusion and differentiation of the magma.

Terranes examined are delineated on the map, Fig. 1, and are described in detail in references 4 through 10. They include the Precambrian of the Death Valley area, Paleozoic sediments of the Inyo and White mountains, Paleozoic sediments of the Bishop Creek, Mt. Morrison, and June Lake pendants, Paleozoic sediments and volcanics of the Calaveras formation of the western foothills, Mesozoic sediments and volcanics primarily of the Mt. Goddard pendant, and Mesozoic sediments and volcanics of the western foothills. With the exception of the pendants, which are predominantly thermally metamorphosed, the Paleozoic rocks have undergone slight to moderate regional metamorphism. Original textures of clastic sediments are quite evident in the slightly metamorphosed rocks of the Inyo and White mountains, while slates and phyllites are abundant in the more heavily metamorphosed Calaveras formation.

DISCUSSION OF DATA

The concentration of radioelements depends closely upon rock type. This is illustrated in the histograms on Fig. 2. In Paleozoic units where carbonate rocks are present, their abundances of U, Th, and K average an order of magnitude lower than those in adjacent clastics; therefore, the radiogenic heat production in the Paleozoics depends mainly on the relative amounts of carbonate and siliceous material. The volcanic components of the Mesozoic rocks and the Calaveras formation, considerably lower in radioactivity than adjacent clastics, also are important factors in the combined heat production of these units.

The heat production of the geographical groups was calculated from radioelement contents of individual units weighted by their stratigraphic thicknesses. These results are summarized on Table 1. Here we also see the influence of the volcanic rocks on the low combined heat production of the western slope's Mesozoic rocks and the Calaveras formation. The generally felsic volcanics of the Mt. Goddard pendant are over three times as radioactive as the more mafic volcanics in the foothills' Mesozoics. Combined with the effects of the higher activity clastics in the Mt. Goddard Pendant, the volcanics influence an east-to-west radioactivity gradient in the Mesozoic rocks.

It is interesting to compare radioelement ratios in the pregranitic and batholithic rocks. The ternary diagrams in Fig. 3 show the relationships between U, Th, and K [normalized to U(ppm)+Th(ppm)+K(%)= 1] in the granitic rocks. Compare these with Fig. 4, where similar diagrams are shown for the old rocks. Here we see the fairly close groupings of points favoring Th in the siliceous units, and the broad range of Th/U ratios in the carbonates. With the exception of the Paleozoic pendants, the combined average Th/U ratios of the various pregranitic units, shown in Table 1, are similar to those ratios found in the batholith's plutons.[1] When we consider granitic and pregranitic rocks from the same regions, we observe that the combined Th/U ratio (3.8) of the Paleozoics of the Inyo and White mountains matches closely the average of ratios in the Tinemaha granodiorite and the granodiorite of Santa Rita Flat (4.0), old units (150 m. y.) that are probably of the same pluton. The average Th/U ratio of the Calaveras formation (3.3) corresponds to a ratio of 3.2 in granitic rocks from the same region

averaged from the granodiorite of Dinkey Creek, "San Joaquin" granitic unit,[1] Sherman Thomas heat-flow hole core,[2] and quartz diorites of the western foothills. In the regional groupings of rock types, the abundance of U with respect to Th in some of the carbonate units is compensated by the siliceous units, where Th predominates strongly. The "excess" U in the pendants was perhaps obtained by contamination from the intruding magma. A careful sampling from granitic rock across a contact into a pendant may substantiate this.

