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THE AVERAGE COMPOSITION OF THE EARTH'S CRUST IN FINLAND

BY

J. J. SEDERHOLM

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* Epuiseé.

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IMPRIMÉRIE DE L'ÉTAT

INTRODUCTION.

Some years ago the present writer endeavoured to arrive at a computation of the average composition of the earth's crust within the borders of Finland. For this purpose the areas occupied by rocks of different chemical composition were measured on the map, and their average composition determined with the aid of all the reliable analyses [1] known. With these data at hand, it was easy to determine the average composition of the bulk of all rock masses, supposing that the quantity of each rock was directly proportional to its area on the map. We shall later discuss how far this assumption is correct.

These measurings on the map and the calculations were made by the assistant geologist Mr J. N. Soikero to whom my thanks are due for the interest he took in this work.

In determining the areas of the rocks the general petrographical map of Finland compiled by me in the year 1910 on a scale of 1 : 2,000,000 was used. At that time, however, 10.8 per cent of the total area of the country (362,224 km^2) had not yet been surveyed in detail. Moreover, 21.8 per cent of the mapped areas were found to consist of migmatitic rocks with a varying composition which therefore had to be left out of consideration. The area for which the calculation was made comprised 244,876 km^2, or 68.4 % of the pre-war area of Finland.

It was my intention to publish these data in connection with other scientific studies which were, however, hampered by many adverse circumstances.

Now that almost all the territory of Finland, augmented by the addition of 11,036 km^2 on the coast of the Arctic Ocean, has been surveyed, and new analyses have been added, it will be possible to make a determination which is more conclusive. Its result would, however, probably not differ very much from that at which I have arrived. I therefore publish here these data, which may be of preliminary service pending a future more accurate determination.

[1] In so doing I did not think it necessary to apply the very highest standard, as I believe there are other sources of error which play a much more considerable role than small discrepancies in some figures in the analyses. The minor constituents other than P_2O_5 and CO_2, have here been left out of consideration.

For the present purpose, the crystalline rocks of the area of Finland surveyed may be conveniently classed into the seven main groups which are named below, with figures showing the percentages of the area which they occupy in the territory mapped.

Granitic rocks	52.5 %
Migmatites	21.8 »
Granulites (leptynites)	4.0 »
Schists	9.1 »
Quartzites and sandstones	4.3 »
Limestones and dolomites	0.1 »
Basic rocks	8.2 »
	100.0 %

Here follow the data on which the calculations have been based.[1]

Table I.

	Rapakivi granites	Post-Kalevian (post-Jatulian?) granites	Post—Bothnian granites of southern Finland	Post—Bothnian granites, syenites &c. of Ostrobothnia	Average of all "Post—Bothnian granites," (the pre-Kalevian granites incl.)	"Older granites"	Granulite (leptynite)	Schists	Sandstones and quartzites	Limestones and dolomites	Basic rocks
Area km[2] ..	18,923	33,575	—	—	60,166	53,304	12,480	26,947	13,625	305	25,425
Per cent of the total area	6.0	10.7	—	—	19.0	16.7	4.0	9.1	4.3	0.1	8.2
SiO_2	72.57	70.87	72.34	64.51	67.12	66.34	76.93	67.77	80.76	—	51.48
TiO_2	0.25	0.33	0.26	0.55	0.45	0.54	0.21	0.31	—	—	0.70
Al_2O_3	12.62	14.50	14.31	16.35	15.66	15.63	12.14	16.30	6.24	0.16	15.93
Fe_2O_3	1.45	0.74	0.72	1.49	1.23	0.99	0.55	} 3.55	2.15	—	3.66
FeO	2.41	1.83	1.40	3.28	2.65	3.55	4.78	}	1.05	—	6.97
MnO	0.02	0.05	0.01	0.01	0.01	0.07	—	0.02	0.02	—	0.14
MgO	0.46	0.63	0.50	1.72	1.31	1.79	1.12	1.82	0.68	8.27	7.01
CaO	1.34	1.81	1.51	3.80	3.04	3.72	1.39	2.47	1.55	43.71	9.49
Na_2O	2.30	3.04	3.09	4.34	3.92	3.69	2.26	2.66	0.84	—	2.39
K_2O	6.10	4.98	5.13	3.08	3.76	3.02	3.69	3.80	1.71	—	1.08
P_2O_5	0.02	0.11	0.04	0.01	0.02	0.18	—	0.05	0.64	—	0.12
H_2O	0.49	0.73	0.61	0.86	0.78	0.60	0.27	0.80	1.80	—	0.88
CO_2	—	0.01	—	—	—	—	—	0.02	1.05	43.51	—
	100.03	99.63	99.92	100.00	99.95	100.12	101.34	99.97	98.49	99.62	99.95

[1] Cf. Victor Hackman, Die chemische Beschaffenheit von Eruptivgesteinen Finlands und der Halbinsel Kola, im Lichte des neuen amerikanischen Systemes. Bull. Comm. géol. Finl. N:o 15. 1905.

RAPAKIVI GRANITES.

The average composition of the rapakivi granites (Table I, Column 1) has been calculated on the basis of 9 analyses. As most of them are good, and the chemical composition of these granites is rather uniform, the average will probably not be very materially altered by the addition of more analyses. These rocks are characterized by their high contents of SiO_2 and K_2O and low content of MgO, Al_2O_3 and CaO.

