SPECTROMETRIC URANIUM AND THORIUM DETERMINATIONS ON SOME HIGH-GRADE METAMORPHIC ROCKS ON LANGØY, NORTHERN NORWAY

By

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Abstract. Results of spectrometric U and Th determinations of a series of high-grade metamorphic rocks from a province in the north of Norway are given. The rocks tend to have low U and average Th contents as compared to plutonic rocks of similar bulk chemistry. High Th/U ratios characterize some red anatectic granites.

The spectrometric determinations of K are compared with earlier flame photometric determinations and a satisfactory check is obtained.

Introduction

The petrology and geochemistry of the rocks on Langøy was described in detail by HEIER (1960). All samples used in this study were petrographically described in that work and the concentrations of the following elements were given: Si, Al, Ga, Ti, Cr, V, Fe, Mg, Li, Ni, Co, Cu, Mn, Na, Ca, Sr, Pb, K, Ba, Rb, Cs (n.d.). The powdered material (— 120 mesh) used for the U and Th determinations was identical to that used for the chemical analyses. In some cases too little material was available, and composite samples were made up to the routine sample weight of 20 gms. Care was taken to make up the composite samples of as closely related rocks as possible.

Analytical method

A Nuclear Data, model ND—100, 256-channel pulse height analyzer (γ-ray spectrometer) with automatic typewriter readout was used. The detector was as described by WHITFIELD et al. (1959).

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Th was determined from the 2.62 MeV peak (the Tl[208] peak in the Th-series); U from the 1.76 MeV peak (the Bi[214] peak in the U series); K from the 1.47 MeV peak. The 0.61 MeV peak, which is commonly used as a check for U and Th, was too insensitive in this case of small sample weights and low concentrations and could only be used for samples with a maximum U and Th content.

The samples were contained in 20 cc glass bottles with plastic top. 20 gms samples were used, and the bottles were filled to constant level. The filled glass bottles were placed on top of the detector crystal.

The silicic rocks were run for an average of 1440 minutes, and the amphibolites and gabbros for double this time. Clock time was used. As the memory of the instrument is fed on a live time basis, use of clock time introduces an error, which, however, is negligible for these low concentrations.

Accuracy and precision of the data

Calibration was made with standards of known U and Th contents prepared by the U.S. Atomic Energy Commission at New Brunswick. The Th standard consists of monazite diluted with dunite, and the U standard consists of uraninite diluted with dunite. The K standard was C. P. Baker's KBr. Many interlaboratory cross calibrations have been made on rocks with very satisfactory results; see for example ADAMS et al (1958), MURRAY and ADAMS (1958).

The reproducibility (precision) of the method was very satisfactory and well within the error calculated from the counting statistics. In general only one run was made of each sample. However, a check was obtained from the potassium determinations ($K^{40} = 0.0119$ per cent of total K) which were compared with earlier flame photometric K determinations, Table 2.

The per cent statistical error due to background and sample fluctuations was calculated from the graph in Fig. 1 in LOEVINGER and BERMAN (1951). For an exposure time of about 1440 minutes (24 hrs.) the counting statistics show that satisfactory results (per cent error = 20) are obtained for concentrations down to about 8 p.p.m. Th, and 3.5 p.p.m. U. For smaller concentrations the error increases rapidly. The detection limit is about 0.5 p.p.m. U (W—1, Table 1), and 1—2 p.p.m. Th. However, the uncertainty in the small values of U and Th is so large that little significance should be placed on

Table 1.

Checks of U, Th, and K in rocks of known composition.