Profiles of heat production in the granitic and Precambrian to Paleozoic rocks are shown on Fig. 5 with Paul Bateman's[3] cross section of the present day Sierra Nevada. We see that in the granitic rocks the heat production varies by a factor of 4.5 from the crestal region to the western edge of the range, while the heat production in the Paleozoic and Mesozoic rocks varies by 1.8 in the same region. There is about twice as much heat production in the granitics exposed in the eastern Sierra Nevada region as in the Paleozoic and Mesozoic rocks of that region; the granitics exposed and drill-sampled on the western edge of the range have about the same heat production as the pregranitic rocks in that area. The pronounced regional gradient of heat production in the granitics is matched less sharply by a gradient in the old rocks. Lachenbruch[2] demonstrates that the gradient observed from surface samples in the granitics can be explained by differential erosion. However, if we assume that the pregranitic rocks represent the source material for the granitics and that there was slight lateral mixing as magma was generated, we should expect that at horizons in the batholith parallel to a surface which predated any erosion, an east-west profile of heat production

comparable to that in the old rocks would be preserved.

CONCLUSION

We have described the heat production of the pregranitic rocks and have shown that there are similarities in radioelement content between them and the granitic rocks, and that there are comparable regional variations in radioactivity. The question remains whether old rocks that produce 3 μcal/g-y, piled to an appropriate thickness, can contribute enough heat to melt and granitize lower crustal material. It appears so. Prior to our sampling of the pregranitic rocks, Arthur Lachenbruch has calculated[11] that in 100 to 150 million years a pile composed of 30 to 40 km of Mesozoic, Paleozoic, and Precambrian material which produces of the order of 2 μcal/g-y overlying a 30-km-thick crust that produces 3 μcal/g-y, and with a normal heat flow of 0.3 μcal/cm^2-sec from the mantle, would have a basal temperature of 800 to 900 degrees. This would be sufficient to cause melting at the 15-kb pressures and to begin to redistribute heat sources by differentiation. Luth et al.[12] demonstrate from their study of the granite system at high pressures, that at pressures (P_{H_2O}) above 5 kb, melting begins at temperatures of 625 to 650 degrees. Therefore, at depths equivalent to 15 kb, temperatures of 800 to 900 degrees are more than sufficient to cause melting and to begin to redistribute sources by differentiation. Furthermore, a heat value somewhat greater than 3 which we measure today in the exposed pregranitics should have caused temperatures 70 to 100 degrees higher at the base. This means that a pile of Paleozoic and Precambrian rocks and Precambrian crust, with an overlying thermal blanket of Mesozoic rocks, in an aggregate thickness of the order of the

present-day root depth of the batholith could generate enough heat at the base of the crust to cause melting and subsequent differentiation. Then it seems reasonable to assume that a regional variation in radioactivity in the pregranitics would be present today in the batholith, upon which the profound effects of erosion are superimposed.

ACKNOWLEDGMENTS

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Table 1. Summary of radiometric data on pregranitic rocks

Unit	No. of Samples	Approx. abundance[a] %	U ppm	Th ppm	K %	Heat μcal/g-y	Th/U
Precambrian of Death Valley area[b]							
carbonates	4	20	0.80	1.47	0.22	0.9	1.8
clastics	6	80	2.25	10.8	2.14	4.4	4.8
weighted average			1.96	8.93	1.76	3.7	4.6
Paleozonic of Inyo and White Mts.[c]							
carbonates	23	45	0.87	1.99	0.41	1.1	2.3
clastics	16	55	3.13	13.2	2.21	5.5	4.2
weighted average			2.11	8.15	1.40	3.5	3.9
Paleozoic pendants[d]							
carbonates	6	20	1.23	1.20	0.24	1.2	0.98
clastics	14	80	4.04	6.06	1.42	4.5	1.5
weighted average			3.48	5.09	1.18	3.8	1.4
Calaveras Formation							
carbonates	8	15	0.53	0.24	0.03	0.4	0.45
clastics	8	60	1.92	6.96	1.53	3.2	3.6
volcanics	3	25	0.45	0.98	0.14	0.6	2.2
weighted average			1.34	4.46	0.96	2.1	3.3
Mesozoic pendants[e]							
clastics	3	20	3.81	10.1	2.23	5.4	2.7
volcanics	4	80	2.70	7.61	2.14	4.1	2.8
weighted average			2.92	8.11	2.16	4.4	2.8
Mesozoic of Western Slope[f]							
clastics	10	45	2.31	8.09	1.65	3.8	3.5
volcanics	5	55	0.83	2.83	0.57	1.3	3.4
weighted average			1.50	5.20	1.06	2.4	3.5

a. Abundances are based on relative stratigraphic thicknesses of lithologic units where available in the cited references; otherwise, relative thicknesses are estimated from cross sections and width of outcrop on maps cited above.