"POST-KALEVIAN" (POST-JATULIAN?) GRANITES.

The granites which are designated on the map as post-Kalevian (Table I, Column 2) and which Mäkinen and others regard as younger even than the Jatulian, have in northern Finland a composition not very different from that of the rapakivi granites, although with a somewhat higher amount of Al_2O_3 and a lower of iron oxides. The grey granites (Lassenoses according to the C. I. P. W. classification) of eastern Finland referred to the same group, have a lower percentage of K_2O and a higher of Na_2O and CaO, which changes the average. As the whole number of analyses is only six, the average is still uncertain, but the question is only whether their composition will be nearer to that of the rapakivi granites or that of the older granitic rocks which are slightly more granodioritic.

POST-BOTHNIAN GRANITES.

Among the granites which are designated as post-Bothnian on the map, two different chemical types occur. In the southern part of the country granites are common of which the Hangö and Perniö granites are typical. They are Toscanoses with occasional variations into rocks richer in soda, Lassenoses, according to the C. I. P. W. classification. All these rocks run high in silica, and their average composition is shown by Table I, Column 3. Although only 5 analyses were available, the rather uniform chemical character of these rocks makes it probable that these analyses give a good idea of their chemical type. The migmatitic character of many of them makes it difficult, in any case, to determine their composition quite exactly.

In other areas, again, where these post-Bothnian granites prevail, they have a more unstable chemical character, and often grade into rocks nearing diorites, or monzonites. Such is the case in the regions in northwestern Finland (Ostrobothnia) investigated by Mäkinen, who has made 10 analyses of these rocks with the average given in Table I, Column 4. For the whole group of rocks classified as post-

Bothnian on the map, an average between these two results (Table I, Column 5) has been used.

The same average has also been used for those granites of northern Finland which are designated on the map as »pre-Kalevian granites». Including them, this group would cover an area of 60,166 km^2, or 19.0 per cent of the area mapped.

OLDER GRANITES.

The rocks which were classified on the map as gneissose granites of pre-Bothnian or undetermined age, comprise on the one hand the oldest gneissose granites of eastern Finland, and on the other hand the gneissose granites of the southwest. The latter have in part now been proved to be later than the schists of Bothnian type. It is characteristic of all these rock formations, however, that granites rich in microcline are rather uncommon among them. Most of them are granites rich in oligoclase, some even grade into quartzdiorites and similar rocks. The average of 12 analyses given in Table I Column 6, is rather near to the final result for the average composition of all rocks, and also corresponds very closely to the composition of the most typical oldest granites of southwestern Finland.

As may be seen from what has been said above, the calculation of the average composition of the Archaean granites of Finland is based on unsatisfactory analytic material, and it may be inferred that this fact invalidates the final result of the calculation. It ought, however, to be remarked that the possible correction lies within the limits of the chemical variation of such rocks as have earlier been mapped as granites. As has been said, the rocks mapped as granites were not only those now stricte sensu regarded as such, but also granodiorites, quartzdiorites, quartzmonzonites and similar rocks. A more exact knowledge of the chemical composition of these rock masses is dependent not only on additional analyses, but also on a revisional survey of regions mapped at a time when petrographical determinations were less exact. In any case, it does not seem probable that such a revision of some portions of the granitic areas would materially alter the final result of the calculations. If we compare the average of all the granites of Finland, according to this calculation [1], with the average computed by Daly [2] for the Pre-Cambrian granites of Sweden

[1] For convenience only the average of the five averages has been taken, irrespectively of the number of analyses which they represent. The difference caused by using any other method would be slight. A final average for all the granites of Finland can only be given when more analyses are available, and with due reference to the areas which they represent.

[2] R. A. Daly, Igneous Rocks and their Origin. New-York London 1914, p. 19.

according to Holmquist, and with that of granites of all periods according to Osann and Clarke, (Table II) we find only slight differences. The MgO content is higher [1], that of CaO lower, that of potash a trifle higher in the Finnish than in the other averages. But if we should use any of them instead of our average, that would not materially change the final result. There are other sources of error much more important than these slight differences in the figures for the granites.

MIGMATITES.

The *migmatites* are of very varying age and also composition. In most cases they consist of an intimate mixture of schists and granites of different ages. The granitic migmatites, however, of the regions adjacent to the coast of the Gulf of Finland, mainly consist of granites rich in microcline containing more or less completely assimilated fragments of older rocks, many of them also originally granitic, or granodioritic. Their bulk composition is therefore not very far from that of a granite, with, however, a somewhat increased amount of iron, magnesia, and soda. But those migmatitic gneisses in which a schistose component is preponderant, have also often been permeated by granite in such a measure that the bulk composition of great portions of them is in many cases very near to that of an eruptive rock.

Table II.

	Average of all Finnish granites (average of the averages)	Pre—Cambrian granites of Sweden (Holmquist)	Granite of all periods (Osann and Clarke)
SiO_2	69.42	69.81	69.92
TiO_2	0.39	0.54	0.39
Al_2O_3	14.70	13.76	14.78
Fe_2O_3	1.08	2.17	1.62
FeO	2.49	1.87	1.67
MnO	0.03	0.26	0.13
MgO	2.02	0.84	0.97
CaO	1.14	2.20	2.15
Na_2O	3.24	3.17	3.28
K_2O	4.46	4.38	4.07
P_2O_5	0.07	0.26	0.24
H_2O	0.66	0.74	0.78
	100.00	100.00	100.00

[1] The MgO content is certainly too high, owing to an undue influence of some analyses of syenitic and dioritic rocks included among the »post-Bothnian» granites of Ostrobothnia.

