Zeitschrift: Eclogae Geologicae Helvetiae

Herausgeber: Schweizerische Geologische Gesellschaft

Band: 63 (1970)

Heft: 1: Geochronology of phanerozoic orogenic belts : papers presented at the "Colloquium on the Geochronology of Phanerozoic Orogenic Belts"

Artikel: Preliminary Rb-Sr geochronoly of the North Ladoga region, Soviet Karelia

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DOI: https://doi.org/10.5169/seals-163821

Eclogae geol. Helv.	Vol. 63/1	Pages 95–104	With 7 figures and 3 tables in the text	Basle, April 1970

Preliminary Rb-Sr Geochronology of the North Ladoga Region, Soviet Karelia

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ABSTRACT

Two main rock complexes of different age and structural position occur in North Ladoga Region, the basement complex forming dome-like tectonic blocks within geosyncline metasediments of Sortavala and Ladoga subseries.

The minimum age of basement granite gneiss is equal to 2320 ± 100 m.y. The age of regional metamorphism of Ladoga phyllitic and biotite schists is 1885 ± 20 m.y. The emplacement of veins and segregations of a younger plagiomicrocline granite in basement granite gneiss blocks and migmatization process proceeded contemporaneously with regional metamorphic event.

The age of the post-folding Tervus microcline granite is 1815 ± 30 m.y. Thus, the minimum time gap between the formation of basement rocks and the emplacement of the post-folding granite is at circa 500 m.y.

КРАТКОЕ СОДЕРЖАНИЕ

В геологическом строении Северного Приладожья участвуют различные по возрасту и структурному положению докембрийские породы. Породы фундамента образуют куполообразные тектонические блоки среди геосинклинальных метаосадочных пород ладожской и сортавальской серий.

Минимальный возраст гранито-гнейсов фундамента составляет 2320 ± 100 млн. лет. Возраст регионального метаморфизма филлитовидных и биотитовых сланцев ладожской серии равен 1885 ± 20 млн. лет. Образование жил и обособлений плагиомикроклинового гранита в гранито-гнейсах фундамента и мигматизация пород ладожской серии протекали одновременно с процессом регионального метаморфизма.

Возраст пост-складчатого микроклинового гранита полуострова Тервус равен 1815 ± 30 млн. лет. Таким образом, минимальный промежуток времени между образованием пород фундамента и внедрением пост-складчатого гранита составляет около 500 млн. лет.

Geologic Setting

The problems of time, place and sequence of metamorphic events in the geosyncline zones are being paid special attention. In this aspect the results of geochronological investigation of North Ladoga Region, Soviet Karelia, appear to be of some interest.

This specially studied region, being a part of the East-Finland zone of Karelides (KRATZ, 1963; KHARITONOV, 1966), is composed of the Precambrian rocks of different age and structural position (Fig. 1).

The basement granite gneiss is exposed in the central parts of oval anticlines, widely known as "granite domes of North Ladoga".