b. Includes Archean, Pahrump series, undivided metamorphics, and Cambrian-Precambrian marine as delineated on Ref. 4.

c. Includes Reward Conglomerate, Keeler Canyon, Rest Spring Shale, Perdido, Vaughan Gulch, Sunday Canyon, Johnson Spring, Barrel Spring, Badger Flat Limestone, Al Rose, Tamarack Canyon Dolomite, Bonanza King Dolomite, Monola, Mule Spring Limestone, Saline Valley, Harkless, Poleta, Campito, Deep Spring, Reed Dolomite, and Wyman formations as delineated on Ref. 5, the geologic map of the Bishop Quadrangle in Ref. 6, and the geologic map of the Independence Quadrangle in Ref. 7.

d. Includes Paleozoic sedimentary units shown on the geologic map of the Mt. Morrison Quadrangle in Ref. 8 and Paleozoic sedimentary units delineated on geologic maps of the Bishop, Mt. Tom, and Mt. Goddard Quadrangles in Ref. 6.

e. Includes six samples from the Mt. Goddard pendant and one sample of metavolcanic rock from the Ritter Range pendant.

f. Includes Jurassic rocks of the Amador group, and the Peñon Blanco, Mariposa, Gopher Ridge, Salt Springs, Merced Falls, and Copper Hill formations, described in Ref. 9, and undifferentiated Precretaceous metamorphic rocks and Precretaceous metasedimentary rocks as delineated and described in Ref. 10.

FIGURE CAPTIONS

Fig. 1. Portion of California between 36° and 39° N, showing major lithologic units of the Sierra Nevada and Great Basin provinces. (Geologic base from U. S. Geological Survey Map I-512).

Fig. 2. Histograms of radioelement concentration and radiogenic heat production in the pregranitic rocks.

Fig. 3. Ternary diagrams of the radioisotope fractions of Sierra Nevada plutons. The radioisotope fraction is based on the normalization U (ppm) + Th (ppm) + K(%) = 1, and represents the relative abundance of each radioelement with respect to the other radioelements.

Fig. 4. Radioisotope fractions of the Premesozoic rock units.

Fig. 5. Profiles of averaged radiogenic heat production in the granitic and pregranitic rocks, shown with Bateman's[3] cross section of the present-day Sierra Nevada. The numbered points for granitic rocks are (1) Granodiorite of Santa Rita flat, (2) Tinemaha and Inconsolable granodiorites, (3) Tunsten Hills quartz monzonite and Cathedral Peak-type granite, (4) Mount Givens and Lamarck granodiorites and Half Dome quartz monzonite, (5) Sentinel granodiorite, (6) El Capitan granodiorite and eastern exposures of Dinkey Creek-type granodiorite, (7) Western exposures of Dinkey Creek-type granodiorite, (8) "San Joaquin unit" of western foothills, (9) Quartz diorite and diorite, and (10) Gneissose quartz diorite of the Sherman Thomas drill core.

The points for pregranitic rocks are (1) Precambrian rocks of the Death Valley area, (2) Paleozoic rocks of the Inyo and White mountains, (3) Paleozoic pendants, (4) Mesozoic pendants, (5) Calaveras formation, and (6) Mesozoic rocks of the western foothills.