In general, however, it seems probable that the composite rocks originated by the mixture of granites and older crystalline rocks have much the same average composition as those parts of the neighbouring areas where more homogeneous granites and schists, metabasites etc. occur in masses more clearly separated one from another. If it were possible to measure the relative amounts of the different constituents in these intricately mixed rock masses, we should probably get about the same figures as we have for the neighbouring areas of better separated rocks. What might be done in the future, is to take samples from rather large exposures of composite rocks and quarter them according to the methods used when sampling ores for the purpose of determining their average content of metals. By analysing these quartered samples, a more exact idea of the bulk composition of the migmatites could be obtained. Because of the extreme variation of the relative amounts of their constituents, however, it would be necessary to make a great many such analyses, and even then the figures might be characteristic mainly of each special area. These mixed rocks will therefore always present a difficulty in the way of every endeavour to arrive at really exact determinations. At the present time they must be left out of consideration.

GRANULITES (LEPTYNITES).

Only 3 analyses are available for the granulites of Lapland which have an area on the map of only 12,480 km^2, making 4.0 procent of the whole territory mapped. Moreover, these rocks are not entirely homogeneous, but nevertheless, the analyses have been used to determine their composition, which in the analysed rocks is rather peculiar and characterized by higher amounts of silica than observed even in granites (Table I, Column 7). There are, however, also more femic rocks among the granulites of Lapland.

SCHISTS.

The schists proper are mainly micaschists or phyllites, but in some cases also leptitic schists with an average composition which in Finland is probably somewhat more basic than that of the former rocks. If the areas of the schistose portions of the migmatites could be added, the percentage of the schists might be higher, but in any case would not exceed 12—15 per cent of the whole, instead of 9.1 per cent in the present calculation.

The schists of the Scandinavian mountain chain are included in the numbers for the percentage, but have been left out of consideration in making out the chemical calculation. The average composition of the schists has been determined from only 3 analyses of Finnish rocks which are regarded as types (Table I, Column 8). One of them, however, is rather quartzitic, and it is possible that the amount of silica may be too high. It would perhaps have been preferable to take the medium of pelitic and metapelitic rocks as given e. g. by F. W. Clarke, in which case we should have a somewhat lower percentage of SiO_2.

SANDSTONES AND QUARTZITIC SCHISTS.

As to the sedimentary quartzitic rocks, psammites and metapsammites, (Table I, column 9) which occupy 13,625 km^2, or 4.3 per cent of the area mapped, their average composition has been computed by taking the average for 15 typical rocks mentioned in Rosenbusch's Textbook of Petrography (German edition 1910) p. 510.

The low relative amount of these rocks, especially among the oldest formations, is a conspicuous feature of the Fenno-Scandian Pre-Cambrian, and shows the inconsiderable role which weathering processes played during the earliest period of the earth's history.

LIMESTONES AND DOLOMITES.

What was said about the quantity of quartzites is true, and in still greater measure, as to the limestones and dolomites (Table I, column 8) which occupy only 0.1 per cent of the area surveyed. For determining their average composition 15 analyses have been used, but as they are very inequally distributed over the different localities, and mainly represent two of the biggest outcrops, a future correction is possible. The final result would not be materially changed thereby.

BASIC ROCKS (GABBROS, DIABASES, BASALTS AND THEIR METAMORPHIC DERIVATIVES).

The percentage of basic rocks, mainly gabbros, diabases, basalts, and their metamorphic derivatives, is only 8.2. This percentage would not be materially changed by also taking into consideration those areas which have been surveyed later. A revision of the bigger areas of basic rocks has in some cases already shown that their areas have been overrated, while on the other hand small areas which have been overlooked may yet be added. I regard the number given rather as a maximum, but hardly think that it could be reduced by even as much as one per cent, probably only by 0.2—0.5 per cent, which might then lead to a corresponding increase in the areas of schists and quartzites.

In general, I think that a survey of the Pre-Cambrian areas of different countries will lead to the same result as in Finland, viz. that the basic rocks form less than 10 % of these territories. In Sweden, the percentage seems to be even lower than in Finland. Moreover, we must remember that a great part of the basic rocks form surface flows or intrusive sheets of no very great thickness, while the granitic masses certainly reach to a considerable depth, even if it be not admitted that many of them form batholiths extending to unknown depths.

What was said about the extension of the basic rocks downwards is true also as to the schists and quartzites. This argument adds still more weight to the conclusion that the granitic constituents preponderate.

In computing the average composition of this group (Table I, Column 11), 33 analyses have been used. Most of them are diabases, metadiabases and metabasalts, among which auvergnoses, according to the C. I. P. W. classification, prevail. Some are also andesitic in composition. There is one group of basic rocks, viz. the anorthosites of Jaala, in which the contents of alumina seem to be much lower than in this average. They possess, however, a very restricted distribution.

Table III.

Average composition of the rocks of Finland.

