RADIOELEMENTS AND RADIOGENIC HEAT IN THE REYNARD LAKE PLUTON, SASKATCHEWAN NEAR FLIN FLON, MANITOBA, CANADA

by Carl M. Bunker and Charles A. Bush; Denver, CO

Open File Report 82-147

1982

This report has not been reviewed for conformity with U.S. Geological Survey editorial standards.

Radioelements and radiogenic heat in the Reynard Lake Pluton,

Saskatchewan, near Flin Flon, Manitoba, Canada

by Carl M. Bunker and Charles A. Bush, Denver, CO

INTRODUCTION

An exploratory test hole drilled by the Canadian government penetrates 3066 m (10,060 ft) into the Reynard Lake pluton, Saskatchewan, Canada. The borehole is at lat $54^{o}43'15''$N., long $101^{o}59'45''$W., about 9 km southwest of Flin Flon, Manitoba (fig. 1); the collar elevation is 336.5 m (1104 ft) above mean sea level.

Cores were obtained at approximately 300-m intervals and drill cuttings were collected at 3.05 m (10 ft) intervals through the depth penetrated by the hole; results of radioelement (uranium, thorium and potassium) analyses of 179 of the cuttings samples are reported here. The radiogenic heat produced in 99 samples of this group were reported previously (Lachenbruch and Bunker, 1971), where the drill hole is identified as "DC". Sass, Lachenbruch, and Jessop (1971) have discussed the effect of radiogenic heat on heat flow in the Reynard Lake pluton; their use of "DH-C" for identifying the drill hole is followed in the present report.

The drilling and sampling of this unusually deep hole in the Canadian Shield provided an opportunity to determine the distribution of uranium, thorium and potassium and the associated radiogenic heat through a thick vertical section of Precambrian crystalline rocks.

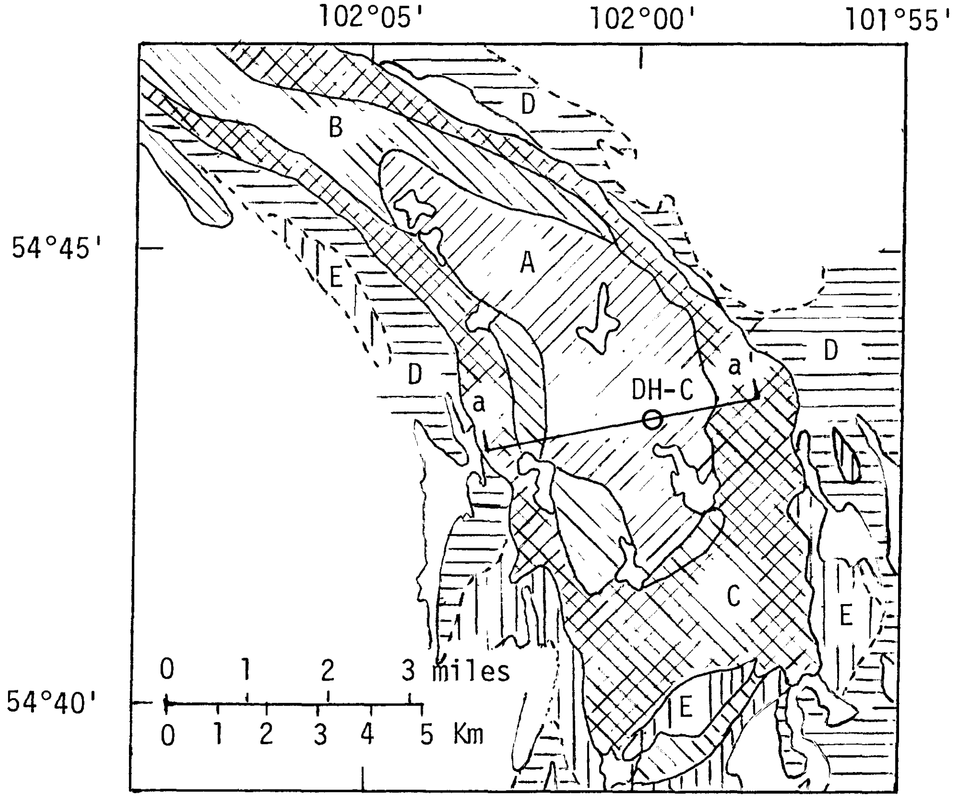

Figure 1a.--General geology of the Precambrian Reynard Lake pluton modified from Gendzwill (1969a). A is microcline granodiorite (core), B is biotite granodiorite, C is contaminated border zone, D is lavas and pyroclastic rocks of Amisk Group, E is basic intrusions. Locations of contacts approximately located.