Rock type	U p.p.m.	Earlier U determinations	Th p.p.m.
G-1, granite[1]	3.9 ± 0.8	3.2 — 3.9	51.0 ± 2.0
W3-399, granite[2]	3.5 ± 0.7	3.8 ± 0.11	16.6 ± 1.7
P15-145 granite[2]	1.1 ± 0.6	1.7 ± 0.1	6.6 ± 1.7
W-1 diabase[1]	n.d.	0.4 — 0.6	4.6 ± 1.3

Rock type	Earlier Th determinations	K %	Earlier K determinations	Exposure time minutes
G-1, granite[1]	45 — 61 (51)	4.72 ± 0.15	4.50	1475
V3-399, granite[2]	12 ± 0.5	3.43 ± 0.14	3.4 ± 0.08	1361
P15-145 granite[2]	4.5 ± 0.3	1.85 ± 0.11	1.5 ± 0.06	1500
W-1 diabase[1]	1.9 — 3.6	0.53 ± 0.10	0.53	2336

[1] Stevens and others (1960).
[2] Whitfield and others (1959).

numerical values of less than about 4—5 p.p.m. Th, and 2 p.p.m. U. The results can be greatly improved if larger samples are used, and such sample weights of 350 gms. are the routine at Rice. However, such large samples were not available for this study.

In order to check the accuracy of the method, four rocks containing known concentrations of U and Th within the range of concentrations shown by the Langøy rocks were run. The results are shown in Table 1.

The accuracy of the K- determinations was checked by comparison with earlier flame photometric K determinations (Table 2, Fig. 1). The correspondence is, in general, very satisfactory.

Geology

Only a short review of the geology of the area is intended here (For detailed description, see HEIER, 1960).

The rocks on Langøy constitute a series of high-rank regionally metamorphosed rocks into which some igneous rocks are intruded.

The major rock type is a series of veined and banded gneisses. The metamorphic grade of these gneisses increases from east to west. In the east they are known as "the amphibolite facies veined gneisses" (nos. 27, 28, 29, 30, 31, Table 2). The continuation of these rocks to the west is represented by "the charnockite border series" (nos. 21, 22, 23, 25, 26, Table 2) and further west by "the banded series" (nos. (14, 17) (16, 17, 24), Table 2) which are proper granulite facies rocks. In these gneisses metasedimentary rocks such as limestones and graphite schists are recognized, and the complex has been explained as high-grade metamorphic geosynclinal sediments and lavas. (The graphite schists have not been examined here. They are known to have the comparatively high U content characteristic of black shales).

The metamorphic boundary which separates the amphibolite facies rocks (to the east) and the granulite facies rocks (to the west) is found to be coincident with a thrust plane beneath an anorthosite body. This coincidence has led to the assumption that the observable boundary is related to the tectonics of the area.

Massive porphyroblastic monzonitic granulites (nos. 9, 10, Table 2) occur in the extreme west of the area. Their origin is doubtful. They are chemically and mineralogically similar to some members of the gneissic series and are metamorphosed to the granulite facies. They may have formed through metamorphic processes, or they may be pre- or syn-metamorphic igneous intrusions.

A second, or retrograde, metamorphism has affected these monzonites along a narrow zone in the SE (nos. 11, 12, Table 2). Also banded gneisses and granitic rocks (no. 13, Table 2) are included in this zone.

A separate intrusion of olivine gabbro and monzonite (quartz syenite) occurs in the granulite facies area (nos. 1—7, Table 2). This intrusion is regarded as a post-metamorphic igneous intrusion.

Unfoliated granites, "young red granites", occur throughout the granulite facies area (nos. 37—43, Table 2). They have never been found within rocks of lower metamorphic grade, but small pegmatitic veins with a reddish feldspar which may be related to them do so occur.

Although the red granites occupy appreciable areas locally within the granulite facies rocks, they most commonly occur as patches of some

ten m² or less in s·ze. In some places (nos. 37, 42, Table 2), they cover more extensive areas which appear to justify the term granite massif.

The granites are believed to have crystallized from palingenic melts.

Discussion of the data

Potassium — Flame photometric K-determinations were available for all of the samples studied, and a crosscheck with the spectrometric determinations was possible, Table 2.

