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GEOLOGICAL SURVEY

Aerial gamma-ray survey in the northern part of the Boulder batholith, Jefferson County, Montana

by

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U.S. Geological Survey, Denver, Colorado 80225

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Introduction

An aerial gamma-ray survey was made on August 9, 1977 in the northern part of the Boulder batholith in Jefferson County, Montana. The area surveyed is shown on Plate 1 and includes part of the proposed Elkhorn Wilderness Area. The survey was done to aid in the assessment of the mineral potential of part of the proposed wilderness area and to test the response of a plastic gamma-ray detector in rough terrain surveying. Flight lines outside of the proposed wilderness area were located so that they cross areas of known uranium mineralization.

Method

Most of the gamma rays detected near the earth's surface are from the decay products of the radioelements K-40, U-238, and Th-232. The distributions of these elements and their decay products are controlled by the complex interaction of geological and geochemical processes such as hydrothermal fluid movement, ground-water flow, weathering, formation of sediments, and formation of igneous and metamorphic rocks.

Because of the relationship between the geologic environment and the radioelement distribution, measurements of these distributions can be used to aid geologic mapping and mineral exploration.

Scintillation detectors are used for aerial gamma-ray surveys, and the detectors with their associated electronics are mounted in aircraft which must follow the contour of the ground with a ground clearance of no more than 220 m. The low ground clearance is required for statistically valid measurements because gamma rays are absorbed exponentially as a function of the thickness of the layer of air beneath the aircraft. The gamma rays measured in this manner originate from within the uppermost 0.5 m of rock and soil at the ground surface.

Detection system

The detection system used for this survey consists of a four channel spectrometer with a digital tape recorder and a 113 ℓ plastic detector. The detector dimensions are 30.5 cm x 61 cm x 61 cm and the detector is viewed by two 13-cm diameter photomultiplier tubes.

The energy windows of the spectrometer were defined so as to provide four measurements of the natural radioactivity. Figure 1 shows gamma-ray spectra for gamma rays from K-40, U-238, and Th-232. Also shown in figure 1 are the energy windows used for total count (T.C.), potassium (K), equivalent uranium (eU), and equivalent thorium (eTh). The term equivalent is applied to the measurements of thorium and uranium because the gamma rays used to measure their concentrations originate from the radioactive isotopes Tl-208 and Bi-214 which are