	%	Mol.	NORM			
			Quartz	25.74	Qu = 25.74	Sal = 88.11
SiO_2	67.45	1124	Orthoclase	21.13	F = 62.37	
TiO_2	0.41	5	Albite	25.67		
Al_2O_3 ...	14.63	143	Anorthite	15.57		
Fe_2O_3 ...	1.27	8	Diopside	—	P = 6.74	Fem = 9.69
FeO	3.28	32	Hypersthene	6.74		
MnO	0.04	1	Apatite	0.34	A = 0.34	
MgO	1.69	42	Ilmenite	0.76	M = 2.61	
CaO	3 39	61	Magnetite	1.85		
Na_2O	3.06	49	$CaCO_3$ 0.20			
K_2O	3.55	38	$MgCO_3$ 0.08	0.28	1.08	
P_2O_5	0.11	1	H_2O	0.79		
H_2O	0.79	36	Minor constituents	0.01		
CO_2	0.12	3		98.88		
Other minor constituents	0.01		I, 4, 3, 3 = Amiatose			
	99.80					

THE AVERAGE COMPOSITION OF ALL THE ROCKS OF FINLAND. DISCUSSION OF THE RESULTS.

On the basis of these calculations a computation has been made of the average composition of the rocks of Finland and its result is given in Table III. The calculation of the normal mineral composition of a rock of this chemical character, determining its place in the C. I. P. W. classification, was kindly made by Dr Mäkinen. It is an *Amiatose* characterized by a rather high percentage of quartz, and with potash and soda in equilibrium.

The figures for this average of Finnish rocks (A F R) according to Niggli's system are given below. For comparison I also give Niggli's figures for the granodioritic rock magma (N G D).

A F R si 295 al 37.5 fm 24 c 16 alk 22.5 k 44 mg 46
N G D si 270 al 39 fm 23 c 17 alk 21 k 43 mg. 40
(In A F R we have further ti = 1.3 si' = + 85).

As we are aware, the similarity is very great. The average of all Finnish rocks has a *granodioritic* composition.

It would be of great interest to have similar calculations made for Sweden, where a more satisfactory analytic material is available. As we may see even from a glance at the map, the main composition of the Swedish Pre-Cambrian is not very different from that of Fin-

Table IV.

	Clarke's average for 830 rocks from the United States.	Harker's average for 397 British rocks.	Washington's average for 1,811 rocks from all parts of the world.	Clarke's and Washington's average for Swedish rocks.	Sederholm's average for Finnish rocks reduced to 100 %.	Clarke's and Washington's average for rocks of Finland and Kola.	Clarke's and Washington's latest average for all igneous rocks.
SiO_2	59.71	58.75	58.24	64.04	67.58	60.58	59.12
TiO_2	0.60	0.12	1.04	0.73	0.41	0.56	1.05
Al_2O_3 ...	15.41	15.64	15.80	14.24	14.66	16.43	15.34
Fe_2O_3 ...	2.63	5.34	3.33	3.65	1.27	2.75	3.08
FeO	3.52	2.40	3.87	3.41	3.29	2.88	3.80
MnO	—	—	—	0.15	0.04	0.19	0.12
MgO	4.36	4.09	3.84	1.82	1.69	2.16	3.49
CaO	4.90	4.98	5.22	3.25	3.40	3.35	5.08
Na_2O	3.55	3.25	3.91	3.70	3.07	6.11	3.84
K_2O	2.80	2.74	3.16	3.82	3.56	3.96	3.13
P_2O_5	0.22	0.12	0.37	0.25	0.11	0.27	0.30
H_2O	1.52	2.23	1.79	0.84	0.79	0.71	1.15
Min. con.	—	—	—	0.10	0.13	0.05	0.40
	99.22	99.56	100.57	100.00	100.00	100.00	100.00

land. There also granites are far the most prevalent and, as already remarked, the percentage of the basic rocks seems to be even less than in Finland. Micaschists are perhaps a trifle less common, while leptites, of which a great portion are rather basic, have a wide distribution. There is little doubt that the average composition of the rock masses of Sweden is fairly similar to that which has been given for Finland. Only the result of a calculation would there be still more conclusive.

It may be asked whether the average composition of the earth's crust in Finland and in Sweden, although representative of the middle of Fennoscandia, is so of all Pre-Cambrian terranes. It is true that there are areas where granitic gneisses are more completely prevalent than in Finland, e. g. in the easternmost parts of Fennoscandia, but even there basic rocks occur, as would seem, in almost the same proportion as in the middle of the territory in question.

In other deeply eroded areas we find very similar conditions. Nowhere do basic rocks prevail over large areas. Granite, not gabbro, is the characteristic rock of the deeper part of the earth's crust.

My calculation is the only one which has so far been made according to the above stated method in any large area consisting mainly of Pre-Cambrian rocks, and I think that my figures are fairly representative for such areas.

As may be seen from the comparative lists in Table IV, these figures are rather different from many of those reached by earlier writers when trying to determine the average composition of the earth's crust. Those computations are based on widely differing presuppositions, and the results are therefore not directly comparable with mine.

The calculations of F. W. Clarke, based on the admirable work of the chemical laboratory of the United States Geological Survey, have, as is well known, inspired all later endeavours to find, by statistical computations, the average composition of the lithosphere.