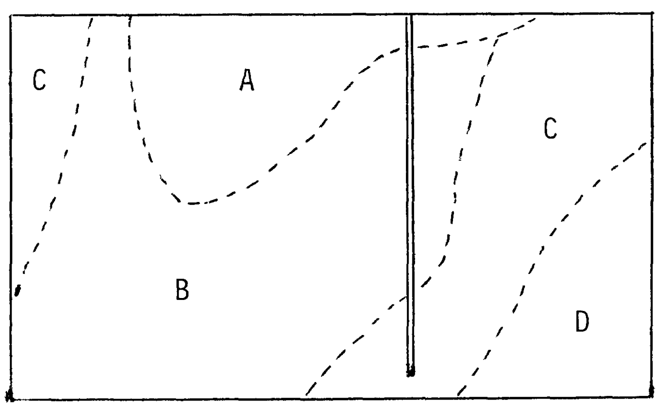

Figure 1 b.-- Diagrammatic section through a-a' from D. C. Findlay (unpublished data, 1966). A is granodiorite, B is quartz diorite, leucocratic quartz diorite and minor granodiorite bands, C is border zone rocks, mainly mafic quartz diorite, D is mainly metavolcanic rocks of the Amisk Group.

ANALYTICAL METHOD

RaeU (radium-equivalent uranium), Th and K 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 have been determined by isotope dilution mass spectrometry or alpha spectrometry.

Uranium contents were measured indirectly by measuring the ^{226}Ra daughters (^{214}Bi and ^{214}Pb) to obtain radium-equivalent uranium (RaeU) values. Radium-equivalent uranium is the amount of uranium required for secular isotopic equilibrium with the ^{226}Ra and its daughters measured in a sample. Isotopic equilibrium between these daughters and ^{226}Ra was accomplished by allowing the sealed sample containers to sit for at least 21 days prior to the analyses. All uranium concentrations measured in the drill-hole samples 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 half-lives of the daughter products measured and the values are considered to be a direct measurement of thorium. Potassium is determined from the ^{40}K 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 ±3 percent for RaeU and Th and about ±1 percent for K. These percentages are in addition to minimum standard deviations of about 0.05 ppm for RaeU and Th and 0.03 percent for K.

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

GEOLOGIC SETTING

The regional geology of the Flin Flon area and the geologic setting of the Reynard Lake pluton have been described elsewhere (Tanton, 1941; Byers and Dahlstrom, 1954a, 1954b; Smith, 1964; Byers and others, 1965; Froese, 1969; and Gendzwill, 1969a, 1969b). The Flin Flon area is just within the southwestern margin of the Churchill structural province of the Precambrian Canadian shield. The oldest rocks in the region, the Amisk Group, consist of basic volcanic flows and associated pyroclastics, acidic to intermediate volcanic rocks, and clastic sediments. Basic intrusions are common in the volcanic rocks of the Amisk Group and most of them are probably related to the same period of igneous activity (Froese, 1969). Some of the basic intrusions adjacent to younger granodiorite masses may be related to the period of granodiorite intrusion (Byers and Dahlstrom, 1954b). The basic intrusions are predominantly metadiorite and metagabbro with lesser amounts of quartz diorite, diorite, gabbro and amphibolite. Although the intrusions occurred at different times, they are petrographically similar and virtually indistinguishable in the field and have, therefore, been mapped as a group (Byers and others, 1965). The Missi Series, which consists of conglomerate, arkose, and greywacke, unconformably overlies the Amisk Group (Byers and Dahlstrom, 1954a). Large bodies of granodiorite intrude the Amisk Group and the Missi Series; the Reynard Lake pluton is one of these granodioritic masses.

The most abundant intrusive rock in the area is granodiorite. These granodioritic intrusions are generally elongated parallel to the regional structure and are considered to be syntectonic with the regional deformation (Byers and others, 1965). The mean value of potassium-argon ages determined on biotite from Churchill Province rocks is 1,735 ± 90 m.y. which reflects the age of the Hudsonian orogeny (Stockwell, 1964) that marks the upper limit of early Proterozoic time. A sample collected from a small island on the southeast end of Reynard Lake, which is within the Reynard Lake pluton, yielded a K-Ar age of 1,705 ± 85 m.y. (Lowdon and others, 1963).

Surface mapping in the vicinity of Reynard Lake indicates that the pluton is a granodioritic mass with well-defined zones (Fig. 1). The central core of porphyritic microcline granodiorite is surrounded by a discontinuous shell of nonporphyritic biotite granodiorite enclosed in a border zone of mixed rocks (Smith, 1964). The central core is coarse-grained and porphyritic, containing large phenocrysts of pink to buff microcline in a medium- to coarse-grained light-pinkish-grey ground mass. The contact with the surrounding shell of biotite granodiorite ranges from sharp to gradational over several tens of feet (Byers and Dahlstrom, 1954 b). The biotite granodiorite is a medium-grained, white to pinkish, leucocratic, quartzose rock which weathers to a very light color. The texture varies from granitoid to a simple foliated mosaic (Byers and others, 1965). The contaminated border zone around the margin of the pluton is a heterogeneous mixture of volcanic, sedimentary, granodioritic and other intrusive rocks among which fine to medium-grained quartz diorites predominate. Angular inclusions of country rock and of the intrusive rocks themselves are abundant. Contacts with volcanic rocks are sharp, but contacts with basic intrusions are sometimes difficult to define because many of the rocks in the border zone are essentially foliated amphibolites closely similar to the amphibolitic intrusions (Smith, 1964; Gendzwill, 1969b).