The K concentrations obtained by the independent methods are plotted against each other in Fig. 1. The ± 10 per cent variation limits are indicated on the figure and most results are better than this. Most of the differences between the results of the two methods are not significantly larger than the calculated uncertainty of the gamma-ray spectrometric method. However, the tendency is for the spectrometric results to be high, possibly owing to a slight error in the calibrations (compare Table 1). A duplicate γ-ray run was made of the granite no. 38. The calculated K-concentration was the same in the two cases, and it is likely that some error was done in the flame photometric determination. In general there is a better agreement between the photometric and spectrometric determinations with increasing K-content (Fig. 1).

Uranium and thorium — Only two rocks have more than 2 p.p.m. U, and most have less than 1.5 p.p.m. U. Thus the U content of the Langøy rocks is well below the average of the outer few kilometers of the continental crust, estimated by ADAMS et al (1959) as 3—4 p.p.m. U. The maximum U content of 7 p.p.m. is found in a light band of the amphibolite facies gneisses (no. 31). This rock has the highest Th content of the gneissic rocks as well (33 p.p.m.).

A comparison of adjacent light and dark bands of the gneisses; i.e., nos. 29, 28; 31, 27; 25, 22; 26, 21; shows similar U contents (except for the pair 31, 27). However, Th tends to be higher in the light acidic bands with a consequent increase in the Th/U ratio. Th contents are plotted against per cent K in Fig. 2. A parallel rough increase in Th with K is indicated.

The highest Th content is in one of the young red granites (37.4 p.p.m.), while the highest in the gneisses (33.4 p.p.m.) is in the rock

Table 2.

U, Th, and K in the Langøy rocks.

Rock type (nos, from Table I, Heier, 1960)	U p.p.m. ± % error	Th p.p.m. ± % error	Th/U	K % ± % error	K % flame photometry (Heier, 1960)	Ex-posure time minutes
Amphibolite facies veined gneisses						
29 light gneiss	<1.5	5.6 ±30%	>3.7	3.83 ±3%	3.69	1560
28 amphibolite	1.2 ±35%	4.6 ±25%	~3.8	0.84 ±9%	0.74	2739
31 light gneiss	7.0 ± 7%	33.4 ± 4%	~4.8	3.38 ±3%	3.29	2428
27 amphibolite	<1	3.0 ±35%	>3.0	2.28 ±3%	1.88	4020
29, 30 composite light gneiss	<1.5	11.3 ±13%	>7.5	3.37 ±3%	3.44	1429
Rocks associated with metasedimentary rocks in the amph. facies veined gneisses						
32 amphibolite	<1	3.0 ±40%	>3.0	0.57 ±12%	0.37	2754
33 amphibolite	n.d.	3.0 ±30%		0.57 ±12%	0.56	2850
34 amphibolite	<1.5	6.3 ±17%	~6	1.84 ±4.5%	1.68	2858
35 qtz. plag. bio. schist	2.8 ±15%	9.3 ±12%	~3.3	3.79 ±2%	3.69	3047
The charnockite border series						
25 light gneiss	<1	12.2 ±12%	>12.2	3.88 ±3%	3.93	1412
22 amphibolite	1.3 ±35%	6.0 ±20%	~4.6	2.06 ±4%	1.65	2783
26 light gneiss	1.5 ±50%	12.9 ±12%	~8.6	4.24 ±3%	4.01	1404
21 amphibolite	1.4 ±35%	3.6 ±30%	~2.6	1.45 ±5%	1.31	2776
23 veined gneiss	<1.5	10.6 ±14%	>7.1	2.56 ±4%	2.40	1428
The banded series (granulite facies)						
14, 17 intermediate gneiss	n.d.	4.3 ±35%	>4.3	0.88 ±10%	0.77	1605
16, 17, 24 composite intermed. gneiss[1]	n.d.	14.2 ±10%	>14.2	2.05 ± 5%	2.03	1465