According to Clarke's opinion, expressed in one of his earlier memoirs[1], this average is very nearly that of the igneous rocks alone; he thinks that he has been able to show, by comparing groups of analyses representing rocks from different regions, that the outermost 10 miles thick shell of igneous rocks has much the same average composition all over the globe; the best material for determining

[1] F. W. Clarke, The Data of Geochemistry. U. S. Geol. Survey. Bull. N:o 330, p. 24—25. Cf. Bull. Phil. Soc. Washington vol. 11, 1889. p. 131, and other papers quoted in Clarke's memoir.

that average is afforded by the analyses of igneous rock made in the laboratory of the U. S. Survey. H. S. Washington, again, based his earlier calculations on 1,811 analyses of igneous rocks from different parts of the world, while Harker has taken the average of 397 analyses exclusively from British localities. If the figures for water are omitted, and the analyses recalculated to 100 per cent, the results of all these computations approach each other nearly. Washington's average shows a slightly more basic composition than the others, while Clarke's shows the most acid. All these averages are, as already remarked, very different from mine.

When the present communication was nearly ready for the press, the writer received the important new memoir of Clarke and Washington: The Composition of the Earth's Crust, [1] wherein they further substantiate and elucidate their former views. These results which are there communicated are also entirely at variance with mine.

If we take into consideration the value of the analytic material on which these calculations made by the Clarke-Washington school of petrological chemistry have been based, as well as the high authority of their authors, the odds seem to be entirely against me. Clarke's American analytic material is certainly the best which is anywhere available, while Washington's analyses have been most carefully sifted and represent different areas of the world. However, as has been so strongly emphasized by many previous writers, in making statistical computations it is necessary not only to scrutinize the exactness of the figures used, but also to take into consideration the theoretical basis on which the problem has been propounded. The methods of calculation of most earlier writers are open to objection from two different points of view. These objections have in great part been made already by Mennell, [2] Daly [3] and others.

First, it is easy to show that in many cases the average of the analyses made in a certain region cannot fairly represent the average composition of the igneous rocks of that area. The rare and interesting rocks receive much more attention on the part of petrologists

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[1] F. W. Clarke and H. S. Washington, The Composition of the Earth's Crust. U. S. Geol. Surv. Prof. Papers 127. Washington 1924. Here are also references to the earlier literature.

[2] F. P. Mennell, The Average Composition of Igneous Rocks. Geol. Mag. 1904, p. 263,264.

— — — — The Constitution of the Igneous Rocks. Geol. Mag. 1909, p. 212—216.

[3] R. A. Daly, Igneous Rocks and their Origin. New York 1904, p. 168—170.

than such common types as granites, which nevertheless in many areas possess the widest extension. For instance, if we should use the available analyses of rocks from the peninsula of Kola for determining the average composition of the rock masses of that region, we should arrive at the result that they consist mainly of nepheline syenites and other highly alkaline rocks. And yet it is well known that the rare and interesting rocks which have become so famous from the classical researches of Wilhelm Ramsay and others, form only a small amount (less than 3 per cent, cf. my map of Fennoscandia) of the rock masses of that country.

In the same way interest in petrochemical work in Norway has been focussed on a few extremely fascinating regions, especially the Christiania basin whose rocks have been studied in such a masterly way by Brögger and his fellow workers, and associated areas, and partly also on the region near Bergen. Great areas of more uniform composition, especially those where granitic gneisses prevail, have attracted much less attention, and from them only a few rock analyses are available. An average of the Norwegian rock analyses will not give anything like an average of the composition of the igneous rocks of Norway.

From the Haliburton—Bancroft area of Canada, visited by the writer on the occasion of the International Congress of 1913, 16 different rocks belonging to the nepheline syenite family had at that time been analysed, and only 2 granites. The area is, however, composed mainly of granites and limestones. Similar examples could be quoted from Greenland and other parts of the world.

In the United States the analytic material is perhaps more equally distributed than elsewhere, but there also the analyses of more interesting rocks preponderate over those of the granites and gneisses which have such a wide extension in many regions.

A discussion of some points in Clarke's and Washington's latest memoir will give additional emphasis to the above remarks.

These authors give the average, calculated according to their method, also for the igneous rocks of Finland, including the peninsula of Kola. 59 analyses have been used, and as many of them represent nepheline-bearing rocks from Kola, there is no wonder that they get the content of Na_2O as high as 6.1 per cent, and in the norm for this area, where however granitic rocks prevail, only 1.35 per cent of quartz. Both figures are very improbable. Clarke and Washington also admit that »the average for Finland is somewhat too alcalic and especially too sodic and too low in silica». To what extent this is true, may be seen from a comparison with my figures. If we adopt the method of Clarke and Washington, and take an average of all those analyses of eruptive rocks in Finland which have been used in calculating my average, but make no reference to the areas, the 34 analyses of basic rocks (representing an area of less than 10 per cent), combined with 42 analyses of granite (representing more than 50 per cent) would lower the SiO_2 in the average to about 60 per cent. If we should also add the six available analyses of ijolite, nepheline porphyry and cancrinite syenite, these analyses would have an influence on the final result by no means proportionate to their area, which is almost imperceptible on the map. [1]

It is true that the figures of Clarke and Washington are the averages of the composition of the igneous rocks alone, while in my averages also the figures for schists, quartzites, limestones and dolomites are included. As we are aware by comparing the figures for the schists in Table I, Column 8, with the average for all Finnish rocks given in Table III, the figures for both are very similar. The quartzitic rocks comprise only 4,3 per cent, and the carbonatites 0,1 per cent of the whole area, and their figures are therefore of small influence. A recalculation for the igneous rocks alone would give only a slightly modified result.

