SELENIUM IN CERTAIN IGNEOUS ROCKS

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The selenium contents of the igneous rocks from Finland and Iceland and a few from West-Greenland studied in this paper can be tentatively summed as follows:

The selenium content shows a general tendency to decrease when passing from a basic to a more siliceous rock.

Excluding ultrabasic rocks, this statement can also be expressed by saying that the selenium content exhibits a positive correlation with the colour index of the rock. Selenium very probably does not enter the structures of the common rock-forming minerals but is largely contained in the accessory sulphide phase. The distribution of selenium between the various calc-alkalic igneous rocks mainly reflects the abundance of the sulphide phase in the rocks.

The volcanic rocks of Iceland are generally more rich in selenium than their abyssal equivalents in the Finnish Precambrian. This fact could possibly result from the slowly advancing crystallisation of the igneous rock masses under deep-seated conditions, thus offering a better opportunity for the sulphide-bearing emanations to escape from the magma and enter the surrounding bedrock.

Adopting the standard section constituting the upper continental earth's crust, tentatively estimated by Wedepohl (1969, 244), the data of Table 1 yields a value of 47 ppb as the average selenium content of abyssal igneous rocks. Using the average of two parts acidic (granite) to one part basic (gabbro) rock, the average selenium content of abyssal igneous rocks amounts to 58 ppb. Both these average estimations are near the value 50 ppb presented by Turekian and Wedopohl (1961) and by Vinogradov (1962).

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Introduction

The mode of occurrence of selenium in Nature is largely dominated by the close relationship between selenium and sulphur. In sulphide deposits of relatively low selenium concentration this element enters the structures of the sulphides where it substitutes for sulphur. In some cases the selenium content of the sulphides may range up to a few percent; scarcely any sulphide minerals are known in which selenium is absent. If the Se/S ratio of the environment exceeds a certain limit, then selenium occurs as specific selenides which may or may not form a solid solution with the sulphides of analogous composition. The mineralogy of selenium and the occurrence of the element in sulphides is covered by considerable literature, the most comprehensive reviews of which have been published by Sindeeva (1964) and Tischendorf (1966).

Excluding the occurrence of selenium in sulphide deposits, the analytical data for the general geochemistry of the element are restricted mainly to soils, waters and various sedimentary materials. In this connexion, the reader is referred only to the bibliography compiled by Luttrell (1959).

The information dealing with the abundance of selenium in igneous rocks is scanty (Goldschmidt and Hefter 1933; Goldschmidt and Strock 1935; Goldschmidt 1958, 532—540). Davidson and Powers (1959) reported a considerable amount of analytical data for the volcanics of the western United States and Hawaii. The contents found are mostly given as less than 1 ppm Se and are generally lower for the crystalline volcanic rocks than for the ashes connected with them. Sindeeva (1964) published a series of 18 selenium determinations made on various igneous rocks of the USSR indicating a range of variation from 0.1 to 0.37 ppm Se, the figures given by her are, on the average, slightly high. The reason for this circumstance is probably the fact that she worked mainly with volcanic and dyke rocks where the selenium content is higher than in their plutonic equivalents. Sindeeva also had the disadvantage that she was compelled to work near the lower limit of detection of her analytical method.

Brunfelt and Steinnes (1967) gave the selenium contents of eight standard rock samples, their analyses being made using the highly sensitive neutron activation method. For comparison with the data of this paper their values are reproduced here:

Diabase W—1	0.110 ppm Se
Basalt BCR—1	0.103 »
Nepheline syenite STM—1	0.010 »
Granite G—2	0.005 »
Granodiorite GSP—1 ...	0.059 »
Andesite AGV—1	0.008 »
Peridotite PCC—1	0.022 »
Dunite DTS—1	0.004 »

In addition, some data for selenium in igneous rocks is also scattered in the literature. The references can be found in the papers mentioned.

The average abundance of selenium in igneous rocks has been estimated by the following authors:

Vogt (1898)	$n \cdot 10^{-7}$ % Se
Clarke and Washington (1924)	$n \cdot 10^{-6}$
Vernadsky (1924)	10^{-4}—10^{-5}
Behrend and Berg (1927) ...	$2.5 \cdot 10^{-6}$
Noddack and Noddack (1936)	$8 \cdot 10^{-5}$
Goldschmidt (1935)	$9 \cdot 10^{-6}$
Vinogradov (1949)	$6 \cdot 10^{-5}$
Vinogradov (1956)	$n \cdot 10^{-6}$
Turekian and Wedepohl (1961)	$5 \cdot 10^{-6}$
Vinogradov [1] (1962)	$5 \cdot 10^{-6}$

[1] Igneous rock mixture containing two parts of acid to one part of basic rock.

Some of these values have been adopted in a number of later reviews and compilations. The scarcity of the original analytical data underlying these figures makes these selenium abundance estimations nothing more than »good guesses». For this reason a study of selenium in igneous rocks was undertaken by the author mainly using specimens from Finland and Iceland and a few from West-Greenland. The results of the study are presented in the following.

Sampling and analytical procedure

Most of the specimens of Finnish rock used in this work were collected on field trips in various parts of the country. The author was privileged to be assisted, during the collection, by colleagues who had mapped the areas concerned and who generously assisted in selecting exposures at which the rocks were considered typical. Consequently, many of the specimens are derived from spots described in the literature. Some other areas, however, were visited without local guidance. A part of the specimens used had been placed at the author's disposal from the collections of the Geological Survey of Finland and the Department of Geology of the University of Helsinki. The specimens from Iceland were collected on a guided field trip in 1968 and those from West Greenland during the author's field work in 1966, carried out jointly with Mr. S. Väisänen, of the Technical University of Helsinki.

A list of the specimens of igneous rocks used and the results of the selenium determinations are compiled in Table 1. When applicable, references to the localities and to the petrological characteristics of the specimens have been added to the table.

The analytical procedure used for the quantitative selenium determination will be described in detail later, and consequently only a brief summary of the method is reported.

From each specimen, ca. 300 g was ground in a vibrating mill (»Schwingmühle» manufactured by Messrs. Siebtechnik G.M.B.H., Mülheim, West Germany). This type of mill is reported as producing a minimum contamination. To test the effect of possible contamination from the mill and from the reagents used, blank analyses were made at intervals during the work and many of the analyses were repeated. The blank analyses were partly made by adding known amounts of selenium to the charge. The reproducibility was found to be within $\pm 10\ \%$ (Koljonen 1965).

