UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

# RADIOELEMENT CONCENTRATIONS AND PRELIMINARY RADIOMETRIC AGES OF ROCKS OF THE KIGLUAIK MOUNTAINS, SEWARD PENINSULA, ALASKA

by

Carl M. Bunker, Carl E. Hedge, and C. L. Sainsbury

Open-File Report 77-735
1977

This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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# RADIOELEMENT CONCENTRATIONS AND PRELIMINARY RADIOMETRIC AGES OF ROCKS OF THE KIGLUAIK MOUNTAINS, SEWARD PENINSULA, ALASKA

By Carl M. Bunker, Carl E. Hedge, and C. L. Sainsbury[1]


## ABSTRACT

A sequence of old metamorphic rocks including the Kigluaik and Nome Groups is exposed in the Kigluaik Mountains of the Seward Peninsula. The high-grade metasedimentary rocks give a whole-rock Rb-Sr age of 735 m.y. This late Precambrian age is believed to be the time of metamorphism. Orthogneisses, intrusive into the metasedimentary rocks, are probably also Precambrian in age; but many samples have had their ages disturbed by Cretaceous intrusions and thrusting.

Samples of Precambrian metagabbro are low in radioelements (U, Th, and K) typical of basalitc rocks. The Precambrian metasedimentary rocks have normal radioelement concentrations, but both the Precambrian orthogneisses and the Cretaceous granitic rocks are unusually rich in thorium.


1/ Present address: AirSamplex Corporation, P.O. Box 477, Indian Hills, Colorado 80454

# INTRODUCTION

The existence of rocks of Precambrian age on the Seward Peninsula, Alaska, has been a matter of lively argument. The rocks discussed herein were suspected by Moffit (1913) to be of Precambrian(?) age, but were subsequently shown on later maps as being of Paleozoic(?) age (Hummel, 1962; Patton, 1967). After several years of mapping on the Seward Peninsula, Sainsbury (1969a) demonstrated that fossiliferous limestones of Early Ordovician age on the western Seward Peninsula were underlain by an older, unfossiliferous limestone that graded downward into slates and phyllites of possible Precambrian age, but which using stratigraphic evidence, could be proven only to be pre-Ordovician. As mapping progressed eastward into the area of this report, the Precambrian age of the rocks seemed almost certain. However, the recognition that the rocks of the Seward Peninsula were involved in widespread thrusting, with both regional dynamic metamorphism and younger thermal metamorphism impressed upon the thrust plates, made dating of the rocks by stratigraphic position and metamorphic rank impossible. Nevertheless, the stratigraphic evidence gathered in the western Seward Peninsula was sufficient to warrant an assignment of Precambrian age to most of the rocks older than the Lower Ordovician limestones.

This study was initiated in an attempt to verify the Precambrian age assignment of certain units and to determine the radioelement characteristics of various suites of metamorphosed rocks. Results of the study are that a Precambrian age has been verified for gneisses in the Kigluaik Mountains and certain units have radioelement "signatures" which can be used for making correlations.

Although the preliminary work was published several years ago, (Sainsbury, Hedge, and Bunker, 1970; Sainsbury, Coleman, and Kachadoorian, 1970), recent maps of the Seward Peninsula still show the bulk of the rocks to be of Paleozoic age (Clark and others, 1972). Since the initial work, more collections of rocks have been dated and analyzed for radioelement content. Because such data are totally lacking for Alaskan rocks, it was considered important to present the data that have been collected so that other workers will have a basis for comparing Alaskan rocks with those studied elsewhere.

The Kigluaik Mountains were chosen for this study for the following reasons: A large variety of rock types ranging in age from Precambrian to Cretaceous are well exposed in a relatively small area. Elsewhere in the Seward Peninsula much of the land surface is covered by tundra, outcrops of similar rocks are isolated, and stratigraphic relationships are less evident. Rocks exposed in the Kigluaiks are less weathered than other outcrops in much of the Seward Peninsula. Thin layers of visible alteration on the samples were common, but these were removed prior to analyses.

The Kigluaik Mountains are about 24 Km wide (north-south) and about 72 Km long within the area of 64°45'-65°05'N. latitude and 164°45'-166°15'W. longitude (fig. 1). The center of the mountain range is about 48 Km north of Nome. Much of the northern part of the range is delineated by an escarpment along the Kigluaik Fault; part of the southern boundary generally coincides with a group of lesser faults. This area includes parts of the Nome and Teller 1:250,000 Alaska Topographic Series maps.

Acknowledgments.--The geologic mapping of the region under study was the responsibility of Sainsbury, who was assisted ably at various times by Travis Hudson, Reuben Kachadoorian, T. W. Smith, Thomas R. Richards, Rodney Ewing, and William R. Marsh. Assignment of units and ages is the responsibility of Sainsbury. The rocks discussed herein were analyzed for radioelements by Bunker, who has guided the writing of the report; Charles A. Bush assisted with the analytical work. The age dating of the rocks by rubidium/strontium methods was done by Hedge, assisted by William T. Henderson, Robert A. Hildreth, and Willis P. Doering. Each of the authors of this report thereby assumes responsibility for his part of the report.

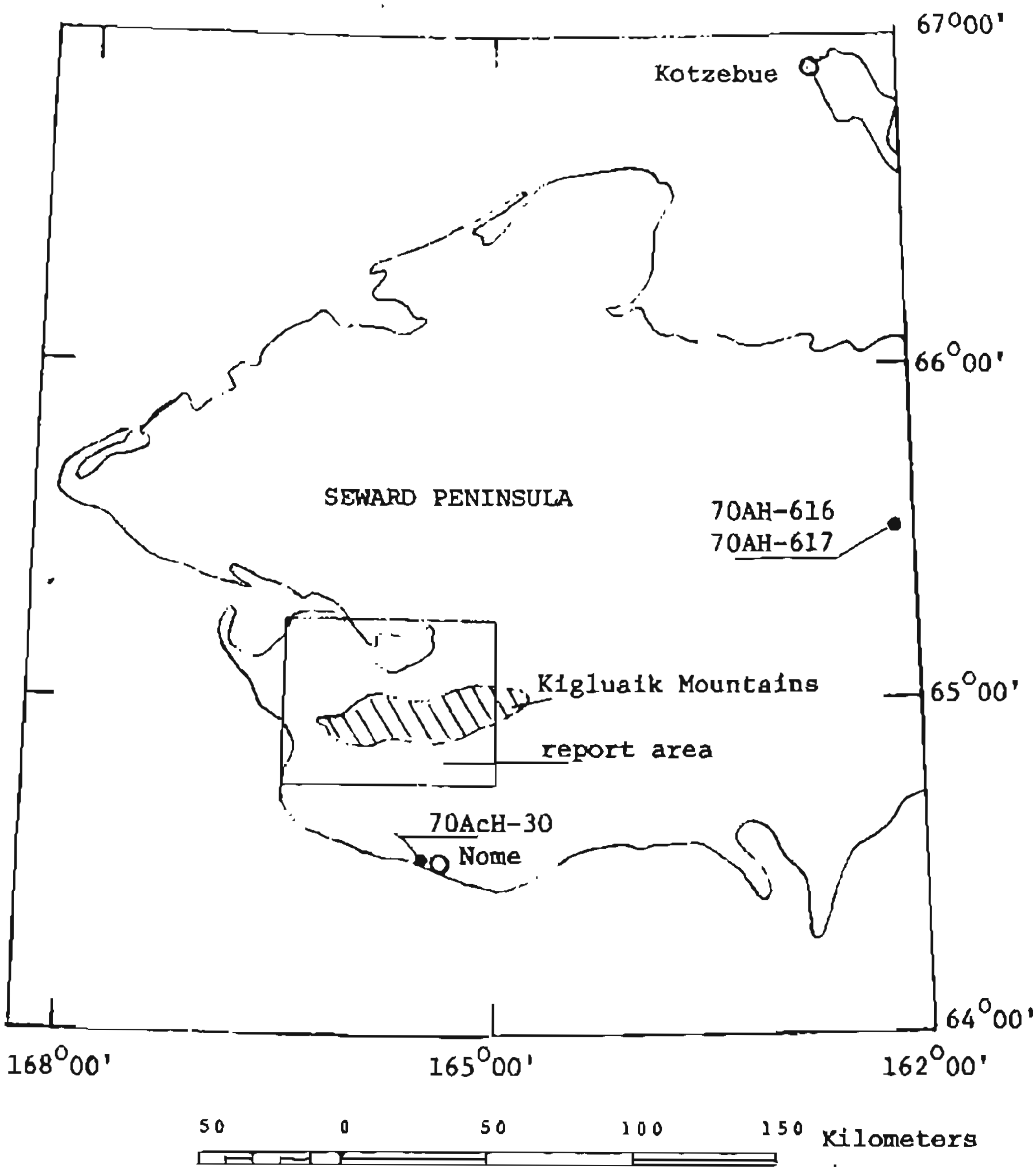


Figure 1. Index map of Seward Peninsula showing area of detailed study and locations of samples outside the area.