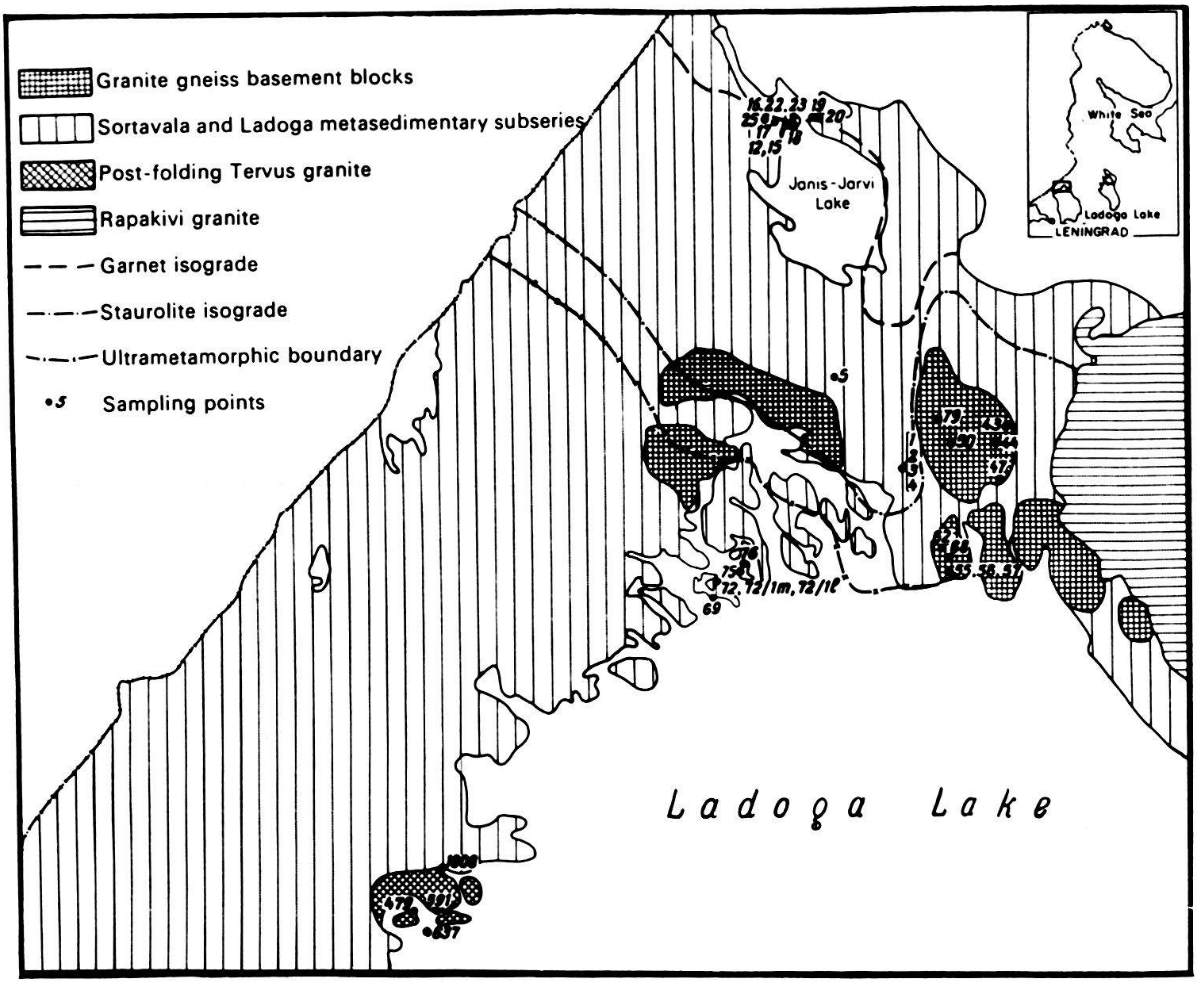

Fig. 1. Generalized sketch-map of the geology of the North Ladoga Region, Soviet Karelia, showing sample locations. Isogrades are drawn after D. A. Velikoslavinsky (personal communication).

There are two alternative hypotheses of their origin. According to TORNEBOHM (1891) the eroded surface of basement rocks was overlain by supracrustal rocks in a normal stratigraphic sequence. Later this surface was folded together with overlying rocks.

Other hypotheses imply that granite gneisses intruded into the supracrustal rocks. Different authors suppose different mode of their emplacement. ESKOLA (1949) supposed the granite gneiss domes to be the result of diapir intrusion of granitized and mobilized masses of Archean basement into the covering rocks, while SUDOVIKOV (1954) believed that rigid blocks of Archean basement were tectonically forced into the overlying Karelian rocks.

The cover consists of two subseries: Sortavala and Ladoga which form the normal stratigraphic sequence. The lower, Sortavala subseries consists of amphibolite-metavolcanics with lenses and beds of carbonate rocks. The overlying Ladoga subseries represents a metamorphosed terrigenous flysch. In addition to the supracrustal rocks there are many basic intrusives of early stages of the mobile belt development and many younger plutonic rocks, connected with ultrametamorphism.

Progressive studies of metamorphic and ultrametamorphic transformations of Karelian rocks in this area made it possible to show the existence of metamorphic zoning. SUDOVIKOV (1954) and some other authors distinguish in this area green schist, epidote-amphibolite, amphibolite and granulite facies units. The grade of metamorphism increases from north-east to south-west, and isogrades are drawn parallel to the ultrametamorphic boundary.

