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A Paleomagnetic Study of Sariolian Conglomerates of the Onega Structure of the Karelian Protocraton: The Problem of Global Paleoproterozoic Remagnetization

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Abstract—A paleomagnetic study of Sariolian (2.4–2.3 Ga) conglomerates of the Onega structure distinguished two characteristic magnetization components. The average direction of the mid-temperature magnetization component has a concentrated distribution and coincides with the direction of the Svecofennian remagnetization within the Karelian protocraton. The directions of high-temperature magnetization components distinguished in conglomerates show a wide scatter of values that is evidence of the primary origin of this magnetization component. Two clusters of high-temperature components associated not only with the protolith composition, but also with the different conditions of rock transformation, in particular their fluid saturation, are distinguished.

Keywords: Karelian protocraton, Sariolian conglomerates, Onega structure, remagnetization, Paleoproterozoic, contact and conglomerate tests

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INTRODUCTION

The multi-year paleomagnetic study of the Archean–Early Paleoproterozoic complexes of the Karelian protocraton indicates that all of these complexes actually have a stable magnetization component of north-northwestern declination and a moderate positive inclination in mid- and, sometimes, high-temperature intervals. This origin is connected traditionally with the Svecofennian remagnetization 1.88–1.80 Ga ago (Mertanen et al., 1999). Sometimes, in samples of Early Proterozoic mafic dikes and layered intrusions two more ancient magnetization components of northeastern and east-southeastern declination and moderate positive inclination (components B and D, respectively; after (Mertanen et al., 1999)) are distinguished. The time when the rocks acquired their magnetization components is estimated to be ~1.75 Ga (comp. B) and 2.45–2.40 Ga (comp. D) (Mertanen et al., 2006). In this case, the primary origin of component D is proven on the basis of a positive contact test (Salminen et al., 2014). Moreover, the average directions of components B and D are “spread” along the arc of a large circle in the first and second quadrants, which is evidence of incomplete separation of Precambrian and Phanerozoic (“Devonian” and “Caledonian”) magnetization components (Lubnina and Zakharov, 2018).

In order to prove the primary origin of the magnetization component D and to evaluate the degree of the contribution of secondary components of different ages another test of paleomagnetic reliability, that is, the conglomerate test, has been applied.

The main subjects of research are Sariolian (2.4–2.3 Ga) conglomerates of the Paljeozero and Penzhina formations of the Onega structure of the Karelian protocraton. This choice was not random: among pebbles of conglomerates are fragments of both country Neoarchean granitoids and underlying Sumian andesites and andesibasalts. In addition, in order to correlate magnetic records in rocks and pebbles we used the paleomagnetic data obtained for Archean granitoids of islands Deda and Gorelyi, intruded by Neoarchean dikes of gabbro-norites (Scherbakova et al., 2017), Sumian Burakovo (Mertanen et al., 2006; Scherbakova et al., 2017) and Kivakka (the authors’ unpublished data) stratified intrusions, as well as Sumian mafic dikes of the Pääjärvi structure.

Geology. The Archean Karelian Craton was formed as a result of the collision of five terranes: Vodlozero, Central Karelian, Kianta, Iisalmi, and Ranua, which occurred approximately 2.70 Ga ago (Slabunov et al., 2006). The basement of the Karelian Craton (3.5–3.2 Ga) is granite–greenstone terrane, composed of the complex combination of Archean and Paleoproterozoic rocks. The main part of the Craton is composed of rocks of the tonalite–trondhjemite–granodiorite association (TTG) with an age of more 3.0 Ga.

The ancient Vodlozero terrane is located in the southeastern part of the Karelian Craton (Fig. 1). The granite–greenstone complexes of this terrane compose the basement of the Paleoproterozoic Onega structure (*Onezhskaya*..., 2011; Slabunov et al., 2006) (Fig. 1). The Sumian formations are represented by metamorphosed volcanogenic and sedimentary rocks of the Glubokozero and Kumsa formations in the marginal part of the Onega structure (Kumsa syncline and other smaller structures), as well as intrusive rocks of the Burakovo peridotite–gabbronorite–gabbrodiorite complex, which is located in the eastern part of the Onega structure. The thicknesses of the Glubokozero Kumsa formations are 145–150 and 1300–1400 m, respectively (*Onezhskaya*..., 2011).

The rocks of the Sariolian System (Paljeozero Formation), represented mainly by eluvial–deluvial breccias (the weathering crust on underlying rocks), conglomerates, sandstones, siltstones and chlorite schists, unconformably overlie the Archean and Sumian rocks. The total thickness of the formation varies widely from a few meters to hundred meters (Korosov et el., 2011). Deposits of the Paljeozero Formation that crop out on the western coast of Lake Paljeozero (Salvalampi) are represented by polymictic conglomerates with predominance of granitogneisses and granites among pebbles. Higher in the succession, they are followed by microfragmental conglomerates. Upsection is a unit of non-banded fine-grained tuffosandstones with lenses of conglomerates, as well as rare clasts of basalt and granite (“flowing” pebbles), which is overlain by a unit of green fine-grained chlorite schists (*Onezhskaya*..., 2011).

After a prolonged stratigraphic hiatus the Jatulian formations, which are widespread within the North Onega synclinorium, overlie the highly eroded surface of the pre-Jatulian complexes with a sharp angular and azimuthal discontinuity.

In order to establish the presence or absence of regional remagnetization associated with the formation of the Svecofennian orogen, detailed petropaleomagnetic studies of Sariolian (2.3–2.1 Ga) conglomerates of the Onega structure of the Karelian protocraton were performed at five sampling sites during field works in 2017. In total, 81 oriented samples were drilled from pebbles; 25 of them were from pebbles of the country Archean granitoids, 41 were samples of pebbles of Sumian (2.45 Ga) stratified intrusions and 15 were samples from Sariolian (2.3–2.1 Ga) matrix (Figs. 1 and 2).

Research Methods. The collections of oriented samples were studied following the standard procedure in the Petromagnetic Laboratory of the Chair of Dynamic Geology of the Moscow State University. In order to identify minerals, the carriers of magnetization in rocks, the continuous temperature dependence of magnetic susceptibility at the absence of an external magnetic field was studied on a KLY_5 kappabridge equipped with a CS4 furnace apparatus (AGICO, Czech Republic). All the samples were subject to a stepwise thermal cleaning up to the temperature of 700°C with a magnetic field of 300 mTl. The residual magnetization during thermal cleaning was measured on a JR-6A spin-magnetometer (AGICO, Check Republic). A TD_48 nonmagnetic furnace (ASC, United States) with an uncompensated magnetic field of no more than 5–10 nTl was used for demagnetization.

All the samples were subject to detailed step temperature demagnetization up to magnetic transformation temperature for minerals–carriers of magnetization in the studied samples. The number of cleaning steps varies from 10 to 20. The cleaning continued up to the complete demagnetization of samples or up to the moment when the magnetization value became comparable with the level of sensitivity of a measuring instrument ($n \times 10^{-5}$ A/m). In order to monitor the possible secondary changes of minerals–carriers of magnetization in the course of the thermal cleaning the magnetic susceptibility was measured after each demagnetization step. The measurements were stopped if the magnetic susceptibility increased by two times or more. In addition, the cleaning was stopped in the case of chaotic NRM vector behavior in the course of the thermal cleaning.

