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AVERAGE CHEMICAL COMPOSITION OF THE CRYSTALLINE ROCKS OF POLAND

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Abstract. The average chemical composition of the crystalline rocks of Poland was calculated on the basis of 1600 chemical analyses published and unpublished in the years 1900 - 1974. Frequency distribution curves for the major components were presented. From the frequency distribution of SiO_2 the average composition of the commonest types of rocks - the acid mode and basic mode - was calculated using mathematical statistics. These modes correspond only approximately to granite-rhyolite and basalt-gabbro.

In geochemical literature tables of elements are successively published, providing information on the chemical composition of the earth's crust and its major units, as well as of the commonest types of rocks. In view of the scope of such studies, the selection of the basal material and computation methods, these tables are a subject of much discussion and controversy.

Statistical computations of the chemical composition of rocks occurring in various geological regions and countries are published as well. Moreover, attempts were made to calculate the average chemical composition of the commonest types of igneous rocks, mainly of granite and basalt (Richardson, Sneesby, 1922; Clarke, Washington, 1924; Nockolds, 1954; Vinogradov, 1962; Turekian, Wedepohl, 1961; Soloviev, 1970, and others).

The average chemical composition of the crystalline rocks of Poland (Table 1, column 1; Table 2, column 1) was calculated on the basis of all the available and reliable data both published till 1974 and unpublished. The calculations comprised igneous rocks and all types of metamorphic rocks that do not show direct evidence of supracrustal origin. The products of low-grade metamorphism - phyllites, sericite and chlorite schists, quartzites, marbles; contact metamorphic rocks - skarns and hornfels; rocks subject to hydrothermal, hypogene and dynamometamorphic alteration were left out of account.

The choice of material was fortuitous, determined by the available collection of chemical analyses. This collection was a result of accomplishment of various

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Average chemical composition of the crystalline rocks in g/t

Component	Pendias, Ryka	Soloviev (1970)	Taylor (1964)	Vinogradov (1962)	Green (1959)	Rankama, Sahama (1952)
	1	2	3	4	5	6
Si	275 900	297 400	281 500	295 000	291 000	277 200
Ti	6 000	3 300	5 700	4 500	4 400	4 400
Al	84 600	76 600	82 300	80 500	81 000	81 300
Fe	53 100	40 400	56 300	46 500	46 500	50 000
Mn	900	600	950	1 100	1 000	1 000
Mg	23 500	22 300	23 300	18 700	17 000	20 900
Ca	37 500	30 600	41 500	29 600	33 000	36 300
Na	24 300	26 000	23 600	25 000	25 000	28 300
K	22 800	23 600	20 900	25 000	25 000	25 900
P	1 100	400	1 050	930	900	1 100
H*	1 900	1 600				
O	467 400	477 200	464 000	470 000	473 000	466 000

H* as H₂O⁺.

research programmes and, frequently, of the interest in rare types of rocks that petrographers are particularly eager to investigate. The collected analyses were heterogeneous, made with different objects in view over a long time interval from

Table 2

Average chemical composition of the crystalline rocks of Poland (1), acid mode and basic mode (2), in wt %

Component	Average com- position	Acid mode	Basic mode
	1	2	
SiO ₂	58.96	74.51	48.51
TiO ₂	0.98	0.15	1.39
Al ₂ O ₃	15.23	13.60	15.73
Fe ₂ O ₃	3.64	0.91	4.04
FeO	3.56	0.53	6.72
MnO	0.12	0.02	0.17
MgO	3.89	0.39	6.42
CaO	5.23	1.17	9.08
Na ₂ O	3.26	3.42	3.16
K ₂ O	2.74	4.06	0.98
P ₂ O ₅	0.26	0.12	0.23
H ₂ O ⁺	1.66	0.63	1.47
Total	99.53	99.51	97.90

1900. In many cases they lacked determinations of some major elements or had gaps in petrographic determination of a rock or its location. Therefore, the material required careful selection, where-upon a collection of 1600 chemical analyses of crystalline rocks was chosen.