As it appears from geological observations the metamorphic zoning has no direct relation to the subsidence of the basement during sedimentation. It may be suggested that the deep-seated tectonic movements were the main geological cause of metamorphism. These movements appeared to be more intensive in the south of the area, where the rocks belonged to high-grade metamorphic facies.

The general course of development of North Ladoga geosyncline zone was revealed after the studies by SUDOVIKOV (1954), GLEBOVITSKY (1969), PETROV and BELYAEV (1968) and SARANCHINA (1968). Nevertheless, there remained some unsolved problems concerning the evolution of metamorphic processes in space and time, such as: the duration of the regional metamorphic cycle, the time correlation of metamorphic processes in different zones, and the positions of migmatization and granitization processes in the general sequence of metamorphic events.

In addition to geological interpretations an attempt has been made to reveal the geological history of the North Ladoga Region by Rb-Sr whole rock method.

Analytical methods

Rubidium and strontium concentrations were determined by stable isotope dilution using enriched Rb^{87} and Sr^{84} spikes. A 20 cm, 60°-sector mass spectrometer MI 1305 and 30 cm, 90°-sector mass spectrometer MI 1311 were used for isotope measurements. Thermal ionization method was employed with one-filament ion source for rubidium and multi-filament ion source for strontium. The samples were loaded on the tungsten filaments. The ion current was registered by d.c. amplifier and digital voltmeter EZPV-3.

Ratios Sr^{87}/Sr^{86} for the samples were calculated from the mixtures of sample and spike Sr. Instrumental discrimination for each experiment could be determined after LONG (1966), and all isotope ratios of strontium were normalized to a Sr^{86}/Sr^{88} value of 0.1194. Calculated isotope ratios of Sr^{87}/Sr^{86} are quoted relative to an arbitrary value of 0.7080 for the Sr^{87}/Sr^{86} ratio in the interlaboratory Eimer and Amend $SrCO_3$. The mean normalized Sr^{87}/Sr^{86} ratio for this standard during this work was 0.7089.

The decay constant used in the age calculations is equal to $1.39 \cdot 10^{-11} yr^{-1}$. Errors quoted in ages and initial ratios are one standard deviation.

The precision of age determinations was verified by analyses of standard samples of muscovite P-207 and biotite Bern 4B. The results are given in the Table 1. The measured contents of rubidium and radiogenic strontium and calculated age value differ from the average results of the summaries of LANPHERE and DALRYMPLE (1967) and JÄGER and others (1963) within only plus/minus one per cent.

Table 1. Rb-Sr measurements on interlaboratory standard minerals.

Mineral	Rb^{87} ppm	Sr^{87r} ppm	Sr^{86} ppm	Sr^{87}/Sr^{86}	Rb-Sr age m.y.
Muscovite	228.1	0.2805	0.8169	1.0454	
P-207	229.5	0.2779	0.8277	1.0378	
	228.4				
	229.2				
	231.2				
Mean	229.3	0.2792	0.8223	1.0416	87.6
Biotite	168.5				
Bern 4B	168.8				
	166.9				
Mean	168.0				

Results

The results of the Rb and Sr analyses are listed in Table 2, and their brief discussion is given below.

Determinations were made on the basement granite gneiss of the Kokkoselka block. Its gneissic structure, banding and lineation are due to intensive thermal and dynamic metamorphism during the folding of the cover.

As it may be seen in Figure 2, there is a scatter of the points relative to the best fitting line. Besides, it is clear that the slope of the line is controlled in fact by the