## GENERAL GEOLOGY

The general geology for that part of the area within the Teller 1:250,000 quadrangle has been described by Sainsbury (1972); for the general area of the Seward Peninsula, the geology was summarized by Sainsbury (1975) and by Sainsbury, Coleman, and Kachadoorian (1970) in the report in which arguments for the Precambrian age of the rocks were presented. Short texts were prepared by Sainsbury and his co-workers to accompany numerous published geologic maps (Sainsbury, 1969a, 1969b; Sainsbury, Kachadoorian, Hudson, and others, 1969; Sainsbury, Kachadoorian, and Smith, 1970; Sainsbury, Hummel, and Hudson, 1972; Sainsbury, 1972; Sainsbury, Smith, and Kachadoorian, 1972; and Sainsbury, 1974), and the rock units were described in some detail.

Briefly stated, the Seward Peninsula consists of a great number of thrust plates of Paleozoic carbonate rocks intimately intermixed tectonically with Precambrian rocks that consist of argillaceous and dolomitic limestone, the slate of the York region, and several types of chloritic schists, feldspathic-chloritic schists, and high-rank gneisses and schists predominantly of leucocratic composition. Whether the chloritic schists are all old volcanic rocks that were intercalated in the slate of the York region, or whether some are younger mafic rocks possibly intruded during the thrusting, is at yet unsettled. All the Paleozoic rocks dated by fossils on the west part of the Seward Peninsula are carbonate rocks; and the Ordovician, Silurian, Devonian, and Mississippian(?) Systems are dated by fossils. Unfossiliferous rocks of noncarbonate composition cannot be assigned to the Paleozoic, and, furthermore, whenever the slate of the York region is overlain by massive carbonate rocks without the intervening argillaceous and dolomitic limestone, the two units are separated by either a thrust fault or an unconformity.

Along the axes of the Kigluaik and Bendeleben Mountains, which trend eastward across the Seward Peninsula, high-rank gneisses, semi-gneisses, and schists are exposed; and these are intruded by numerous granitic intrusive rocks mostly of Cretaceous age. However, some gneissic intrusives of granitic composition have been mapped, and these may be of Precambrian age. Because the gneisses and intrusive rocks of the Kigluaik Mountains have been studied more extensively, the initial work of age dating and determining radioelement contents has been concentrated in this area, but data from elsewhere on the Seward Peninsula are included.

The complications introduced as a consequence of the intense tectonic deformation of the thrust belt, named the A. J. Collier thrust belt to honor a pioneer worker of the Seward Peninsula (Sainsbury, 1969b), are immense. Large-scale migration of material took place during thrusting, and the thermal metamorphism imprinted upon the dynamically metamorphosed rocks has been widespread. Nevertheless, the data that have been gathered substantially support the geologic interpretations made over the years. More importantly, the Precambrian age of most of the metamorphic rocks of noncarbonate composition is clearly established. Only by application of whole-rock Rb-Sr age dating was the correct age established, because dating of the high-rank schist by K/Ar methods yielded Cretaceous dates similar to the ages of the intrusive rocks.

The geology of the Kigluaik Mountains and the location of samples analyzed in this study are shown in figure 2. Three samples of orthogneiss, which were included in the Rb/Sr dating, are outside of this map area and are shown on figure 1.

The oldest rocks are the paragneisses of the Kigluaik Group. These rocks are well exposed in the Kigluaik Mountains. The dominant lithologies of the Kigluaik Group are plagioclase-orthoclase-biotite-hornblende gneiss and gneissic marble. These paragneisses are intruded by orthogneisses ranging in composition from granite to quartz monzonite.

EXPLANATION FOR FIGURE 2.

EXPLANATION

| | | |
|---|---|---|
| Qmo | Glacial deposits<br>Includes moraine and outwash | QUATERNARY |
| Kic | Igneous complex of Kigluaik Mts. Includes rocks ranging from granite to diorite, and numerous roof pendants of Kigluaik Group | CRETACEOUS |
| p€l | Argillaceous limestone | PRECAMBRIAN |
| p€g | Gabbro<br>Includes metagabbro and other highly altered mafic rocks | PRECAMBRIAN |
| p€s, p€sb | Slate and schist<br>p€s; slate, phyllite, and quartz siltite; minor black limestone<br>p€sb; graphite-bearing biotite schist, slate, and calc-silicate rocks. Believed to be metamorphosed equivalent of p€s, but may be an older unit. | PRECAMBRIAN |
| p€o | Orthogneiss<br>Derived from granites to quartz monzonites | PRECAMBRIAN |
| p€n | Nome Group<br>Chloritic schists, metavolcanics and thick marbles and micaceous marble schists; subordinate graphitic schists | PRECAMBRIAN |
| p€k | Kigluaik Group<br>Includes an upper unit of calc-silicate rocks with numerous schistose marbles, a middle unit of marble gneiss, and a lower unit of paragneiss with calc-silicate rocks | PRECAMBRIAN |

EXPLANATION FOR FIGURE 2 -- continued

Sample locations and field numbers

| Sample Location | Sample Number | Sample Location | Sample Number |
|---|---|---|---|
| 1 | 70AcH-17 | 20 | 70AcH-2 |
| 2 | 70AcH-18 | 21 | 67ATs-159 |
| 3 | 70AcH-21 | 22 | 67ATs-80 |
| 4 | 70AcH-26 | 23 | 67ATs-156 |
| 5 | 70AcH-15 | 24 | 67ATs-156A |
| 6 | 70AcH-16 | 25 | 67ATs-163 |
| 7 | 67ATs-132 | 26 | 67ATs-195 |
| 8 | 70AcH-27 | 27 | 67ATs-223 |
| 9 | 70AcH-24 | 28 | 67AKd-190 |
| 10 | 68ASn-282 | 29 | 67ATs-161 |
| 11 | 68ASn-282A | 30 | 67ATs-197A |
| 12 | 67ATs-184-1 | 31 | 67ATs-222 |
| 13 | 67ATs-184-2 | 32 | 67AKd-212 |
| 14 | 68ASn-301B | 33 | 70AcH-23 |
| 15 | 70AcH-28 | 34 | 67ASn-31A |
| 16 | 70AcH-14 | 35 | 67ATs-184A |
| 17 | 70AcH-20 | 36 | 68ASn-280 |
| 18 | 70AcH-19 | 37 | 67ASn-124 |
| 19 | 70AcH-1 | | |