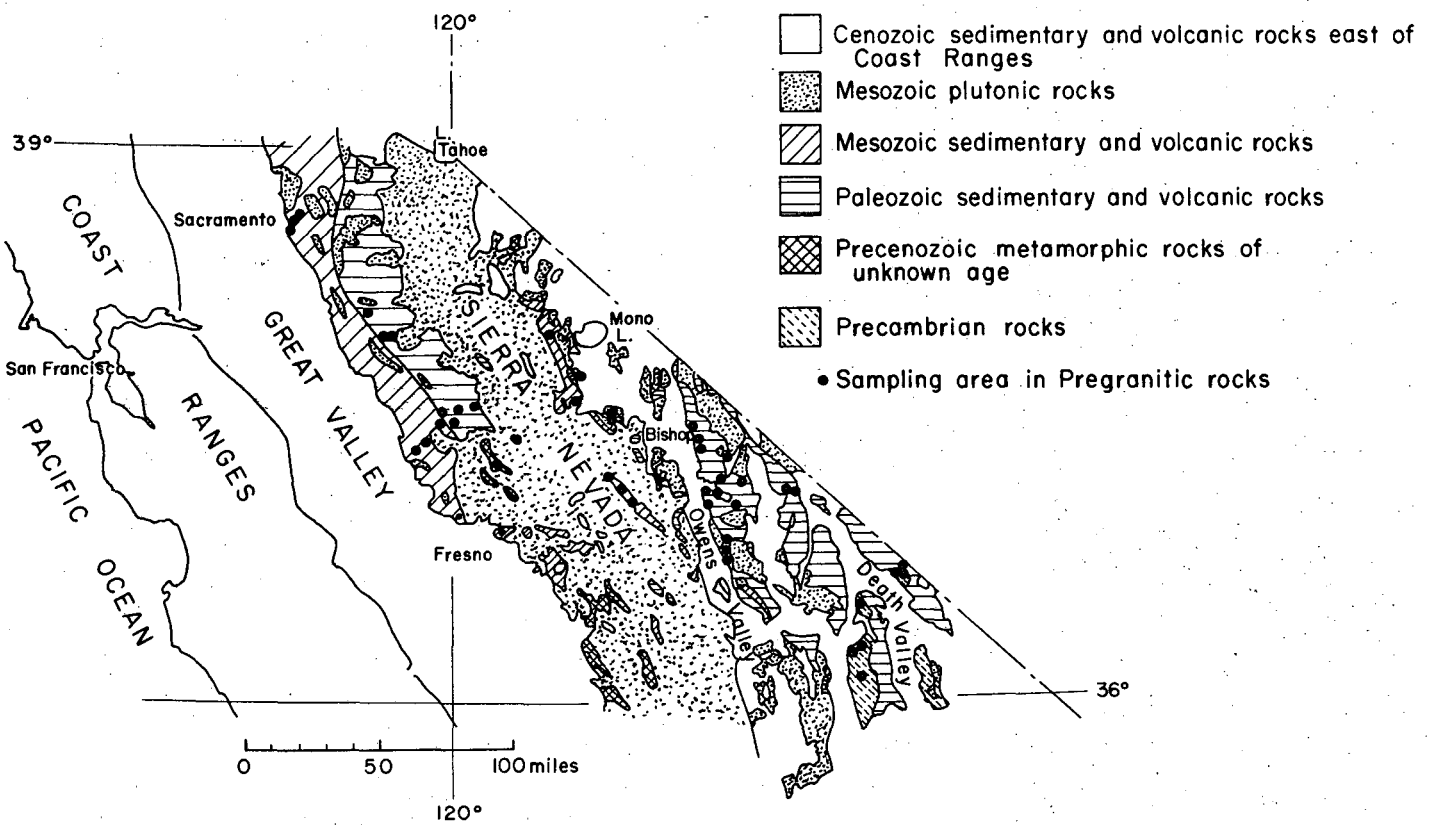

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