Cuttings and core samples from the drill hole were examined and described by D. C. Findlay, Geological Survey of Canada (unpublished data, 1966) whose work is summarized here. The terminology used in the following descriptions do not always coincide with those used in reports on the surface geology.

The borehole penetrates granodiorite from the surface to about 262 m (860 ft), quartz diorite and leucocratic quartz diorite with minor granodioritic bands from 262 m to about 2307 m (7,570 ft), and mafic quartz diorite with subordinate quartz diorite from 2307 m to 3066 m (10,060 ft). Gradations are common between all the principal rock types within the zones, but there is a distinct overall trend toward more mafic types with depth. No systematic trend in the distribution of quartz and potassium feldspars exists above about 1920 m (6,300 ft), but below that depth both minerals, particularly the latter are present in significantly smaller amounts.

Contacts between the three major lithologic zones are broadly transitional. The presence of crude compositional banding with fairly sharp contacts in parts of the section is suggested by the common appearance of alternating mafic-rich and leucocratic cuttings and confirmed by the presence of such features in some of the cores. Small granitic or aplitic dikes are probably common in the section and at least two such dikes observed in core samples. Dark green chlorite-rich schist fragments are common throughout the section and undoubtedly represent inclusions of Amisk Group volcanic material.

Samples from the surface to about 914 m (3,000 ft) are moderately to intensely altered. Alteration decreases generally with depth, but minor alteration of plagioclase and chloritization of biotite and hornblende were present to the total depth of the borehole.

DISCUSSION

The samples commonly contain red or brown oxidized material; many contain metallic chips and cuttings of the drill string. One sample contained about 17 percent magnetically-separated iron, most of which appeared to be metallic fragments. Inasmuch as the radioelement concentrations are reported by weight, the amount of anomalous metallics have a significant dilution effect on the reported analyses.

The distribution of the radioelements, radioelement ratios and radiogenic heat (Fig. 2, Table 1) indicates the presence of four depth intervals in which these trace element constituents are different. The approximate depths of the contacts between the intervals appear to be about 225 m, 1000 m and 2300 m. The data are highly variable in the depth intervals from the surface to 225 m and from 1000 m to 2300 m. Variations in the radioelement content in the near-surface interval may be caused by redistribution resulting from