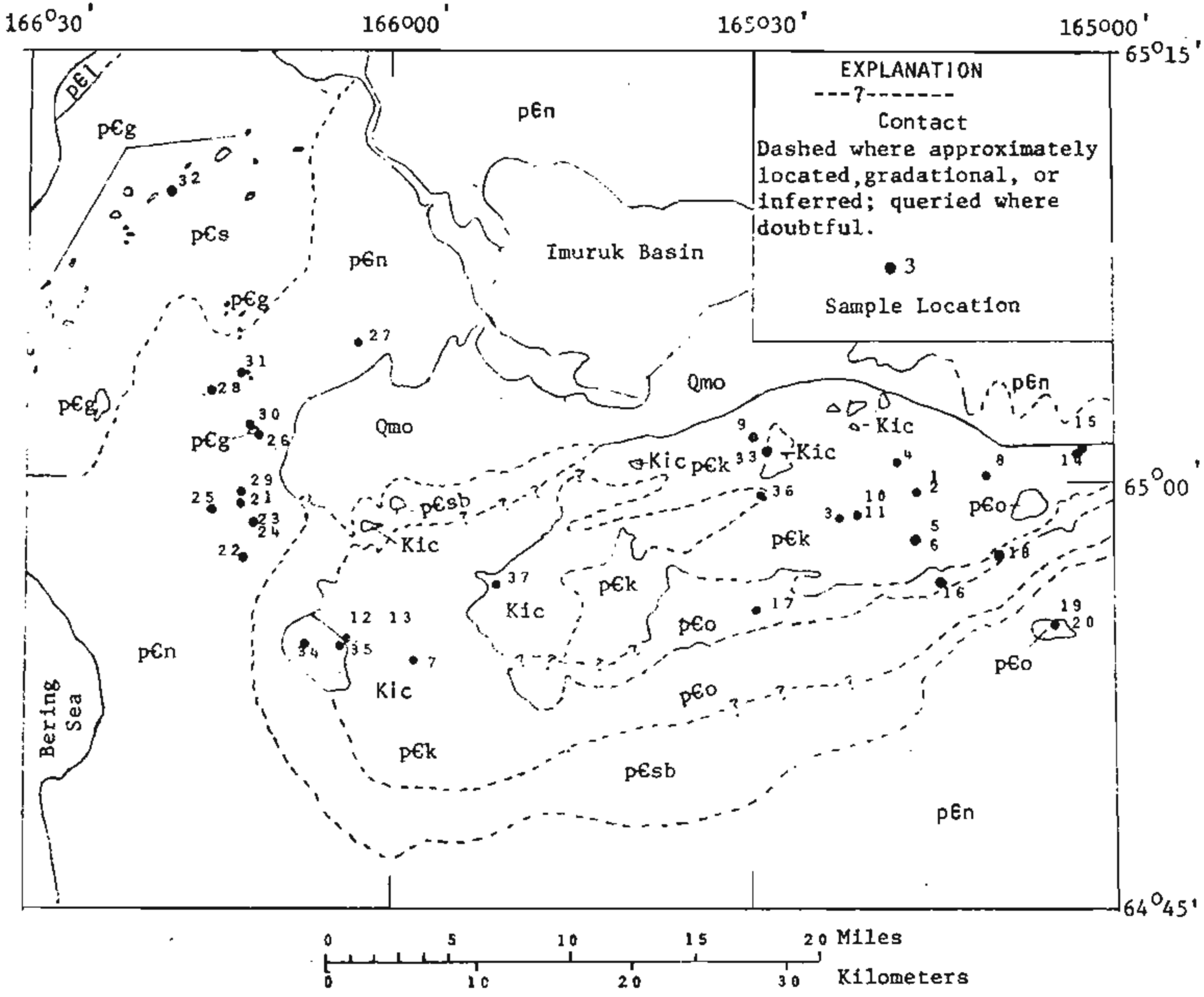


Figure 2.--Generalized geologic map and sample locations, Kigluaik Mountains area.

Two major lithologic units, which may be either the unmetamorphosed equivalents of part of the paragneisses herein discussed, or somewhat younger in age, are found in the Kigluaik Mountains and nearby areas of this report. These were named the Nome Group and the Kuzitrin Series by Moffit (1913) and Brooks, Richardson, and Collier (1901), respectively; but in his latest publication, written after a detailed study of the metamorphic rocks in the Kigluaik Mountains and elsewhere on the Seward Peninsula, Sainsbury (1975, p. 8-19) presented evidence that the high-rank gneisses of the Kigluik Mountains are transitional at least in part into graphitic slates and siltites of the Kuzitrin Series, which he includes with the slate of the York region. He further concluded that the rocks of the Nome Group as originally defined by Brooks, Richardson, and Collier (1901) included chloritic schists, probably derived from volcanic material originally included in the slate of the York region, as well as thrust slices of Paleozoic carbonate rocks and younger metagabbroic rocks of uncertain age. Thus, the Nome Group rocks may be a sub-unit within the slate of the York region, but only detailed study will solve the problem.

No rocks of proven Paleozoic age are found in the Kigluaik Mountains, but thick carbonates containing relict fossils occur immediately south and west of the range. These were grouped by earlier workers as part of the Nome Group rocks, but the known existence of relict fossils and the lithologic resemblance to other carbonate rocks of Paleozoic age that occur nearby are considered by Sainsbury to be sufficient evidence to assign these carbonate rocks to the Paleozoic.

The rocks forming the core of the Kigluaik Mountains are intruded by stocks, bosses, and batholiths of probable Cretaceous age. In broad outline, the high-rank gneisses herein discussed tend to form mantles around these intrusives, as they do elsewhere on the Seward Peninsula (Sainsbury, 1974, 1975).

## METHOD OF ANALYSIS

Rubidium and strontium concentrations were determined either by x-ray fluorescence or isotope-dilution techniques. Concentrations in all of the samples with more extreme Rb/Sr ratios were measured by isotope dilution. The Rb/Sr ratios have a precision of ±3 percent. $Sr^{87}/Sr^{86}$ ratios were measured on a separate unspiked run; they were normalized to correspond to a $Sr^{86}/Sr^{88}$ of 0.1194 and have a precision of ±0.0005.

Radioelement (K, RaeU, and Th) contents of the samples were measured by gamma-ray spectrometry. Basic operational procedures, calibration techniques, and sample preparation were described by Bunker and Bush (1966, 1967). Approximately 600 g of the material were sealed in 15-cm-diameter plastic containers. The containers were placed on a sodium iodide crystal, 12.5 cm in diameter and 10 cm thick. The gamma radiation penetrating the crystal was sorted according to energy by the associated electronic devices, and the resulting spectra were stored in a 100-channel 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 concentrations is a modification of a program written by Schonfeld (1966). Standards used to reduce the data include the USGS standard rocks, New Brunswick Laboratories standards, and several samples for which uranium and thorium concentrations had been determined by isotope dilution and mass or alpha spectrometry.

Uranium contents were measured indirectly by measuring the $Ra^{226}$ daughters ($Bi^{214}$ abd $Pb^{214}$) to obtain radium-equivalent uranium (RaeU) values. Isotopic equilibrium between these daughters and $Ra^{226}$ was accomplished by allowing the sealed sample containers to sit for at least 21 days prior to the analyses. Radium-equivalent uranium is the amount of uranium required for secular isotopic equilibrium with the $Ra^{226}$ and its daughters measured in a sample. Unless otherwise stated, all uranium concentrations referred to in this paper are radium-equivalent values.

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

All the radioelement data reported in this paper are based on replicate analyses. The coefficient of variation for the accuracy of these data, when compared to isotope-dilution and flame-photometry analyses, is about ±2 percent for RaeU and Th and about ±1 percent for K. These percentages are in addition to minimum standard deviations of about 0.06 ppm for RaeU and Th and 0.03 for K.

# RADIOMETRIC AGES

Seven whole-rock samples of paragneiss from the Kigluaik Group were dated by the Rb/Sr method. Samples were obtained from both the uppermost and lowermost accessible portions of the unit. Analytical data for the paragneiss samples are given in table 1 and plotted on an isochron diagram in figure 3. Also dated from the Kigluaik Group were one sample of biotite separated from the paragneiss and a whole-rock sample of a conformable pegmatite.

The scatter in apparent ages is quite large (table 1). Five of the seven paragneiss samples do fit a single line on the isochron diagram (fig. 3), however, and this line corresponds to an age of 735 m.y. Experience from other areas indicates that such whole-rock isochrons, for high-rank metamorphic rocks, are usually dating the time of metamorphism, and this is the interpretation that we make from these data. If this is the case, then the gneisses, which tend to occur as mantles around the Cretaceous intrusives, were metamorphosed much prior to the Cretaceous intrusion. The alternative explanation must be considered: that the original age of the slate of the York region and/or other rocks which were metamorphosed to the dated gneisses was not seriously disturbed during the intrusion of the Cretaceous intrusives.