Fig. 1

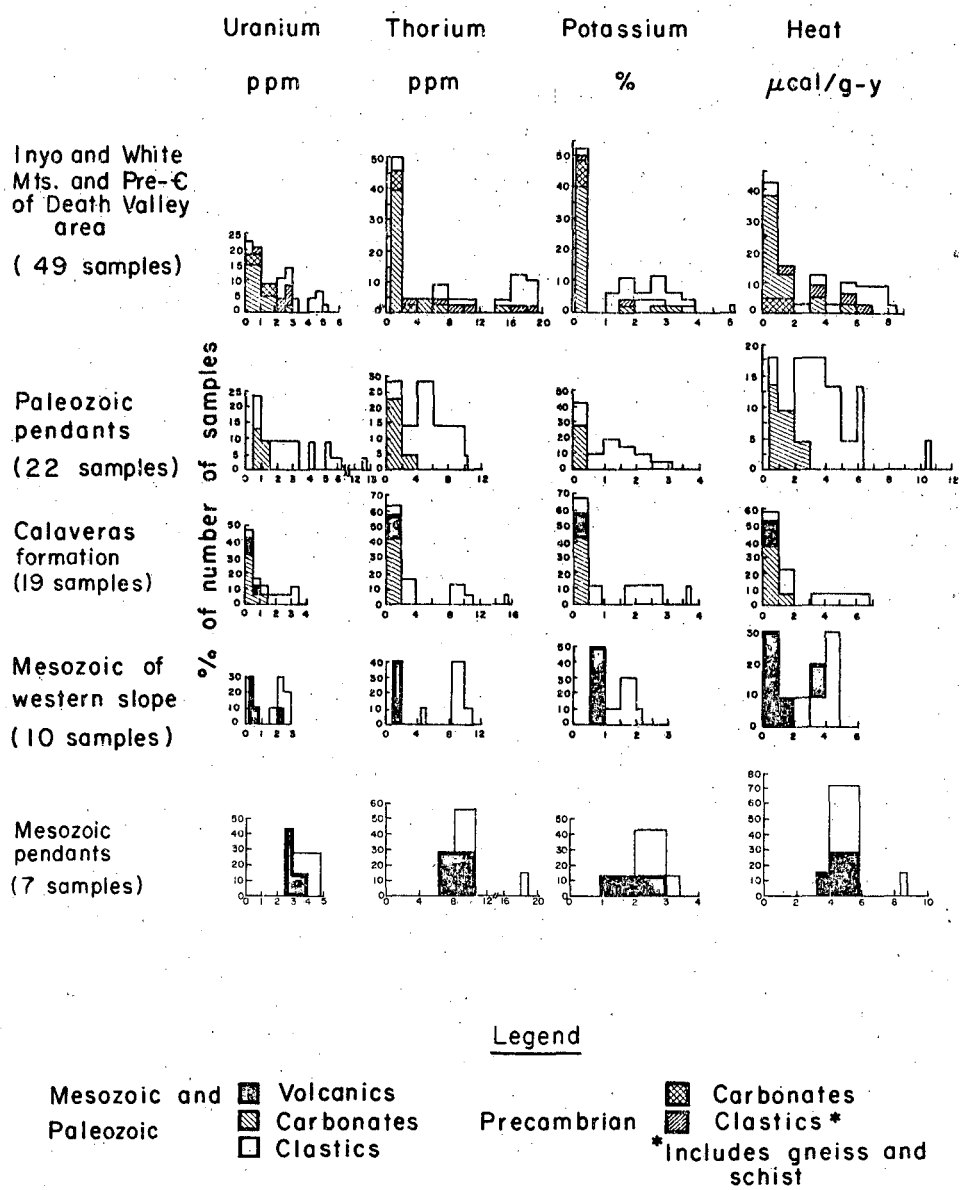