Briefly, the analytical procedure was as follows: A sample of 20—70 g, on average 50 g, was decomposed by fusing with $NaOH—Na_2O_2$ in a nickel crucible. To prevent evaporation of selenium, 5 g Fe_2O_3 was added to the charge. The cake was dissolved in sulphuric acid and the selenium was distilled quantitatively from the solution to which $HBr—Br_2$ had been added. Arsenious acid was added to the distillate and the selenium was collected by co-precipitation with metallic arsenic in reducing conditions. Selenium was finally determined colorimetrically as diphenylpiazselenol.

The selenium contents given in Table 1 are expressed in ppb (1 ppb = 0.001 ppm = $10^{-7}\ \%$ = 1 mg/ton). The concentration given in the table corresponds to 1 μg in the charge which, for an average charge of 50 g, corresponds to 20 ppb in the rock. This value amounts to about twice the background obtained in the blank determinations, viz., 0.5 μg. Selenium concentrations lower than 20 ppb are marked »n.d.» (not detected) in the table.

Plutonic rocks

On the basis of the data summarised in Table 1, the selenium contents of the rocks belonging to the calc-alkalic igneous rock suite are diagrammatically presented in the histogram of Fig. 1. The following specimens have been included in this figure:

Ultrabasic rocks	Nos.	1— 11
Gabbroic rocks		12— 32
Dioritic rocks		33— 39
	and	59— 72
Granitic rocks (excluding rapakivi granites)		73—109
Finnish rapakivi granites		110—128

It is understood that, especially in the intermediate to acidic rock groups mentioned, some of the rocks studied may not be strictly magmatic in origin. A few remarks may be added concerning these groups. The gabbroic rock group also includes anothosites, the selenium contents in the anorthosites studied (Nos. 27—32) tend to be lower than those of the different gabbro varieties (Nos. 12—26). The difference in the spread of the selenium contents between the anorthosites and the gabbros proper is, however, not sufficiently pronounced to warrant presentation of the anothosites as a separate rock group. In a qualitative manner, both in the anorthosites and in the gabbros proper, the selenium content shows a positive correlation with the colour index of the rock.

In general, the darker the rock, the higher its selenium content. The dioritic group ranges from quartz-free or slightly quartz-bearing varieties to granodiorites. As in the gabbroic rocks, the selenium content of the dioritic rocks shows a tendency to increase with the colour index. Among the granitic rocks the rapakivi granites were distinguished as a separate group.

Inspection of the histogram in Fig. 1 reveals the fact that the selenium content found varies within relatively wide limits in most of the rock groups concerned. In addition, the ranges of variation overlap considerably and thus, on the basis of the data availabale, a presentation of the average selenium contents of the calc-alkalic igneous rock groups in the conventional manner is considered only of limited value. With this reservation in mind, the following averages are tentatively given:

Ultrabasic rocks	72	ppb Se
Gabbroic rocks	108	»
Dioritic rocks	72	»
Granitic rocks	25	»
Finnish rapakivi granites	56	»

In their order of magnitude these figures compare reasonably well with those listed by Brunfelt and Steinnes (1967) for the standrad igneous rock samples, reproduced in the introduction of this paper. The figure for the ultrabasic rocks is, however, clearly higher than those given by these authors for peridotite and dunite, respectively.

Despite the merely semi-quantitative character of the average selenium contents listed above, the histogram of Fig. 1 makes it evident that selenium becomes somewhat enriched in the ultrabasic to intermediate rocks, preferably in the polymineralic gabbros. The main dark, iron rich

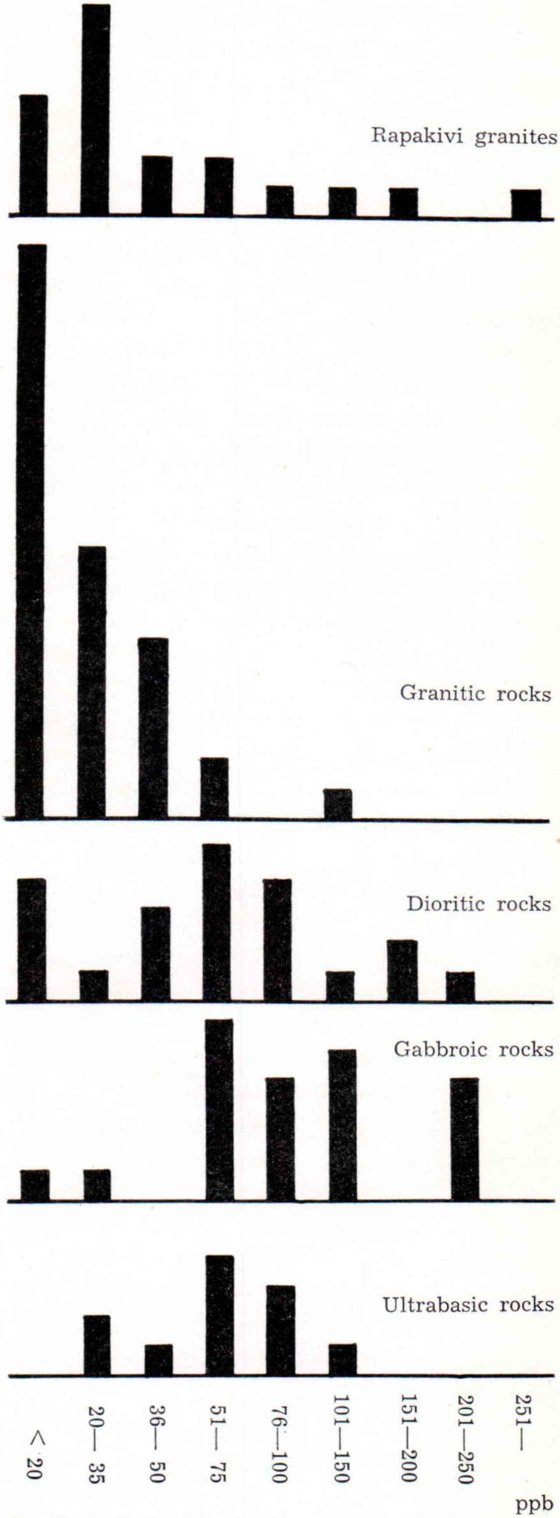

Fig. 1. Review of the selenium contents in the plutonic rocks studied (■ one sample)