The average and norm for the rocks of Sweden given by Clarke and Washington is much nearer to the truth, simply for the reason that more attention has there been given to the granites than in Finland. This average is anyhow too low in silica. The figures of the average for all Fennoscandia, which is the mean of the averages for Sweden and Finland, including Kola, (without reference to the different numbers of Swedish and Finnish analyses) are certainly not representative for those regions.

I hardly need say that the polemic which I am here carrying on against my two distinguished colleagues and friends is not intended to detract a whit from the fame which they have justly won as petrological chemists, both by their many brilliant and suggestive ideas and by their admirable laboratory work. Amicus Cato, sed magis amica veritas. Trusting that they will understand that

[1] Their average was in fact also calculated in my computation, but as owing to their small area it would have had no influence on the final result, it was left out of consideration in calculating the final average. The most important figures of the average of the alkaline rocks are SiO_2 46.87, Al_2O_3 19.98, Na_2O 10.36 and K_2O 4.11. On a mechanical calculation, the figures for Na_2O would increase those of the final average by 0.5 per cent.

my purpose is only to come as near as possible to the truth, I will continue my argument.

Another comment which, as I am aware, has also been made already by Mennell, may further elucidate my line of argument. If we desire to get an idea of the average metal quantities in all known ores, we could not do it simply by taking the average of all known analyses. As is well known, besides the analyses of carefully sampled and quartered ores, made for the purpose of determining their average content of metals, a great number of analyses have been made of picked samples of very high content, and the number of analyses is by no means proportional to the extent of the ore deposits. The innumerable assays of gold ores would lead us to the conclusion that the average of all ores contains a very high percentage of gold, and I think we might possibly also prove, by using the same argument, that radium is a very common metal.

The above reasoning leads to the conclusion that it is absolutely necessary, in making such computations, to take into consideration the dimensions of the different rock masses which have been analyzed.

The extension in a horizontal direction gives, however, only some of the dimensions of the rock masses. In order to get an exact knowledge of their sizes, we should also determine their extension downwards, or their thickness, which in most cases is little known.

In any case, we are not entitled to assume beforehand that the composition of the earth's crust is on the whole uniform down to a certain depth, or that the average composition of the deeper parts is exactly mirrored by that of the effusive rocks. On the contrary, it seems rather probable that the shell of plutonic rocks which everywhere on the globe underlies the supracrustal sediments and the volcanics which are intercalated with them, is more acid, on an average, than the effusive rocks.

In supracrustal igneous formations of younger age the basic rocks are much more common than the acid, and this seems to be true also of the Pre-Cambrian rocks. In the Swedish Archaean, rhyolitic and metarhyolitic rocks, such as quartzporphyries, hälleflintas and similar ones, seem to be more common than in most othler Pre-Cambrian territories, but in any case there also femic supracrustal rocks have a larger extension than the salic ones. And as to the Pre-Cambrian of Finland, femic rocks are far the most prevalent among the supra- and infracrustal formations.

It has been often assumed that there is a fundamental difference in the character of eruptive activity between Pre-Cambrian and later ages. For my part, I think that the difference, especially as to the chemical composition of the rocks, for a great part of the Pre-Cambrian is not very conspicuous. If granites are more prevalent among the older rocks, that may be in large measure due to the fact that plutonic rocks from those epochs have been exposed by denudation in a greater extension than the granites which certainly also underlie most of the younger mountain chains. And as to the supracrustal rocks, we meet in the Bothnian formations of southwestern Finland, to quote an example, a volcanic activity which has not been materially different, in the chemical character of the rocks, from that e. g. of the southern portions of the Andes in late Mesozoic and Tertiary times.

In Lapland and also in southern Finland there occur surface flows of metabasaltic rocks which resemble in size the great areas of similar rocks in the Keewatin of North-America, and whose original characters have in no way differed from those of later volcanics.

In general, I think that a revision of the average composition of the supracrustal rocks of all ages, which should also take into consideration their relative masses, would show that femic rocks prevail among them everywhere. It would be interesting to recalculate the analyses on which the calculations of Clarke, Harker and Washington have been based, separating the effusive and plutonic rocks, and if possible also taking the relative areas into consideration. I think that such a calculation would give the r sult that the effusive rocks are much more basic than the plutonic.

The area for which my computations are made, contains both plutonic and supracrustal rocks, but whether both categories occur in the same proportions as in the uppermost shell of the earth's crust, reckoned, let us say with Clarke to a depth of 10 miles, it is difficult to say. In any case, it is possible and even probable that if a somewhat deeper level should be exposed by erosion than that where the roots of old mountain chains are still present, the average composition would be more uniformly granitic. That may partly account for the difference between my figures and those of Mennell and Daly [1] which give a more acid composition for the uppermost shell of the earth's crust than mine. In any case, my computation concerns a larger area, and has been made in more detail.