The results of stepwise thermal cleaning of samples were compared with the data that were obtained as a result of the cleaning of the group of reference samples with an alternating magnetic field. The demagnetization was performed on a LDA-3A-AF (AGICO, Check Republic) with an alternating magnetic field varying in a range from 1 to 100 mTl. The total number of steps of magnetic cleaning was as high as 15. Remasoft 3.0 software was used for the component analysis (Kirschvink, 1980). A component was considered to be distinguished if there are no less then three points (demagnetization steps) on the same line on the Zijderveld plot (Zijderveld, 1967).

For each component distinguished in the mid-temperature spectrum, the average directions were calculated taking statistical parameters into account (the clustering of vectors K and a confidence circle radius of $\alpha95$). The time when rocks acquired the magnetization components was estimated based on tests of paleomagnetic reliability (conglomerate test). In order to check the hypothesis of the regular distribution of magnetic field vectors on the sphere the Rayleigh pebble test (Watson, 1956) and the modified conglomerate test (Shipunov and Muraviev, 1997).

The positions of paleomagnetic poles were recalculated from the average directions of secondary magnetization components to the coordinates of sampling sites.

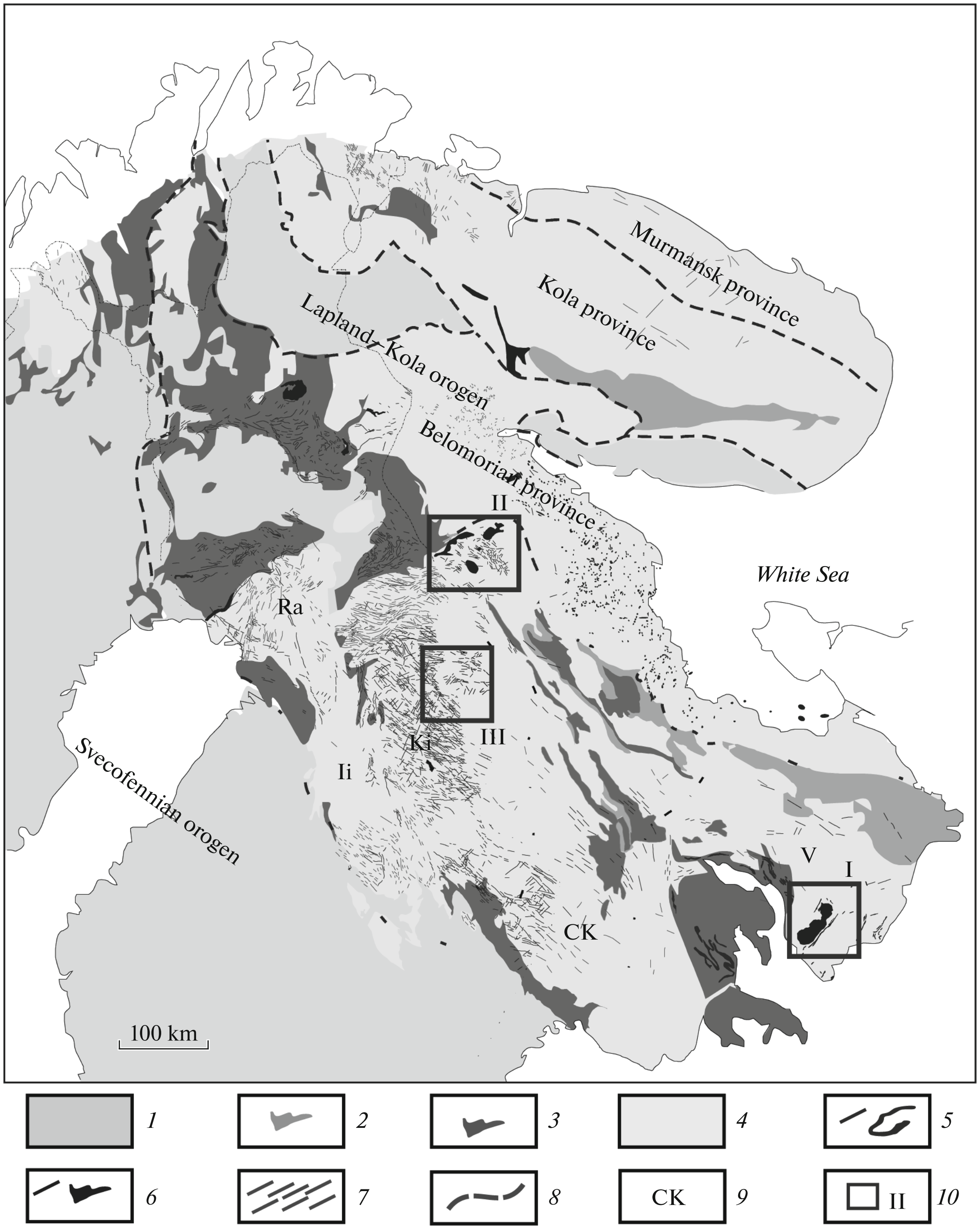


Fig. 1. The schematic geological map of the Fennoscandian Shield, showing the paleomagnetic sampling sites (after (Lubnina et al., 2017) with amendments): (*1*) Paleoproterozoic complexes of the Svecofennian orogen; (*2*) Paleoproterozoic volcanogenic–sedimentary complexes, 2.3–1.8 Ga; (*3*) Paleoproterozoic volcanogenic–sedimentary complexes, 2.06–1.95 Ga; (*7*) Archean–Early Paleoproterozoic complexes of the Fennoscandian Shield; (*5*) Paleoproterozoic (Ludicovian, 1.98 Ga) dikes and sills; (*6*) Early Paleoproterozoic (Sumian, 2.45 Ga) dikes and layered intrusions; (*7*) Paleoproterozoic (?) dikes undated; (*8*) boundaries of main tectonic units of the Fennoscandian Shield; (*9*) terranes of the Karelian Craton: Ra, Ranua; Ii, Iisalmi; Ki, Kianta; CK, Central Karelian; V, Vodlozero; (*10*) sites of paleomagnetic sampling.