TABLE 1.--Rb/Sr analytical data

| Sample No. | ppm Rb | ppm Sr | $Rb^{87}/Sr^{86}$ | $Sr^{87}/Sr^{86}$ | Apparent Age[1] |
|---|---|---|---|---|---|
| Whole-rock paragneiss (Kigluaik Group) samples | | | | | |
| 70-AcH-15 | 87.2 | 130 | 1.949 | 0.7247 | 750 m.y. |
| 70-AcH-16 | 101 | 199 | 1.467 | .7193 | 732 m.y. |
| 70-AcH-17 | 214 | 51.3 | 12.20 | .8292 | 733 m.y. |
| 70-AcH-21 | 193 | 85.5 | 6.579 | .7744 | 763 m.y. |
| 70-AcH-26 | 75.3 | 121 | 1.806 | .7296 | 985 m.y. |
| 70-AcH-27 | 150 | 283 | 1.536 | .7180 | 639 m.y. |
| 68-ASn-282 | 137 | 79.2 | 5.024 | .7293 | 357 m.y. |
| Biotite from paragneiss (Kigluaik Group) | | | | | |
| 68-ASn-282 | 340 | 15.9 | 62.04 | .7920 | 102 m.y. |
| Whole-rock segregation pegmatite | | | | | |
| 70-AcH-18 | 209 | 307 | 1.975 | .7257 | 775 m.y. |
| Whole-rock orthogneiss samples | | | | | |
| 70-AcH-1 | 29.7 | 58.3 | 1.490 | .7316 | 1306 m.y. |
| 70-AcH-2 | 15.9 | 44.6 | 1.033 | .7243 | 1380 m.y. |
| 70-AcH-14 | 228 | 25.8 | 26.07 | .8821 | 489 m.y. |
| 70-AcH-19 | 564 | 37.4 | 43.91 | .7600 | 91 m.y. |
| 70-AcH-20 | 359 | 40.9 | 25.74 | .8393 | 376 m.y. |
| 70-AcH-28 | 332 | 91.7 | 10.65 | .7713 | 451 m.y. |
| 70-AcH-30 | 189 | 90.5 | 6.086 | .7653 | 717 m.y. |
| 70-AH-616 | 55.8 | 115 | 1.406 | .7157 | 581 m.y. |
| 70-AH-617 | 70.7 | 144 | 1.423 | .7165 | 614 m.y. |
| 68-ASn-300 | 109 | 116 | 2.736 | .7136 | 714 m.y. |
| 68-ASn-282a | 234 | 469 | 1.448 | .7191 | 732 m.y. |
| 68-ASn-301B | 516 | 77.9 | 19.34 | .8051 | 374 m.y. |
| K-feldspar from orthogneiss | | | | | |
| 68-ASn-282a | 321 | 219 | 4.251 | .7292 | 420 m.y. |

[1]Assuming an initial $Sr^{87}/Sr^{86}$ of 0.7043.

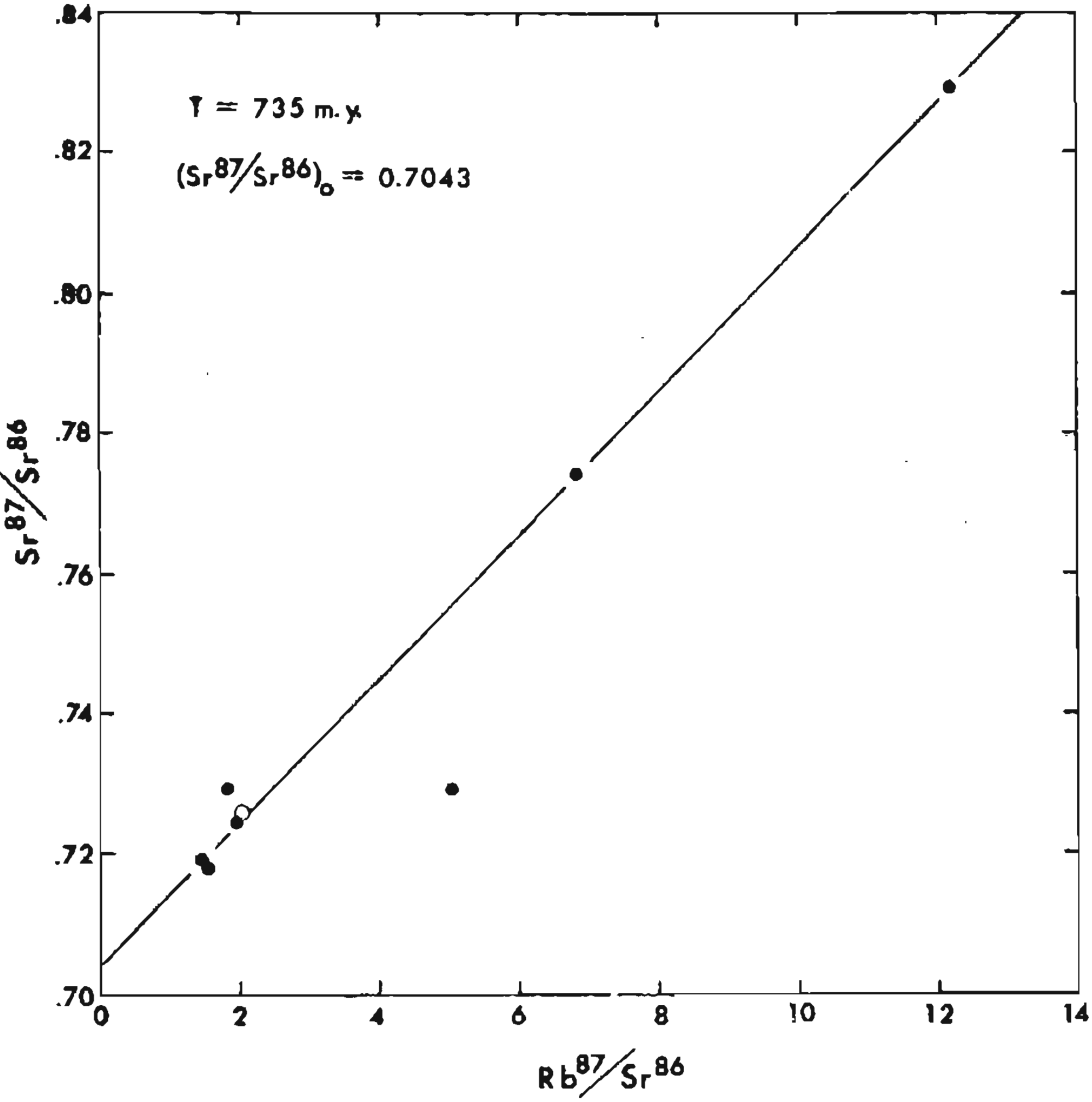


Figure 3.--Isochron diagram of Rb-Sr data for whole-rock paragneiss samples. Open circle is the segregation pegmatite sample 70-AcH-18.

That the 735-m.y. age probably represents the time of metamorphism and not the age of the sedimentation or the age of the source terrane of the sediments is confirmed by sample 70 AcH-18. This sample is from a conformable pegmatite. The pegmatite is entirely enclosed in paragneiss, and the field evidence indicates that it formed by segregation from the gneiss during metamorphism. Sample 70-AcH-17 is from the gneiss immediately adjacent to the pegmatite. A cord connecting the two points places the time at which the samples were in equilibrium, in terms of strontium isotopic composition, at 725 m.y. ago, an age not significantly different analytically from that obtained from the paragneiss samples. If our interpretation, that the pegmatite is a segregation, is incorrect and it is actually of igneous origin, its age would still provide a minimum for the paragneiss unit.