Different methods can be used for calculation of the average composition of crystalline rocks. The desired values for a selected area, including the earth's crust, are usually computed from the percentage (or volume) of the basic types of rocks and their average composition (Sederholm, 1925), sometimes taking into account their density (Shaw, 1967), or the arithmetic mean (Clarke and Washington, 1924). A combination of various methods was also proposed (Wedepohl, 1969). Taylor (1964) calculated the average chemical composition of the continental crust combining averages for granites and basalts in the proportions 1:1 (Table 1, column 3). Vinogradov (1962) based the average composition of igneous rocks in the earth's crust on the 2:1 ratio of acid

Table 1

rocks — granites, granodiorites, etc., to basic rocks — basalts, gabbro, etc. (Table 1, column 4). Similar averages for the igneous rocks of the earth's crust were also calculated by Green (1959; Table 1, column 5), Rankama and Sahama (1952; Table 1, column 6), and earlier by Polański (1948), Goldschmidt (1937), Clarke and Washington (1924), and others.

The average composition of the crystalline rocks of Poland was computed on the basis of a random set consisting in 35% of chemical analyses of basic rocks (basalt, gabbro, etc.), 52% — acid rocks (granitoid rocks, rhyolites, etc.), 4% — ultramafic rocks, and 9% — other rocks, including "andesite", diorite, etc. The ratio of acid to basic rocks was determined at 1.5:1, i.e. it was intermediate between the proportions 1:1 and 2:1 assumed arbitrarily by Taylor and Vinogradov.

Averages for the crystalline rocks of Poland are close to those published by Taylor (1964). Differences in the contents of Si, Ti, Al, Fe, Mg, Na are of the order of 1–2%, Mn — 3%, P — 5%, and Ca and K up to 10%. It is worth noting that the differences in the content of elements, particularly of Ca and K, in the crystalline rocks of Poland are the smallest compared with Taylor's data. In comparison with the averages computed by other investigators (except those obtained by Soloviev), these differences are: 5% for Al, 7% for Si, 12% for Fe, 14% for K, 16% for Na, 18% for P, 21% for Ca, 27% for Ti, 28% for Mg, and 33% for Mn. Marked differences were noted between the average composition of the crystalline rocks of Poland and the average composition of the igneous rocks of the USSR (Table 1, column 2) which was published by Soloviev (1970). Particularly great discrepancies were noted in the contents of Ti — 45%, P — 37%, Mn — 33%, Fe — 24%, and lesser for Ca — 18%, Al — 9%, Si — 8%, Na — 7%, K — 6%, and Mg — 5%.

Frequency distribution curves for the constituents of the major crystalline rocks of Poland are presented in Figure 1. Curves for magnesium and iron (ferrous and ferric) show positive skewness (Ahrens, 1976a) whereas those for manganese

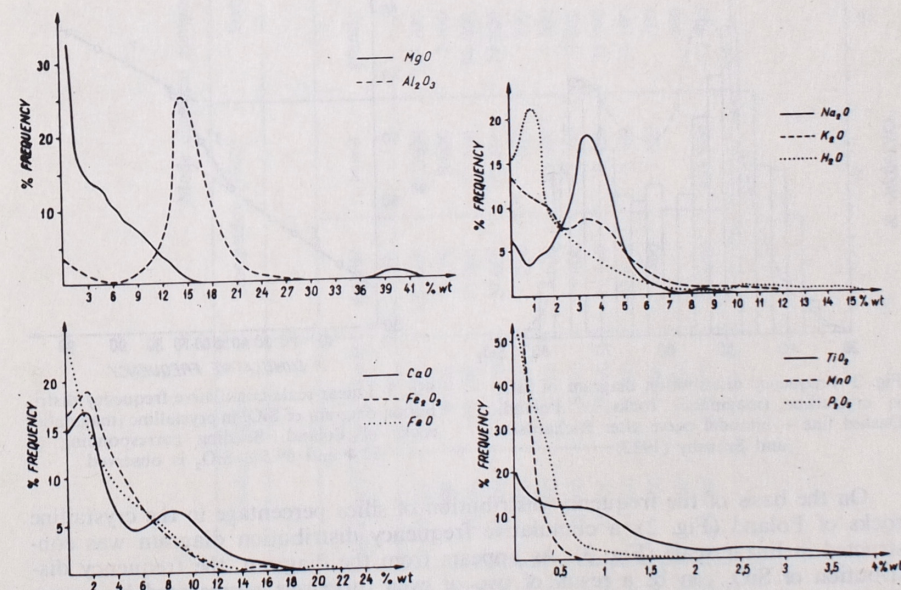


Fig. 1. Frequency distribution curves for several elements in crystalline (magmatic) rocks of Poland

and phosphorus show extreme positive skewness. The frequency curves for aluminium and sodium are nearly normal or show slight positive skewness. Curves for potassium and titanium are lognormal according to Ahrens's law, which was substantiated by a great number of analyses of igneous rocks from different regions (Ahrens, 1963b).