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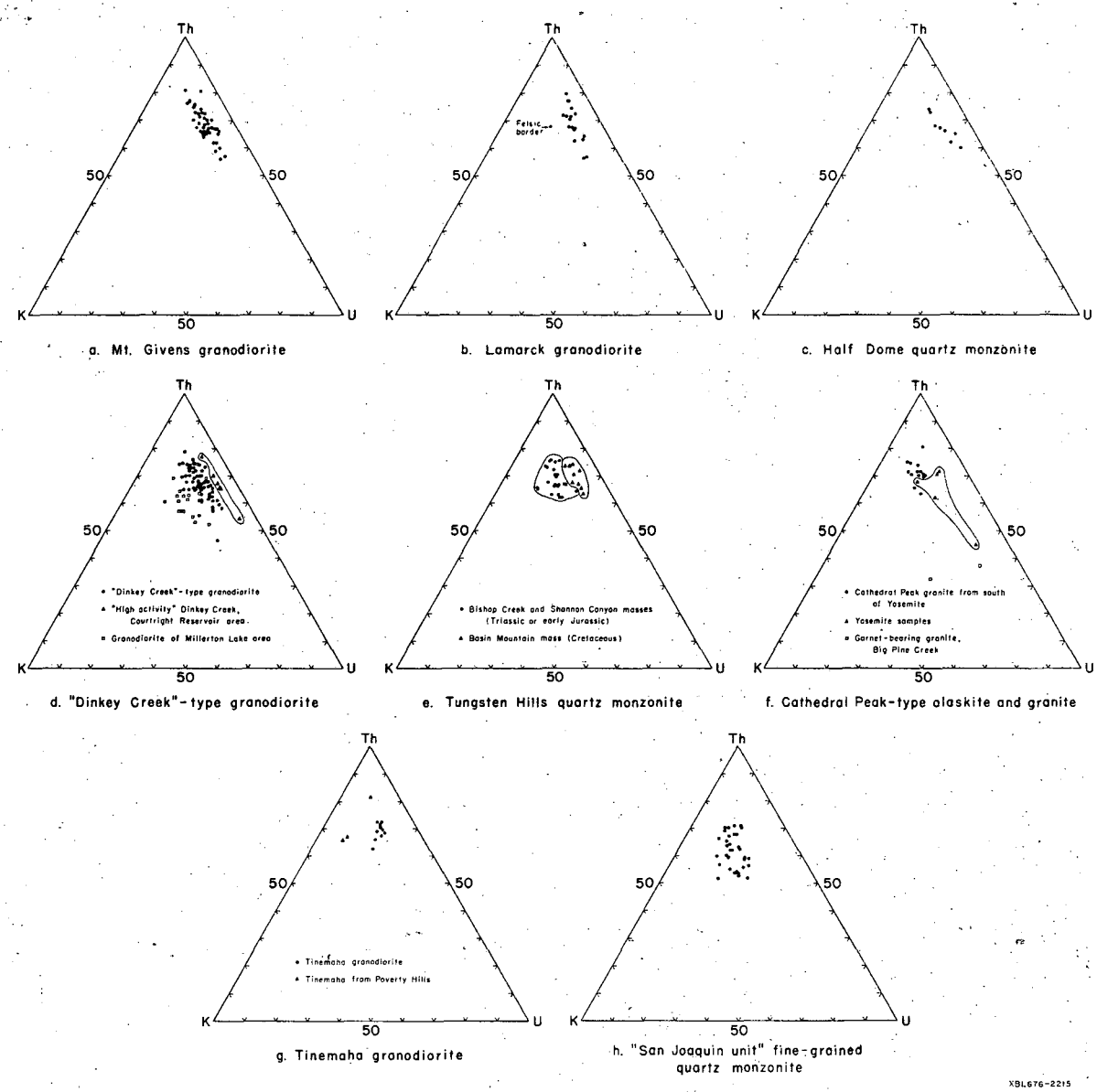
Fig. 2



