

Paleointensity derived from igneous rocks of Kamchatka volcanoes of the Late Pleistocene-Holocene epoch



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Purpose of the work:

Clarification of the age of the lava flows of the Avachinsky, Gorely and Tolbachik volcanoes and replenishment of the data of the Kamchatka magnetochronological scale for the Late Pleistocene and Holocene.

Relevance of the work:

It is important for constructing global models of the geomagnetic field in the Holocene, since there are currently insufficient paleomagnetic data for the Holocene volcanic rocks of Kamchatka and generally of the northwest coast of the Pacific Ocean.

Objects of study

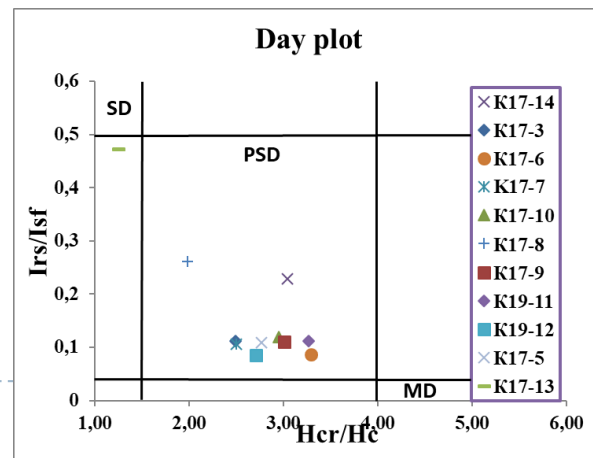
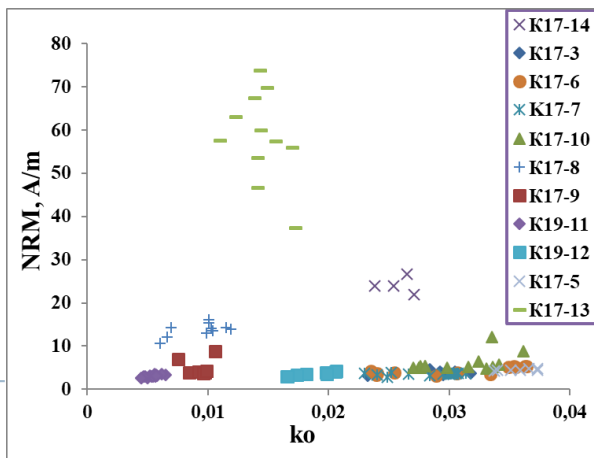
Volcano	№	Approximate age	Latitude, °	Longitude, °	Altitude, m
Tolbachik	K17-14	Eruption 2012	≈N55.81667	≈E160.31667	-
Avachinsky	K17-3	Eruption 1827	N53.214806	E158.807556	1050
	K17-6		N53.216111	E158.814028	1065
	K17-7		N53.214917	E158.812694	1007
	K17-10		N53.222556	E158.806139	1150
	K17-8	More than 3800 years	N53.266306	E158.818028	2134
	K17-9		N53.266333	E158.817806	
	K19-11		N53.266329	E158.818286	
	K19-12		N53.266273	E158.818086	
	K17-5	About 30000-50000 years	N53.215861	E158.807306	1017
Gorely	K17-13	Less than 8000 years	N52.559222	E158.058389	1555