Two of the Kigluaik Group paragneiss samples do not lie on the 735-m.y. isochron defined by the other samples. The sample which plots to the left of the line (70-AcH-26) also has a peculiar Th/U ratio. There is no obvious reason why 68-ASn-282 plots to the right of the line and appears to give a young age. Biotite was separated from 68-ASn-282 and analyzed for Rb, Sr, and $Sr^{87}/Sr^{86}$. The apparent age of the biotite is 103 m.y. if we assume the initial $Sr^{87}/Sr^{86}$ of the paragneiss suite (0.7043 from fig. 3); or it is 80 m.y. if we assume that the biotite came into isotopic equilibrium with the whole-rock sample. In either case, the biotite age has been reset during Cretaceous time.

The Precambrian paragneisses of the Kigluaik Group are intruded by bodies of gneissic granite. The foliation of these orthogneisses tends to be parallel to that of the surrounding paragneisses. If this foliation was imparted 735 m.y. ago, then the orthogneisses must also be of Precambrian age. Unfortunately, the Rb-Sr data for the orthogneiss samples does not define a single line (fig. 4, data given in table 1). The sample from near Nome (70-AcH-30), the two samples from Kawalik Mountain (70-AH-616 and 70-AH-617, fig. 1), and one sample from the Kigluaik Mountains (68-ASn-282a) plot near the same isochron as the paragneisses. The other samples from the Kigluaik Mountains give apparent ages both younger and older than 735 m.y. Five of these samples define a crude isochron of about 335 m.y. (dashed line, fig. 4). One orthogneiss (70-AcH-14) gives an apparent age of about 490 m.y. and another (70-AcH-19), about 90 m.y. This scatter in the orthogneiss data can be interpreted in several ways, and no unique interpretation can be made at this time. Our preferred interpretation is that the orthogneisses are all of Precambrian age and that those in the Kigluaik Mountains have been more or less reset by the Cretaceous plutonism and tectonism. Thus, the crude alignment of the five samples along a 335-m.y. isochron is fortuitous.

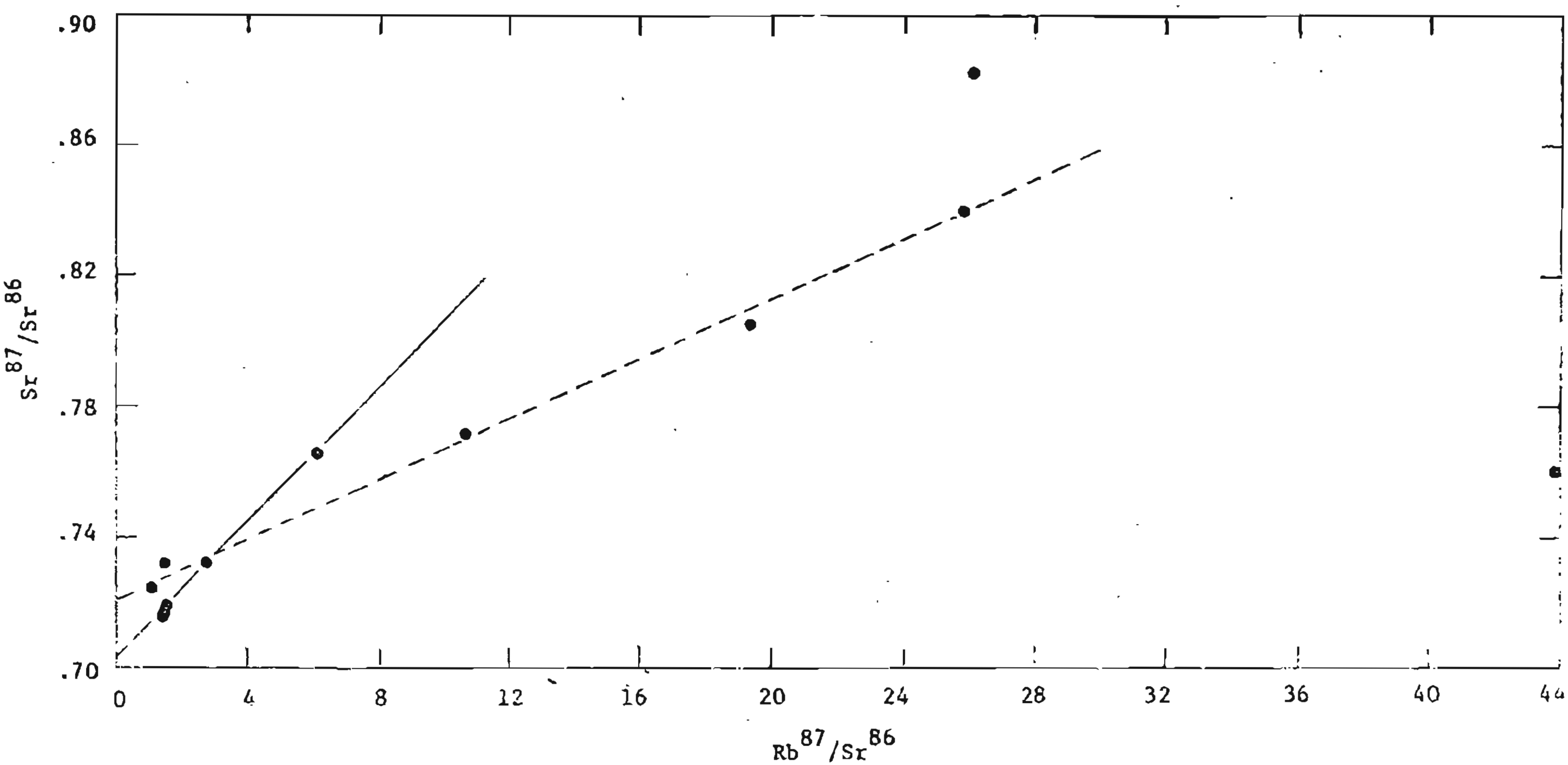


Figure 4.--Isochron diagram of Rb-Sr data for whole-rock orthogneiss samples.

Sainsbury (oral commun., 1976) stated that he revisited the Kigluaik Mountains area in 1972 and 1973. He believed that these rocks (70-AH-616 and 70-AH-617) may be hybrid rocks formed by K-metasomatism of Precambrian rocks, the potash being derived from a granitic intrusive of Cretaceous age. If so, the anomalous ages derived for these rocks are explained on the basis of isotopic mixing.

To give credence to the 335-m.y. age would require that the Kigluaik orthogneisses formed by anatexis of a preexisting crustal rock 335 m.y. ago. This conclusion is based on the high initial $Sr^{87}/Sr^{86}$ ratio (0.720) of the 335-m.y. isochron. Such crustal anatexis would require an unusual geothermal gradient and presumably there would be other manifestations of such an event. No known evidence in the geologic record supports such an interpretation.

Inspection of figure 4 might also suggest that the 335-m.y. isochron is a metamorphic isochron (that is, an older rock was metamorphosed at 335 m.y. causing the strontium isotopes to equilibrate between samples). The samples are too widely spaced, however, for such an interpretation to be plausible.

## RADIOELEMENT DISTRIBUTION

The radioelement (RaeU, Th, and K) contents of all the major geologic units of the Kigluaik Mountains except an unnamed slate-phyllite-schist unit were determined. The purposes of this analysis were to confirm the presence of the regional high thorium contents found in a few early reconnaissance samples and to ascertain whether the various geologic units might have characteristic radioelement contents and ratios that could be used in reconnaissance mapping.

The radioelement contents of the samples collected in the vicinity of the Kigluaik Mountains are given in table 2 and are shown in relation to the geologic units in figure 5. Averages of radioelement contents and ratios in the rocks are given in table 3; literature values for average radioelement contents in major categories of igneous rocks are included for comparison. The relation between Th and RaeU contents in the rocks of the Kigluaik Mountains is shown in figure 6; similar data for RaeU and K contents are shown in figure 7.

The radioelement contents in the paragneiss samples of the Kigluaik Group are near the averages for intermediate igneous rocks (table 3). The RaeU content in the paragneiss is slightly lower than the average, and the high Th/RaeU and low RaeU/K ratios indicate that the paragneiss may be depleted in RaeU. The depletion may be a near-surface effect of weathering and surface-water movement which has removed soluble $Ra^{226}$ from the rock. The Th/K ratio is close to the average for most igneous rocks, which indicates that the process causing the RaeU depletion had little effect on the other radioelements.