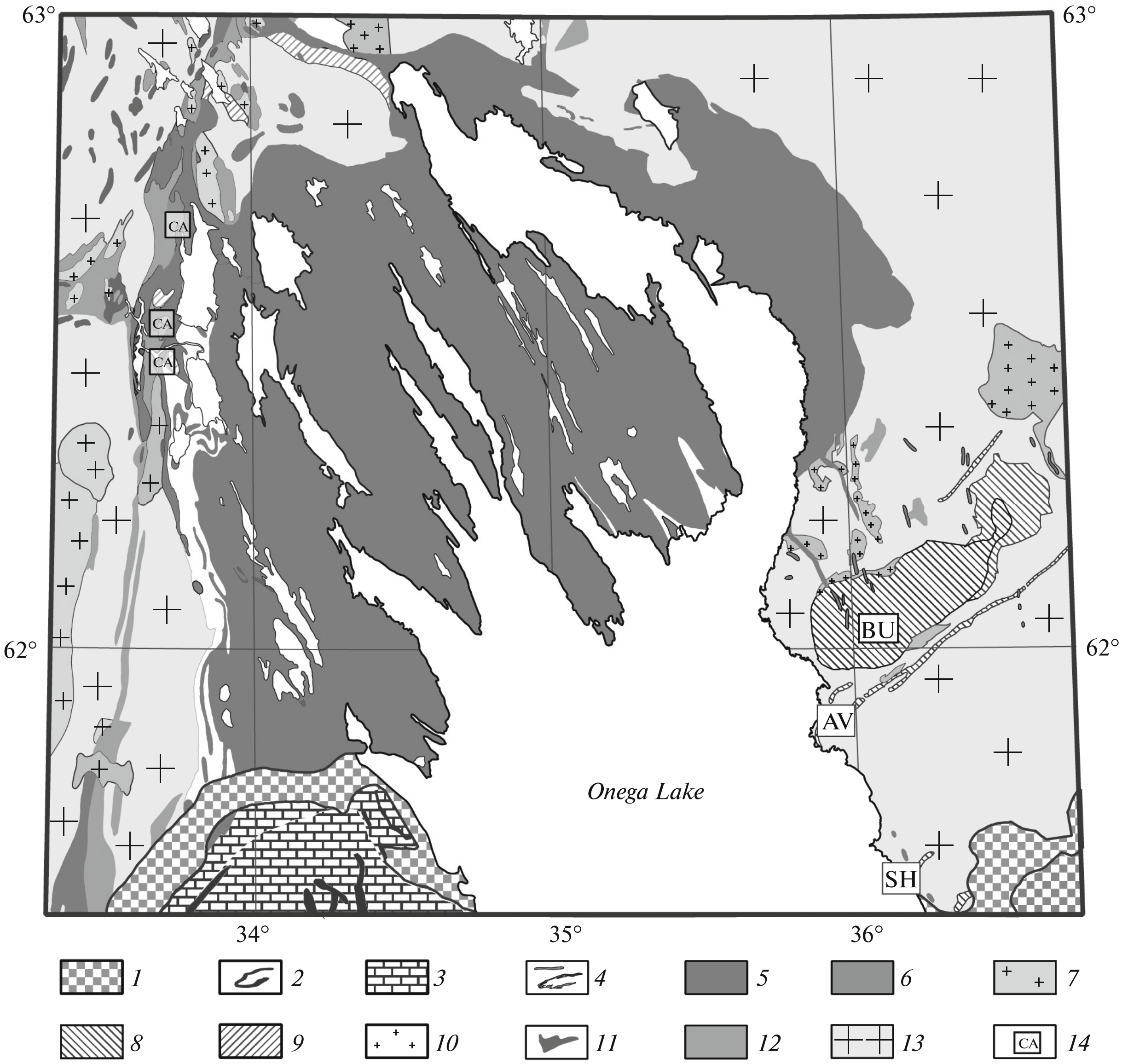


Fig. 2. A review geological map of the Onega structure, showing the paleomagnetic sampling sites (after (*Onezhskaya*..., 2011) with amendments): (*1*) Phanerozoic platform cover; (*2–9*) Proterozoic formations: (*2*) Vepsian (1752 Ma) sill of mafic rocks; (*3*) Vepsian (1800–1650 Ma) sedimentary complexes; *4*, Ludicovian (1985–1956 Ma) dikes, sills and intrusions of gabbroids, dolerites, and peridotites; (*5*) Ludicovian and Jatulian (2300–1920 Ma) volcanogenic–sedimentary complexes; (*6*) Sariolian (2400–2300 Ma) volcanogenic–sedimentary complexes; (*7*) granites (2440 Ma); (*8*) peridotite–gabbronorite layered intrusions and dikes of gabbroids (2500–2450 Ma); (*9*) Sumian (2500–2450 Ma) volcanogenic–sedimentary complexes; (*10–13*) Archean formations: (*10*) coarse-grained granites of the Onega complex (2884–2690 Ma); (*11*) mafic and ultramafic intrusions (2890–2895 Ma); (*12*) volcanogenic (3020–2850 Ma) and sedimentary complexes; (*13*) Mesoarchean (>2895 Ma) tonalites and granodiorites; (*14*) sites of paleomagnetic sampling.

Paleomagnetic Results. In order to identify minerals, which are the carriers of magnetization in samples of Sariolian conglomerates, eight curves—temperature dependences of magnetic susceptibility (TMA) were recorded. It was established that samples of Archean granitoids contain magnetic iron sulfides (pyrrhotite) and that some of these samples contain magnetite (Fig. 3a).

The magnetization in samples of pebbles of early Paleoproterozoic (Sumian) layered intrusions is connected with a maghemite–magnetite association (Fig. 3b). One can observe an insignificant (no more than 10–15%) increase in magnetic susceptibility at the thermal cleaning, which is probably due to the transformation of maghemite into hematite. The behavior of magnetic susceptibility during the thermal cleaning of samples of gabbro-norites that were collected in the central part of the Kivakka stratified intrusive massif is similar to that in samples of pebbles of layered intrusions from Sariolian conglomerates