constituents of such rocks are represented by amphiboles (hornblende) and/or micas (biotite-phlogopite) which are both known to be capable of incorporating a diversity of trace elements in the structure. No studies dealing with the partition of selenium between the different melanocratic rock-forming silicate minerals are, however, known to the author. The ultrabasics of the Sukkertoppen complex in West Greenland (Nos. 4—10) show a fairly narrow range of variation in their selenium content despite the considerable mineralogical diversity exhibited by these rocks. In this connexion it is worth noting that the silicate-phosphate rocks of the Siilinjärvi carbonatite complex, which contain phlogopite, amphibole or serpentine as the sole silicate constituents, (Nos. 50—54) are decidedly more rich in selenium than the carbonate-apatite rocks of the same complex (Nos. 55—58).

A very pronounced feature in the distribution of selenium among the rock groups of Fig. 1 is its improverishment in the precambrian granitic rocks of Finland(excluding the rapakivi granites). In more than half of the specimens analysed the selenium content is below the limit of detection.

The data explained above seems to indicate that the behaviour of selenium in magmatic differentiation is not governed by any incorporation into the structures of the main silicate constituents. Fig. 1 can be more plausibly explained by assuming that the enrichment or depletion of selenium in a particular rock has little or nothing to do with the main silicate phases. The paramount feature of the geochemistry of selenium in the evolution of calc-alkalic magmas is apparently its incorporation in the sulphide phase in which it substitutes for sulphur. The rocks in which the sulphide phases are more abundant, as in many gabbroic rocks, are enriched in selenium. The Finnish precambrian granitic rocks are usually devoid of sulphides.

In contrast to the other granitic rocks of the Finnish precambrian studied, the selenium content of the specimens of rapakivi granite analysed varies within a more extended range. The population of the lowest concentration ranges in Fig. 1 is less pronounced for the rapakivi granites than for the other granitic rocks. This circumstance is possibly due to the fact that the rapakivi granites represent intrusions posterior to the metamorphism of the surrounding bedrock and thus have better retained their selenium content.

Hypabyssal and dyke rocks

The selenium contents of the hypabyssal and dyke rocks analysed are summarised in the histogram of Fig. 2. The following specimens have been included in this figure:

Various dyke rocks	Nos. 129—145
Pegmatites and aplitic veins	146—167
Acid porphyries	168—175

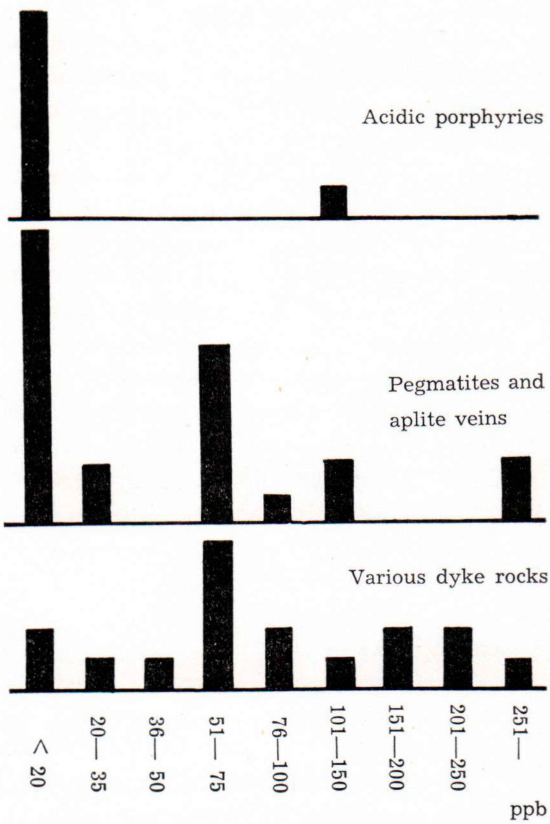

Fig. 2. Review of the selenium contents in the hypabyssal and dyke rocks studied (■ one sample)

The specimens of the acidic porphyries analysed belong to the suite of the rapakivi granites and represent porphyritic dykes cutting the rapakivi itself. It is interesting to note that these porphyries are strongly depleted in selenium (Fig. 2), even more so than the »granitic rocks» of Fig. 1. This depletion is remarkable because the rapakivi granites, the host of the porphyries, show a tendency to contain more selenium than the other granitic rocks of the Finnish Precambrian. The porphyry dykes apparently offered more or less open channels along which selenium was able to escape. The only high-selenium porphyry in Fig. 2 (No. 168 in Table 1) represents the glassy margin of a dyke the core of which (No. 169) is devoid of selenium. The margin probably was chilled and consolidated sufficiently rapidly to retain the selenium.

On the other hand, the pegmatites and the aplitic veins studied display a frequency pattern (Fig. 2) which resembles that of the rapakivi granites. The data seems to confirm the known tendency of selenium to become enriched in pegmatitic and hydrothermal crystallizations of a granitic magma.

The various dyke rocks comprise lamprophyres, diabases, plagioclase porphyries etc. mainly from the Finnish Precambrian. Judging from the field relations none of these dyke rocks (excluding No. 144) are genetically connected with the rapakivi granites. The dyke rocks are often remarkably enriched in selenium, especially the lamprophyres and the olivine-free diabases. The range of variation of the selenium content is, however, quite variable and the histogram of Fig. 2 exhibits a rather evenly distributed frequency pattern.