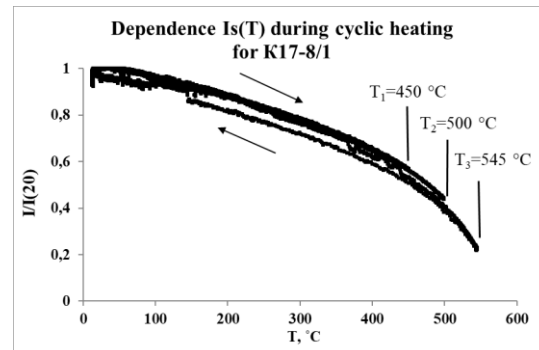
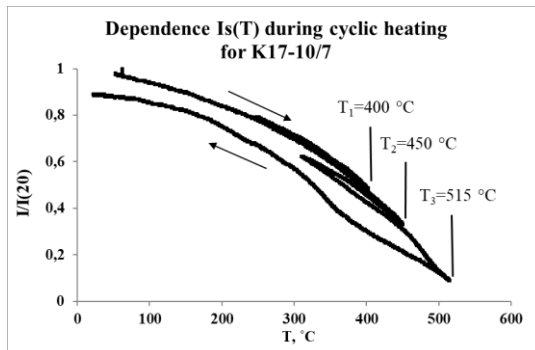
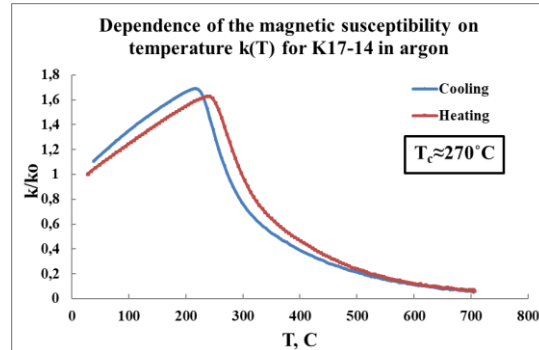
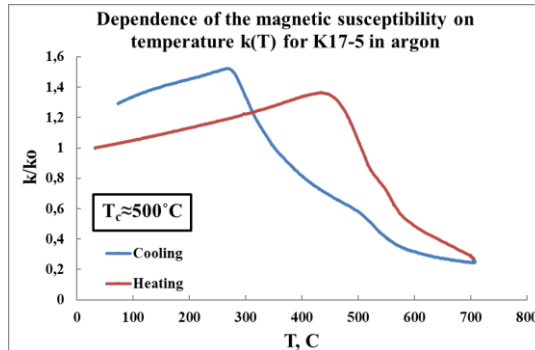
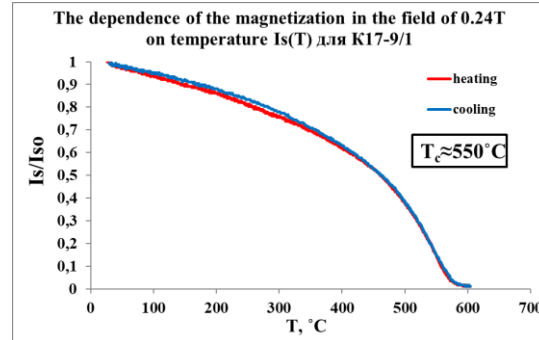
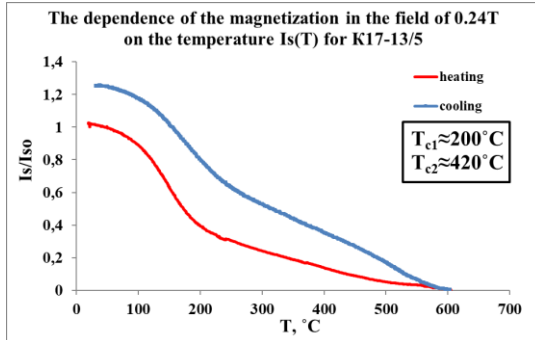


Natural and hysteretic magnetic characteristics

Volcano	Sample	Number of specimens	NRM, A/m	ko, 10 ⁻³ SI units	Qn	Irs, A/m	Isf, A/m	Hc, mT	Hcr, mT	Irs/Isf	Hcr/Hc
Tolbachik	K17-14	9	21.9–26.7	24–27	19–24	548.0	2390	11.2	34.2	0.23	3.0
Avachinsky	K17-3	10	3.0-4.5	23-32	2.8-3.4	406.6	3650	12.4	30.7	0.11	2.5
	K17-6	13	3.2-5.3	23-36	2.5-4.3	318.6	3690	8.6	28.3	0.09	3.3
	K17-7	15	2.7-3.8	23-31	2.7-3.8	447.2	4240	11.5	28.8	0.11	2.5
	K17-10	18	4.2-8.8	27–36	3.5–5.9	334.5	2810	11.3	33.2	0.12	2.9
	K17-8	11	10.6-16.0	6.0-11.9	28–50	335.8	1280	25.3	50.1	0.26	2.0
	K17-9	14	3.5-8.8	7.5–10.6	9.5–22.2	194.9	1770	14.1	42.5	0.11	3.0
	K19-11	16	2.5-3.5	4.5-6.5	12-15	115.6	1040	14.8	48.4	0.11	3.3
	K19-12	8	2.9-4.3	16-21	4.2-5.0	343.9	4030	12.3	33.2	0.09	2.7
	K17-5	8	4.2-4.8	34-37	2.8-3.1	580.1	5360	11.3	31.4	0.11	2.8
Gorely	K17-13	12	37.3-73.9	11-22	52-127	841.0	1780	21.6	27.0	0.47	1.2

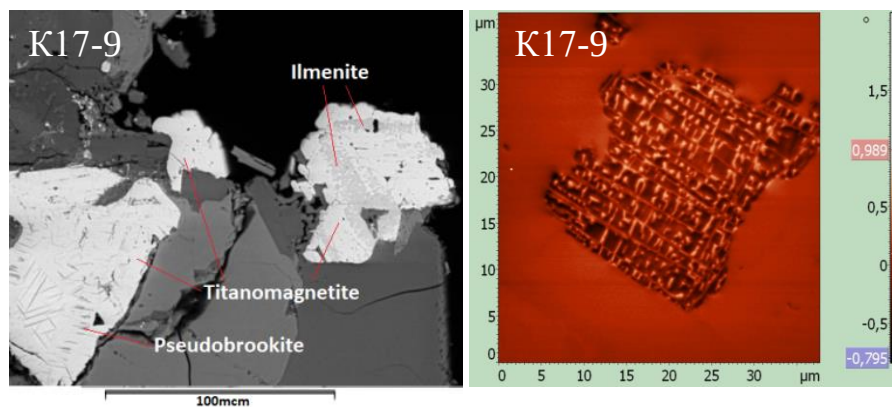


Thermomagnetic analysis



N_2	$T_b, ^\circ\text{C}$ по $I_{rs}(T)$	$T_c, ^\circ\text{C}$ по $I_s(T)$	$T_c, ^\circ\text{C}$ по $k(T)$
Volcano Tolbachik			
K17-14	300	280	270
Volcano Avachinsky			
K17-3	520	500	520
K17-6	520	500	490
K17-7	540	540	520
K17-10	540	500	500
K17-8	560	560	560
K17-9	550	550	560
K19-11	550	-	-
K19-12	550	-	-
K17-5	540	520	500
Volcano Gorely			
K17-13	180, 420	200, 420	180