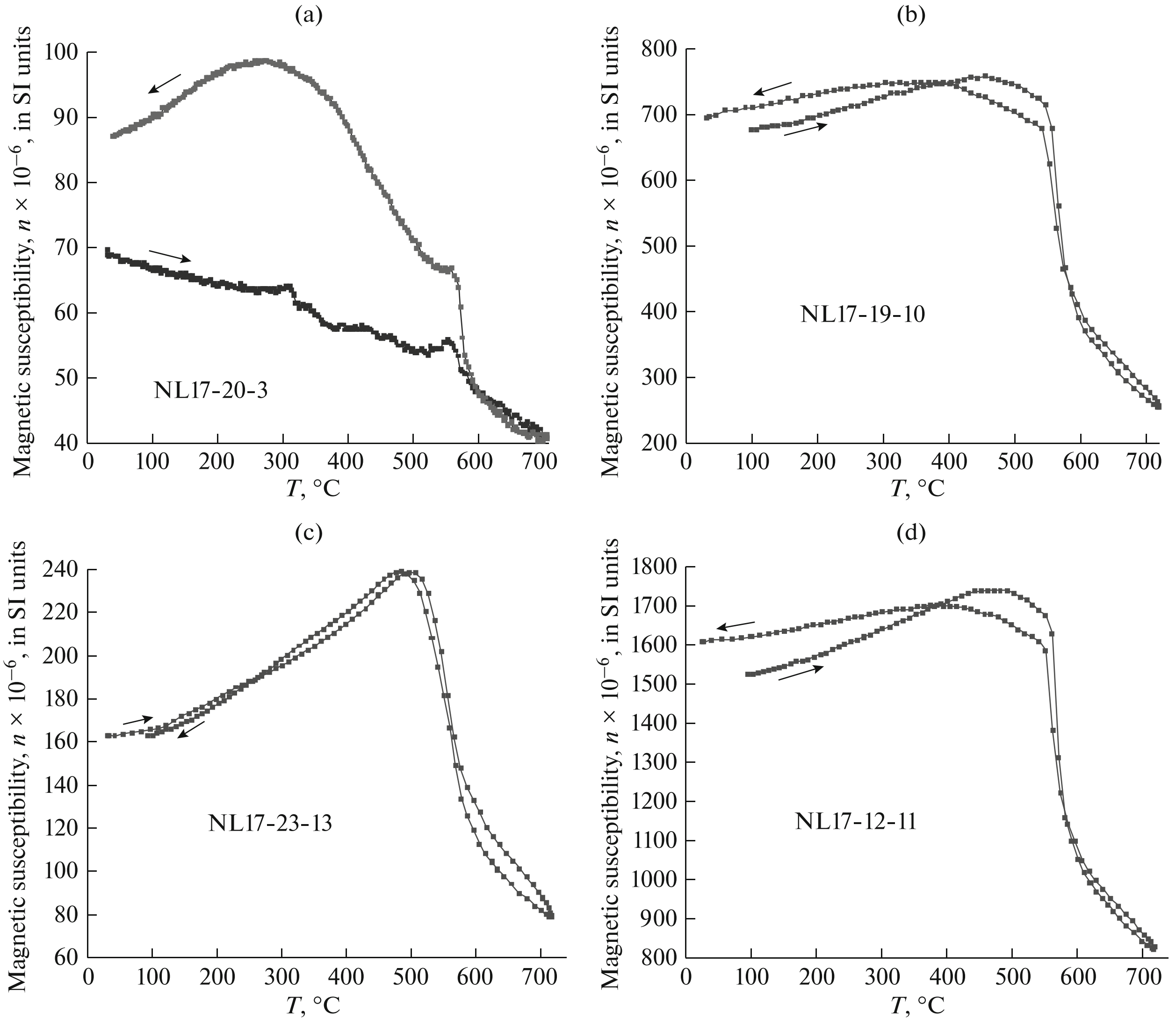


Fig. 3. Temperature dependence curves of magnetic susceptibility (the first heating and cooling curves are shown: (a) a pebble sample of Archean (?) granitoid; (b) a pebble sample of Early Paleoproterozoic stratified intrusions; (c) a sample of the matrix of Sariolian conglomerates; (d) a sample of Early Paleozoic stratified intrusions (Kivakka massif).

(Figs. 3d and 3b, respectively). Samples collected directly from the matrix of the Sariolian conglomerates were poorly magnetic (Fig. 3c). During the thermal processing of samples one can observe a significant (by 1.5–2 times) increase in magnetic susceptibility, associated with the crystallization of magnetite (Fig. 3c).

As a result, the detailed stepwise thermal demagnetization of all samples and the demagnetization of reference samples with an alternating magnetic field were performed. Unfortunately, approximately 30% of the collection of samples turned out to be inapplicable for paleomagnetic studies due to the absence of a stable paleomagnetic record and were excluded from further consideration. Finally, only 15 pebbles of Archean granitoids, 32 pebbles of Sumian mafic rocks, and 10 pebbles from the Sariolian matrix were chosen for further research.

The Archean granitoids in bedrocks were sampled in two sampling sites: on the Deda and Gorelyi islands (the eastern part of the Onega structure, Vodlozero terrane), where they are cut by Neoarchean Shalskii dikes of gabbro-norites.

In a large number of samples of Archean granitoids, which were sampled at a distance exceeding 100 m from the contact zone, the most stable low-temperature (low-coercivity) magnetization component of north-northeastern/western declination and steep positive inclination, which becomes broken in a temperature range of 20–180°C and a magnetic field of 3–12 mTl, is distinguished (Fig. 4a).

Table 1. The paleomagnetic poles of Sariolian conglomerates of the Onega structure of the Karelian protocraton

Ser. ID	Research subject	Designation of sampling site	Coordinates of sampling sites		Paleomagnetic direction					Paleomagnetic pole			
			φ, deg	λ, deg	*B*/*N*	Dec, deg	Inc, deg	*K*	α_{95}, deg	Φ, °N	Λ, °E	d_p, deg	d_m, deg
High-temperature magnetization component													
1	Pebbles of Archean granitoids	AR_{HT}	62.45	33.67	2/10	82.3	73.8	2.52	20.2	52.9	89.4	18.4	27.3
2	Pebbles of Sumian stratified intrusions	PPR_{HT}	62.45	33.67	5/33	69.2	42.0	1.13	63.7	–	–	–	–
3	Matrix of Sariolian conglomerates	MAT_{HT}	62.45	33.67	2/10	178.3	63.7	1.32	52.3	–	–	–	–
Mid-temperature magnetization component													
4	Pebbles of Archean granitoids	AR_{MT}	62.45	33.67	1/15	47.3	82.0	66.5	4.7	69.8	68.9	8.6	9.0
5	Pebbles of Sumian stratified intrusions	PPR_{MT}	62.45	33.67	4/29	341.4	58.5	14.7	7.2	–64.1	68.1	7.9	10.7
6	Matrix of Sariolian conglomerates	MAT_{MT}	62.45	33.67	2/10	309.7	74.1	84.3	5.3	–66.4	141.4	8.6	9.6

B, the number of sites; *N*, the number of samples; POL, the polarity of paleomagnetic directions (N, direct, R, reverse); φ, λ, latitude and longitude of sampling sites, deg.; Dec, declination, Inc, inclination; *K*, the clustering of vectors; α_{95}, confidence circle radius at a 95% probability for average direction; Φ, Λ, latitude and longitude of a paleomagnetic pole, respectively; d_p, d_m, semiaxes of the 95% confidence interval, respectively.

The direction of this component is close to that of the recent magnetic field in the study area (Dec = 12.9°; Inc = 74.9°), which may indicate its viscous nature and recent age. On the Zijderveld plots this component is designated as PDF (Fig. 4). It was excluded from further consideration. Apart from the recent PDF-component, a component of west–southwestern declination and steep negative inclination is distinguished in a high-temperature/high-coercivity interval (component UBG1 in Fig. 4a).