Volcanic rocks

The volcanic rocks studied originate from Iceland and consist of lavas and pyroclastics. Two main groups are distinguished and the selenium contents presented in the histograms of Fig. 3:

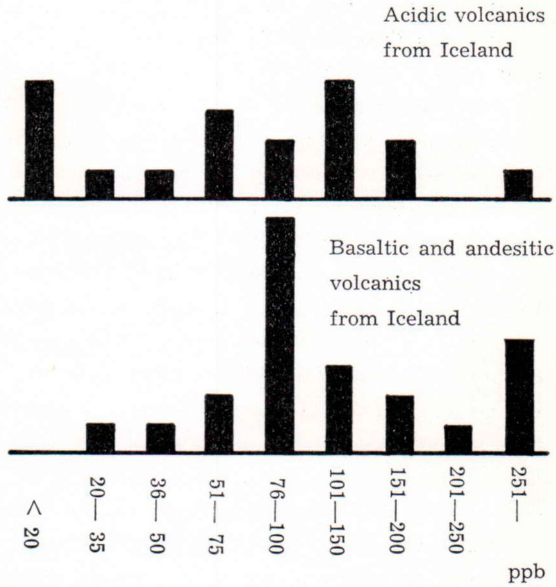

Fig. 3. Review of the selenium contents in the volcanic rocks studied (■ one sample)

Basaltic-andesitic volcanics	Nos. 176—195; 211—212
Acidic volcanics	197—210; 213—216

The difference between the frequency patterns of these two groups is considerably less pronounced than that between those of the deep-seated granitic and gabbroic rocks of the Finnish precambrian. The rhyolites (Nos. 197—200) show relatively high values for selenium, higher than most of the obsidians analysed (Nos. 202—207), and especially higher than the rhyolitic ashes (Nos. 213—216). The selenium contents of the basalts (and andesites) show wide variation with only a few examples, however, in the lowest concentration range. In contrast to the rhyolitic ashes, the two specimens of basaltic ash (Nos. 211—212) show very high values for selenium.

It seems possible that the selenium content in these volcanics is, to a considerable extent, contained in the vesicles of the rock. This possibility is indicated by specimen No. 182 (130 ppb Se) which is highly vesicular compared with specimen No. 188 (78 ppb Se) which represents a compact and dense variety of the same lava.

Another example is represented by specimen No. 202 (280 ppb Se), a highly vesicular core of an obsidian vein, compared with specimen No. 207 (selenium not detected) which represents a dense and glassy margin of the same vein.

The enrichment of selenium in the volcanic exhalations is demonstrated by specimen No. 177 (360 ppb Se), a basaltic lava collected in the immediate vicinity of an active vent and burned red by the escaping gases. Specimen No. 218 (3 700 ppb Se) of sulphur from a hot spring and specimens Nos. 219—220 (860 and 260 ppb Se, respectively) represent further examples illustrating the enrichment of selenium in the exhalative crystallizations.

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Mr. Olavi Y. Nurminen assisted me in handling the samples and Mr. Urpo Eklund drew the histograms.

Mr. John Nelson, Lic. Tech., checked the language of the English manuscript.

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Finally, I would like record my warm appreciation to my wife, Ritva, for her patience and support during the various laborious phases of my work.

TABLE 1.