The frequency distribution of silica in the crystalline rocks of Poland (Fig. 2) is composed, indicating two populations with maximum class intervals between 47.5 and 50.0% SiO_2 and 72.5–75.0% SiO_2 , which corresponds to the commonest silica contents in basalts and granitoid rocks. On the basis of similar populations in the frequency distribution of SiO_2 , Richardson and Sneesby (1922) calculated the composition of the commonest acid and basic rocks (acid mode and basic mode), with the maximum SiO_2 percentage in the populations, 52.5% and 73% SiO_2 , corresponding to the composition of basalt and granite. These authors based their calculations on Washington's collection of superior analyses of fresh rocks from the years 1884–1913. The frequency distribution curve for silica (Fig. 2) obtained by Richardson and Sneesby (1922) is similar in shape to the histogram of silica distribution in the crystalline rocks of Poland. It differs from the latter in a somewhat lower percentage of ultramafic rocks and a higher content of intermediate rocks. The frequency maxima of the two populations in the crystalline rocks of Poland, computed by various statistical methods, showed values of 48.52% SiO_2 and 74.52% SiO_2 and served as a basis for calculation of the acid mode and basic mode (Table 2, column 2; Table 3, column 1). The results were found to deviate substantially from the average composition of the basalts and granites of Poland, for which the initial data were taken from the literature, basing on the information that they belonged to granites or basalts. These differences can be accounted for by inaccurate petrographic naming of rocks.

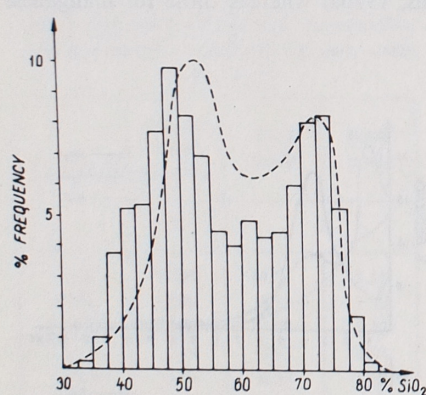


Fig. 2. Frequency distribution diagram of SiO_2 in crystalline (magmatic) rocks of Poland. Dashed line – bimodal curve after Richardson and Sneesby (1922)

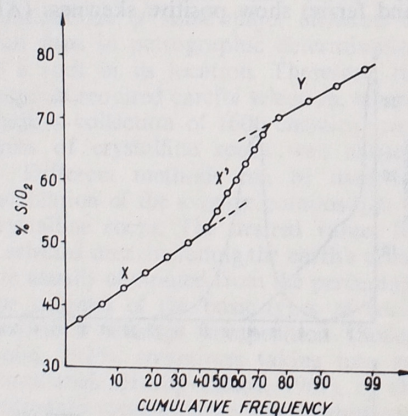


Fig. 3. Linear-scale cumulative frequency distribution diagram of SiO_2 in crystalline (magmatic) rocks of Poland. Bending corresponding to 52.4 and 69.5% SiO_2 is observed

On the basis of the frequency distribution of silica percentage in the crystalline rocks of Poland (Fig. 2), a cumulative frequency distribution diagram was constructed in linear scale (Fig. 3). As appears from the diagram, the frequency distribution of SiO_2 can be a result of two or even three sets represented by curves X, Y and X'. From the inclination of these curves it is evident that set Y shows

Table 3

Mode chemical composition of crystalline rocks, in g/t

Com- po- nent	Pendias, Ryka		Vinogradov (1962)		Daly (1933)		Richardson, Sneesby (1922)		Turekian, Wedepohl (1961)		
	1		2		3		4		5		
	acid mode	basic mode	granite	basalt	granite	basalt	acid mode	basic mode	highcalcium granite	lowcalcium granite	basalt
Si	349 700	232 000	323 000	240 000	327 700	229 100	340 900	245 200	314 000	347 000	230 000
Ti	900	8 400	2 300	9 000	2 400	8 300			3 400	1 200	13 800
Al	75 700	89 200	77 000	87 600	80 200	95 500	77 600	88 600	82 000	72 000	78 000
Fe	10 500	81 600	27 000	85 600	24 800	87 100	11 000	74 400	29 600	14 200	86 500
Mn	200	1 400	200	600	900	2 400			540	390	1 500
Mg	2 400	39 500	5 600	45 000	5 300	37 200	1 200	36 200	9 400	1 600	46 000
Ca	8 400	66 500	15 800	67 200	14 200	64 000	3 800	64 300	25 300	5 100	76 000
Na	25 500	23 900	27 700	19 400	25 800	23 100	29 700	22 300	28 400	25 800	18 000
K	33 900	8 300	33 400	8 300	34 100	12 600	29 000	8 300	25 200	42 000	8 300
P	500	1 000	700	1 400	900	1 900			920	600	1 100
H*	700	1 600			482 900	437 000	481 800	427 700			
O	491 600	446 600	487 000	435 000							