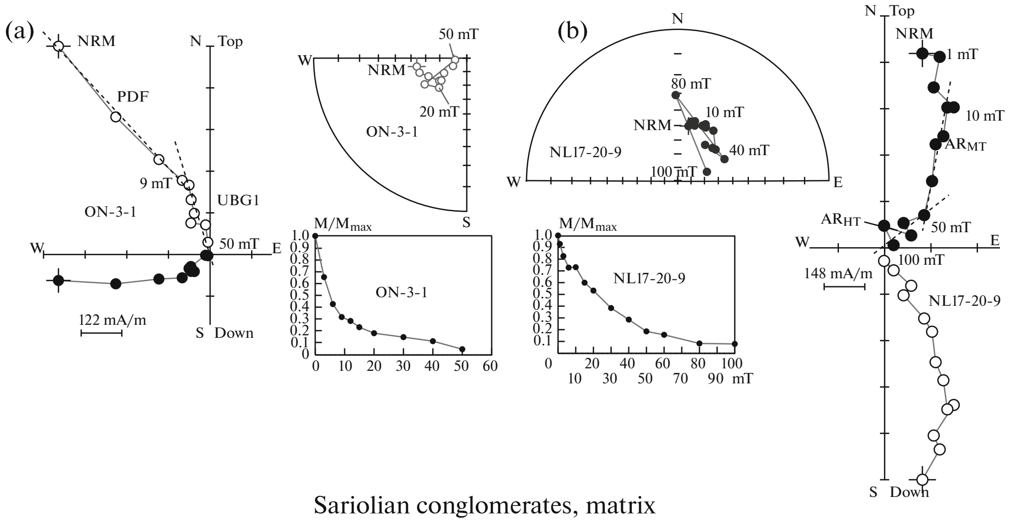
The average direction of this magnetization component is significantly different from the directions of the high-temperature component in Neoarchean gabbro-norite dikes (Table 1), which is indirect evidence of the absence of the remagnetization of Archean granitoids in the eastern part of the Onega structure after intrusion of Neoarchean dikes (Scherbakova et al., 2017).

Apart from the recent PDF-component, a second magnetization component (UBG1) of south–southeastern declination and high negative inclination is distinguished in samples of Archean granitoids in a range of blocking temperatures of 575–590°C and an alternating magnetic field of 40–100 mTl (site UBG1; Fig. 4a, Table 1). The average direction of this component is significantly different from the high-temperature component directions in Neoarchean gabbronorite dikes and in Sumian stratified intrusions (Fig. 4e, Table 1), which indirectly may indicate the absence of remagnetization in Archean granitoids after intrusion of Neoarchean dikes (Scherbakova et al., 2017).

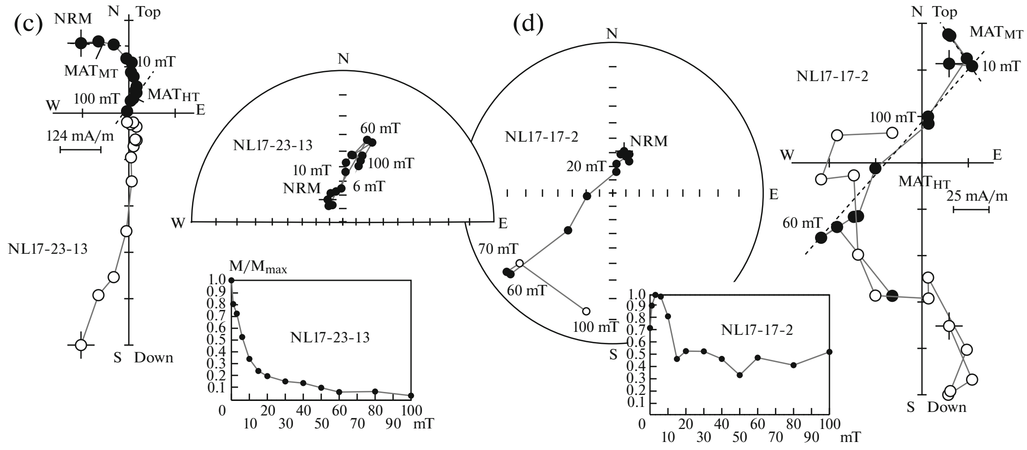
Apart form the recent PDF-component, two metachronous magnetization components were distinguished in two samples of granitoid pebbles.

The AR_{MT} component with north–northwestern declination and moderate positive inclination was distinguished in a mid-temperature range (Fig. 3b). The average direction of this component coincides with the Svecofennian remagnetization direction, which is widely distributed within the Fennoscandian segment of the Karelian protocraton (AR_{MT} and SFR; Figs. 4a and 4d and Tables 1 and 2, respectively). A second high-temperature magnetization component, AR_{HT}, was distinguished in the temperature interval of 420–450°C and alternating magnetic fields of 50–100 mTl (Fig. 3b). This component is monopolar (northeastern declinations and low-to-high positive inclinations). The high-temperature component AR_{HT} only has negative inclinations in two samples of Archean granitoid pebbles (Fig. 3b). The single directions of this magnetic component are uniformly distributed in the bedding plane of Sariolian conglomerates (Fig. 4b).

Archean country granitoids



Sariolian conglomerates, matrix



Sumian stratified intrusions

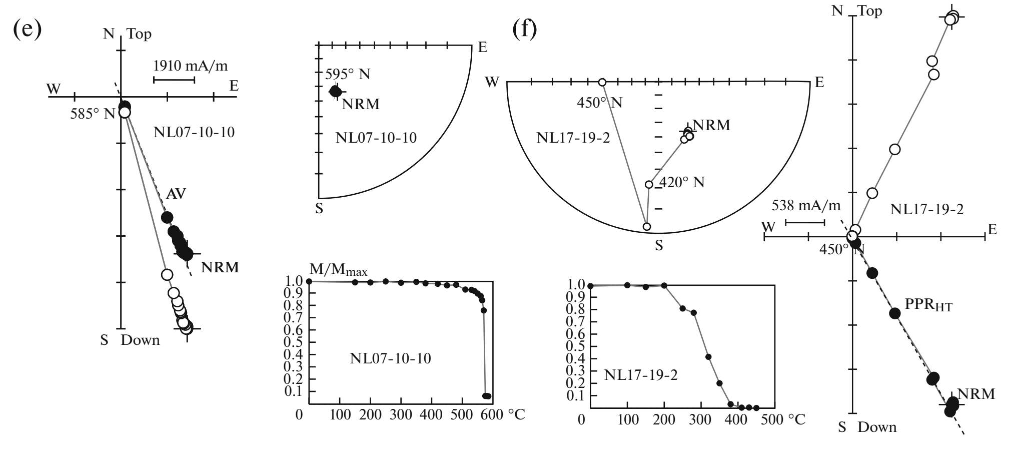


Fig. 4. Examples of stepwise thermal demagnetization of samples of Sariolian conglomerates and country Archean granitoids of the Onega structure of the Karelian protocraton: (a) Archean country granitoids on Deda Island (the eastern part of the Onega structure); (b) pebble of Archean granitoids from the Sariolian conglomerates; (c–d) the matrix of Sariolian conglomerates in the western part of the Onega structure; (e) gabbro-norites of the Sumian Kivakka stratified intrusion; (f) pebbles of the Sumian layered intrusion from the Sariolian conglomerates in the western part of the Onega structure. Every sample is characterized by a Zijderveld plot in the geographic system of coordinates, an NRM behavior curve during the stepwise thermal demagnetization, and orthogonal projections in the geographical system of coordinates. Open circles, projections of geomagnetic field vectors onto the upper hemisphere (projection onto a vertical plane for Zijderveld plots); black circles, projections of geomagnetic field vectors onto the lower hemisphere (projection onto a horizontal plane for Zijderveld plots). The numbers next to the circles indicate the temperature of thermal cleaning in °C. The letters on the Zijderveld plots give the distinguished magnetization components (Fig. 5 and Table 1).