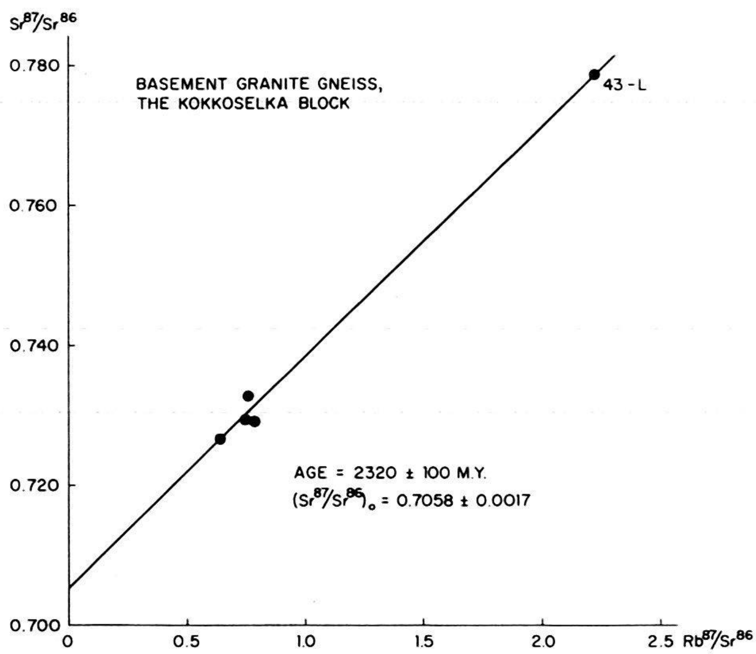

Fig. 2. Isochron plot for basement granite gneiss, the Kokkoselka block.

Table 2. Rb-Sr analytical data.

Sample No.	Rb^{87} ppm	Sr^{86} ppm	$\frac{Rb^{87}}{Sr^{86}}$	$\frac{Sr^{87}}{Sr^{86}}$
Microline granite, Tervus peninsula				
479-T	65.55	13.00	4.985	0.8319
591-T	53.46	8.95	5.904	0.8547
637-T	42.87	32.07	1.321	0.7399
1008-T	26.67	53.85	0.490	0.7152
Plagiomicrocline granite veins and segregations in basement granite gneiss, the Impilahti block				
55-L	88.06	12.60	6.908	0.8878
56-L	61.13	11.88	5.086	0.8398
57-L	83.50	10.91	7.565	0.9049
62-L	58.37	5.84	9.872	0.9663
68-L	43.21	6.66	6.411	0.8772
Migmatite				
72/1m-L	41.97	50.47	0.822	0.7267
72/1l-L	14.61	48.88	0.295	0.7133
Phyllitic schist (epidote-amphibolite facies zone)				
16-L	53.93	13.59	3.921	0.8115
19-L	39.45	20.71	1.883	0.7572
20-L	54.07	19.25	2.777	0.7788
22-L	49.91	10.61	4.650	0.8318
23-L	44.68	22.08	2.001	0.7607
Fine-grained biotite schist (staurolite-andalusite subfacies), north zone				
12-L	28.91	18.71	1.528	0.7481
15-L	56.39	11.21	4.971	0.8378
17-L	44.90	13.03	3.406	0.7977
18-L	59.50	18.86	3.119	0.7870
25-L	53.14	13.35	3.936	0.8188
Fine-grained biotite schist (staurolite-andalusite subfacies), south-east zone				
1-L	61.80	15.47	3.948	0.8128
2-L	31.94	24.46	1.291	0.7403
3-L	53.82	28.96	1.837	0.7527
4-L	20.11	23.16	0.858	0.7299
5-L	66.00	11.64	5.603	0.8534
Gneiss (cordierite-almandine-orthoclase subfacies)				
69-L	36.96	52.60	0.6945	0.7227
72-L	21.19	55.79	0.3755	0.7132
75-L	23.46	71.05	0.3264	0.7121
76-L	30.05	179.3	0.1657	0.7079
Basement granite gneiss, the Kokkoselka block				
43-L	38.21	17.07	2.212	0.7784
44-L	24.87	38.33	0.641	0.7265
47-L	19.54	25.84	0.748	0.7294
50-L	24.84	32.36	0.759	0.7293
79-L	26.38	34.09	0.765	0.7337

position of sample 43-L point with the highest Rb/Sr ratio. Therefore the calculated age of 2320 m.y. must be considered as minimum one. New analyses on granite gneiss samples of the same block which are in progress will give a possibility to arrive at more definite conclusions.