Table 2.--Concentrations and ratios of radioelements, Kigluaik Mountains

| Sample No. | ppm RaeU | ppm Th | % K | Th/RaeU | RaeU/K x $10^{-4}$ | Th/K x $10^{-4}$ |
|---|---|---|---|---|---|---|
| Paragneisses of Kigluaik Group | | | | | | |
| 70-AcH-17 | 0.37 | 1.10 | 4.13 | 2.8 | 0.09 | 0.27 |
| 70-AcH-21 | 1.07 | 7.48 | 4.77 | 7.0 | 0.22 | 1.6 |
| 70-AcH-26 | 0.77 | 9.44 | 1.93 | 12.3 | 0.40 | 4.9 |
| 70-AcH-15 | 1.82 | 9.91 | 1.90 | 5.4 | 0.96 | 5.2 |
| 67-ATs-132 | 2.29 | 10.77 | 2.61 | 4.7 | 0.88 | 4.1 |
| 70-AcH-16 | 1.98 | 11.05 | 2.31 | 5.6 | 0.86 | 4.8 |
| 70-AcH-27 | 1.52 | 11.49 | 3.51 | 7.6 | 0.43 | 3.3 |
| 70-AcH-24 | 2.22 | 15.21 | 3.02 | 6.9 | 0.74 | 5.0 |
| 68-ASn-282 | 1.69 | 8.45 | 2.58 | 5.0 | 0.66 | 3.3 |
| 68-ATs-184-1 | 2.01 | 19.31 | 3.88 | 9.6 | 0.52 | 5.0 |
| 68-ATs-184-2 | 1.86 | 10.28 | 2.21 | 5.5 | 0.84 | 4.6 |
| Orthogneisses | | | | | | |
| 68-ASn-282A | 9.76 | 39.48 | 4.79 | 4.0 | 2.0 | 8.2 |
| 68-ASn-301B | 12.66 | 41.46 | 4.67 | 3.3 | 2.7 | 8.9 |
| 70-AcH-28 | 6.30 | 42.25 | 4.20 | 6.7 | 1.5 | 10.1 |
| 70-AcH-14 | 7.60 | 33.79 | 4.56 | 4.4 | 1.7 | 7.4 |
| 70-AcH-20 | 15.21 | 39.87 | 4.04 | 2.6 | 3.8 | 9.9 |
| 70-AcH-19 | 11.93 | 51.91 | 4.20 | 4.4 | 2.8 | 12.4 |
| 70-AcH-30 | 3.28 | 25.95 | 2.38 | 7.9 | 1.4 | 10.9 |
| 70-AcH-1 | 3.60 | 45.99 | 0.34 | 12.8 | 10.6 | 135 |
| 70-AcH-2 | 1.82 | 52.35 | 0.26 | 28.8 | 7.0 | 202 |
| 70-AH-616 | 3.17 | 28.34 | 1.20 | 8.9 | 2.6 | 23.6 |
| 70-AH-617 | 3.69 | 27.81 | 1.46 | 7.5 | 2.5 | 19.0 |

Table 2.--Concentrations and ratios of radioelements, Kigluaik Mountains continued

| Sample No. | ppm RaeU | ppm Th | % K | Th/RaeU | RaeU/K x $10^{-4}$ | Th/K x $10^{-4}$ |
|---|---|---|---|---|---|---|
| **Schists of the Nome Group** | | | | | | |
| 67-ATs-159 | 0.25 | 1.25 | 0.33 | 5.0 | 0.76 | 3.8 |
| 67-ATs-80 | 1.95 | 8.06 | 0.98 | 4.1 | 2.0 | 8.2 |
| 67-ATs-156 | 1.69 | 8.55 | 1.61 | 5.1 | 1.0 | 5.3 |
| 67-ATs-163 | 2.01 | 8.18 | 0.85 | 4.1 | 2.4 | 9.6 |
| 67-ATs-195 | 2.01 | 8.54 | 1.96 | 4.2 | 1.0 | 4.4 |
| 67-ATs-223 | 1.72 | 7.98 | 1.95 | 4.6 | 0.88 | 4.1 |
| 67-AKd-190 | 1.60 | 7.16 | 0.39 | 4.5 | 4.1 | 18.4 |
| **Metagabbro** | | | | | | |
| 67-ATs-156A | 0.39 | 0.51 | 0.01 | 1.3 | 39.0 | 51.0 |
| 67-ATs-161 | 0.41 | 0.40 | 0.08 | 1.0 | 5.1 | 5.0 |
| 67-ATs-197A | 0.35 | 1.21 | 0.25 | 3.5 | 1.4 | 4.8 |
| 67-ATs-222 | 0.54 | 1.63 | 0.62 | 3.1 | 0.87 | 2.6 |
| 67-AKd-212 | 0.91 | 1.94 | 0.12 | 2.1 | 7.6 | 16.2 |
| **Cretaceous granitic rocks** | | | | | | |
| 70AcH-23 | 3.44 | 26.99 | 4.15 | 7.9 | 0.83 | 6.5 |
| 67-ASn-31A | 3.97 | 41.39 | 5.15 | 10.4 | 0.77 | 8.0 |
| 67-ATs-184A | 4.52 | 27.85 | 4.60 | 6.2 | 0.98 | 6.1 |
| 68-ASn-280 | 6.17 | 48.48 | 4.49 | 7.9 | 1.4 | 10.8 |
| 67-ASn-124 | 8.25 | 57.39 | 4.52 | 7.0 | 1.8 | 12.7 |