The conglomerate test is negative: the Rayleigh number *r* is below a critical value *rc* (*r*/*rc* = 0.612/0.307), which indicates the presence of a regular secondary component in the set of vectors (Shipunov and Muraviev, 1997; Watson, 1956).

In samples from the matrix of the Sariolian conglomerates two metachronous magnetization components were also distinguished (Figs. 3c and 3d). It is a difficult task to correctly distinguish two magnetization components, since in the mid-temperature/high-coercivity interval the magnetization component directions are spread along the arc of a large circle (Figs. 3c and 3d). Moreover, the average direction of the MAT_{MT} component distinguished in the low temperature/low-coercivity interval (Figs. 4a and 4d) is close to that of the mid-temperature magnetization component distinguished in samples of Archean granitoid pebbles and Sumian stratified intrusions Fig. 4a), which may be evidence of partial remagnetization of these rocks in the Paleoproterozoic (~1.86 Ga ago). In addition, a second metachronous magnetization component, MAT_{HT}, is distinguished in samples of the matrix of the Sariolian conglomerates in the high temperature/high-coercivity interval (Fig. 3d). The component is bipolar: the components with west-northwestern declination and positive inclination (Figs. 3c and 3d) and east-southeastern declination and steep negative inclination (Fig. 4b) dominate in samples. The reversal test is negative. The contact test supports the occurrence of some regular secondary component in the combination of vectors (*r*/*rc* = 0.359/0.290) (Shipunov and Muraviev, 1997; Watson, 1956).

In samples of Sumian gabbro-norites of the Kivakka stratified intrusion a single high-temperature/high-coercivity monopolar magnetization component is distinguished (AV in Fig. 4e). Following from the range of the blocking temperatures and the data of thermomagnetic analysis (Fig. 3d) the mineral that is the main carrier of magnetization in rocks is magnetite with insignificant maghemization. The high-temperature magnetization component has a south-southeastern declination and moderate positive inclination.

The average direction of this component is distinguished by 30–40° in declination from that previously obtained for the Sumian Burakovo stratified intrusion and Neoarchean Avdeevo dike of the Vodlozero terrane (BU and AV in Fig. 5d, respectively). In samples of pebbles of Sumian mafic intrusions two magnetization components are more often distinguished.

In a temperature range of up to 350°C and at an alternating field of up to 30 mTl a PPR_{MT} component of north-northwestern declination and moderate positive inclination is distinguished (Figs. 3e and 3f). The average direction of this component lies between the average directions of the mid-temperature/moderate-coercivity magnetization components that were distinguished in pebbles of Archean granitoids and the matrix of Sariolian conglomerates (AR_{MT} and MAT_{MT} in Fig. 5a, respectively), and the direction of the Svecofennian remagnetization (SFR in Fig. 5d). The concentrated distribution of the mid-temperature/moderate coercivity magnetization component indicates the partial remagnetization of rocks in the Svecofennian time.

It should be also noted that the paleomagnetic pole recalculated from the direction of this component to the coordinates of sampling sites is close to the pole of the Svecofennian remagnetization in 1.88 Ga (Pesonen et al., 2003) and coincides with a paleomagnetic pole of 1.86 Ga of the Murmansk block (Samsonov et al., 2018).

The second, the monopolar magnetization component, distinguished in a temperature range of 420–480°C, has a chaotic distribution on the sphere (comp. PPR_{HT} in Fig.4c). The correlation test of conglomerates is positive: the Rayleigh number *r* is below a critical value *rc* (*r*/*rc* = 0.214/0.350), which indicates the absence of some regular secondary component in the set of magnetic field vectors (Shipunov and Muraviev, 1997; Watson, 1956). Thus, these results support partial preservation of the initial magnetization component in pebble samples from layered intrusions.

DISCUSSION

The paleomagnetic poles that were recalculated from the directions of the mid-temperature magnetization components distinguished in pebbles of Archean granitoids and Sumian stratified intrusions, as well as from the matrix of Sariolian conglomerates, are close to the direction of the Svecofennian remagnetization (Fig. 5, Table 2). The remagnetization of this type in Archean–Paleoproterozoic complexes of the Karelian protocraton is connected apparently with the exhumation of the Precambrian complexes in Lapland ((Lahtinen et al., 2018) and reference therein) and Svecofennian ((Nivonen et al., 2017) and reference therein) orogens 1.88–1.86 and 1.80 Ga ago, respectively. It is remarkable that the paleomagnetic pole that was recalculated from the Svecofennian remagnetization direction coincides with a key pole of ~1.88 Ga for the Kola–Karelian Craton (Samsonov et al., 2018).

Apart from the Svecofennian component (Comp. A in Fig. 4d and in Table 2), the second magnetization component B of north-northwestern declination and low to moderate positive inclination is often distinguished in rocks of the Karelian Craton in a mid- to high-temperature range (Comp. B in Fig. 4d and in Table 2). In this case, the occurrence of the component B in Archean and Paleoproterozoic complexes of the Karelian protocraton is confined spatially to its marginal parts: the east-northeastern part of the Vodlozero terrane along the boundary with the Belomorian belt, Ludicovian dolerite sills in the western part of the Onega structure of the Karelian protocraton

Table 2. The paleomagnetic poles that were obtained previously in the Neoarchean–Paleoproterozoic complexes of the Karelian Craton and the Svecofennian orogen