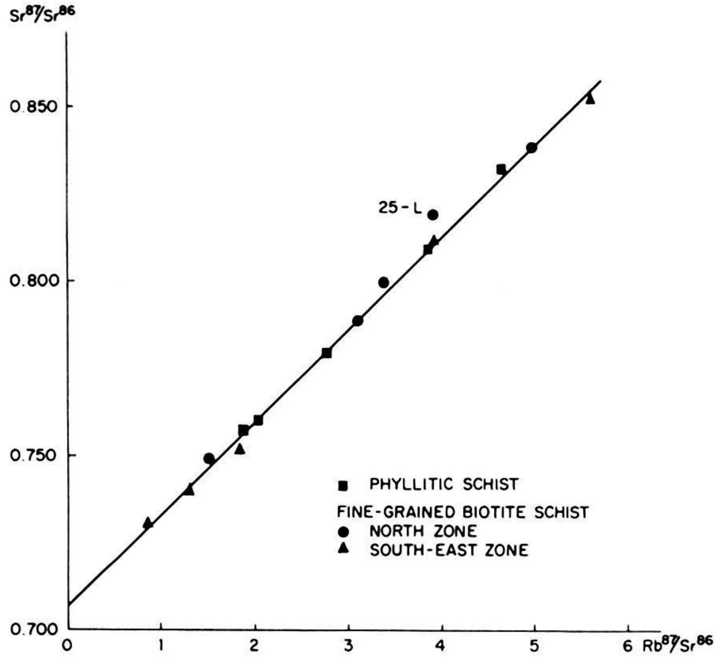

Fig. 3. Isochron plot for schists (epidote-amphibolite facies and staurolite-andalusite subfacies zones).

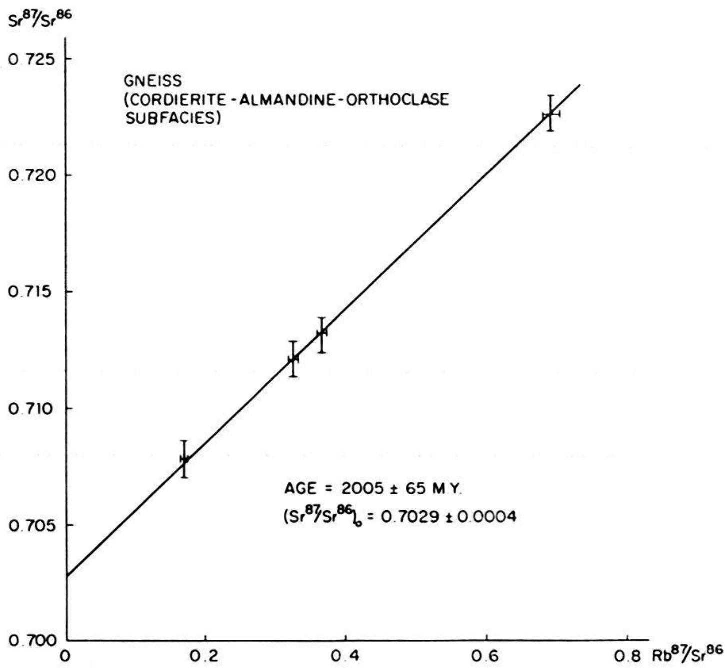

Fig. 4. Isochron plot for gneiss from the ultrametamorphic zone (cordierite-almandine-orthoclase subfacies).

The results of determination on phyllitic schists from the epidote-amphibolite facies zone and on biotite schists from the staurolite-andalusite subfacies zone of Ladoga subseries are plotted in Figure 3. Squares represent phyllitic schists, dots – fine-grained biotite schists from the north zone, and triangles – fine-grained biotite schists from the south-east zone, where the metamorphic grade is higher. The point corresponding to the sample 25-L is out of whole succession, and it was not taken into account in calculating isochrons. It is seen from Table 3 that the ages of the rocks of all these groups are of non significant difference. The generalized isochron corresponds to the age of 1885 $\pm$ 20 m.y., and the initial ratio equals 0.7066 $\pm$ 0.0010.