Electron microprobe analysis

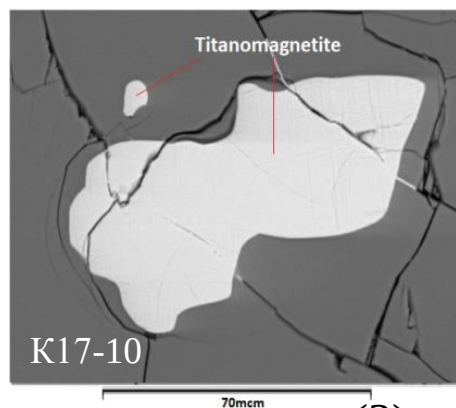


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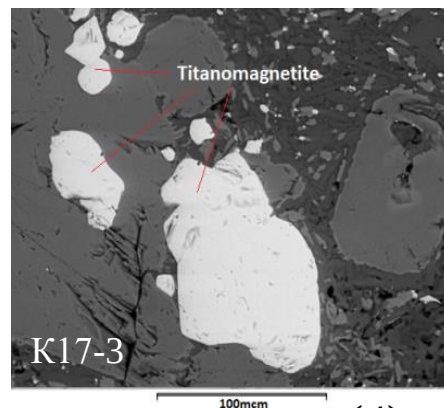
(2)

The results of electron microprobe analysis (minerals)

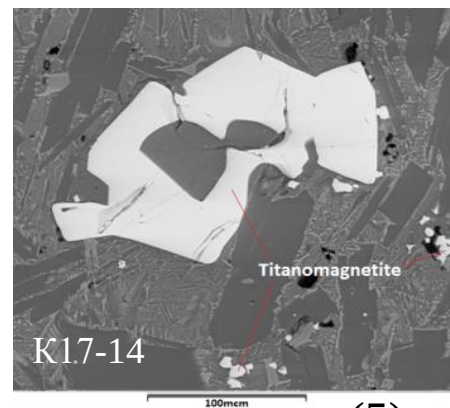
№	Fe_3O_4	Fe_2TiO_4	MgAl_2O_4	MgFe_2O_4
K17-3	0,60±0,06	0,28±0,06	0,07±0,03	0,02±0,02
K17-10	0,54±0,06	0,30±0,08	0,08±0,02	0,05±0,03
K17-9	0,76±0,15	0,14±0,15	0,04±0,03	0,05±0,04
K17-14	0,42±0,03	0,34±0,03	0,10±0,02	0,08±0,04



(3)