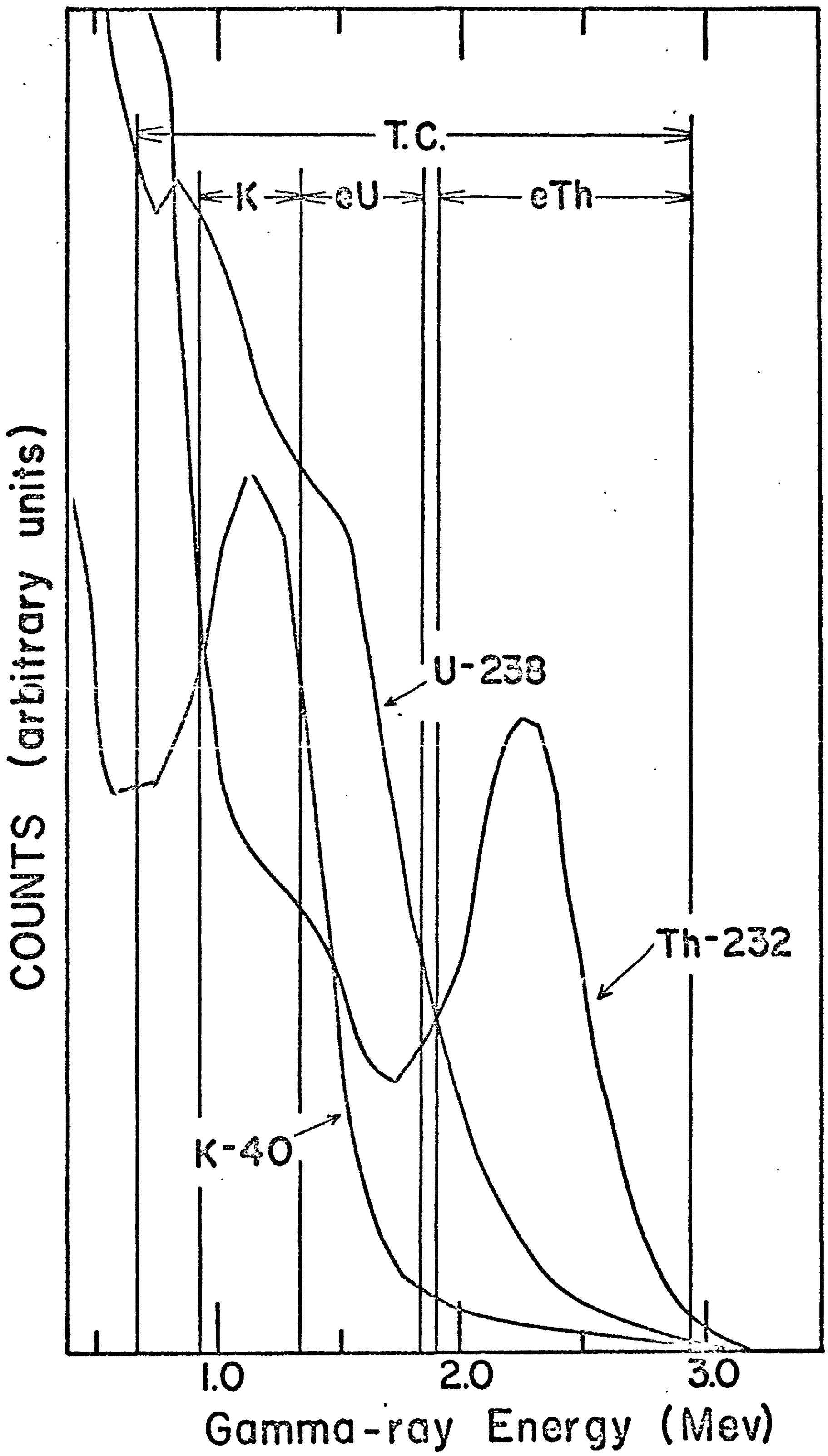

Figure 1.--Gamma-ray spectra from plastic detector showing window positions.

daughter products in the respective thorium and uranium decay chains (for details on the decay series see International Atomic Energy Agency, 1976).

The data from the four energy windows are accumulated for one-second time intervals and were recorded by a digital magnetic tape recorder. The tape recorder also recorded data from a radar altimeter and from a digital clock. The clock time was additionally recorded by a 35-mm frame camera that took pictures of the flight path of the aircraft. Additional location data were provided by a manually activated fiducial marker that was recorded both on the film and on the magnetic tape.

Survey

The single engine Pilatus Porter used for this survey averaged 160 km/hr at a nominal ground clearance of 122 m. The effective ground area measured at this height above the ground is a strip about 244 m wide. Ten flight lines, 3 to 20 km long, were oriented to cover different geologic targets. The flight lines are shown on Plate 1. Dashed segments of the flight lines indicate portions where data were not obtained and the numbers along the flight lines are fiducial numbers. The fiducial numbers are also shown on the profiles presented on Plates 2-5.

Data reduction

The data were processed to obtain profiles of the apparent surface concentrations of potassium, uranium, and thorium, the total count rate, ground clearance, and the ratios eU/eTh, eU/K, and eTh/K. These profiles are shown on Plates 2-5.

Corrections applied to the data include background corrections to remove counts due to cosmic rays and aircraft contamination and altitude corrections to remove variations caused by changes in the ground clearance. The final processing step converted the corrected count rates to apparent surface concentrations of the radioelements. The equations used for this conversion were based on calibration data obtained over the calibration pads established by ERDA at Walker Field Airport, Grand Junction, Colorado.

Geologic setting

Rocks of the Boulder batholith, of Cretaceous age, underlie most of the study area. Older rocks intruded by the batholith within the study area are sedimentary rocks of Palezoic and Mesozoic age and the Elkhorn Mountains Volcanics of Cretaceous age. Younger rocks intruding or overlying the batholith include Tertiary rhyolite and Quaternary glacial deposits, alluvium, and colluvium. More detailed discussions of the geology may be found in Becraft, Pinckney, and Rosenblum (1963), Smedes (1966), Tilling and Gottfried (1969), and Knopf (1963).

The Boulder batholith in the study area is composed of Butte Quartz Monzonite and late-stage alaskite and related felsic rocks. Hydrothermal quartz and chalcedony veins have intruded the batholith. Sulfide-rich quartz veins have produced economic quantities of silver with some gold, lead, and zinc. Known uranium mineralization occurs mostly in the chalcedony veins and is restricted to the northern part of the batholith.

Discussion of the data

Table 1 presents mean values of the radiometric data for arbitrarily selected flight-line segments which are shown on Plates 2-5. Some of the line segments were chosen on the basis of geology, and the others were selected using the data. Tilling and Gottfried (1969) give radioelement concentrations for rocks of the Boulder batholith and some volcanic rocks; table 2 lists those values.

The radiometric values given in table 1 for K and eTh are generally within the range of values of K and Th given in table 2, but eU and eU/eTh values are higher than the U and U/Th values. Overall the radiometric values are in reasonable agreement with the chemical values given in table 2, and this agreement suggests that the radiometric values can be used to estimate the radioelement concentration of the rocks along the survey lines.