Selenium contents of the igneous rocks

No.	Rock and locality	Selenium content ppb
	Ultrabasic rocks	
1	Peridotite, porphyritic. Orimattila, Mallusjoki, Finland (Laitakari and Simonen 1962; Laitakari and Simonen 1963, 19, Anal. 2)	104
2	Peridotite. Mäntsälä, Soukkio, Finland (Kaitaro 1956)	70
3	Peridotite. Pihlajavesi, Finland (Marmo 1963 b, 26, Anal. 1)	34
4	Olivinite, hyperstehene-and chromite-bearing. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 47—50)	75
5	Olivinite, tremolite- and phlogopite-bearing. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 39—47)	72
6	Olivinite, chromite-bearing. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 39—47)	40
7	Dunite. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 26—38)	95
8	Dunite, metamorphosed to tremolite-antigorite rock. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 36—38)	98
9	Pyroxenite. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 11—14)	75
10	Pyroxenite, anortite-bearing. Sukkertoppen, Itipilua, Greenland (Väisänen 1967, 11—14)	90
11	Hornblendite. Pihtipudas, Mäntymäki, Finland (Nykänen 1963, 21, 35, Anal. 1)	34
	Gabbros	
12	Gabbro. Hyvinkää, Finland (Hackman 1905, 55; Kaitaro 1956)	230
13	Gabbro. Hyvinkää, Finland (Hackman 1905, 55; Kaitaro 1956)	215
14	Gabbro. Kemiö, Rosendal, Finland (Seitsaari 1955; Härme 1958 b; and 1960, 26)	210
15	Gabbro. Kuru, Syvälänkylä, Finland (Matisto 1960)	200
16	Gabbro. Snæfellsnes, Setberg, Kolgrafajördur, Iceland (Sigurdsson 1966)	135
17	Quartz gabbro. Pyhäjoki, Finland (Salli 1965, 22—27)	104
18	Pyroxene gabbro. Virrat, Kotala, Finland (Marmo 1965 a; and 1965 b, 33—35)	104
19	Gabbro. Hyvinkää, Kytäjä, Finland (Härme 1953, 20—22)	99
20	Gabbro. Hyvinkää, Usmi, Finland (Kaitaro 1956; Härme 1958 b; and 1960, 26, 61)	98
21	Olivine gabbro. Pihtipudas, Mäntymäki, Finland (Nykänen 1962; and 1963, 21, 35, Anal. 2)	87
22	Hornblende gabbro, near the contact against gneiss. Kangaslampi, Rauhamäki, Finland (Kurki 1964, 17—31)	82
23	Gabbro. Mäntsälä, Soukkio, Finland (Kaitaro 1956)	58
24	Gabbro. Mäntsälä, Soukkio, Finland (Kaitaro 1956)	58
25	Norite. Kinnula, Kivijärvi, Finland (Nykänen 1963, 17—20)	52
26	Gabbro, leucocratic. Snæfellsnes, Lýsuskard, Iceland (Sigurdsson 1966)	n.d.
	Anorthosites	
27	Anorthosite gabbro. Pihtipudas, Mäntymäki, Finland (Nykänen 1963, 21, 35, Anal. 3)	140
28	Anorthosite. Pertunmaa, Haapasaari, Finland (Savolahti 1956, 19—29; and 1966, 173—197)	130
29	Anothosite gabbro. Karjaa, Mustio, Hållsnäs, Finland (Härme 1954, 34—38, 43; and 1960, 26)	69
30	Anorthosite. Kemi, Finland (Näykki 1964, 59—65, Anal. 15)	69
31	Anorthosite, partly saussuritized. Kemi, Finland (Näykki 1964, 59—65, Anal. 16)	34
32	Bytownitite. Ylämaa, Tervalainen, Finland (Wahl 1925, 15—21; Rankama 1944, 32)	72
	Diorites	
33	Diorite, cummingtonite-bearing. Petäjävesi, Vanha Puttola, Finland (Rouhunkoski 1959, 61—64)	228
34	Diorite, cummingtonite-bearing. Petäjävesi, Puttola, Finland (Rouhunkoski 1959, 61—64)	176
35	Diorite. Siilinjärvi, Finland (Puustinen 1968, 15—17; 1969, 90; and 1971)	120
36	Diorite. Jyväskylä, quarry near Pohjanlahti, Finland (Frosterus 1900; and 1903, 102; Hall 1936, 78)	90
37	Diorite. Keuruu, Haapamäki, Finland (Marmo 1963 a; and 1963 b, 28, Table VI, 30—32, Anal. 2)	52
38	Quartz monzodiorite. Keuruu, Lihjamo, Finland (Marmo 1963 a; 1963 b, 30—32, Table IX, Anal. 3)	52
39	Diorite. Siilinjärvi, Särkilampi, Finland (Puustinen 1968, 15—17; 1969, 90; and 1971)	n.d.
	Monzonite	
40	Monzonite. Brändö, Åva, Finland (Kaitaro 1953, 13—31)	104
	Syenitic rocks, Siilinjärvi, Finland	
41	Syenite. Pahkalampi (Puustinen 1968, 62—68; 1969; and 1971, 29—31)	33
42	Syenite. Kuuslahti (Puustinen 1968, 62—68; 1969; and 1971, 29—31)	20
43	Syenite (unakite). Kuuslahti (Puustinen 1968, 62—68; 1969; and 1971, 29—31)	n.d.
44	Syenite. Siilinjärvi railway cut (Puustinen 1968, 62—68; 1969; and 1971, 29—31)	n.d.
45	Syenite. Asikkala (Puustinen 1968, 62—68; 1969; and 1971, 29—31)	n.d.
46	Melasyenite. Pahkalampi (Puustinen 1968, 74—75; 1969; and 1971, 29—31, 34, Anal. 1)	n.d.
	Alkali rocks of Iivaara, Finland	
47	Ijolite. Kuusamo (Lehijärvi 1960, 32—35)	40
48	Ijolite. Kuusamo (Lehijärvi 1960, 32—35)	30
49	Melteigite. Kuusamo (Lehijärvi 1960, 35—38)	25
	Carbonatite complex of Siilinjärvi, Finland	
50	Serpentine rock. Pahkalampi (Puustinen 1969; and 1971, 25)	107
51	Phlogopite rock. Särkilampi (Puustinen 1969; and 1971, 23—24)	132
52	Phlogopite-apatite rock. Särkilampi (Puustinen 1969; and 1971, 19, 23—24)	164
53	Amphibole rock. Särkilampi (Puustinen 1969; and 1971, 19)	84
54	Apatite-phlogopite rock. Särkilampi (Puustinen 1969; and 1971, 14—19, 23—24)	72
55	Carbonate-apatite rock. Särkilampi (Puustinen 1969; and 1971)	37
56	Carbonate-apatite rock. Särkilampi (Puustinen 1969; and 1971)	n.d.
57	Carbonate rock. Särkilampi (Puustinen 1969; and 1971, 21—23)	n.d.
58	Carbonate rock. Särkilampi quarry (Puustinen 1969; and 1971, 21—23)	n.d.
	Quartz diorites	
59	Quartz diorite. Kalajoki, Finland (Salli 1955; and 1961, 33—34, 45)	87
60	Quartz diorite, porphyritic. Lappeenranta, Lappee, Saikkola, Finland (Vorma 1964; and 1965, 27—35, 67)	86
61	Quartz diorite. Ylöjärvi, Ylinen, Finland (Simonen 1952, 30)	80
62	Quartz diorite. Kivijärvi, Finland (Nykänen 1963, 21—25)	52
63	Quartz diorite. Lavia, Finland (Huhma, Salli and Matisto 1952 a; and 1952 b, 31—38)	40
	Granodiorites	
64	Granodiorite, porphyritic, contains xenoliths. Nokia N-side, Finland (Matisto 1961; 1962, 118—120; and 1968, 7)	190
65	Granodiorite. Järvenpää, Vanhakylä, Finland (Härme 1965, 7—11)	56
66	Granodiorite. Kinnula, Kontumäki, Finland (Nykänen 1963, 25—28)	52
67	Granodiorite. Haapajärvi, Latvainen, Finland (Salli 1963)	50
68	Granodiorite. Kivijärvi, Finland (Nykänen 1962; and 1963, 25—28)	43
69	Granodiorite. Nurmijärvi, Palojoki, Finland (Härme 1958 a)	20
70	Granodiorite. Kerava, Yli-Kerava, Kaskela, Finland (Härme 1958 a)	n.d.
71	Granodiorite. Teisko, Värmälä, Finland (Seitsaari 1951, 77—80)	n.d.