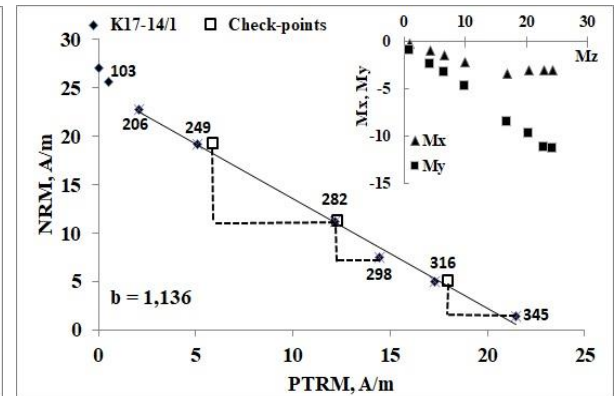
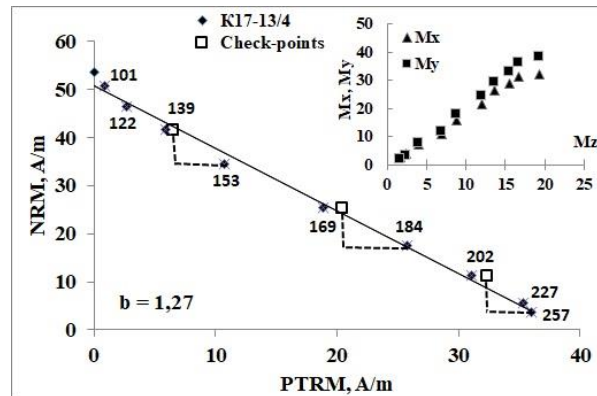
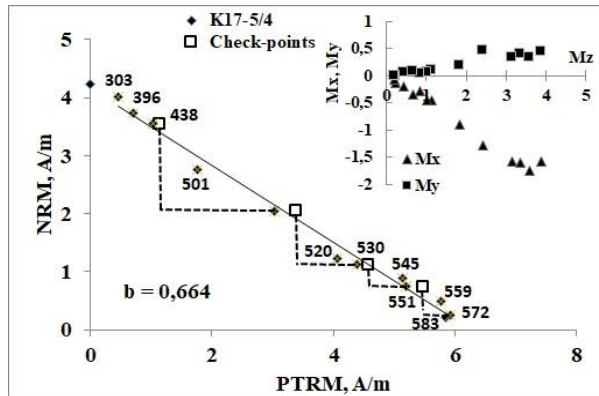
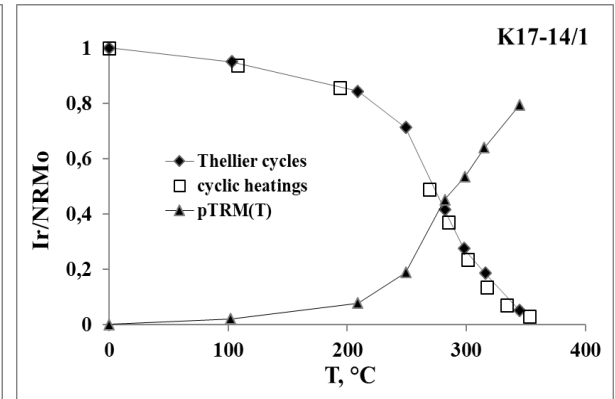
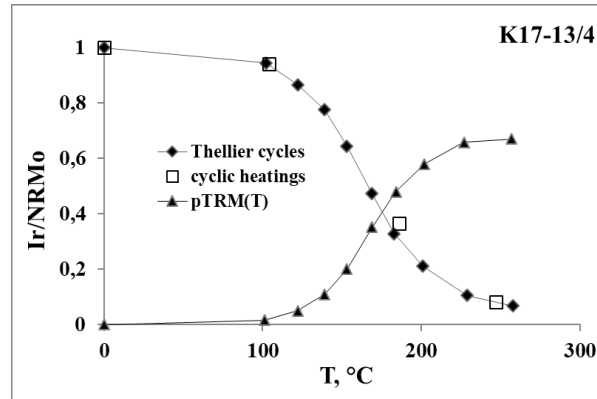
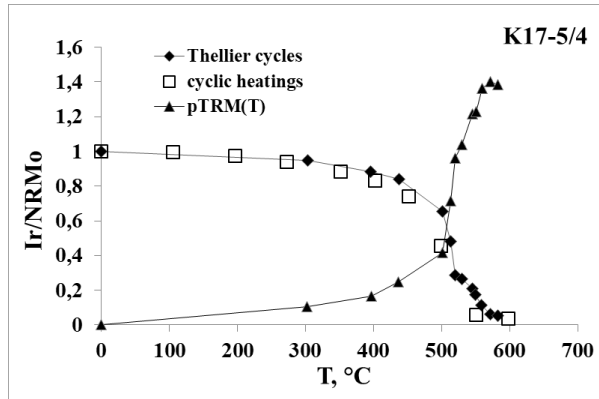
(4)



(5)

Backscattered electron (1,3,4,5) and magnetic force (2) microscope images of ferrimagnetic grains of samples.

Determination of paleointensity: the Thellier-Coe method (samples **K17-5**, K17-13, K17-14)