In order to define anomalous values for the radiometric data, frequency distributions of the number of data points with a given value were determined for the entire data set. Anomalous values have been defined as the mean value (determined by inspection of the frequency distribution) plus or minus 0.75 times the full width of the distribution curve at one half of the maximum number of data points. Table 3 lists the mean values and the limits above or below which the values are considered anomalous.

Table 1.--Mean values of the radiometric data for line segments shown on Plates 2-5. Geologic symbols are: bqm, Butte Quartz Monzonite; fla, a subdivision of the Butte Quartz Monzonite that is fine-grained, light-gray prophyritic monzonite; a, alaskite and related felsic rocks: Kv, Elkhorn Mountains Volcanis; Tr, Tertiary rhyolite; Dj, Jefferson Formation, dolomite and limestone; and Mm, Madison Group, predominantly limestone.

Line Segment	eTh (ppm)	eU (ppm)	K (%)	Total Count (cps)	eU/eTh	eU/K	eTh/K	Geologic Unit
1a	14.2	5.7	2.3	580	0.42	2.5	6.2	Kv
1b	11.3	6.1	1.8	500	0.55	3.6	6.4	bqm+a
2a	20.9	9.5	2.4	790	0.46	4.0	8.6	bqm
2b	16.7	5.2	2.6	640	0.32	2.1	6.5	bqm
2c	25.1	7.7	2.7	810	0.31	3.0	9.4	bqm
2d	19.8	7.2	2.6	730	0.37	2.8	7.7	bqm
3a	23.5	6.9	2.6	770	0.29	2.7	8.9	bqm
3b	19.6	6.9	2.6	720	0.36	2.8	7.6	bqm
3c	21.9	9.5	2.6	820	0.44	3.8	8.5	bqm
3d	20.6	6.6	2.7	740	0.33	2.6	7.6	bqm
3e	19.3	7.2	2.8	750	0.38	2.6	6.9	bqm
3f	24.2	6.2	3.0	800	0.26	2.2	8.2	bqm+a
3g	20.4	7.1	3.1	810	0.35	2.4	6.5	bqm
3h	25.7	7.9	3.1	890	0.31	2.6	8.4	bqm
4a	15.6	7.0	2.4	650	0.46	3.1	6.7	bqm
4b	19.6	7.9	2.6	750	0.42	3.2	7.5	bqm
4c	18.8	6.8	2.7	720	0.36	2.7	7.2	bqm
4d	24.0	8.4	2.9	850	0.36	3.0	8.2	bqm+a
4e	21.7	7.6	2.7	780	0.37	2.9	8.1	bqm+a
4f	29.8	9.0	2.9	940	0.32	3.2	10.2	bqm+fla+a
4g	22.8	7.3	2.9	810	0.33	2.6	7.8	fla+a
5a	20.0	8.4	2.8	800	0.42	3.0	7.2	bqm
5b	13.3	6.8	2.6	650	0.53	2.7	5.1	fla+bqm
5c	23.2	7.3	3.1	850	0.32	2.3	7.4	bqm+a
5d	19.7	9.5	2.6	800	0.49	3.6	7.5	bqm
5e	25.7	8.7	3.1	900	0.34	2.8	8.4	a+bqm
6a	23.4	10.5	2.8	910	0.46	3.8	8.3	bqm
6b	32.1	13.1	3.2	1110	0.41	4.2	10.2	a+bqm
6c	21.2	11.0	2.7	870	0.53	4.2	7.8	bqm+a
7a	27.1	11.4	2.6	930	0.42	4.4	10.3	bqm
8a	26.1	9.0	2.9	880	0.35	3.2	9.1	bqm
8b	15.9	6.9	2.0	610	0.43	3.4	7.9	bqm+Kv
8c	16.5	8.0	2.1	650	0.50	3.9	7.9	bqm
8d	19.8	8.8	2.2	730	0.46	4.2	9.1	bqm
9a	21.9	7.0	2.5	740	0.33	2.9	8.8	bqm
9b	22.1	7.1	2.7	770	0.32	2.7	8.2	a
9c	16.9	4.1	2.0	550	0.24	2.2	8.7	Mm
9d	8.5	6.7	1.2	420	0.81	5.6	7.1	Dj+Tr
10a	25.2	10.5	2.3	840	0.42	4.7	11.2	bqm
10b	28.5	12.7	2.0	900	0.45	6.7	14.8	Tr
10c	20.0	7.8	2.3	710	0.39	3.4	8.7	bqm

Table 2.--Radioelement concentrations given by Tilling and Gottfried (1969).