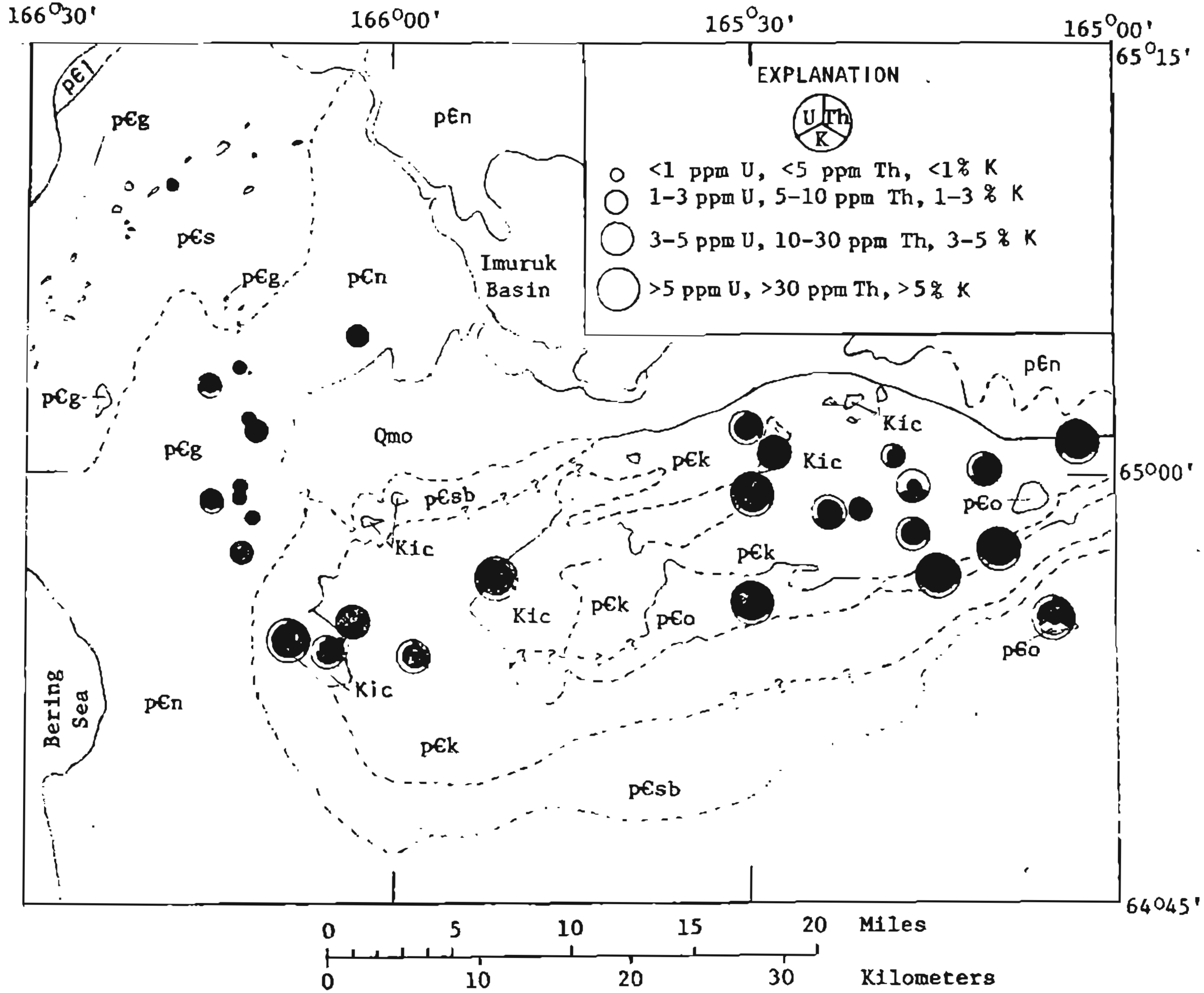


Figure 5.--Radioelement concentrations related to geology, Kigluaik Mountains area. Complete geologic descriptions given on fig. 2.

Table 3.--Averages of radioelement contents and ratios in rocks of the Kigluaik Mountains and summary of published averages for igneous rocks

| | ppm RaeU | ppm Th | % K | Th/RaeU | RaeU/Kx$10^{-4}$ | Th/Kx$10^{-4}$ |
|---|---|---|---|---|---|---|
| Paragneiss of Kigluaik Group -------- | 1.60 | 10.4 | 2.98 | 6.6 | 0.60 | 3.8 |
| Orthogneiss, all samples ----------- | 7.18 | 39.0 | 2.92 | 8.3 | 3.5 | 41 |
| Orthogneiss, >6 ppm RaeU, >4% K ----- | 10.6 | 41.5 | 4.41 | 4.2 | 2.4 | 9.1 |
| Orthogneiss, <4 ppm RaeU, <3% K ----- | 3.11 | 36.1 | 1.12 | 13 | 4.8 | 78 |
| Schists of Nome Group -------------- | 1.61 | 7.10 | 1.15 | 4.5 | 1.7 | 7.7 |
| Metagabbro ------------------------- | .50 | 1.13 | .21 | 2.2 | 10.8 | 16 |
| Cretaceous granitic rocks ---------- | 5.27 | 40.4 | 4.58 | 7.9 | 1.2 | 8.8 |
| Averages in igneous rocks: (references in parentheses) | | | | | | |
| Continental crust ------------------ | 2.8 (1a,2) | 6-10 (1b)<br>10.0 | 1.6-2.6 (4)<br>2.6 (2) | 3.5-4 (1b)<br>3.6 (2) | 1 (1a) | 3.3 (1b) |
| Mafic ------------------------------ | .9 | 2.7 | .6-.75 (4) | ≤3 (1b)<br>4.8 (2) | .6 (2) | 2.8 (2) |
| Intermediate ----------------------- | 2.0-2.6 (3) | 8.5-9.3 (3) | 2.7,3.0 (4) | 4.1 (5) | .7-1 (6) | 2.8-3.4 (6) |
| Silicic ---------------------------- | 4.7 (3)<br>4 (1a)<br>4.75 (2) | 20 (3)<br>18 (1a) | 3.6 (1a)<br>3.79 (2) | 4.5 (5)<br>4.0 (3) | 1.29 (2)<br>1.3 (2) | 5.0 (3)<br>4.9 (2) |

(1a) Rogers and Adams, 1969b.

(1b) Rogers and Adams, 1969a.

(2) Heier and Rogers, 1963.

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

(4) Cocco and others, 1970.

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

(6) Calculated from publishing values.

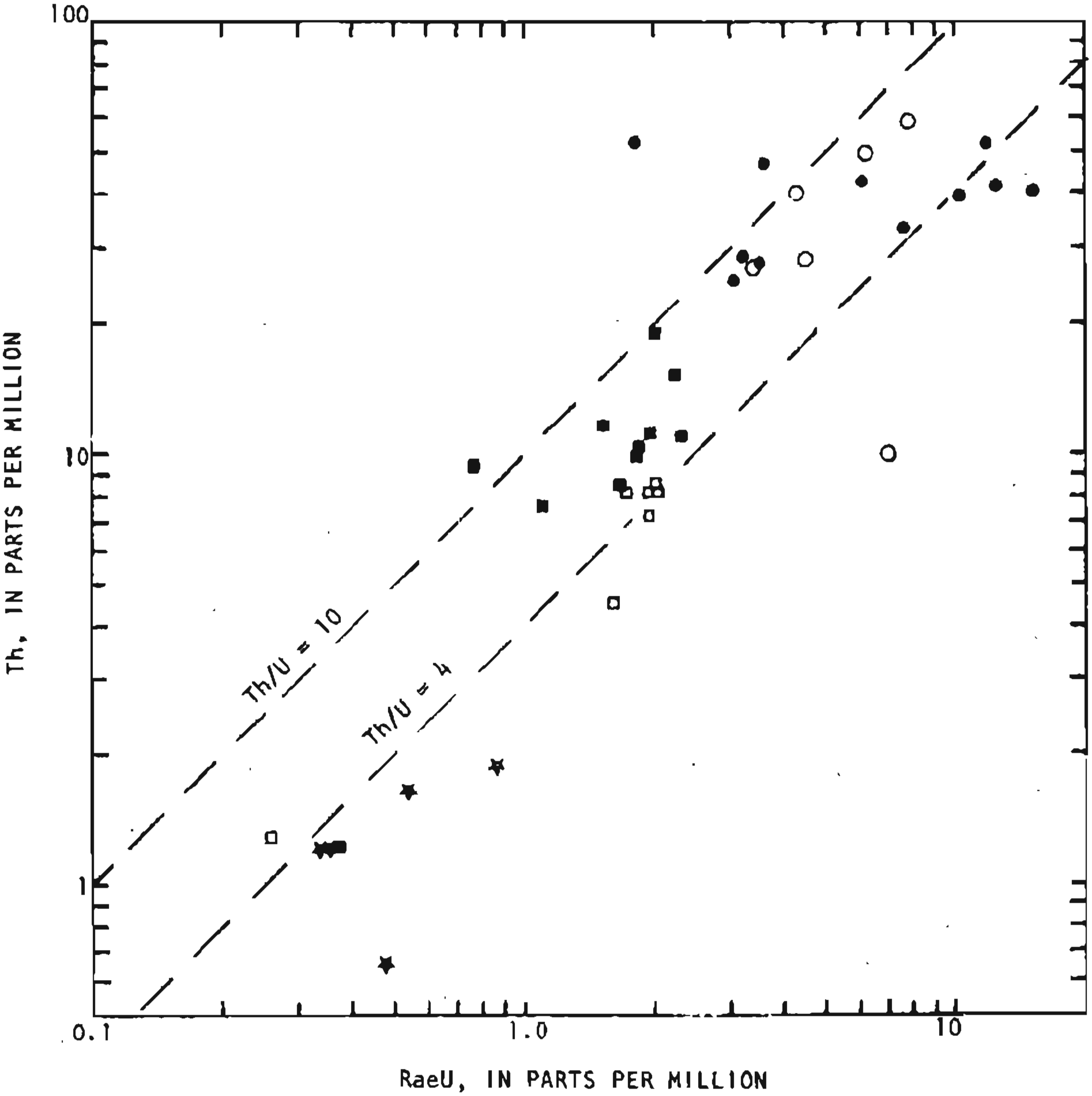


Figure 6.--Log-log plot of thorium and uranium (RaeU) concentrations. Dots are Precambrian orthogneisses; circles are Cretaceous granitic rocks; solid squares are paragneisses of the Kigluaik Group; open squares are schists of the Nome Group; and stars are Precambrian metagabbro samples.