H* as H_2O^+ .

the least, set X intermediate, and set X' the greatest dispersion. It also follows from the diagram that the curves become discontinuous at 52.4% SiO_2 and 69.5% SiO_2 , and the frequency maxima of the sets are at 53% SiO_2 for X , 58% SiO_2 for X' , and 68% SiO_2 for Y .

From the slopes of curves X , X' and Y normal curves were plotted (Fig. 4). The cumulative frequency distribution (Fig. 5) obtained from the normal curves (Fig. 4) indicates that curves X and X' are smoothed, and that the cumulative curve becomes discontinuous at 68% SiO_2 . The shape of the curve at the dispersion $X > Y$ gives a distribution of negative skewness, and it appears that from the cumulative frequency distribution (Fig. 5), a lognormal distribution can be obtained (Fig. 6).

In fig. 4 curve X represents the frequency distribution of SiO_2 for the basic mode, but only the left-hand side of the curve is true because on the right-hand side it exceeds 70% SiO_2 while the percentage of this component in basic rocks cannot be more than 53–55% SiO_2 . On the other hand, curve Y for the acid mode

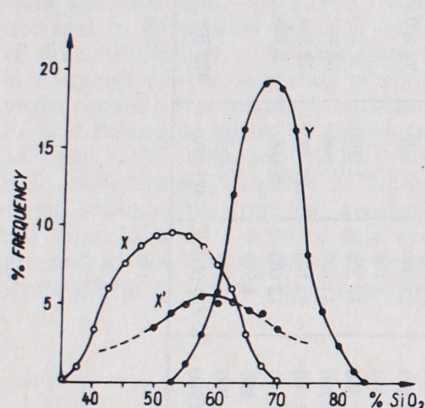


Fig. 4. Constructed normal distribution curves for SiO_2 corresponding to the slopes of the straight lines X , X' and Y (Fig. 3)

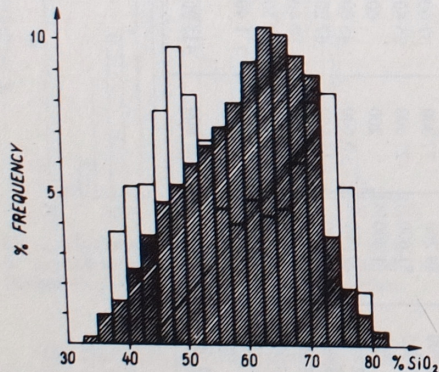


Fig. 6. Frequency distribution diagram of SiO_2 constructed from the data of fig. 5 (shaded area) compared with frequency distribution diagram for SiO_2 as Figure 2