Geologic Unit	Th(ppm)		U(ppm)		K(%)		U/Th	
	Range	Average	Range	Average	Range	Average	Range	Average
bqm	11.8-19.0	16.2	1.6- 7.1	4.0	1.8-3.7	3.4	.09-.37	.25
a	26.0-42.0	36.3	4.4-20.0	9.2	3.9-4.9	4.5	.14-.48	.20
Kv	2.5- 8.9	6.6	0.7- 3.0	2.1	1.7-5.0	2.6	.21-.67	.31

Table 3.--Mean values and limits used to define anomalous values of the radiometric data.

Data	Low Limit	Mean	High Limit
eTh (ppm)	13.0	21.0	29.0
eU (ppm)	4.1	7.5	10.9
K (%)	1.8	2.6	3.4
T.C. (cps)	550.0	780.0	1000.0
eU/eTh	0.2	0.38	0.56
eU/K	1.0	2.8	4.6
eTh/K	5.4	7.8	10.2

Anomalously high values of eU and/or of the ratios eU/eTh and eU/K can be a direct indication of uranium mineralization or an indirect indication of other types of mineralization such as those associated with hydrothermal veins. Within the survey data, anomalous values of eU and/or eU/eTh and eU/K occur in a number of line segments. Table 4 lists the line segments and indicates those which have anomalous values for the different radiometric parameters. The asterisks in table 4 indicate segments which have anomalous data that are interpreted to be of greater interest regarding possible mineralization. The interpretation is based upon the requirement that the line segment have anomalies in both of the ratios eU/eTh and eU/K or anomalies in one of the ratios and in eU. The mapped geology was also taken into consideration in the interpretation of data; for example, the volcanic and sedimentary rocks were excluded because they are not part of the batholith and known U mineralization is restricted to the batholith. The relationship between the anomalies and the mapped geology is not obvious; however, most of the anomalies appear to be associated with the presence of hydrothermal veins or alaskite intrusives.

Some of the data suggest the existence of zones within the Butte Quartz Monzonite. For example, the rocks along line 7 and line segment 8a have significantly higher eU and eTh values than the remaining part of line 8.

Conclusions

The radiometric data indicate a number of areas with anomalously

Table 4.--List of line segments with an indication of anomalously high radiometric data. Asterisks denote segments considered most favorable for possible mineralization.

Segment	eTh	eU	K	T.C.	eU/eTh	eU/K	eTh/K
1a	no	no	no	no	yes	yes	no
* 1b	no	no	no	no	yes	yes	no
* 2a	no	no	no	no	yes	yes	no
2b	no	no	no	no	no	no	no
* 2c	no	yes	no	no	yes	yes	yes
2d	no	no	no	no	no	no	no
3a	no	no	no	no	no	no	no
3b	no	no	no	no	no	no	no
* 3c	no	yes	no	no	yes	yes	no
3d	no	no	no	no	no	no	no
3e	no	no	no	no	no	no	no
3f	no	no	yes	no	no	no	no
3g	no	no	no	no	no	no	no
3h	no	yes	yes	no	no	no	no
* 4a	no	yes	no	no	yes	yes	no
* 4b	no	no	no	no	yes	yes	no
* 4c	no	no	no	no	yes	yes	yes
* 4d	no	yes	no	no	yes	yes	no
* 4e	no	no	no	no	yes	yes	yes
* 4f	no	yes	yes	yes	no	yes	yes
4g	no	no	no	no	no	no	no
5a	no	no	no	no	no	no	no
5b	no	no	no	no	yes	no	no
5c	no	no	no	no	no	no	no
5d	no	no	no	no	no	no	no
5e	no	no	no	no	no	no	no
* 6a	no	yes	no	no	yes	yes	no
* 6b	no	yes	no	no	no	yes	yes
* 6c	no	yes	no	no	yes	yes	no
* 7a	no	yes	no	yes	yes	yes	yes
8a	no	no	no	yes	no	no	yes
8b	no	no	no	no	no	yes	no
* 8c	no	no	no	no	yes	yes	no
* 8d	no	yes	no	no	yes	yes	no
* 9a	no	no	no	no	yes	yes	no
9b	no	no	no	no	no	no	no
9c	no	no	no	no	no	no	no
9d	no	no	no	no	yes	yes	no
* 10a	no	yes	no	no	no	yes	yes
10b	no	yes	no	no	no	yes	yes
10c	no	no	no	no	no	no	no

high values of eU and/or eU/eTh and eU/K. These areas should be further investigated to determine whether some type of mineralization occurs. Some of the areas are within or near the proposed Elkhorn Wilderness Area.

Because the data suggest possible zoning of the Butte Quartz Monzonite, a detailed aerial gamma-ray survey of the batholith would provide useful data to aid both geologic mapping and mineral exploration.

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