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Rocks associated with metasedimentary rocks in granulite facies						
19 amphibolite	<1	2.0 ±50%	>3	0.72 ±10%	0.65	2871
20 granulite	<1	<3	>2	4.21 ± 3%	4.23	1365
Porphyroblastic monz.						
granulites, 9, 10, composite	<1.5	4.0 ±40%	>2.7	2.84 ±4%	2.96	1320
Retrograde metamorphic gneisses						
11, monzonite	<1	3.6 ±35%	>3.6	3.73 ±3.5%	3.48	1369
12, monzonite	<1.5	3.0 ±60%	>2.0	3.10 ±4%	3.20	1569
13, granite	<1	4.3 ±35%	>4.3	7.61 ±2%	7.51	1420
Young red granites						
37,	n.d.	<4	~28.8	4.91 ±2.5%	4.77	
38,	1.3 ±50%	37.4 ± 5%	>17.5	4.66 ±3%	5.31	1387
39,	n.d.	17.5 ± 9%	>12.9	5.29 ±2.5%	5.17	1481
40,	<1	12.9 ±11%	~11.7	5.24 ±2.5%	5.11	1462
41,	1.7 ±45%	19.9 ± 8%	>8.4	4.87 ±3%	4.84	1402
42,	<1.5	12.6 ±12%	>6.6	4.72 ±3%	4.73	1442
43,	<1	6.6 ±25%		4.08 ±10%	4.15	1090
The Eidet-Hovden intrusion						
1, 2, composite gabbro	n.d.	2.3 ±50%	>2.3	0.54 ±15%	0.32	2944
3, gabbro	<1	<1.5		0.75 ±10%	0.56	2920
4, 5 composite monzonite	n.d.	<4		3.88 ±3%	4.07	1407
6, 7 composite dyke in gabbro	<1	<3.5		2.81 ±4.5	2.61	1509

[1] No. 24 is from the charnockite border series.
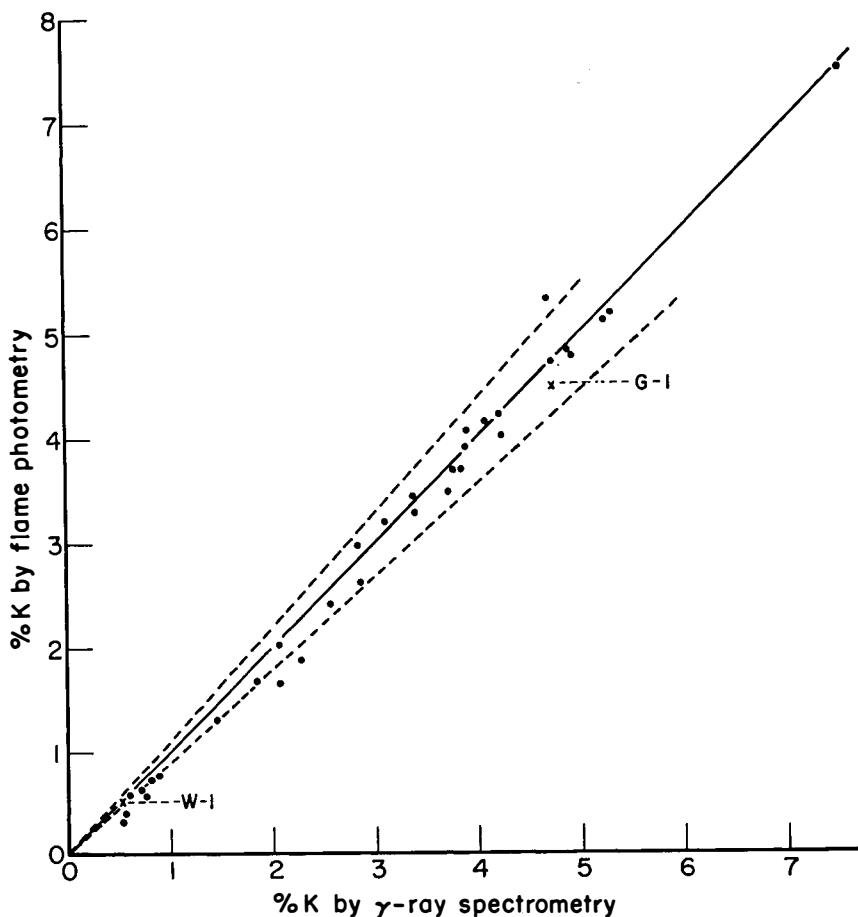
Fig. 1. Comparison between photometric and spectrometric K-determinations.
Dashed lines indicate the 10 per cent error.