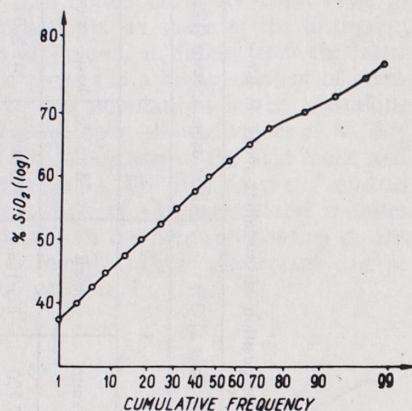


Fig. 5. Cumulative frequency distribution diagram of logarithms of % SiO_2

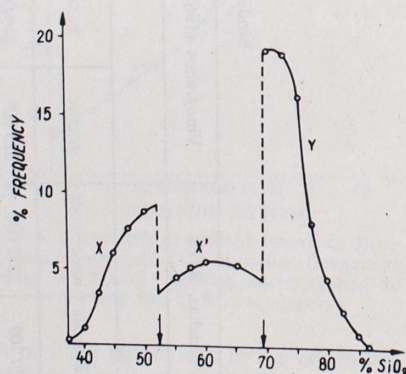


Fig. 7. Juxtaposed truncated normal distribution curves X , X' and Y

is only true for the right-hand side of the diagram because on the left-hand side it should not exceed a value of 63–65% SiO_2 , which is a limit characteristic of intermediate rocks. The points of discontinuity on the cumulative frequency distribution curves (Fig. 3) appeared to be extremely helpful for the explanation of these ambiguities as they permitted constructing juxtaposed truncated normal curves (Fig. 7) for the three-set SiO_2 distribution. Accordingly, the arithmetic means for the acid mode were computed for a set above 69.5% with the maximum frequency at 74.52% SiO_2 , whereas the arithmetic means for the basic mode – for a set below 54.5% with the maximum at 48.52% SiO_2 .

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ŚREDNI SKŁAD CHEMICZNY SKAŁ KRystalicznych POLSKI

Streszczenie

Przeciętny skład chemiczny skał krystalicznych Polski obliczono na podstawie 1600 wyników analiz chemicznych nie publikowanych i opublikowanych w latach 1900–1974. Obejmuje on skały magmowe i metamorficzne, jeśli nie ujawniają one wyraźnego pochodzenia suprakrustalnego. Stwierdzono, że przeciętny skład

chemiczny skał krystalicznych Polski (tab. 1) jest podobny do danych opublikowanych przez Greena (1959) oraz zajmuje pośrednią pozycję pomiędzy wynikami obliczonymi przez Taylora (1964) i Vinogradova (1962), czyli odpowiada stosunkowi 1,5:1 skał kwaśnych do zasadowych.

Krzywe rozkładu MgO , Fe_2O_3 , FeO , MnO , P_2O_5 , Al_2O_3 i Na_2O (fig. 1) wskazują na rozkłady dodatnio skośne z wyjątkiem lognormalnych rozkładów K_2O i TiO_2 . Rozkład SiO_2 wskazuje na dwie populacje o maksymalnych przedziałach klasowych 47,5–50,0 oraz 72,5–75,0%. Metodami statystycznymi obliczono ekstremalne punkty krzywych tych populacji – 48,52% oraz 74,52% SiO_2 , jakie były podstawą obliczeń modelu skał kwaśnych i zasadowych (tab. 3).

Z wykresu częstości kumulatywnej SiO_2 (fig. 3) wynika, że złożoność rozkładu jest wynikiem nałożenia się trzech zbiorów, ujawniających się za pośrednictwem krzywych X , X' i Y . Na podstawie nachylenia tych krzywych wykreślono krzywe normalne (fig. 4), a w dalszej kolejności sporządzono wykres częstości kumulatywnej (fig. 5), wskazujący na wyrównanie X i X' oraz poznane już wcześniej załamane krzywej kumulatywnej przy zawartości 68% SiO_2 . Przy dyspersji $X > Y$ układ jest skośnie ujemny i z częstości kumulatywnej można otrzymać rozkład lognormalny (fig. 6).

Krzywa X na figurze 4 dla modelu skał zasadowych jest prawdziwa tylko po lewej stronie, bowiem po prawej przekracza zawartość 70% SiO_2 , podczas gdy dla skał zasadowych nie może być ona większa niż 53–55% SiO_2 . Z podobnych względów krzywa Y modelu skał kwaśnych jest prawdziwa tylko po prawej stronie, bowiem po lewej nie może ona przekraczać wartości granicznej ze skałami obojętnymi określanej na 63–65% SiO_2 . Do wyjaśnienia tego problemu niezwykle pomocne okazały się punkty załamania częstości kumulatywnej (fig. 3), które pozwoliły na wydzielenie głównych układów trzonowych (fig. 7) normalnych krzywych trójbiorowego układu SiO_2 . Z tego też względu średnie arytmetyczne modelowych skał kwaśnych obliczono dla zbioru powyżej 69,5% przy maksimum 74,52% SiO_2 , a średnie arytmetyczne modelu skał zasadowych dla zbioru poniżej 54,5% przy maksimum 48,52% SiO_2 .