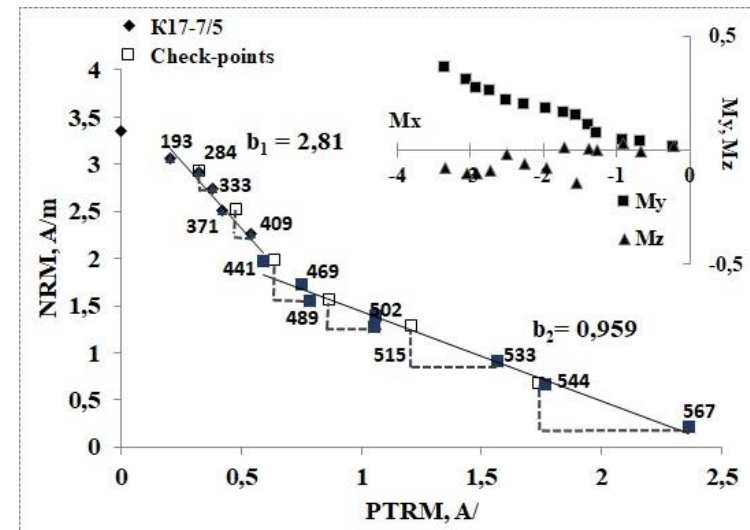
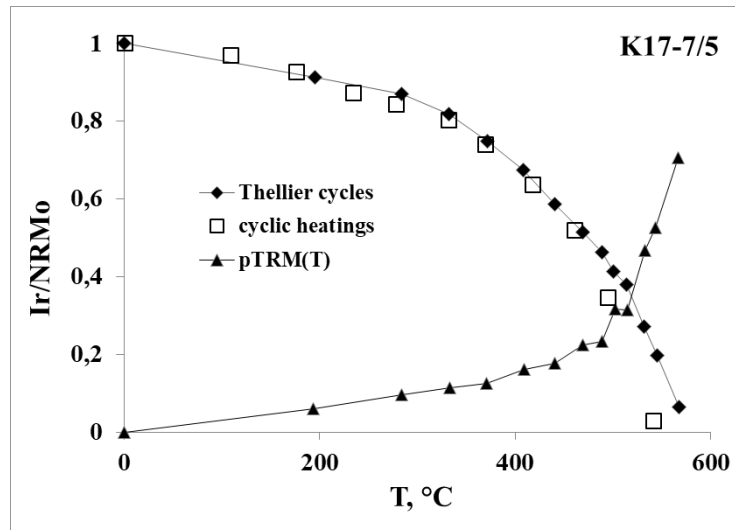
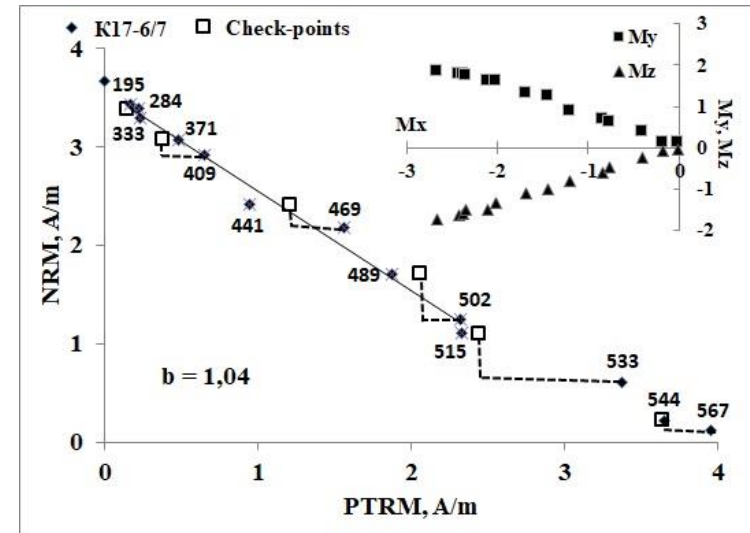
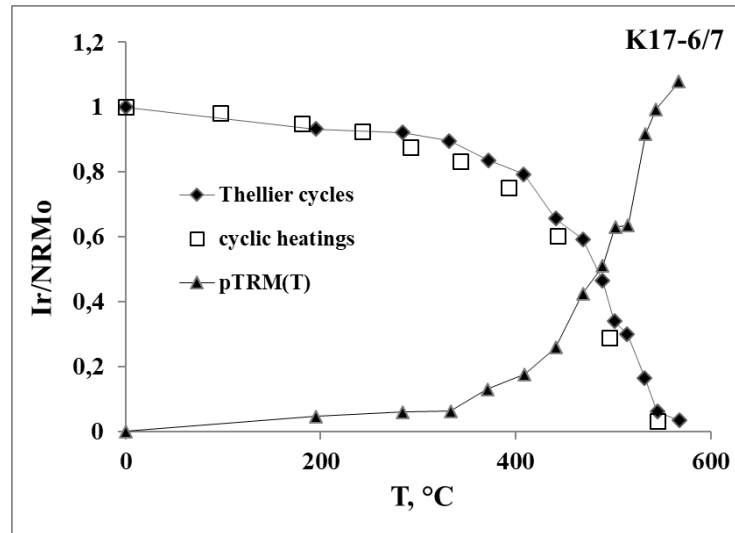