a. Mt. Givens granodiorite

b. Lamarck granodiorite

c. Half Dome quartz monzonite

d. "Dinkey Creek"-type granodiorite

e. Tungsten Hills quartz monzonite

f. Cathedral Peak-type alaskite and granite

g. Tinemaha granodiorite

h. "San Joaquin unit" fine-grained quartz monzonite

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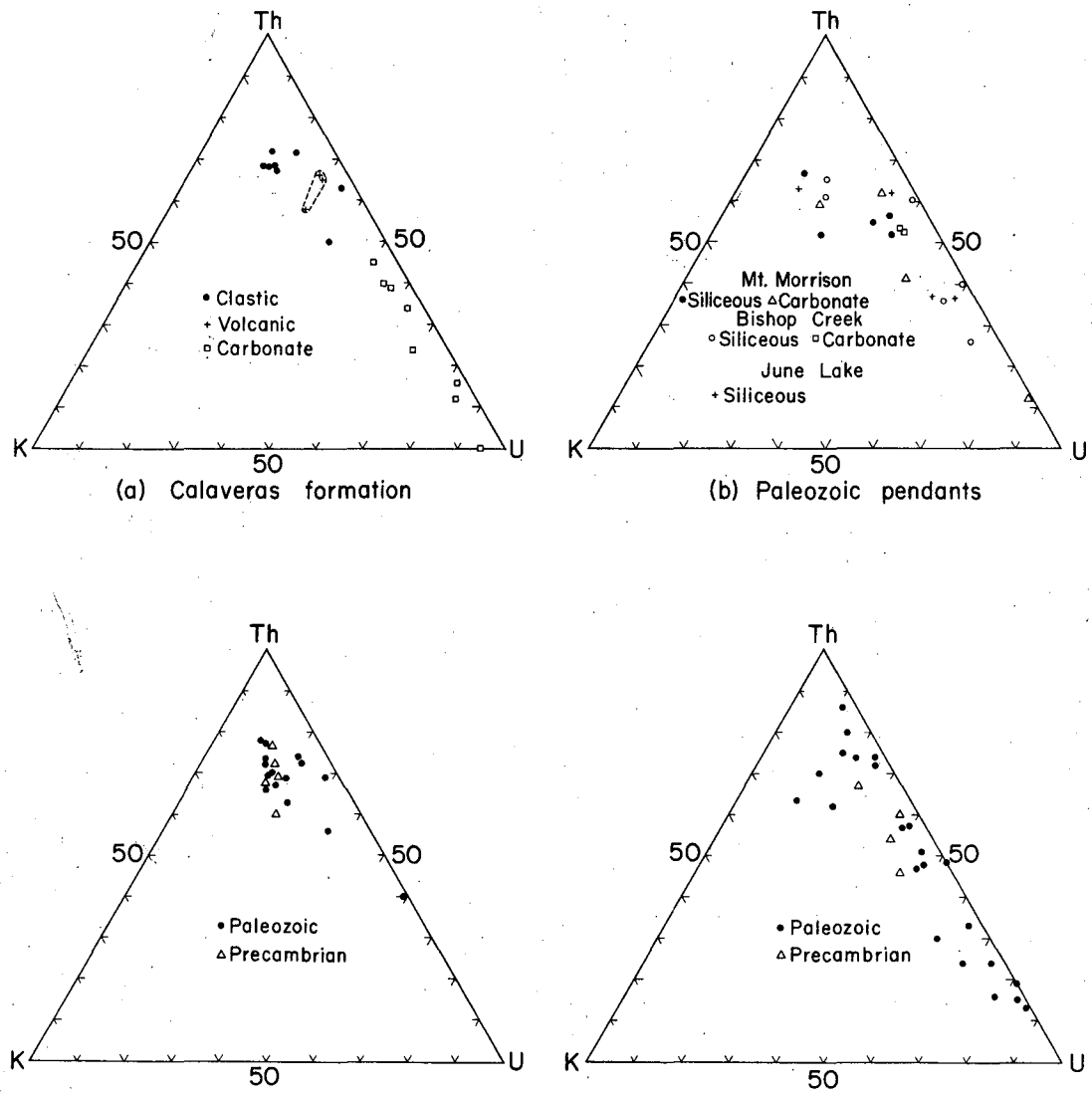
Fig. 3