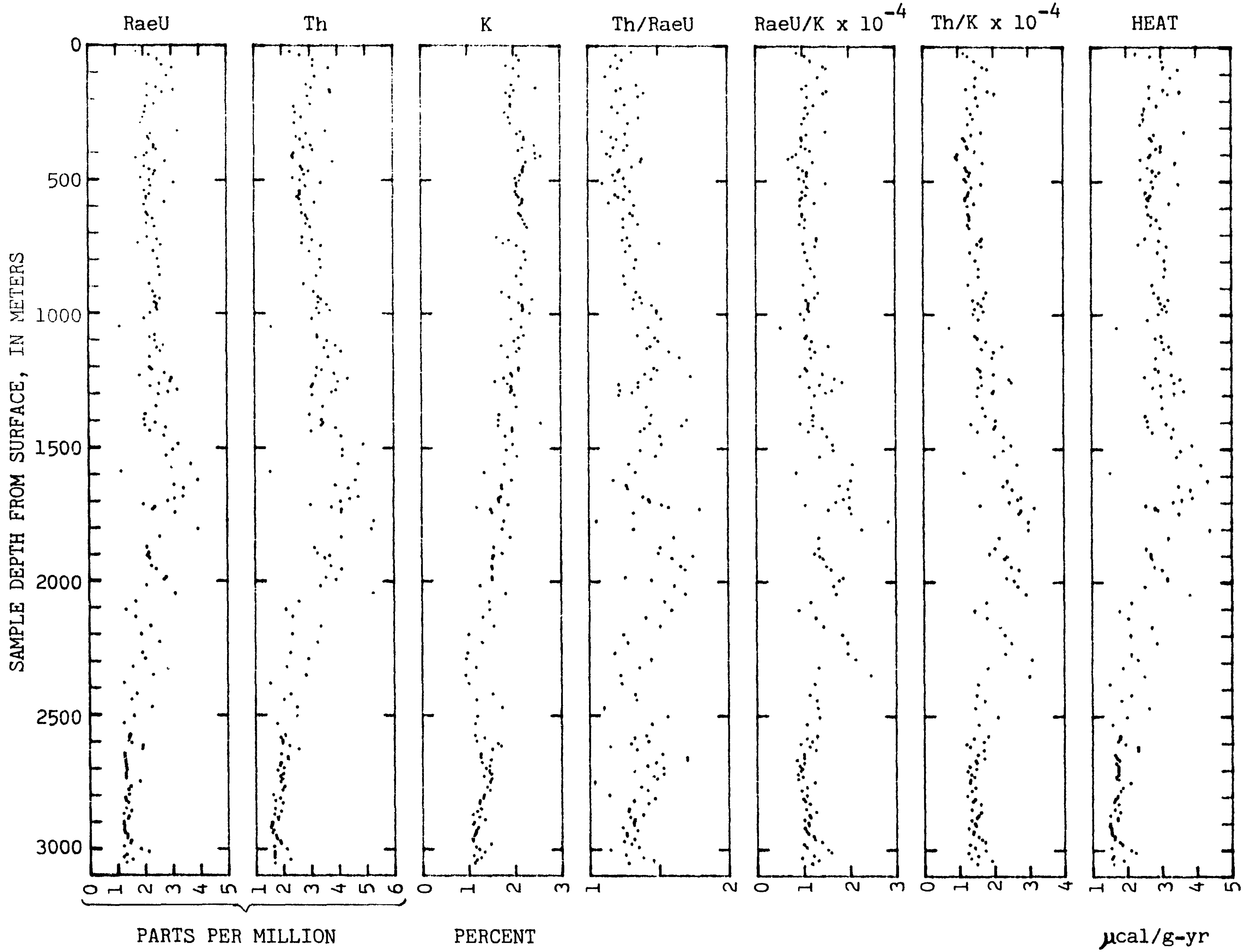

Figure 2. Radioelement concentrations and ratios and radiogenic heat in 3,054-m-deep drill hole, DH-C. Sample depths are at midpoint of sampled interval.

Table 1.--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
22.9	1.75	2.30	1.99	1.31	0.88	1.66	2.77
35.0	2.21	2.66	2.08	1.20	1.06	1.28	2.71
53.3	2.51	3.13	2.13	1.25	1.18	1.47	3.03
74.7	2.67	3.11	1.84	1.16	1.45	1.69	3.07
83.8	3.03	3.68	2.00	1.21	1.51	1.84	3.49
114.3	2.83	3.18	2.12	1.12	1.33	1.50	3.27
144.8	2.14	2.89	1.96	1.35	1.09	1.47	2.67
157.0	2.47	3.06	2.48	1.24	1.00	1.23	3.08
166.1	3.09	3.73	2.01	1.21	1.54	1.86	3.54
175.3	2.68	3.76	1.84	1.40	1.46	2.04	3.21
187.4	2.15	2.93	1.93	1.36	1.11	1.52	2.68
217.9	2.40	3.03	1.93	1.26	1.24	1.57	2.88
227.1	2.07	2.43	1.93	1.17	1.07	1.26	2.52
248.4	2.04	2.48	1.81	1.22	1.13	1.37	2.47
266.7	1.98	2.70	1.89	1.36	1.05	1.43	2.50
288.0	1.91	2.46	1.93	1.29	0.99	1.27	2.41
318.5	3.25	3.58	2.16	1.10	1.50	1.66	3.67
327.7	2.27	2.88	2.08	1.27	1.09	1.38	2.79
339.9	2.16	2.52	2.22	1.17	0.97	1.14	2.68
349.0	2.21	2.67	2.22	1.21	1.00	1.20	2.75
370.3	2.37	3.04	2.44	1.28	0.97	1.25	3.00
379.5	2.35	2.78	2.18	1.18	1.08	1.28	2.86
388.6	2.46	3.10	2.10	1.26	1.17	1.48	2.98
400.8	2.13	2.42	2.46	1.14	0.87	0.98	2.70
410.0	2.03	2.36	2.57	1.16	0.79	0.92	2.65
419.1	1.73	2.40	2.47	1.39	0.70	0.97	2.41
431.3	2.78	3.83	2.26	1.38	1.23	1.69	3.41
449.6	2.03	2.67	2.21	132	0.92	1.21	2.61

Table 1.--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
461.8	2.23	2.74	2.19	1.23	1.02	1.25	2.77
467.9	2.43	2.96	2.20	1.22	1.10	1.35	2.96
480.1	2.37	2.80	2.14	1.18	1.11	1.31	2.87
492.3	1.90	2.39	2.03	1.26	0.94	1.18	2.41
501.4	2.23	2.67	2.13	1.20	1.05	1.25	2.74
510.6	3.10	3.42	2.06	1.10	1.50	1.66	3.50
522.7	2.25	2.85	2.07	1.27	1.09	1.38	2.77
541.0	2.03	2.64	2.03	1.30	1.00	1.30	2.56
553.2	2.21	2.64	2.06	1.19	1.07	1.28	2.70
562.4	2.09	2.54	2.11	1.22	0.99	1.20	2.60
571.5	2.09	2.63	2.19	1.26	0.95	1.20	2.64
583.7	2.76	3.17	2.18	1.15	1.27	1.45	3.24
592.8	2.02	2.69	2.13	1.33	0.95	1.26	2.59
623.3	2.09	2.72	2.11	1.30	0.99	1.29	2.64
632.5	2.16	2.86	2.16	1.32	1.00	1.32	2.73
644.7	2.34	2.93	2.20	1.25	1.06	1.33	2.89
662.9	2.11	2.87	2.24	1.36	0.94	1.28	2.72
675.1	2.41	3.02	2.29	1.25	1.05	1.32	2.98
714.8	2.13	2.73	1.63	1.28	1.31	1.67	2.54
723.9	2.48	3.09	1.90	1.25	1.31	1.63	2.94
736.1	1.80	2.72	1.77	1.51	1.02	1.54	2.34
745.2	2.63	3.41	2.06	1.30	1.28	1.66	3.16
766.6	2.35	2.98	2.23	1.27	1.05	1.34	2.91
797.1	2.50	3.36	2.26	1.34	1.11	1.49	3.11
827.5	2.55	3.40	2.16	1.33	1.18	1.57	3.12
858.0	2.58	3.23	2.05	1.25	1.26	1.58	3.08
888.5	2.20	2.78	2.17	1.26	1.01	1.28	2.75
919.0	2.33	1.13	1.74	1.34	1.34	1.80	2.80
937.3	2.41	3.31	1.91	1.37	1.26	1.73	2.94
949.5	2.58	3.42	2.40	1.33	1.07	1.42	3.22