**Volcano
Avachinsky**

**Volcano
Gorely**

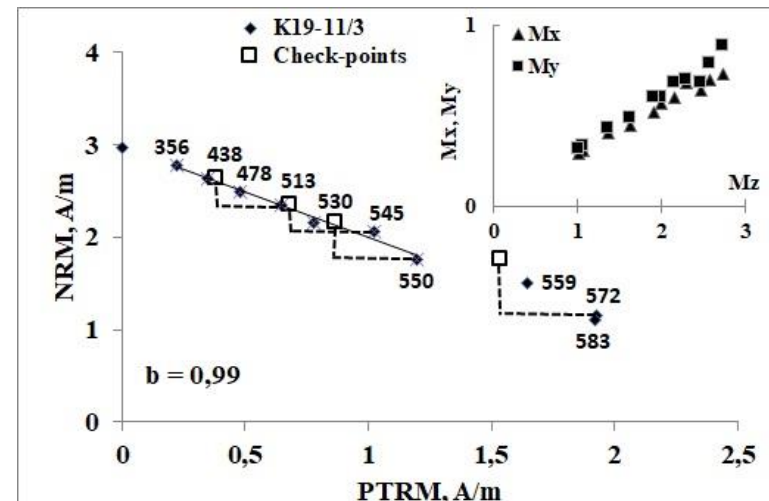
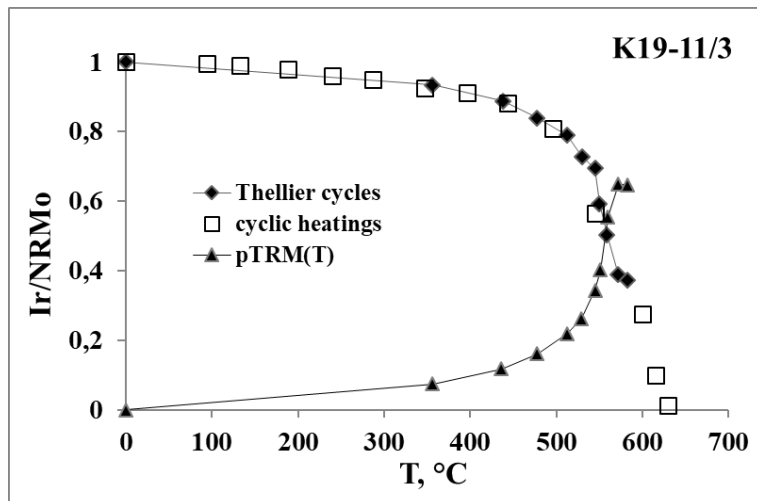
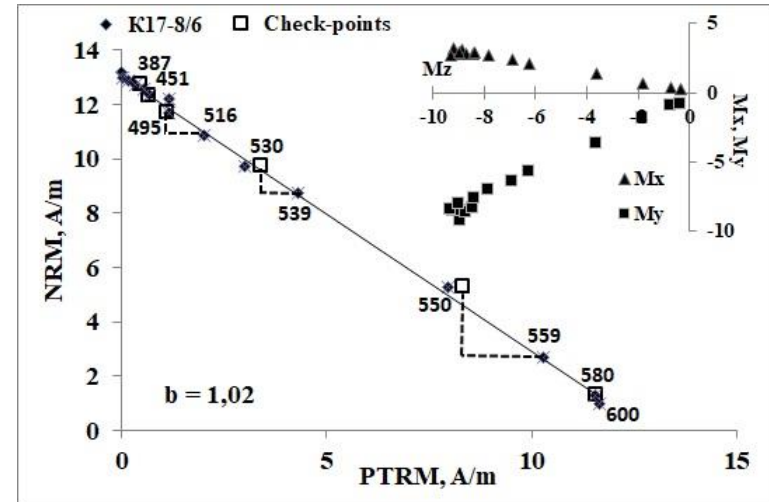
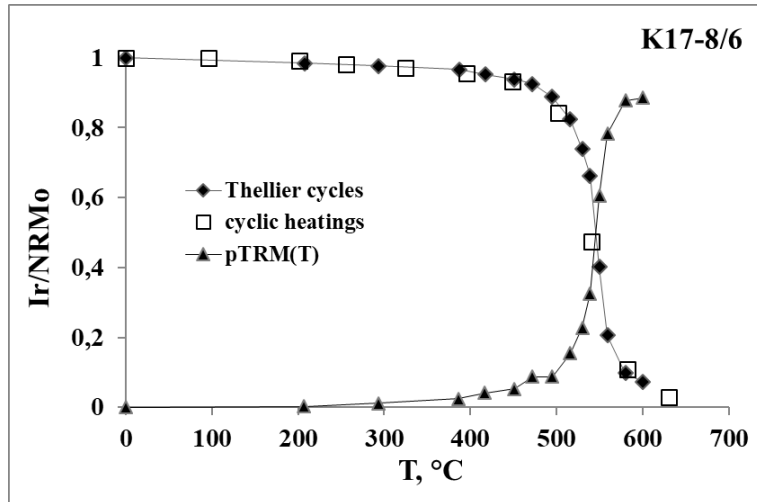
**Volcano
Tolbachik**

Determination of paleointensity: the Thellier-Coe method (lava flow of eruption 1827)



Volcano Avachinsky

Determination of paleointensity: the Thellier-Coe method (5000-5500 year old lava flow)



Results of determination of the magnitude of paleointensity by the method of Thellier-Coe

Volcano	Sample	Specimen	T_1-T_2	N	q	g	f	b	$DRAT_{max}'$ %	$B_{lab}, \mu T$	$B_{anc}, \mu T$
Avachinsky	K17-5	4	303-572	11	20,40	0,800	0,886	0,66±0,02	5,5	50	33±1
		6	303-559	13	26,88	0,879	0,864	0,66±0,02	9,0	50	32±1
Gorely	K17-13	4	101-257	9	32,79	0,859	0,876	1,27±0,03	2,8	50	64±2
Tolbachik	K17-14	1	206-345	6	13,75	0,760	0,790	1,14±0,07	2,8	50	57±4
		2	150-378	10	39,34	0,871	0,915	1,00±0,02	1,7	53	53±1
		3	150-378	10	40,70	0,870	0,877	1,05±0,02	1,8	53	56±1
		5	150-378	10	40,56	0,869	0,925	1,02±0,02	2,4	53	54±1

T_1-T_2 – temperature range for determining paleointensity

N – number of points involved in the calculation of paleointensity

q – paleointensity determination quality parameter [Coe, 1978]

g – uniformity of distribution of points on the Arai-Nagata diagram

f – fraction NRM used to determine paleointensity

b – coefficient of linear approximation of data on the Arai-Nagata diagram

$DRAT_{max}$ – parameter quantitatively characterizing errors in determining the paleointensity [Selkin, 2000]