No.	Rock and locality	Selenium content ppb
72	Granodiorite, contains quartz veins. Hyvinkää, Finland (Härme 1958 b; and 1960, 27—30)	n.d.
	Granites	
73	Orbicular granite. Kuru, Parkusjärvi, Finland (Simonen 1966)	126
74	Granite. Suomenniemi, Finland (Frosterus 1900; and 1903, 41—42; Simonen and Tyrväinen 1965)	72
75	Granite. Kuopio, Neulamäki, Finland (Preston 1954, 64—81)	51
76	Granite, porphyritic. Kalajoki, Mehtäkylä, Finland (Salli 1961, 34, 46)	46
77	Granite, »Kakola-granite», contains cordierite and garned porphyroblasts. Lemu, Järäinen, Finland (Hietanen 1947, 1073—1078; Härme 1965, 17—19)	45
78	Charnockite. Naantali, Ukkopekka bridge, Finland (Hietanen 1947, 1032, 1035—1051)	40
79	Granite. Espoo, Bodom, Finland (Erämetsä, Sahama and Kanula 1943, 83; Rankama 1943, 37—38; and 1946; Härme 1960, 36; Marmo and Siivola 1966, 170; Härme 1969)	40
80	Granite, porphyritic. Jämsänkoski, Koskenpää, Finland (Frosterus 1903, 43—45)	37
81	Granite. Jämsänkoski, Koskenpää, Finland (Frosterus 1900; and 1903, 43—45)	37
82	Granite, porphyritic. Ylöjärvi, Kaihari, Finland (Simonen 1952, Map I)	35
83	Granite, porphyritic. Kalajoki, Mehtäkylä, Finland (Salli 1955; and 1961, 33—34)	34
84	Granite, porphyroblastic. Keuruu, Haapamäki, Finland (Marmo 1963 a; and 1963 b, 31, Anal. 6, 34—39)	34
85	Orbicular granite. Espoo, Nuuksio, Pitkäjärvi, Finland (Simonen 1941, 129—136)	30
86	Granite. Iisalmi, Paloisvuori, Finland (Wilkman 1931, 226—227)	30
87	Granite, porphyritic. Petäjävesi, Kintaus, Finland (Rouhunkoski 1959, 106—108)	26
88	Granite. Espoo, Nuuksio, Pitkäjärvi, Finland (Simonen 1941, 129—136)	20
89	Granite. Jäppilä, Finland (Wilkman 1938, 92, 113)	20
90	Trondhjemite. Uusikaupunki, Arvassalo, Finland (Hietanen 1947, 1032—1035)	20
91	Granite. Suomenniemi, Finland (Frosterus 1903, 41—42; Simonen and Tyrväinen 1965)	n.d.
92	Granite. Kuru, Niemikylä, Finland (Simonen 1952; Matisto 1960; Aurola 1967)	n.d.
93	Oligoclase granite. Kisko, Orijärvi, Finland (Eskola 1914, 40—47; Rankama 1946, 29—31, 36; Eskola 1952, 128—130; Tuominen 1957, 18, 30; and 1961, 499—515)	n.d.
94	Granite. Vihti, Olkkola, Finland (Härme 1958 a, 45—61)	n.d.
95	Granite. Nurmijärvi, Palojoki, Finland (Härme 1958 b)	n.d.
96	Granite. Petäjävesi, Kintaus, Finland (Rouhunkoski 1959, 106—108)	n.d.
97	Granite. Petäjävesi, Kintaus, Finland (Rouhunkoski 1959, 106—108)	n.d.
98	Granite. Petäjävesi, 1 km W from railway station, Finland (Rouhunkoski 1959, 94—102)	n.d.
99	Granite. Petäjävesi, Pitkälä, Finland (Rouhunkoski 1959, 94—102)	n.d.
100	Granite (»Tirilitic»). Petäjävesi, 1 km W from railway station, Finland (Rouhunkoski 1959, 71—90, 94—102; Marmo and Siivola 1966, 170)	n.d.
101	Granite (»Tirilitic»). Petäjävesi, Koskensaari, Finland (Rouhunkoski 1959, 71—90; Marmo and Siivola 1966, 170)	n.d.
102	Granite, monzonitic. Keuruu, Finland (Marmo 1963 a; and 1963 b, 34—39, Table XII)	n.d.
103	Granite. Pihtipudas, Alvajärvi, Finland (Nykänen 1962; and 1963, 29—31)	n.d.
104	Granite. Hämeenkyrö, Komi, Mattila, Finland (Stigzelius 1944, 38—42; Simonen 1952, 35)	n.d.
105	Granite. Hämeenkyrö, Komi, Mattila, Finland (Stigzelius 1944, 38—42; Simonen 1952, 35)	n.d.
106	Granite, tourmaline-bearing. Kiihtelysvaara, Raatevaara, Pölkkylampi, Finland (Frosterus and Wilkman 1916, 137—138)	n.d.
107	Granite. Kaavi, Maarianvaara, Finland (Frosterus and Wilkman 1916, 128—136; Sahama and Vähätalo 1941, 67; Erämetsä, Sahama and Kanula 1943, 83; Rankama 1946, 29, 33, 36)	n.d.
108	Granite. Tuusniemi, Maarianvaara, Finland (Frosterus and Wilkman 1916, 128—136; Sahama and Vähätalo 1941, 67; Erämetsä, Sahama and Kanula 1943, 83; Rankama 1946, 29, 33, 36)	n.d.
109	Granite, aplitic. Kalajoki, Finland (Salli 1955; and 1961, 34)	n.d.
	Rapakivi granites	
110	Rapakivi, syenitic. Lappeenranta, Lappee, Armila, Finland (Wahl 1925, 71—73; Hackman 1934, 17—24; Vorma 1965)	250
111	Viborgite. Vehkalahti, Finland (Rankama 1946, 37)	180
112	Viborgite. Lapinjärvi, Finland (Laitakari and Simonen 1962; and 1963, 26—31, Table III, Anal. 2)	103
113	Rapakivi. Lappeenranta, Sinkkola, Finland (Wahl 1925; Hackman 1934, 24—25)	80
114	Biotite rapakivi, near the contact to gneiss. Mäntyharju, Ahvenisto, Finland (Savolahti 1956, 47—49)	73
115	Biotite rapakivi. Suomenniemi, Finland (Pipping 1956, 5—10)	60
116	Biotite rapakivi. Heinola, Ahvenisto, Finland (Savolahti 1956, 47—49)	44
117	Biotite rapakivi, near granite porphyry. Heinola, Kukkamäki, Finland (Savolahti 1956, 47—49)	36
118	Pyterlite. Liljendal, Finland (Laitakari and Simonen 1962; and 1963, 26—31, Table III, Anal. 3)	32
119	Hornblende rapakivi. Suomenniemi, Finland (Pipping 1956, 11—13)	30
120	Viborgite. Artjärvi, Pyhäjärvi, Finland (Laitakari and Simonen 1963, 26—27)	30
121	Rapakivi, even-grained. Pernaja, Koskenkylä, Finland (Laitala 1964)	30
122	Rapakivi, even-grained. Lapinjärvi, Finland (Laitakari and Simonen 1962; and 1963, 29—30)	27
123	Viborgite, dark. Kotka, Langinkoski, Finland (Vorma 1961, 399—400)	23
124	Rapakivi, even-grained. Vehmaa, Finland (Kanerva 1928; Hietanen 1943, 63—66)	20
125	Hornblende rapakivi. Suomenniemi, Finland (Pipping 1956, 11—13)	19
126	Tirilite. Lappeenranta, Tirilä, Finland (Wahl 1925, 69—71; Hackman 1934, 27—32)	n.d.
127	Rapakivi, even-grained, small-grained. Lappeenranta, Tyysterniemi, Finland (Vorma 1965, 43, 49)	n.d.
128	Rapakivi, even-grained. Kalanti, Finland (Kanerva 1928; Hietanen 1943, 63—66)	n.d.
	Lamprophyres	
129	Minette. Brändö, Åva, Finland (Kaitaro 1953, 31—47)	360
130	Quartz kersantite. Kuopio. Petosenmäki, Finland (Hackman 1914; Wilkman 1938, Plate I)	210
131	Kersantite. Parainen, Timmerkärr, Finland (Härme 1960, 34—35)	71
	Diabases	
132	Diabase. Siilinjärvi, Asikkala, Finland (Puustinen 1968, 82)	210
133	Diabase. Helsinki, Pitäjänmäki, Finland (Härme 1960, 34—35)	200
134	Metadiabase. Tohmajärvi, Finland (Nykänen 1967)	170
135	Diabase. Siilinjärvi, Kuuslahti, Finland (Puustinen 1968, 82)	110
136	Diabase. Salla, Jokinenä, Finland (Lauerma 1967)	87
137	Olivine diabase. Eurajoki, Finland (Laitakari 1925, 17—20; Kahma 1951, Plate V)	69
138	Olivine diabase. Heinola, Ahvenisto area, Finland (Savolahti 1956, 41—46; Laitakari 1969, 22—24)	24
	Albite diabase	
139	Albite diabase. Alatornio, Finland (Härme 1949, 13—14; Mikkola 1949, 29—30; Meriläinen 1961)	69
	Trachyandesite (keratophyre)	
140	Trachyandesite (quartz keratophyre). Ylöjärvi, from Mastojärvi to E., Kiviniemi, Finland (Simonen 1952, 66—67, Anal. 14)	81
	Plagioclase porphyrites	
141	Plagioclase porphyrite. Pernaja, Runholm, Finland (Laitakari and Simonen 1963)	62
142	Plagioclase porphyrite. Ylöjärvi, Antaverkka, Finland (Simonen 1952, 20—22)	60
143	Plagioclase porphyrite. Pernaja, Koskenkylä, Finland (Laitakari and Simonen 1963, 13—17, Table I, No. 1)	50
	Felspar porphyry	
144	Felspar porphyry. Espoo, Finland	n.d.