Table 1 .--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
958.6	2.39	3.31	2.11	1.38	1.13	1.57	2.98
967.7	2.48	3.61	2.18	1.46	1.14	1.66	3.12
979.9	2.45	3.24	2.20	1.32	1.11	1.47	3.03
989.1	2.50	3.73	2.18	1.49	1.15	1.71	3.16
998.2	2.23	3.32	2.34	1.49	0.95	1.42	2.92
1019.6	2.01	3.06	1.94	1.52	1.04	1.58	2.60
1050.0	1.12	1.60	2.16	1.43	0.52	0.74	1.72
1080.5	2.41	3.26	2.21	1.35	1.09	1.48	3.01
1089.7	2.21	3.27	2.10	1.48	1.05	1.56	2.83
1101.9	2.41	3.62	2.01	1.50	1.20	1.80	3.03
1120.1	2.71	3.92	1.73	1.45	1.57	2.27	3.23
1129.3	2.47	3.51	2.12	1.42	1.17	1.66	3.08
1141.5	2.61	4.12	2.06	1.58	1.27	2.00	3.29
1162.8	2.20	3.64	1.86	1.65	1.18	1.96	2.84
1202.4	2.20	3.23	2.10	1.47	1.05	1.54	2.82
1211.6	2.29	3.42	2.10	1.49	1.09	1.63	2.92
1223.8	2.75	3.86	1.93	1.40	1.42	2.00	3.30
1232.9	1.85	3.21	1.96	1.74	0.94	1.64	2.52
1242.1	3.00	4.35	1.78	1.45	1.69	2.44	3.54
1254.3	2.94	3.99	1.59	1.36	1.85	2.51	3.37
1263.4	2.54	3.09	1.86	1.22	1.37	1.66	2.97
1272.6	2.23	3.03	1.94	1.36	1.15	1.56	2.76
1284.7	3.20	3.93	1.96	1.23	1.63	2.01	3.65
1293.9	2.87	3.77	1.92	1.31	1.49	1.96	3.37
1303.0	2.51	3.05	2.01	1.22	1.25	1.52	2.98
1345.7	2.43	3.44	2.05	1.42	1.19	1.68	3.02
1376.2	2.04	2.96	1.67	1.45	1.22	1.77	2.53

Table 1.--Radiolement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pctK	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
1394.5	2.00	3.41	1.66	1.70	1.20	2.05	2.59
1406.7	2.41	3.47	2.57	1.44	0.94	1.35	3.15
1415.8	2.03	3.39	1.66	1.67	1.22	2.04	2.61
1425.0	2.79	3.91	1.96	1.40	1.42	1.99	3.35
1437.1	2.20	3.02	1.96	1.37	1.12	1.54	2.74
1455.4	2.72	4.11	1.80	1.51	1.51	2.28	3.29
1485.9	3.23	4.91	1.97	1.52	1.64	2.49	3.87
1507.2	3.03	4.16	1.83	1.37	1.66	2.27	3.54
1528.6	2.80	4.15	2.06	1.48	1.36	2.01	3.43
1559.1	3.69	4.74	1.78	1.28	2.07	2.66	4.12
1589.5	1.16	1.55	1.35	1.34	0.86	1.15	1.52
1620.0	3.93	4.61	1.94	1.17	2.03	2.38	4.31
1638.3	3.07	3.89	1.72	1.27	1.78	2.26	3.48
1650.5	3.41	4.36	1.73	1.28	1.97	2.52	3.83
1681.0	3.40	4.72	1.70	1.39	2.00	2.78	3.88
1690.1	3.09	4.41	1.65	1.43	1.87	2.67	3.58
1699.3	2.84	4.08	1.67	1.44	1.70	2.44	3.34
1711.5	1.97	3.00	1.87	1.52	1.05	1.60	2.54
1720.6	2.39	3.76	1.19	1.57	2.01	3.16	2.82
1729.8	2.30	4.13	1.49	1.80	1.54	2.77	2.91
1741.9	3.11	4.11	1.52	1.32	2.05	2.70	3.50
1772.4	5.02	5.28	1.77	1.05	2.84	2.98	5.20
1802.9	3.93	5.19	1.74	1.32	2.26	2.98	4.38
1833.4	2.55	4.10	1.91	1.61	1.34	2.15	3.20
1873.0	2.08	3.14	1.55	1.51	1.34	2.03	2.56
1894.3	2.17	3.25	1.74	1.50	1.25	1.87	2.70
1903.5	2.11	3.69	1.55	1.75	1.36	2.38	2.70
1912.6	2.20	3.51	1.53	1.60	1.44	2.29	2.72
1943.1	2.25	3.73	1.50	1.66	1.50	2.49	2.79