The results of determination on gneiss from the ultrametamorphic zone (cordierite-almandine-orthoclase subfacies) of Ladoga subseries are plotted in Figure 4. The resulting isochron corresponds to the age of 2005 $\pm$ 65 m.y. with comparatively low intercept of 0.7029 $\pm$ 0.0004. In spite of good fitting of the sample points to the isochron it should be mentioned that due to the low Rb/Sr ratios the slope of the isochron is very sensitive to slightest changes of the Sr^{87}/Sr^{86} ratios. Therefore future determinations which are in progress may change the estimated age (possibly, up to about hundred million years), while the initial ratio would not change significantly.

An attempt was made to evaluate the age of migmatization in the region. For this purpose isotope determinations have been made on leucocratic and melanocratic parts of one migmatite sample separately. The results are plotted in Figure 5. Supposing the isotope composition of strontium in both parts of migmatite at the time of migmatization being the same, one can calculate the isochron age of 1815 m.y. and the intercept at 0.7057. We believe that such an approach will enable to distinguish migmatites, which originated metasomatically, from those, which originated by selective melting.

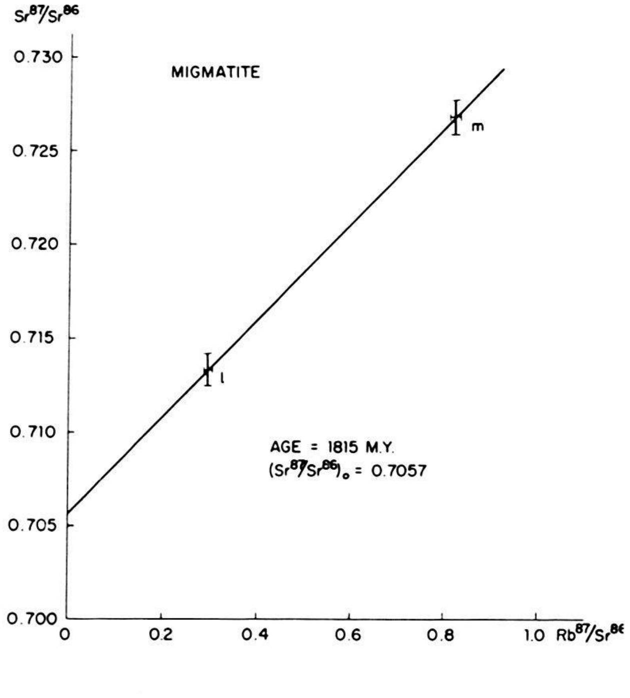

Fig. 5. Isochron plot for migmatite.

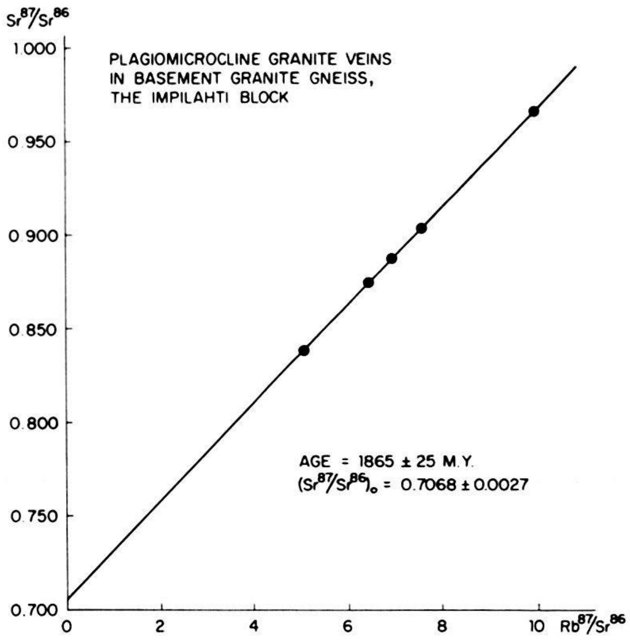

Fig. 6. Isochron plot for the younger plagiomicrocline granite from the Impilahti block.