which also has the maximum U content (Th/U = 4.8). ADAMS et al
(1959) suggested an average Th content of 10—15 p.p.m. in the upper
few kilometers of the earth crust, and the acidic gneisses on Langøy
are within this range. Thus, Th seems not to be depleted in the same
manner as U in these rocks, and the tendency is towards a higher than
average Th/U ratio, which contradicts the possibility of a lower Th/U
ratio in metamorphic rocks mentioned by ADAMS et al (1959). A
relative depletion of U in ultrametamorphic rocks is to be expected,
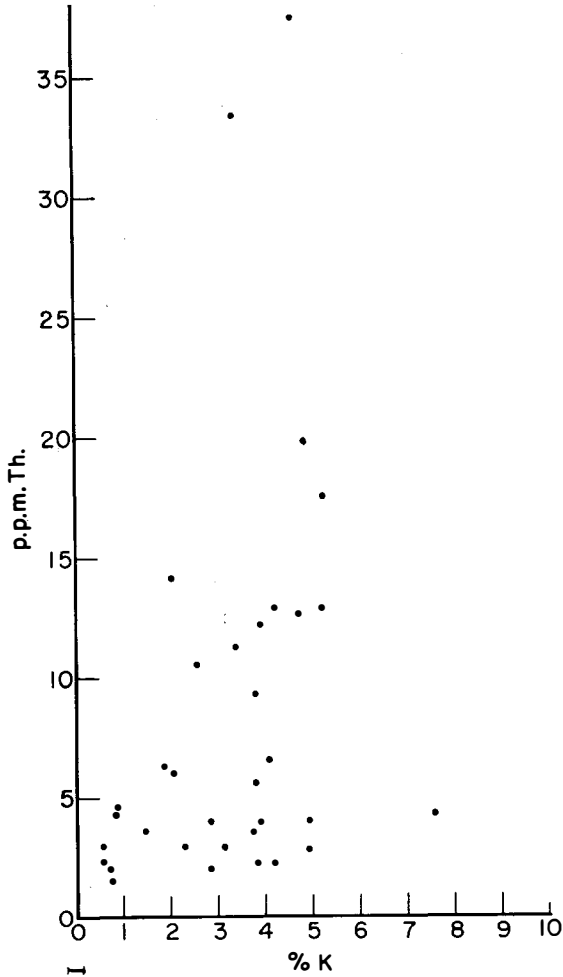inasmuch as possible oxidation of U into the very soluble uranyl ion

Fig. 2. Plots of Th versus K in the Langøy rocks.

renders it more susceptible to metamorphic differentiation under the action of water vapor. A similar explanation was given by WHITFIELD et al (1959) for rocks from the Canadian shield which show similar relations as the Langøy rocks. Recent work, i.e., FYFE, TURNER and VERHOOGEN (1958); JAMES (1955); EUGSTER (1959); CHINNER (1960), show that little oxidation or reduction is achieved during conservative regional metamorphism, but some experimental data of SHAW (1956) suggest that increasing metamorphism tends to cause some reduction.

THOMPSON (1957) and YODER (1957) pointed out that pelitic assemblages were most successfully treated when assumed to be closed to oxygen (see also RANKAMA and SAHAMA, 1952, p. 232). The problem is controversial but it seems that redox processes most readily (and only?) occur during metamorphism where water is present (EUGSTER, 1959). Apparently the water liberated in metamorphic reactions involving hydrous silicates does not, under normal circumstances, oxidise the rocks (CHINNER, 1960).