Ser. ID	Research subject	Designation of a site	Coordinates of sampling sites		Paleomagnetic direction					Paleomagnetic pole				Age, Ma	Reference
			φ, deg	λ, deg	*B*/*N*	Dec, deg	Inc, deg	*K*	α95, deg	Φ, °N	Λ, °E	d_p, deg	d_m, deg		
	Key paleomagnetic poles														
1	Archean granitoids, Deda Island, the eastern part of the Onega structure	ARG1	61.82	35.86	1/9	245.9	–64.8	36.4	8.7	50.7	117.1	11.2	13.9	2680 (?)	1
2	Archean granitoids, Gorelyi Island, the eastern part of the Onega structure	ARG2	61.82	35.88	1/15	236.6	–65.5	168.1	3.0	55.5	123.9	3.9	4.8	2680 (?)	1
3	Neoarchean Shalskii gabbro-norite dikes	SH	62.1	36.2	5/154	175.8	–0.7	61.2	9.9	28.5	220.7	4.9	9.9	2504	2
4	Neoarchean Avdeevo gabbro-norite dike	AV	61.95	36.08	8/26	138.0	52.0	112.0	5.0	–11.0	251.0	5.0	7.0	2504	3
5	Burakovo stratified intrusion	BU	61.95	36.08	4/67	139.1	56.5	54.9	7.5	14.3	68.5	7.9	10.9	2449 ± 1	3
6	Sumian dikes of Northern Karelia	Comp D	64.1	27.7	11/65	98.1	44.4	58	6.1	–19.9	278.7	6.1	6.1	2450	4
7	Sumian dikes of Northern Karelia	Comp A	64.1	27.7	22/116	347.1	46.3	126	2.8	52.6	226.7	2.8	2.8	1880(?)	4
8	Svecofennian remagnetization	SFR	65.9	34.8	67	334.6	47.9	5.2	8.4	49.9	250.4	7.2	11.0	1880	5
9	Sumian dikes of Northern Karelia	Comp B	64.1	27.7	16/57	25.3	50.9	33	6.3	53.9	169.6	6.3	3.6	1750(?)	4
10	Ropruchey sill	RS	61.3	35.51	12/145	9.7	5.3	61.2	5.6	30.9	204.0	4.7	4.7	1752 ± 3	6
11	Transscandinavian belt, Smaland intrusion	SML	57.03	15.92	11/46	9.4	24.0	21.8	10.2	45.7	182.7	8.0	8.0	1784–1769	7
12	Turinge gabbro-dolerite dikes	TUR	62.48	14,81	6/56	342.8	44.1	199.3	4.8	51.6	220.2	4.8	4.8	1700 ± 4	8

B, the number of sites; *N*, the number of samples; POL, polarity of paleomagnetic directions (N, direct, R, reverse); φ, λ, latitude and longitude of sampling sites; Dec, declination, Inc, inclination; *K*, vector clustering; α95, confidence circle radius at a 95% probability for average direction; Φ, Λ, latitude and longitude of a paleomagnetic pole, respectively; d_p, d_m, semiaxes of 95% confidence interval, respectively. References: 1, Lubnina et al., 2017; 2, Scherbakova et al., 2017; 3, Mertanen et al., 2006; 4, Mertanen et al., 1999; 5, Pesonen et al., 2003; 6, Pasenko and Lubnina, 2014; 7, Pisarevsky and Bylund, 2011; 8, Elming et al., 2018.