Table 1.--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
1955.3	2.43	4.11	1.52	1.69	1.60	2.70	3.01
1985.8	2.81	3.54	1.51	1.26	1.86	2.34	3.17
1994.9	2.70	3.91	1.52	1.45	1.78	2.57	3.16
2016.3	2.07	3.34	1.25	1.61	1.66	2.67	2.52
2046.8	3.11	5.26	1.81	1.69	1.72	2.91	3.81
2077.2	1.67	2.57	1.45	1.54	1.15	1.77	2.12
2107.7	1.32	2.10	1.46	1.59	0.90	1.44	1.78
2138.2	1.67	2.35	1.31	1.41	1.27	1.79	2.04
2168.7	2.23	3.37	1.55	1.51	1.44	2.17	2.72
2199.2	1.87	2.33	1.01	1.25	1.85	2.31	2.10
2229.6	2.54	3.24	1.30	1.28	1.95	2.49	2.85
2269.3	1.92	2.27	0.98	1.18	1.96	2.32	2.12
2290.6	2.02	2.92	0.95	1.45	2.13	3.07	2.32
2321.1	1.56	2.12	1.17	1.36	1.33	1.81	1.88
2351.6	2.31	2.83	0.94	1.23	2.46	3.01	2.51
2382.0	1.25	1.54	1.01	1.23	1.24	1.52	1.49
2421.7	1.71	2.27	1.52	1.33	1.12	1.49	2.11
2443.0	1.51	2.02	1.17	1.34	1.29	1.73	1.82
2473.5	2.27	2.51	1.73	1.11	1.31	1.45	2.63
2504.0	1.60	2.50	1.19	1.56	1.34	2.10	1.99
2534.4	1.23	1.78	1.15	1.45	1.07	1.55	1.56
2576.1	1.47	2.07	1.14	1.41	1.29	1.82	1.79
2583.2	1.43	1.89	1.34	1.32	1.07	1.41	1.78
2595.4	1.39	1.98	1.17	1.42	1.19	1.69	1.73
2604.6	1.52	1.97	1.63	1.30	0.93	1.21	1.94
2613.7	1.93	2.22	1.70	1.15	1.14	1.31	2.31
2625.9	1.91	2.56	1.51	1.34	1.26	1.70	2.31
2644.2	1.26	1.92	1.26	1.52	1.00	1.52	1.64
2656.4	1.27	2.16	1.26	1.70	1.01	1.71	1.70
2665.5	1.28	2.18	1.49	1.70	0.86	1.46	1.77

Table 1 .--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/ReaU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
2674.5	1.30	1.92	1.28	1.48	1.02	1.50	1.68
2686.8	1.33	1.88	1.46	1.41	0.91	1.29	1.74
2696.0	1.32	2.02	1.37	1.53	0.96	1.47	1.74
2705.1	1.35	1.78	1.45	1.32	0.93	1.23	1.73
2717.3	1.30	1.99	1.49	1.53	0.87	1.34	1.75
2726.5	1.29	1.88	1.32	1.46	0.98	1.42	1.67
2735.6	1.32	1.96	1.50	1.48	0.88	1.31	1.76
2747.8	1.82	1.89	1.46	1.04	1.25	1.29	2.10
2766.1	1.49	2.04	1.40	1.37	1.06	1.46	1.87
2778.3	1.39	1.97	1.46	1.42	0.95	1.35	1.80
2796.6	1.42	1.62	1.33	1.14	1.07	1.22	1.72
2808.9	1.28	1.88	1.31	1.47	0.98	1.44	1.66
28.7.9	1.29	1.70	1.24	1.32	1.04	1.37	1.62
2827.0	1.39	1.98	1.23	1.42	1.13	1.61	1.74
2848.4	1.31	1.68	1.26	1.28	1.04	1.33	1.63
2857.3	1.49	1.90	1.18	1.28	1.26	1.61	1.79
2869.7	1.20	1.66	1.08	1.38	1.11	1.54	1.50
2878.9	1.40	1.80	1.22	1.29	1.15	1.48	1.71
2888.0	1.36	1.80	1.35	1.32	1.01	1.33	1.72
2900.2	1.21	1.59	1.11	1.31	1.09	1.43	1.50
2909.3	1.20	1.58	1.08	1.32	1.11	1.46	1.48
2918.5	1.23	1.52	1.21	1.24	1.02	1.26	1.53
2930.7	1.22	1.64	1.16	1.34	1.05	1.41	1.53
2939.8	1.26	1.59	1.15	1.26	1.10	1.38	1.55
2949.0	1.36	1.72	1.12	1.26	1.21	1.54	1.64
2961.2	1.34	1.77	1.08	1.32	1.24	1.64	1.62
2970.3	1.51	1.88	1.09	1.25	1.39	1.72	1.77
2979.5	1.47	1.91	1.48	1.30	0.99	1.29	1.85
2991.6	1.22	1.65	1.15	1.35	1.06	1.43	1.53
3000.8	1.85	2.12	1.22	1.15	1.52	1.74	2.10