B_{lab} – magnetic field in which pTRM is formed

B_{anc} – calculated paleointensity

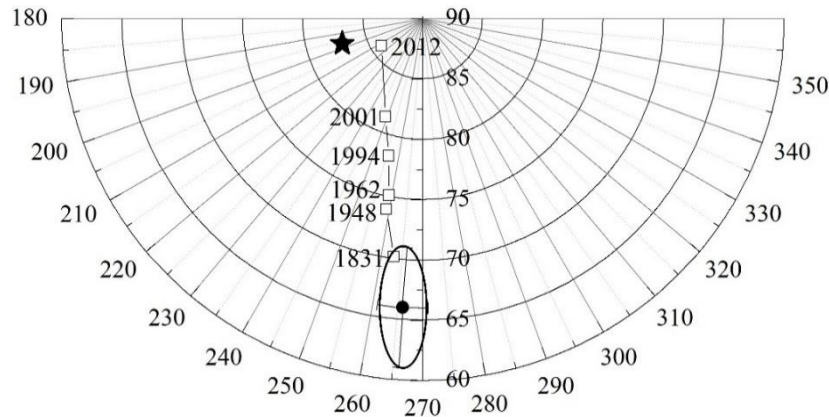
Volcano, age	Sample	Specimen	T ₁ -T ₂	N	q	g	f	b	DRAT _{max} , %	B _{lab} , μT	B _{anc} , μT
Avachinsky, eruption 1827	K17-3	5	375-536	6	2,99	0,785	0,612	1,12±0,16	7,6	50	56±8
		6	390-511	6	3,89	0,777	0,494	1,12±0,13	12,9	50	56±6
	K17-6	5	193-487	9	54,9	0,879	0,691	1,08±0,01	5,7	50	54±1
		7	195-515	10	7,24	0,804	0,632	1,04±0,07	8,2	50	52±4
		8	195-515	10	35,1	0,823	0,940	1,03±0,02	7,4	50	52±1
	K17-7	5	441-567	8	7,01	0,831	0,522	0,96±0,06	6,5	50	48±3
		6	441-567	8	4,36	0,838	0,495	0,90±0,09	6,5	50	45±4
	K17-10	8	110-511	9	24,67	0,817	0,917	0,93±0,03	11,3	53	50±2
		9	207-559	12	25,78	0,943	0,697	0,88±0,02	4,4	50	44±1
		10	207-530	9	14,02	0,932	0,621	0,84±0,04	8,4	50	42±2
Avachinsky, 5000-5500 years	K17-8	4	298-591	10	21,15	0,865	0,905	1,11±0,04	2,1	50	55±2
		6	208-600	14	68,13	0,833	0,911	1,02±0,01	2,3	50	51±1
	K17-9	7	108-594	12	29,63	0,865	0,862	1,12±0,03	1,2	53	59±2
		8	208-630	15	65,61	0,900	0,873	1,02±0,01	2,5	50	51±1
	K19-11/3	3	356-550	7	4,65	0,809	0,341	0,99±0,06	6,1	50	50±3
	K19-12/2	2	356-530	7	13,55	0,794	0,387	0,88±0,02	4,7	50	44±1

Results of determination of the direction of paleointensity

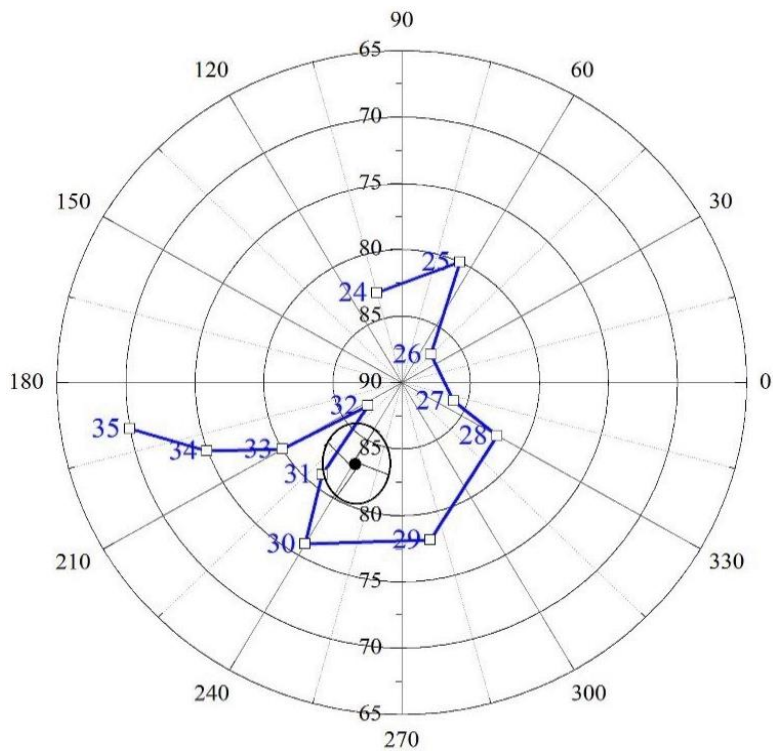
Volcano	Age	Sample	Number of specimens	J _{anc} before demagnetization, °	D _{anc} before demagnetization, °	J _{anc} after demagnetization (h=10 mT), °	D _{anc} after demagnetization (h=10 mT), °	Paleopole coordinates	
								Plat, °	Plong, °
Avachinsky	eruption 1827	K17-3	4	55÷59	29÷34	57÷58	26÷30	65±2	275±3
		K17-6	5	57÷58	34÷37	55÷56	37÷39	59±2	267±2
		K17-7	9	63÷65	23÷29	63÷65	26÷29	71±2	261±2
		K17-10	4	57÷64	-(15÷22)	59÷64	-(16÷21)	73±2	212±5
	5000-5500 years	K17-8	5	70÷72	15÷28	70÷72	17÷30	77±3	267±4
		K17-9	6	64÷67	-(5÷10)	64÷67	-(3÷11)	84±2	217±28
		K19-11	16	64÷71	2÷15	68÷72	-2÷10	86±2	275±16
		K19-12	8	68÷73	-16÷7	69÷72	-17÷5	82±2	230±8
Gorely	2500-3500 years	K17-13	6	3÷12	-(34÷55)	3÷12	-(35÷53)	31±3	206±3

At the sampling points, the inclination of the modern geomagnetic field is $J_{IGRF}=65^\circ$, and the declination is $D_{IGRF}=-6,5^\circ$, the measured value of the inclination at the sampling point of K17-3 is $J_{GMF}=63.3^\circ$.