(a) Calaveras formation

(b) Paleozoic pendants

(c) Siliceous rocks of Inyo and White Mts. and Death Valley area

(d) Carbonate rocks of Inyo and White Mts. and Death Valley area

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Fig. 4

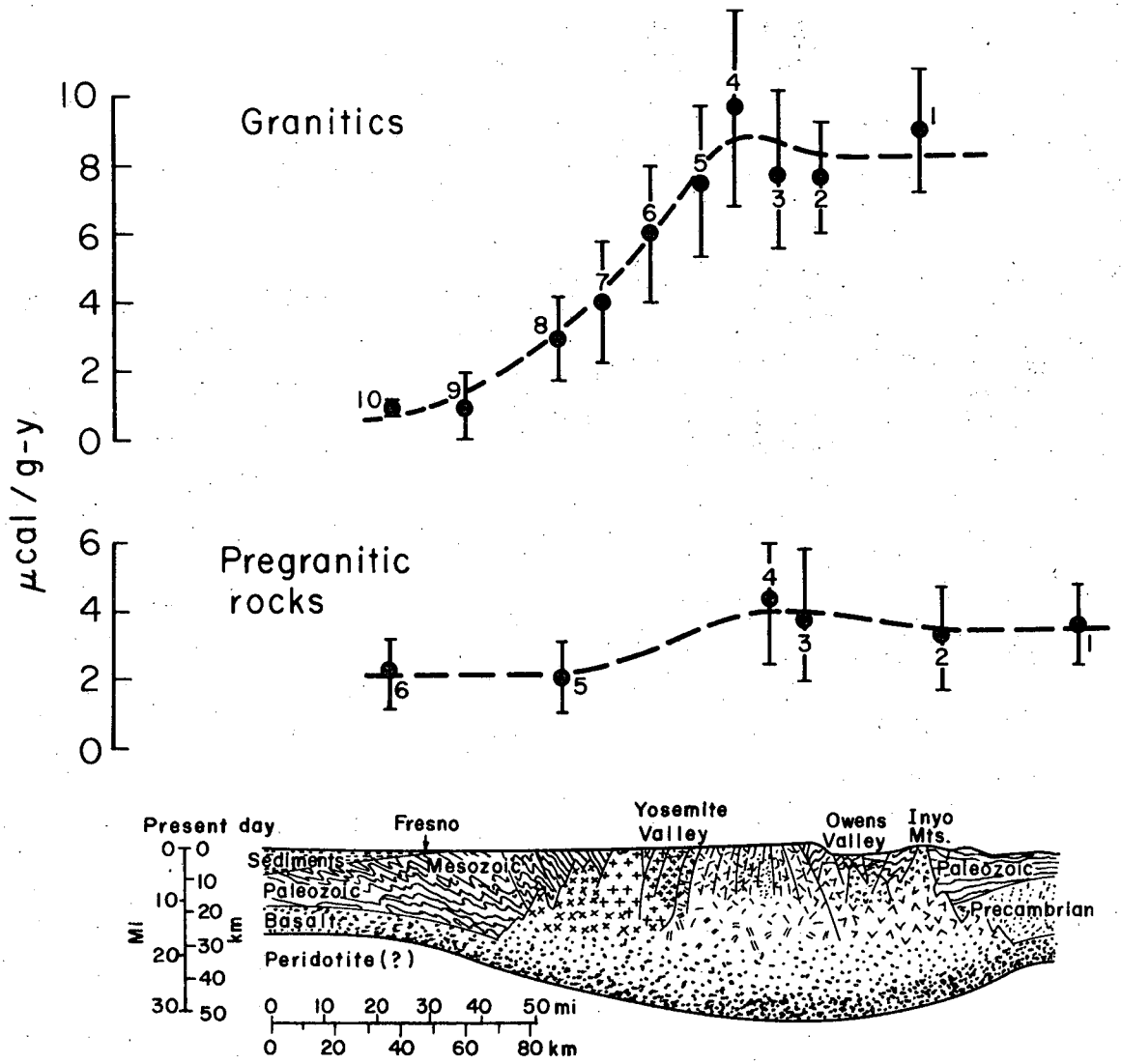

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Fig. 5

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