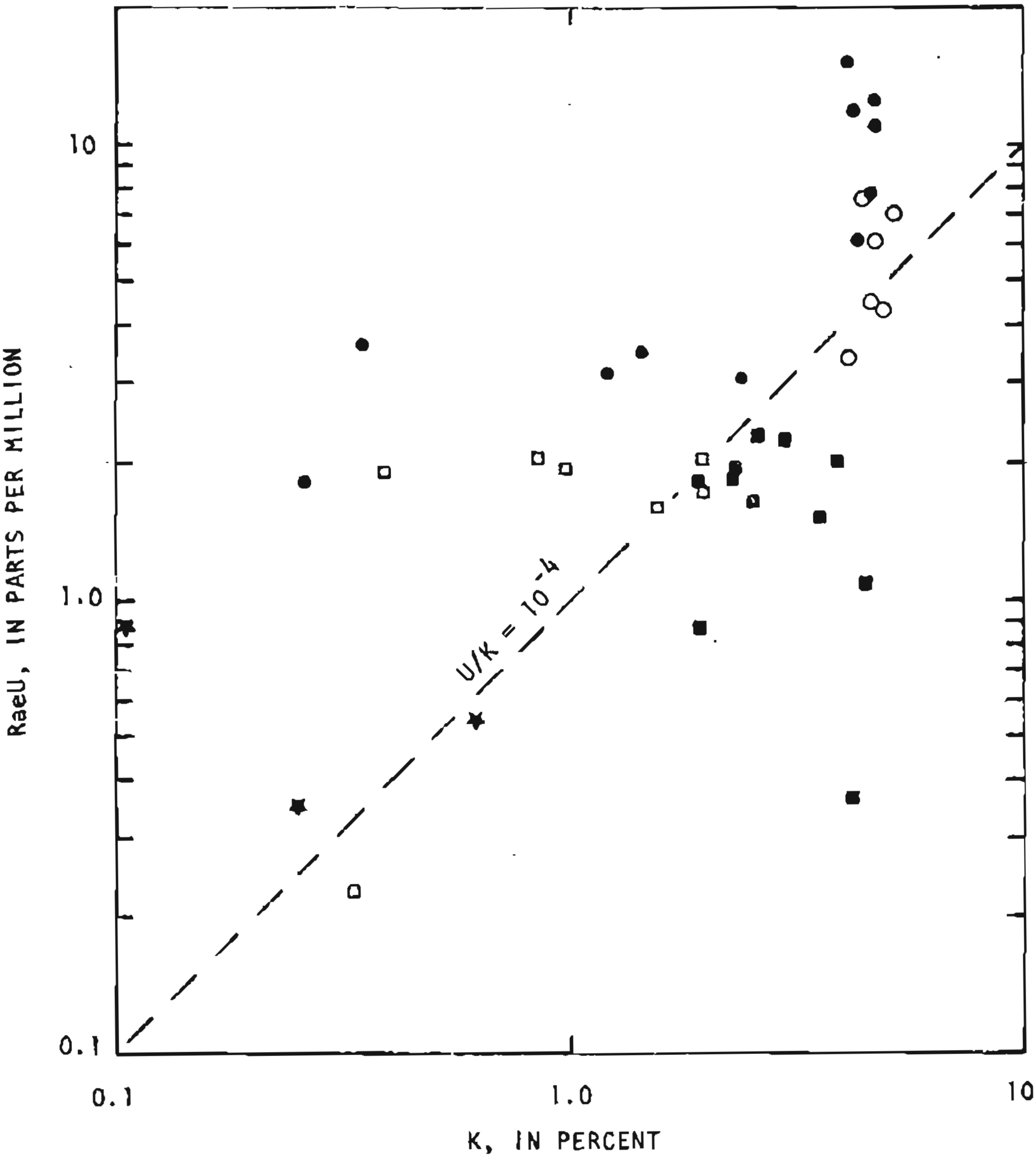


Figure 7.--Log-log plot of uranium (RaeU) and potassium concentrations. Dots are Precambrian orthogneisses; circles are Cretaceous granitic rocks; solid squares are paragneisses of the Kigluaik Group; open squares are schists of the Nome Group; and stars are Precambrian metagabbro samples.

The orthogneiss samples appear to form two groups distinguished by the RaeU and K contents; the average Th content is nearly the same in both groups. The samples in one group contain more than 6 ppm RaeU and more than 4 percent K; samples in the other group contain less than 4 ppm RaeU and less than 3 percent K (table 3). The group with the higher RaeU and K contents has radioelement contents and ratios similar to those in typical alkali granites. The near-normal ratios in the samples indicate little disturbance or migration of the radioelements in the rock during metamorphism. The group containing lower amounts of RaeU and K appears to be either depleted in both of those radioelements or enriched in Th, and the radioelement ratios are abnormal. The data indicate that the radioelement contents in the group containing the lower RaeU and K have been altered greatly, and that the two distinctively different types of rocks comprising the orthogneiss were either of different materials initially or were subjected to different conditions during metamorphism.

Most of the samples of schists of the Nome Group have radioelement contents similar to the averages for intermediate igneous rocks (table 3). The normal ratios of the radioelements (figs. 6 and 7) in most of the samples indicate that neither metamorphism nor recent weathering has preferentially mobilized the radioelements. The RaeU and Th contents of the schists of the Nome Group and paragneiss of the Kigluaik Group are very similar, but the K contents are significantly different.

The lowest radioelement contents occur in gabbro and metagabbro, which intrude slate and chloritic schists. This rock occurs as a series of small intrusives with a northward trend in the western part of the Kigluaiks. The radioelement contents in the metagabbro are less than 0.9 ppm RaeU, less than 2.0 ppm Th, and less than 0.7 percent K. Radioelement contents such as these are typical for basalts and gabbros.

The average Th and K contents of the Cretaceous granitic rocks and the Precambrian orthogneisses containing the greater abundances of RaeU and K are very similar (table 3). The characteristic that distinguishes between the granitic rocks and the orthogneisses is the greater RaeU abundance in the orthogneiss. The Th content in both groups is about twice the average for silicic igneous rocks. The above-average thorium content in the Kigluaik Mountains samples is not unique. Similar Th contents have been reported (Rogers and Adams, 1969a, p. 90-E-1) for Precambrian mica granites in the Ukranian shield (33 ppm average), second intrusive-phase alkalic granodiorites to alkalic granites in Tertiary Megrinsk intrusives of Armenia (32 ppm average), and the Conway Granite, an alkalic granite of New Hampshire (56 ppm average).

The radioelement analyses of the samples from the Kigluaik Mountains show that unusually high thorium contents measured in a few reconnaissance samples were representative and confirm the presence of regional high thorium contents. In this area, Th contents of about 25-55 ppm are common; a long-lived thorium-rich province is indicated by the similarity in the Th contents in the rocks of a wide range of geologic age. The data also show that most rocks in the major geologic units can be identified from the radioelement content and ratios.

Sainsbury reported (oral commun., 1976) that exploration for radioactive minerals during the years 1972-1974 by AirSamplex Corporation, under contract to Wyoming Minerals Corporation, led to the discovery of highly radioactive deposits containing ore-grade concentrations of uranium and thorium along the eastward continuation of the Kigluaik and Bendeleben Mountains. Descriptions of these deposits have not yet been published.

From the above, we can conclude that the work reported herein, which demonstrates the unusually high thorium content of many rocks in the Kigluaik Mountains, may be expected to delineate other belts of rocks favorable for the occurrence of primary deposits of uranium and thorium if applied elsewhere in Alaska. It is hoped that the data presented in this report will enable the serious worker to recognize what must be considered abnormal variations and concentrations of uranium and thorium in rocks similar to those studied in the Kigluaik Mountains.

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