No.	Rock and locality	Selenium content ppb
	Granophyre	
145	Granophyre, olivine-bearing, in basalt. Snæfellsnes, Laxá, Iceland (Sigurdsson 1966, 77—79)	n.d.
	Pegmatites	
146	Pegmatite. Mikkeli, Koskentaipale, Finland (Frosterus 1900; and 1903)	110
147	Pegmatite, contains abundantly biotite. Helsinki, Tikkurila, Finland (Härme 1969)	80
148	Pegmatite. Petäjävesi, 1 km W from railway station, Finland (Rouhunkoski 1959, 101—102)	72
149	Pegmatite. Porvoo, Suurpellinki, Finland (Laitala 1965)	69
150	Pegmatite. Petäjävesi, Kintaus, Finland (Rouhunkoski 1959, 101—102)	56
151	Pegmatite. Suomenniemi area, Finland (Pipping 1956)	55
152	Pegmatite. Peräseinäjoki, Haapaluoma, Finland (Haapala 1966; Lappalainen and Neuvonen 1968, 61)	52
153	Pegmatite. Siilinjärvi, Asikkala, Finland (Puustinen 1968, 16—17)	18
154	Pegmatite. Vimpeli, Koivujärvi, Finland (Saksela 1934)	n.d.
155	Pegmatite. Vihti, Olkkola, Finland (Härme 1960, 45—47)	n.d.
156	Pegmatite. Mäntsälä, Soukkio, Finland (Kaitaro 1956)	n.d.
157	Pegmatite. Järvenpää, Vanhakylä, Finland (Härme 1969)	n.d.
158	Pegmatite. Kuhmoinen, Finland (Seitsaari 1955; Lappalainen and Neuvonen 1968, 61)	n.d.
159	Pegmatite. Helsinki, Malmi, Kivikko, Finland (Härme 1969)	n.d.
160	Quartz pegmatite. Suomenniemi area, Finland (Pipping 1956)	n.d.
161	Quartz pegmatite. Suomenniemi area, Finland (Pipping 1956)	n.d.
	Aplitic vein rocks	
162	Aplitic vein in quartzite. Kiihtelysvaara, Heinävaara, Finland (Frosterus and Wilkman 1916, 81—84)	290
163	Aplitic vein. Kuopio, Neulamäki, Finland (Preston 1954, 73—75)	285
164	Quartz vein in mica schist. Kiihtelysvaara, Heinävaara, Finland (Frosterus and Wilkman 1916, 100—102)	102
165	Siliceous vein in kinzigite, contains cordierite. Helsinki, Käpylä, Taivaskallio, Finland (Laitala 1967)	68
166	Aplitic vein. Kuopio, Jynkänlahti, Finland (Preston 1954, 73—75)	29
167	Siliceous vein in cordierite gneiss. Helsinki, Viinikkala, Finland (Härme 1969)	20
	Acid porphyries	
168	Quartz porphyry, glassy margin. Hamina, Huutokallio, Finland	125
169	Quortz porphyry, middle part. Hamina, Huutokallio, Finland	n.d.
170	Granite porphyry. Lappeenranta, Tyysterniemi, Finland (Vorma 1965, 42—45)	n.d.
171	Granite porphyry. Heinola, Ahvenisto area, Finland (Savolahti 1956, 50—51)	n.d.
172	Granite porphyry. Heinola, Ahvenisto area, Finland (Savolahti 1956, 50—51)	n.d.
173	Porphyry aplite. Suomenniemi area, Finland (Pipping 1956)	n.d.
174	Porphyry aplite. Suomenniemi area, Finland (Pipping 1956)	n.d.
175	Porphyry aplite. Artjärvi, Finland (Laitakari and Simonen 1963 31, 44)	n.d.
	Volcanic rocks from Iceland	
176	Basalt, tholeiitic, 2600 years old. Snæfellsnes, Raudamelskúlúr (Sigurdsson 1966)	650
177	Basalt, burned red, near a small vent. Mývatn, Skútustadir (Rittman 1938; Thorarinsson 1953 a; Thorarinsson, Einarsson and Kjartansson 1959, Fig. 13)	360
178	Basalt, pahoehoe lava, tholeiitic, year 1961. Askja (Thorarinsson and Sigvaldason 1962, 641—651; Heier, Chappell, Arriens and Morgan 1966, 427—437; Edelman 1969, 45)	200
179	Basalt, altered, contains pyrite, Pleistocene. Snæfellsnes, Lýsuskard (Sigurdsson 1966)	180
180	Basaltic pillow lava, porphyritic. Askja, Öskjuvatn (Thorarinsson and Sigvaldason 1962, 641; Heier, Chappell, Arriens and Morgan 1966, 427—437)	150
181	Basalt, Recent. Snæfellsnes, Háahraun (Sigurdsson 1966)	130