Table 1 .--Radioelement contents and ratios, and radiogenic heat production in samples of cuttings, drill hole DH-C.-continued

Depth(m)[1/]	ppm RaeU	ppm Th	pct K	Th/RaeU	RaeU/K x 10^{-4}	Th/K x 10^{-4}	H(μcal/g-yr)
3009.9	2.12	1.66	1.33	0.78	1.59	1.25	2.24
3022.1	1.32	1.66	1.09	1.26	1.21	1.52	1.59
3031.3	1.20	1.66	1.26	1.38	0.95	1.32	1.55
3040.4	1.54	2.24	1.17	1.45	1.32	1.91	1.89
3052.6	1.31	1.67	1.12	1.27	1.17	1.49	1.59

1/ Depth to middle of 3.05 m sample.

weathering and fluid movement. The variable character of the radioelement distribution on the interval from 1000 to 2300 m suggests heterogeneity in mineral content or rock type; the variable character would also suggest a highly fractured zone through which additional amounts of the radioelements were introduced, but drill-hole samples do not indicate major fracturing in the depth interval. The narrow range of radioelement contents in the depth intervals from 225 to 1000 m and 2300 to 3054 m strongly suggest that these sections consist of homogeneous rock virtually unaffected by fracturing and alteration. RaeU and K contents decrease with depth; this relationship is uncertain for Th because the Th content, relative to the rest of the drill hole, is high in the depth interval from about 1000 to 2300 m. The K content below about 350 m decreases almost linearly with depth. The Th content in all the rock penetrated by the drill hole is significantly less than the average for the rock types (Table 2).

The averages and standard deviations of the uranium (RaeU) content of the rocks are 2.49 ± .39 ppm (21.4-225m), 2.30 ± .29 ppm (225-1000 m), 2.52 ± .66 (1000-2300 m) and 1.45 ± .27 (2300 -3054 m). The averages for the depth intervals to 2300 m are near the average for granodiorite (Clark and others, 1966). The uranium content in the 21.4-225 m interval is appropriate for the granodioritic core but in the 225-2300 m interval it is greater than the average value for quartz diorite (Table 2) which, according to D. C. Findlay (unpublished data, 1966), is the dominant rock type. The mafic quartz diorite and quartz diorite from 2300-3054 m is reflected in the relatively low RaeU content.

The thorium contents are 3.12 ± .44 ppm (21.4 to 225 m) 2.86 ± .55 ppm (225 to 1000 m), 3.60 ± .79 ppm (1000 to 2300 m) and 1.87 ± .22 ppm (2300 to 3054 m). These values are consistently and significantly low and they are

Table 2. Averages of radioelement contents and ratios and radiogenic heat in drill hole DH-C and summary of published averages for similar rock types

	Typical Crustal Rocks[1]				Drill Hole-C			
	Mafic igneous rocks	Diorite, quartz diorite	Grano-diorite	Canadian[2,3] shield	0-225 m	225-1000 m	1000-2300 m	2300-3054 m
RaeU (ppm)[4]	0.9	2.0	2.6	2.45, 2.1	2.49	2.30	2.52	1.45
Th (ppm)	2.7	8.5	9.3	10.3, 13.0	3.12	2.86	3.60	1.92
K (percent)	0.46[5]	1.1	2.55	2.58, 2.68	2.03	2.13	1.74	1.28
Th/RaeU[6]	3.0	4.3	3.6	4.2, 6.2	1.26	1.28	1.45	1.34
RaeU/K x 10^{-4}[6]	2.0	1.8	1.0	.95, .78	1.24	1.08	1.48	1.14
Th/K x 10^{-4}[6]	5.9	7.7	3.6	4.0, 4.8	1.59	1.39	2.12	1.52
Heat (μ cal/g-yr)[6]	1.32	3.46	4.45	4.55, 4.86	3.03	2.84	3.03	1.79

1/ Clark, and others, 1966.

2/ First column: Shaw, 1967.

3/ Second column: Eade and Fahrig, 1971.

4/ Literature values are reported as U.

5/ Value for gabbro; andesite is 0.92 percent K.

6/ Calculated from published averages.

more similar to mafic igneous rocks than to the granodiorite, quartz diorite, and mafic quartz diorite (table 1). The abnormally low Th content is reflected in the unusually low Th/RaeU and Th/K x 10^{-4} ratios, which are commonly about 4 (table 2) in similar rocks.

Average potassium contents are 2.03 ± .17 percent (21.4 to 225 m), 2.13 ± .18 percent (225 to 1000 m), 1.74 ± .31 percent (1000 to 2300 m) and 1.29 ± .16 percent (2300 to 3054 m). These values are between the averages for diorite and granodiorite (table 2) (Clark and others, 1966). The potassium contents appear to be related closer to depth (fig. 2) than to rock type.