If the idea is true which is rather general among geologists, that the composition of the earth's crust becomes gradually more basic

[1] ll. c. Mennell gives for the Buluwayo region an average of SiO_2 69.88 per cent, for Central Matabele Land 69.45 per cent, for Victoria 68.4 per cent, and for West Kootenay, British Columbia, 69.3 per cent.

downwards, it is possible that this influence may be felt already at the levels to which erosion has penetrated. In this case there is at least a possibility that the largest areas of granites or granitic gneisses exposed by erosion, may be slightly more femic, on an average, than the granites of the smaller areas. In that case a recalculation for the preponderantly granitic areas, based on a greater number of analyses, may perhaps give figures more similar to mine.

The only geologist who has used a method of calculation similar to mine, is Adolph Knopf [2] who has determined the average composition of the igneous rocks mapped in the Cordilleran and Appalachion folios of the United States Geological Survey. His result is rather similar to Clarke's average, only with an increase in the silica and a relatively strong decrease in magnesia and potash. As the rocks to which Knopf's numbers refer, comprise 23.86 per cent of andesite and 20.77 per cent of basalt, against only 23.21 per cent of granite and 12.19 per cent of granodiorite, there is no wonder that the result differs from mine. For reasons already stated, I do not think that these rock masses, among which effusive rocks are in preponderance, are really representative of the deeper parts of the earth's crust.

The conclusions at which we have here arrived are the following:

The method of determining the average of igneous rocks by taking the average of all good analyses, without any regard to the size of the rock masses which they represent, does not give any true idea of the average composition of these rock masses down to a depth of 10 miles. Therefore also all conclusions based on that average concerning the average composition of sedimentary rocks &c., are subject to revision.

The method which has here been used, taking into account the extension of the rock masses, although likewise open to many objections, gives a far better result, especially in regions where plutonic rocks prevail. As the masses of supracrustal rocks which there exist do not in any case exceed in thickness the masses of plutonic rocks, the figures indicating the quantities of the former are to be regarded as maxima. A correction as to the thicknesses would make the final result still nearer to the composition of a granite, but cannot change it in the opposite direction.

Also when determining the average of the effusive rocks, it is preferable to take into account their extensions. Then, although the thicknesses are unknown, we eliminate at least some of the errors which are inevitable in all these statistical methods.

[2] Adolph Knopf, The Composition of the Average Igneous Rock. Journ. of Geology, XXIV, p. 620—622.

The calculations for the fundamental rock complexes show with certainty that they are in bulk granitic or granodioritic in composition.

As all calculations from analyses which represent effusive rocks to a large extent give an average indicating a more basic composition, it seems probable that the supracrustal rocks are in bulk more basic than the plutonic.

These results are in harmony with the observations in the field which show that basalt prevails among the effusive rocks, and granite or granodiorite at a greater depth.

This conclusion may easily be confirmed by calculations made separately for the effusive and plutonic rocks of different regions.

If my conclusion is tentatively admitted, these relations may be explained in two different ways.

The basic effusive rocks may have been derived from a more acid magma which has undergone differentiation. In this case it is only necessary to assume, owing to the quantitative preponderance of granitic rocks, that the original granitic magma has been slightly more basic than a typical granite, i. e. possessed a granodioritic composition. Or else the basic effusive rocks have been derived from a basaltic shell underlying the granitic shell. In this case also differentiation processes have probably taken place, but at an early epoch, and separated the original magma, which included all eruptive rocks, into shells of different composition.

Field observations seem to show that both explanations are true for different cases. Some basaltic rocks seem to have an indubitable connection with granitic, or granodioritic, masses at the depth, for others an origin from larger masses of basic magma lying below the granitic shell seems more probable.

There are no field observations directly indicating the existence of a deep-seated shell of basaltic composition. It cannot be too often repeated that granite, not gabbro, is the prevalent plutonic rock[1]. Nor are there any observations to indicate that granitic rocks, apart from small quantities of rocks of a rather exceptional character, have been derived from gabbroid masses through differentiation.

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[1] This statement refers to the continental areas. It may be possible that the earth's crust shows a different composition in the oceanic areas. However, as continental and oceanic areas have repeatedly overlapped during geological history, it seems strange that the basaltic floor should not have somewhere become detected at the margins of the continental areas, where strong dislocations have often taken place, if it would really, as many geologists admit, alone form the oceanic floor without being covered by more acid rocks.

If granite were a segregation product of gabbro, it would be necessary to suppose that the latter many times exceeded the former in quantity.

We do not derive the basaltic shell from the more basic shells which probably underlie it. Why should we then regard the basaltic magma as the mother magma of the granite? Let us simply state that there is a probability for a change in a vertical direction, in the composition of the rock masses constituting the earth's crust, and the underlying hypothetic magma.

The explanation of this change, and especially of the genetical relations of granite and basalt, remains one of the fundamental problems of petrology. It cannot be solved solely by mechanically making numerical calculations, but only by the concomitant work of chemists, and laboratory and field petrologists. Of course, chemistry plays the most prominent role, and it is the unforgetable merit of the great American authorities on rock analysis to have introduced here new standards and new methods which will gradually lead us to a more definite conception on these difficult problems.

ERRATA.