No.	Rock and locality	Selenium content ppb
182	Basalt. Grænavatn (Thorarinsson 1953 a; Tryggvason 1960; Kjartansson 1960; Jónsson 1965)	130
183	Basalt, olivine-bearing, 2600 years old. Snæfellsnes, Raudamelskúlúr (Sigurdsson 1966)	100
184	Basalt, Aa-lava. Mývatn, Reykjahlíd, Jörundur (Thorarinsson 1951, 12—14)	88
185	Basalt, altered partly to clay minerals. Akyreyri, Valagil (Thorarinsson, Einarsson and Kjartansson 1959)	85
186	Basalt. Fostastadavatn (Kjartansson 1962)	83
187	Basalt, chlorite-bearing, hydrothermaly altered. Setberg, Grund (Sigurdsson 1966)	78
188	Basalt, dense. Grænavatn (Kjartansson 1960; Jónsson 1965)	78
189	Basalt, 5 cm from contact against an obsidian vein (No. 207), Tertiary. Varmaland, Hraunfossar (Thorarinsson, Einarsson and Kjartansson 1959)	76
190	Basalt, olivine-bearing, columnar flow, 2 m thick. Snæfellsnes, Grísholsa (Sigurdsson 1966)	70
191	Ankaramite. Skógar, Hvammsmúli, Pöst (Kjartansson 1960; Steinhorsson 1964)	65
192	Basalt, pillow lava (under No. 190). Snæfellsnes, Grísholsa (Sigurdsson 1966)	37
193	Andesite. Snæfellsnes, Drápuhlídarfjall (Sigurdsson 1966)	215
194	Hyperstehne andesite. Mývatn, Hverfjall (Thorarinsson, Einarsson and Kjartansson 1959, Fig. 13)	83
195	Andesite (»Icelandite»). Snæfellsnes, Háahraun (Sigurdsson 1966, 121)	20
196	Trachyte. Landmannalaugar (Kjartansson 1962; Thorarinsson 1968)	79
197	Rhyolite spherulitic. Snæfellsnes, Drápuhlídarfjall (Sigurdsson 1966; Walker 1966)	195
198	Rhyolite. Snæfellsnes, Drápuhlídarfjall (Sigurdsson 1966; Walker 1966)	160
199	Rhyolite, layer in basalt. Varmaland, Hraunfossar (Walker 1966)	120
200	Rhyolite. Snæfellsnes, Lýsuskard (Sigurdsson 1966)	120
201	Pumice. Near Askja, Viti eruption year 1875 (Thorarinsson and Sigvaldason 1962, 642; Heier, Chappell, Arriens and Morgan 1966, 427—437; Edelman 1969, 46)	112
202	Obsidian with flow texture, contains abundantly vesicles. Varmaland, Hraunfossar (Walker 1966)	280
203	Obsidian Mývatn, Skútustadir (Thorarinsson and Kjartansson 1959, Fig. 13; Walker 1966)	120
204	Obsidian. Frostastadavatn (Kjartansson 1962; Walker 1966)	85
205	Obsidian. Snæfellsnes, Drápuhlídarfjall (Sigurdsson 1966; Walker 1966)	82
206	Obsidian. Landmannalaugar (Kjartansson 1962; Walker 1966; Thorarinsson 1968)	44
207	Obsidian, glassy contact to basalt (No. 189). Varmaand, Hraunfossar (Walker 1966)	n.d.
208	Ignimbrite. Thórsmörk (Thorarinsson 1969, 139—154)	n.d.
209	Ignimbrite. Thórsmörk (Thorarinsson 1969, 139—154)	n.d.
210	Agglomerate, rhyolitic. Snæfellsnes, Setberg, Hrafnagil (Sigurdsson 1966)	54
211	Basaltic ash, 10 000 years old. Akyreyri (Thorarinsson, Einarsson and Kjartansson 1959, Fig. 10)	630
212	Basaltic ash, 500 years old. Akyreyri (Thorarinsson, Einarsson and Kjartansson 1959, Fig. 10)	390
213	Rhyolitic ash, Hekla III. Akyreyri (Thorarinsson 1953 b; Thorarinsson, Einarsson and Kjartansson 1959, Fig. 10)	63
214	Rhyolitic ash. Akyreyri (Thorarinsson, Einarsson and Kjartansson 1959, Fig. 10)	52
215	Rhyolitic ash. Askja (Thorarinsson and Sigvaldason 1962)	23
216	Rhyolitic ash. Thórsmörk (Thorarinsson 1969, 139—154)	n.d.
217	Tuff, chloritized. Landmannalaugar (Kjartansson 1962; Thorarinsson 1968)	26
218	Sulphur, hot spring. Grænavatn (Kjartansson 1960; Jónsson 1965)	3 700
219	Geyserite. Great Geysir (Kjartansson 1960)	860
220	Opal. Snæfellsnes, Setberg (Sigurdsson 1966)	260
221	Travertine. Snæfellsnes, Lýsuskard (Sigurdsson 1966)	105
	Miscellaneous	
222	Iron ore. Kemijärvi, Otanmäki, Misi, Finland (Nuutilainen 1968)	n.d.
223	Barite rock. Meggen, West Germany	n.d.

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