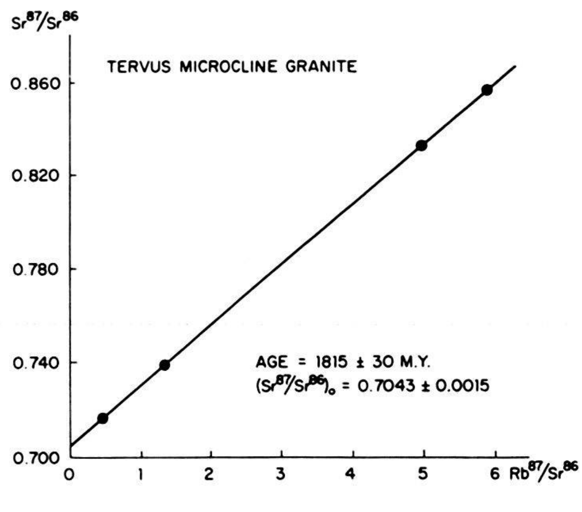

Fig. 7. Isochron plot for the post-folding microcline granite, Tervus peninsula.

Isochron for the younger plagiomicrocline leucocratic granite from the Impilahti block (Fig. 6) shows the age of 1865 $\pm$ 25 m.y., the initial ratio being 0.7068 $\pm$ 0.0027. This granite intruded basement granite gneiss, basic dyke rocks and intersected their superimposed structures. It forms segregations and veins situated along shearing zones.

Microcline granite of the Tervus peninsula is post-folding. The calculated age of this granite is 1815 $\pm$ 30 m.y. with initial ratio of 0.7043 $\pm$ 0.0015 (Fig. 7).

All the geochronological data are listed in Table 3.

The basement granite gneiss has the minimum age of 2320 ± 100 m.y.

The age values of phyllitic and biotite schists appear to correspond to a certain time in the metamorphic history of these rocks. Up to this time intervals of migration of rubidium and strontium apparently exceeded the dimensions of the samples. It is not quite clear, whether the calculated values for schists correspond to the culmination of the metamorphic event or to close approach to its end, when the mobility of rubidium and strontium decreased. In any case, available results show that the appearance of the metamorphic zoning, the migmatization and the emplacement of the plagiomicrocline granite occured simultaneously within the experimental errors. The value of about two billion years for the gneiss of the ultrametamorphic zone does not get any satisfactory explanation as yet. Possibly it is due to the analytical uncertainty.

Table 3. Geochronological data of North Ladoga rocks.

Rock	Rb-Sr age m.y.	$\left(\frac{Sr^{87}}{Sr^{86}}\right)_0$
Microcline granite, Tervus peninsula	1815 ± 30	0.7043 ± 0.0015
Plagiomicrocline granite veins and segregations in basement granite gneiss, the Impilahti block	1865 ± 25	0.7068 ± 0.0027
Migmatite	1815	0.7057
Phyllitic schist (epidote-amphibolite facies)	1915 ± 40	0.7060 ± 0.0018
Fine-grained biotite schist (staurolite-andalusite subfacies)		
North zone	1855 ± 50	0.7076 ± 0.0023
South-east zone	1880 ± 35	0.7062 ± 0.0016
All schists	1885 ± 20	0.7066 ± 0.0010
Gneiss (cordierite-almandine-orthoclase subfacies)	2005 ± 65	0.7029 ± 0.0004
Basement granite gneiss, the Kokkoselka block	2320 ± 100	0.7058 ± 0.0017

The average initial ratio of 0.7066 ± 0.0010, calculated for the schists, makes it possible to evaluate the time gap between the sedimentation and metamorphic event. The studies carried out at our Institute by S. B. LOBACH-ZHUCHENKO showed that metamorphism in zones of epidote-amphibolite facies and staurolite-andalusite subfacies had proceeded isochemically. One can suppose the extreme case when the age of the source rocks was equal to zero and the initial ratio was as low as 0.703. The supposition had to lead to the maximum gap of about one hundred million years between the sedimentation and the moment of metamorphic event dated by our determinations.

Thus, all available data concerning the North Ladoga Region allow to estimate the time gap between the formation of basement rocks and the emplacement of post-folding granite. This time gap appears to be of about 500 m.y.

Acknowledgments.

The authors wish to acknowledge the interest and encouragement of Professor E. K. Gerling. They are also indebted to Professor K. O. Kratz for his critical reading of the manuscript. The advice and assistance of S. P. Samsonov in the mass spectrometry is greatly appreciated. Special thanks are due to Drs. I. N. Krylov and V. P. Chekulaev for their assistance during sampling.

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