OBJAŚNIENIA FIGUR

- Fig. 1. Krzywe rozkładu liczebności dla kilku pierwiastków w skałach krystalicznych (magmowych) Polski
 Fig. 2. Histogram rozkładu liczebności SiO_2 w skałach krystalicznych (magmowych) Polski. Linia przerywana – dwumodalna krzywa według Richardsona i Sneeby'ego (1922)
 Fig. 3. Rozkład liczebności kumulatywnych SiO_2 w skałach krystalicznych (magmowych) Polski. Widoczne jest załamanie odpowiadające 52,4 oraz 69,5% SiO_2
 Fig. 4. Zrekonstruowane krzywe rozkładów normalnych dla SiO_2 , odpowiadające poszczególnym odcińkom linii prostych X , X' i Y (fig. 3)
 Fig. 5. Rozkład liczebności kumulatywnych logarytmów zawartości procentowej SiO_2
 Fig. 6. Histogram rozkładu liczebności SiO_2 , sporządzony na podstawie figury 5 (obszar zakresowany na tle histogramu rozkładu liczebności, jak figura 2)
 Fig. 7. Nałożone na siebie obcięte krzywe rozkładów normalnych X , X' i Y

СРЕДНИЙ ХИМИЧЕСКИЙ СОСТАВ КРИСТАЛЛИЧЕСКИХ ПОРОД ПОЛЬШИ

Резюме

Средний химический состав кристаллических пород Польши был вычислен на основании 1600 опубликованных и неопубликованных химических анализов, которые были сделаны с 1900 г. по 1974 г. Изучению подвергались преобразованные и магматические породы, если они не проявляли явного супракристаллического происхождения. Было обнаружено, что средний химический состав кристаллических пород Польши (табл. 1) похож составу, который изучил Грин (1959), и находится между составом по Тэйлору (1964) и Виноградову (1962), это означает, что соотношение кислых пород к основным равно 1,5:1,0.

Кривые распределения MgO , Fe_2O_3 , FeO , MnO , P_2O_5 , Al_2O_3 и Na_2O (фиг. 1) свидетельствуют о том, что это положительное наклонное распределение. Исключением является логарифмическо-нормальное распределение K_2O и TiO_2 . Распределение SiO_2 свидетельствует о двух семьях с максимальными классовыми интервалами равными 47,5–50,0 и 72,5–75,0%. При помощи статистических методов были вычислены экстремальные точки кривых этих семейств – 48,52% и 74,52% SiO_2 . Стали они основой вычисления модели кислых и основных пород (табл. 3).

По графику кумулятивной частоты SiO_2 (фиг. 3) было обнаружено, что сложность распределения обусловлена наложением трёх множеств, которые выделяются кривыми X , X' , Y . На основании этих кривых были вычислены нормальные кривые (фиг. 4), а потом был построен график кумулятивной частоты (фиг. 5), по которому видно уравнивание кривых X и X' , а также видно раннее изученное переломление кумулятивной кривой при содержании SiO_2 68%. После дисперсии $X > Y$ система становится отрицательно наклонной, а по кумулятивной частоте получаем логарифмическо-нормальное распределение (фиг. 6).

Кривая X на фигуре 6 для модели основных пород правдива только с левой стороны, так как с правой стороны она больше содержания SiO_2 равного 70%, а для основных пород не может превышать 53–55% SiO_2 . По схожим причинам кривая Y модели кислых пород правдива только с правой стороны, так как с левой не может превышать величины на границе с нейтральными породами, определяемой на 63–65% SiO_2 . Для объяснения этой проблемы очень подсобными оказались пункты переломления кумулятивной частоты (фиг. 3), которые помогли выделить главные стержневые системы (фиг. 7) нормальных кривых трёхмножественной системы SiO_2 . Потому средние арифметические модельных кислых пород были вычислены для множества свыше 69,5%, с максимумом при 74,52% SiO_2 , а средние арифметические модели основных пород для множества меньше 54,5%, с максимумом при 48,52% SiO_2 .

ОБЪЯСНЕНИЯ К ФИГУРАМ

- Фиг. 1. Кривые распределения численности для нескольких элементов в кристаллических (магматических) породах Польши
- Фиг. 2. Гистограмма распределения численности SiO_2 в кристаллических (магматических) породах Польши. Пунктирная линия — двухмодальная кривая по Ричардсону и Сноби (1922)
- Фиг. 3. Распределение кумулятивных численностей SiO_2 в кристаллических (магматических) породах Польши. Видно переломление соответствующее 52,4 и 69,5% SiO_2
- Фиг. 4. Реконструированные кривые нормального распределения SiO_2 , соответствующие одинаковым отрезкам прямых X, X' и Y (фиг. 3)
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- Фиг. 7. Наложённые, обрезанные кривые нормального распределения X, X' и Y