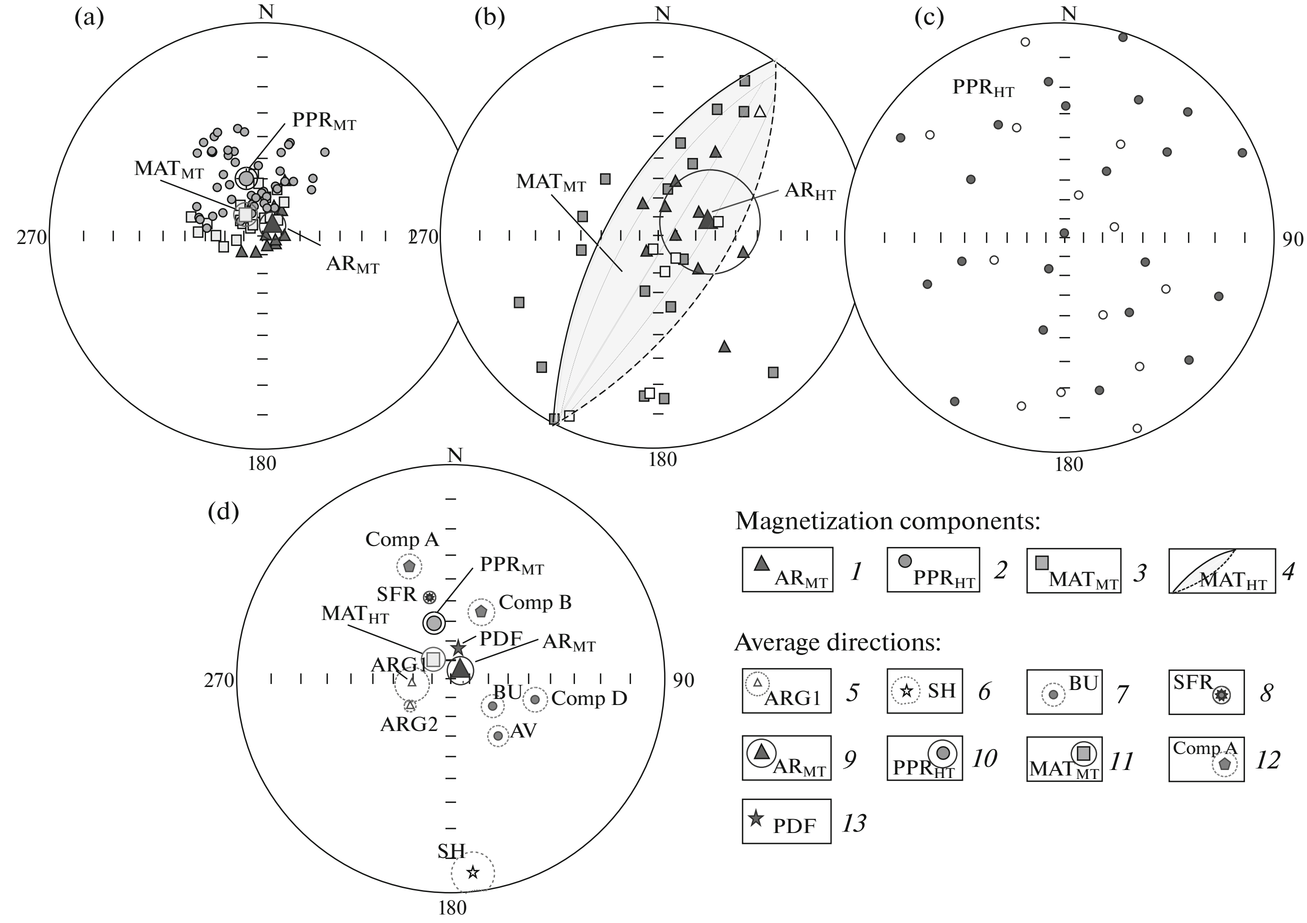


Fig. 5. The distribution of mid- (a) and high-temperature (b–c) NRM components on the sphere in the geographical system of coordinates, distinguished in Sariolian conglomerates of the Onega structure and comparison of average directions with those distinguished in Archean and Paleoproterozoic complexes of the Karelian protocraton (d): (*1–3*) magnetization components, isolated in Sariolian conglomerates: (*1*) in pebbles of Archean granitoids (2884–2690 Ma); (*2*) in pebbles of Sumian (2500–2400 Ma) mafic layered intrusions; (*3*) in the matrix of Sariolian (2300–2100 Ma) conglomerates; (*4*) the remagnetization plane of high-temperature magnetization components in the matrix of Sariolian conglomerates; (*5–13*) comparison of average directions of magnetization components isolated in Sariolian conglomerates with those, obtained for Archean and Paleoproterozoic complexes of the Karelian protocraton: (*5*) Archean granitoids in the eastern part of the Onega structure (Deda and Gorelyi islands) (Scherbakova et al., 2017); (*6*) Neoarchean (2505 Ma) Shalskii dike (Scherbakova et al., 2017); (*7*) Sumian (2450 Ma) Burakovo stratified intrusion (Mertanen et al., 2006); (*8*) Svecofennian remagnetization of the Fennoscandia (Pesonen et al., 2003); (*9*) average temperature magnetization component in pebbles of Archean granitoids from Sariolian conglomerates (this work); (*10*) mid-temperature magnetization component in pebbles of Sumian mafic intrusions in Sariolian conglomerates (this work); (*11*) mid-temperature magnetization component in the matrix of Sariolian conglomerates (this work); (*12*) mid-temperature components in mafic dikes of the Paanajarvi structure (Mertanen et al., 1999); (*13*) direction the recent geomagnetic field in the study area. On stereograms: open signs, projections of geomagnetic field vectors onto the upper hemisphere; black signs, projections of geomagnetic field vectors onto the lower hemisphere. Letter designations of magnetization components are given in Table 1.

near its boundary with the Svecofennian orogen, and the northern part of the Central Karelian terrane near its boundary with the Lapland–Kola orogen. Based on the isotope age dates, the possible time when rocks acquired the magnetization components is indirectly estimated to be 1.76–1.79 Ga. The magnetic component of the same direction is broadly distributed directly within the Svecofennian orogen as the primary one in the Paleoproterozoic mafic intrusions (Lubnina et al., 2018; Piserevsky and Bylund, 2010) or as the secondary one in rocks that crop out near the Transscandinavian volcanic belt (Elming et al., 2018; Lubnina et al., 2018).

CONCLUSIONS

(1) The paleomagnetic study of Sariolian conglomerates of the Onega structure of the Karelian protocraton distinguished a secondary metachronous magnetization component connected with the formation of the Svecofennian accretionary belt.

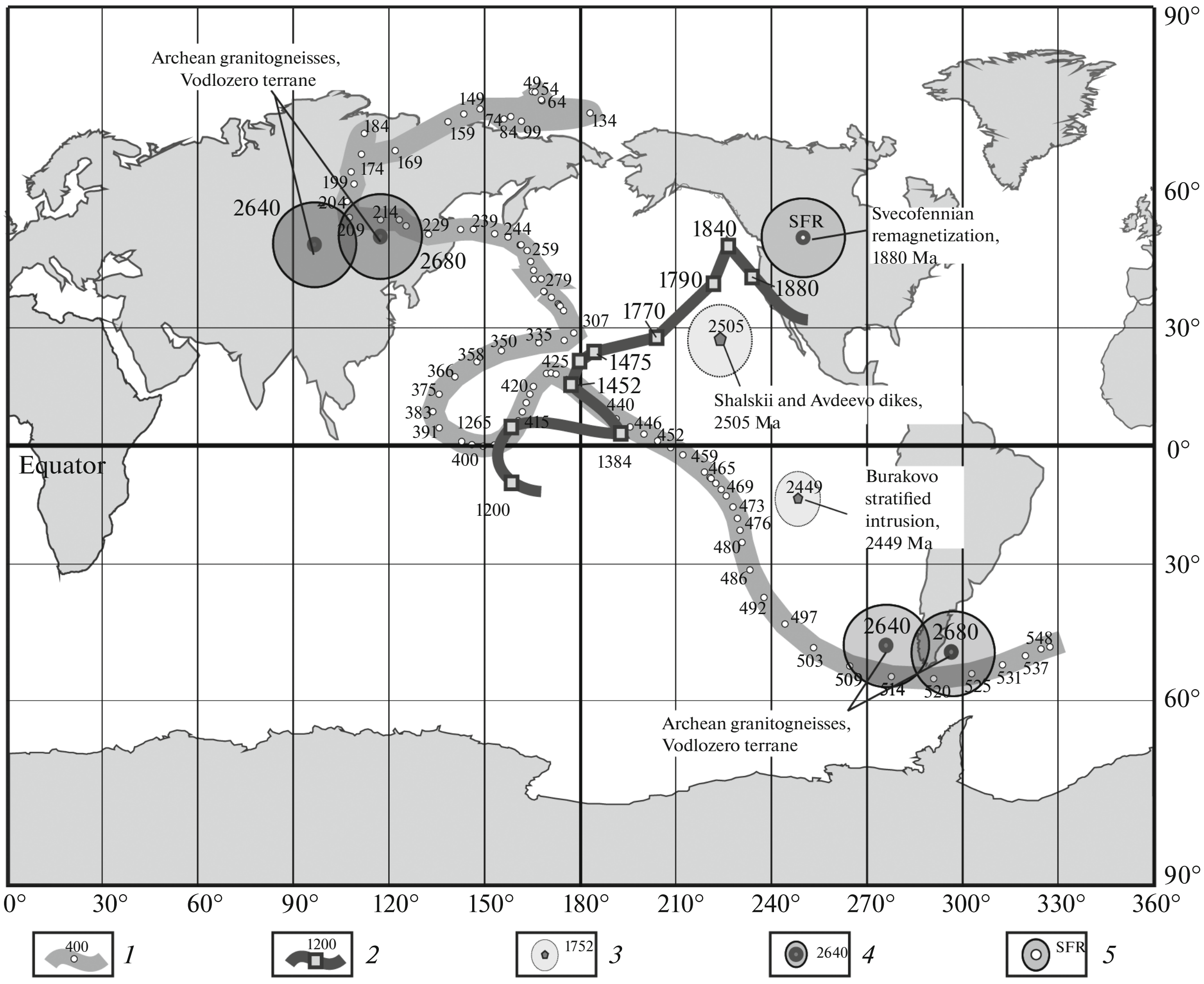


Fig. 6. Comparison of new paleomagnetic poles with the proposed trajectory of the apparent migration of the pole (TAMP) of the Karelian (East European) Craton in an age interval of 2.45–0.92 Ga, after (Lubnina et al., 2016) with amendments: (*1*) Phanerozoic segment of TAMP of the East European Craton; (*2*) Precambrian segment of TAMP of the Karelian protocraton; (*3*) previously obtained Paleoproterozoic poles of the Karelian protocraton (Table 2); (*4*) previously obtained Archean poles of the Karelian protocraton (Table 2); (*5*) direction of the Svecofennian remagnetization.

(2) Under similar conditions the remagnetization processes are manifested in rocks, that vary in composition in different manners. In Archean granitoids and the matrix of Sariolian conglomerates one more secondary magnetization component is distinguished in the high-temperature/high-coercivity interval (negative contact test). In pebbles of Sumian stratified intrusions we were able to distinguish the primary high-temperature magnetization component (positive contact test). This result indicates the partial preservation of initial magnetization components in the Paleoproterozoic complexes of the Karelian protocraton.

(3) It is probable that the degree of preservation of secondary early and late magnetization components is connected not only with the protolith composition, but also with varying conditions of rock transformation, including their fluid saturation.

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