The gneissic rocks on Langøy are considered to have formed primarily on the surface (sediments, lavas, tuffs, etc.). They have therefore been subjected to the oxidizing actions of the exogenic processes, and the consequent possibility of selective loss of U. Thus their low U contents may reflect an inherited sedimentary feature. The similar U contents of the amphibolitic bands and the adjacent light bands in the gneisses (Table 2) may be significant in this respect. The amphibolitic bands are considered metabasalts, and though they have been erupted on the surface of the earth, they have not been weathered and oxidized under atmospheric conditions. There is no evidence of selective leaching of U from these rocks. If the low U content of their light-coloured neighbours was secondary and brought about by metamorphism, one might expect that the amphibolites had been equally affected. (The mineral(s) containing the U are unknown, and a different mineralogy in the two types of rocks could explain a difference in U leaching.)

The porphyroblastic monzonitic granulites (nos. 9, 10), and the related monzonites of the retrograde metamorphic gneisses (11, 12) have low Th contents. The granite within the latter series (13), and also the granulite (20) have similar low Th contents. These rocks, and also the two composite intermediate gneisses of the banded series, are also relatively low in U. The monzonites of the petrologically different Eidet—Hovden intrusion have similar low U and Th contents.

The data do not allow a rigid distinction between the rock groups in Table 2 on the basis of their U and Th contents and the Th/U ratio. However, the young red granites on this basis separate out as a special type of rocks characterized by high Th/U ratios and low U contents. WHITFIELD et al (1959) pp. 261 and 265 found red granites to contain an abnormally large amount of Th with an average amount of U. Some of the granites examined by them contained appreciable allanite,

Table 3.

Fe^3/Fe^2 ratios of rocks from Langøy (Heier, 1960, Table 43).

Rock series	Fe^3/Fe^2	Rock series	Fe^3/Fe^2
1 Gabbro	0.17	21 The charnockite	0.12
2	0.06	22 border series	0.10
3	0.06	23	0.19
Average	0.10	24	0.27
4 Monzonite	0.71	25	0.46
5	0.45	26	0.37
Average	0.58	Average	0.25
6 Dyke	0.72	27 The amphibolite	0.43
7	0.76	28 facies veined	0.36
8	0.73	29 gneisses	0.26
Average	0.74	30	0.12
		31	0.35
9 Porphyroblastic	0.75	Average	0.30
10 monzonitic granulites	0.86		
Average	0.80	32 Rocks associated	0.41
		33 with metamorphic	0.67
11 Retrograde	0.74	34 sedimentary rocks	0.87
12 metamorphosed	0.43	35 in the amph. facies veined	
13 gneisses	2.21	gneisses	0.33
Average	1.13	Average	0.57
14 The banded series	0.53	36 Young red granite	2.49
15	0.08	37	0.72
16	0.72	38	1.50
17	0.27	39	1.31
Average	0.40	40	1.59
		41	0.57
18 Rocks associated	0.54	42	1.56
19 with metamorphic	0.52	43	1.05
20 sed. rocks in the banded		Average	1.35
series	0.02		
Average	0.36		

(Rows 1–5 are bracketed as **The Eidet-Hovden intrusion**.)

which might have been secondarily introduced and probably accounts for the high Th content. They argued that the red colour indicates oxidizing during magmatic activity and consequent loss of U. The red granites on Langøy are explained as anatectic granites formed by local melting of rocks similar to the granulite facies gneisses (HEIER, 1960, p. 216). A comparison of the Fe^{3+}/Fe^{2+} ratios of the Langøy

rocks indicates that the red granites are the more oxidized, Table 3. Thus the anatectic melting presumably was accompanied by oxidation of the magma (possibly through oxygen derived from thermal dissociation of water locally concentrated in the loci of remelting), resulting in a selective solution of U into the escaping vapour phase.

Acknowledgment

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