CONCLUSIONS

Variations in the distribution of the radioelement contents and ratios reflect the depths to the contacts between lithologic units determined from examining the drill cuttings. Based on the averages for typical crustal rocks, none of the radioelement contents of the samples from DH-C firmly characterize the rock types in the pluton. The Th content is unusually low in all the rocks. Potassium content neither characterizes the rock types nor indicates the location of contacts between them; it decreases almost linearly with depth. Lower than average radiogenic heat values are due to the low Th content. The radioelement data indicate an interval from 1000-2300 m in which RaeU and Th contents are highly variable and anomalously high relative to those in the remainder of the hole. This anomalous interval may represent a section, perhaps a shear zone, in which the radioelements have been mobilized and redistributed in fractures. The radioelement contents from 2300-3054 m are consistent with Findlay's identification of the rock type (mafic quartz diorite with subordinate quartz diorite) but they do not indicate a contaminated border zone consisting of a heterogeneous mixture of rocks. The

2300-3054 m interval may penetrate an unusually homogenous and unfractionated section of the predominant quartz diorite.

REFERENCES

Birch, Francis, 1954, Heat from radioactivity in Faul, Henry (ed.), Nuclear Geology, John Wiley and Sons, New York, Chapt. 5, pp. 148-174.

Bunker, C. M., and Bush, C. A., 1966, Uranium, thorium, and radium analyses by gamma-ray spectrometry (0.184-0.352 million electron volts): U.S. Geol. Survey Prof. Paper 550-B, p. B-176-B181.

______, 1967, A Comparison of potassium analyses by gamma-ray spectrometry and other techniques: U.S. Geol. Survey Prof. Paper 575-B, p. B164-B169.

Byers, A. R., and Dahlstrom, C. D. A., 1954a, Structure of the Amisk-Wildnest Lakes area, Saskatchewan: Proc. Geol. Assoc. Can., v. 6, pt. 2, pp. 27-36.

______, 1954b, Geology and mineral deposits of the Amisk-Wildnest Lakes area, Saskatchewan: Dept. Min. Res. Sask., Geol. Branch, Rept. No. 14.

Byers, A. R., Kirkland, S. J. T., and Pearson, W. J., 1965, Geology and mineral deposits of the Flin Flon area, Saskatchewan: Sask. Dept. Min. Res., Rept. No. 62.

Clark, S. P., Jr., Peterman, Z. E., and Heier, K. S., 1966, Abundances of uranium, thorium, and potassium in Handbook of physical constants: Geol. Soc. America Memoir 97, section 24, pp. 521-541.

Eade, K. E., and Fahrig, W. F., 1971, Geochemical evolutionary trends of continental plates - a preliminary study of the Canadian Shield: Geol. Survey Canada, Bull. 179, 51 p.

Froese, E., 1969, General geology of the Coronation mine area in Byers, A. R. (ed.), Symposium on the geology of the Coronation Mine, Saskatchewan: Geol. Survey Can. Paper 68-5, pp. 7-35.

Gendzwill, D. J., 1969a, Densities of Precambrian rocks of the Amisk Lake-Flin Flon area. A detailed study: Can. Jour. Earth Sciences, v. 6, pp. 1227-1243.

_____, 1969b, A gravity survey in the Amisk Lake area, Saskatchewan in Byers, A. R. (ed.), Symposium on the geology of the Coronation Mine, Saskatchewan: Geol. Survey Can. Paper 68-5, pp. 263-290.

Lachenbruch, A. H., and Bunker, C. M., 1971, Vertical gradients of heat production in the continental crust, 2, Some estimates from borehole data: J. Geophys. Res., v. 76, no. 17, pp. 3852-3860.

Lowdon, J. A., Stockwell, C. H., Tipper, H. W., and Wanless, R. K., 1963, Age determinations and geologic studies: Geol. Survey Can. Paper 62-17, 140 p.

Sass, J. H., Lachenbruch, A. H., and Jessop, A. M., 1971, Uniform heat flow in a deep hole in the Canadian Shield and its paleoclimatic implications: J. Geophys. Res., v. 76, no. 35, pp. 8586-8596.

Schonfeld, Ernest, 1966, Alpha M--An improved computer program for determining radioisotopes by least-squares resolution of the gamma-ray spectra: U.S. Natl. Lab., Oak ridge (Pub.), ORNL 3975, 42 p.

Shaw, D. M., 1967, U, Th, and K in the Canadian Precambrian shield and possible mantle compositions: Geochim. et Cosmochim. Acta, v. 31, pp. 1111-1113.

Smith, J. R., 1964, Distribution of nickel, copper, and zinc in bedrock of the East Amisk area, Saskatchewan: Sask. Res. Council Rept. No. 6, 36 p.

Stockwell, C. H., 1964, Fourth report on structural provinces, orogenics, and time-classification of rocks of the Canadian Precambrian Shield: Geol. Survey Can. Paper 64-17, pt. 2, pp. 1-21.

Tanton, T. L., 1941, Schist Lake, Saskatchewan and Manitoba: Geol. Survey Can. Map 633A, Scale 1:63,360.