In Table I, Column 7, giving the average for Granulite, the figures for FeO should be:

1.78

and for the total:

100.34

N:o 22. Granitporphyr von Östersundom, von L. H. Borgström. Mit 3 Figuren im Text und einer Tafel. Juni 1907 .... 6: —

N:o 23. Om granit och gneis, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia, af J. J. Sederholm. Med 8 taflor, en planteckning, en geologisk öfversiktskarta öfver Fennoskandia och 11 figurer i texten. English Summary of the Contents: On Granite and Gneiss, their Origin, Relations and Occurrence in the Pre-Cambrian Complex of Fenno-Scandia. With 8 plates, a coloured plan, a geological sketch-map of Fenno-Scandia and 11 figures. Juli 1907 .... 16: —

N:o 24. Les roches préquaternaires de la Fenno-Scandia, par J. J. Sederholm. Avec 20 figures dans le texte et une carte. Juillet 1910 .... 7: —

N:o 25. Über eine Gangformation von fossilienführendem Sandstein auf der Halbinsel Långbergsöda-Öjen im Kirchspiel Saltvik, Åland-Inseln, von V. Tanner. Mit 2 Tafeln und 5 Fig. im Text. Mai 1911 .... 5: —

N:o 26. Bestimmung der Alkalien in Silikaten durch Aufschliessen mittelst Chlorkalzium, von Eero Mäkinen. Mai 1911 .... 4: —

N:o 27. Esquisse hypsométrique de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dans le texte. Juillet 1911 .... 6: —

* N:o 28. Les roches préquaternaires de la Finlande, par J. J. Sederholm. Avec une carte. Juillet 1911 .... 6: —

N:o 29. Les dépôts quaternaires de la Finlande, par J. J. Sederholm. Avec une carte et 5 figures dansle texte. Juillet 1911 .... 6: —

N:o 30. Sur la géologie quaternaire et la géomorphologie de la Fenno-Scandia, par J. J. Sederholm. Avec 13 figures dans le texte et 6 cartes. Juillet 1911 .... 10: —

N:o 31. Undersökning af porfyrblock från sydvästra Finlands glaciala aflagringar, af H. Hausen. Mit deutschem Referat. Mars 1912 .... 6: —

N:o 32. Studier öfver de sydfinska ledblockens spridning i Ryssland, jämte en öfversikt af is-recessionens förlopp i Ostbaltikum. Preliminärt meddelande med tvenne kartor, af H. Hausen. Mit deutschem Referat. Mars 1912 .... 5: —

N:o 33. Kvartära nivåförändringar i östra Finland, af W. W. Wilkman. Med 9 figurer i texten. Deutsches Referat. April 1912 .... 6: —

N:o 34. Der Meteorit von St. Michel, von L. H. Borgström. Mit 3 Tafeln und 1 Fig. im Text. August 1912 .... 9: —

N:o 35. Die Granitpegmatite von Tammela in Finnland, von Eero Mäkinen. Mit 23 Figuren und 13 Tabellen im Text. Januar 1913 .... 10: —

N:o 36. On Phenomena of Solution in Finnish Limestones and on Sandstone filling Cavities, by Pentti Eskola. With 15 figures in the text. February 1913 .... 7: —

N:o 37. Weitere Mitteilungen über Bruchspalten mit besonderer Beziehung zur Geomorphologie von Fennoskandia, von J. J. Sederholm. Mit einer Tafel und 27 Figuren im Text. Juni 1913 .... 9: —

N:o 38. Studier öfver Kvartärsystemet i Fennoskandias nordliga delar. III. Om landisens rörelser och afsmältning i finska Lappland och angränsande trakter, af V. Tanner. Med 139 figurer i texten och 16 taflor. Résumé en français: Études sur le système quaternaire dans les parties septentrionales de la Fennoscandia. III. Sur la progression et le cours de la récession du glacier continental dans la Laponie finlandaise et les régions environnantes. Oktober 1915 .... 50: —

N:o 39. Der gemischte Gang von Tuutijärvi im nördlichen Finland, von Victor Hackman. Mit 4 Tabellen und 9 Figuren im Text. Mai 1914 .... 6: —

N:o 40. On the Petrology of the Orijärvi region in Southwestern Finland, by Pentti Eskola. With 55 figures in the text, 27 figures on 7 plates and 2 coloured maps. October 1914 .... 26: —

N:o 41. Die Skapolithlagerstätte von Laurinkari, von L. H. Borgström. Mit 7 Figuren im Text. August 1914 .... 5: —

N:o 42. Über Camptonitgänge im mittleren Finnland, von Victor Hackman. Mit 3 Figuren im Text. Aug. 1914 .... 5: —

N:o 43. Kaleviska bottenbildningar vid Mölönjärvi, af W. W. Wilkman. Med 11 figurer i texten. Résumé en français. Januari 1915 .... 6: —

N:o 44. Om sambandet mellan kemisk och mineralogisk sammansättning hos Orijärvitraktens metamorfa bergarter, af Pentti Eskola. Med 4 figurer i texten. With an English Summary of the Contents. Maj 1915 .... 12: —

N:o 45. Die geographische Entwicklung des Ladogasees in postglazialer Zeit und ihre Beziehung zur steinzeitlichen Besiedelung, von Julius Ailio. Mit 2 Karten und 51 Abbildungen. Dezember 1915 .... 15: —

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* Epuisée.