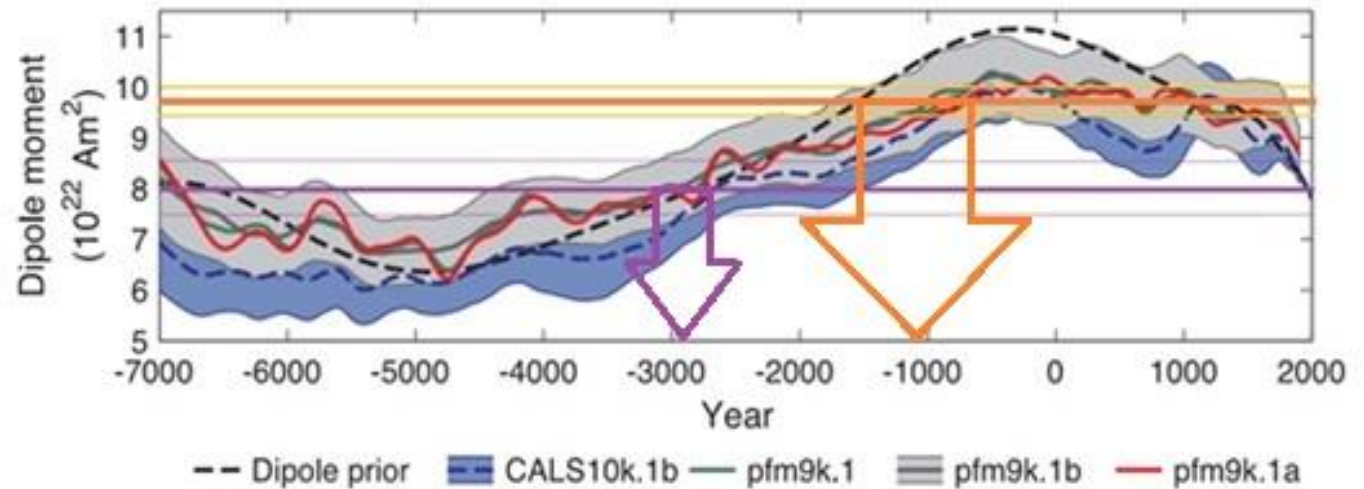
Volcano	Age	Sample	$B_{anc}, \mu T$	$J_{anc}, ^\circ$	$D_{anc}, ^\circ$	Plat, $^\circ$	Plong, $^\circ$	VADM, $10^{22} A \cdot m^2$	VDM, $10^{22} A \cdot m^2$
Avachinsky	eruption 1827	K17-3	56.0±7.2	57÷58	26÷30	65±2	275±3	8.5±1.0	8.6±1.0
		K17-6	52.5±1.8	55÷56	37÷39	59±2	267±2	8.0±0.3	8.2±0.3
		K17-7	46.5±3.7	63÷65	26÷29	71±2	261±2	7.1±0.6	6.8±0.6
		K17-10	45.2±4.5	59÷64	-(23÷27)	73±2	212±5	6.9±0.7	6.8±0.7
	5000-5500 years	K17-8	53.1±2.5	70÷72	17÷30	77±3	267±4	8.1±0.4	7.4±0.4
		K17-9	55.0±4.5	64÷67	-(3÷11)	84±2	217±28	8.4±0.7	8.0±0.7
		K19-11	49.5±3.0	68÷72	-2÷10	86±2	275±16	7.5±0.5	7.0±0.5
		K19-12	43.8±1.0	69÷72	-17÷5	82±2	230±8	6.7±0.2	6.1±0.2



The black dot with an oval is the position of the paleomagnetic pole, obtained from the NRM of samples K17-3, K17-6 and K17-7 (the oval shows the determination error), the hollow squares are registered coordinates of the north magnetic pole [Thébault, 2015] (the numbers indicate the year of registration), the black star is the position of the modern magnetic pole calculated by the dipole approximation [Khramov, 1982].



- Comparison of the paleomagnetic pole position (black star) obtained from the NRM of samples K17-8, K17-9, K19-11 and K19-12, with the positions of the north magnetic pole (hollow squares) determined from archaeomagnetic measurements, the numbers indicate the century BC [Burlatskaya, 2007], the oval shows the determination error .
- Change in the Earth's dipole moment over 9000 years according to various models of the geomagnetic field [Nilsson, 2014], purple lines - the obtained VDM value and the error range for the samples K17-8 and K17-9, orange lines - the obtained VADM value and the error range for the sample K17-13.



Conclusions

1. The most reliable results for determining the paleointensity are given by lavas containing practically unoxidized titanomagnetite, which has high thermal stability, and also titanomagnetite with signs of high temperature oxidation. The difference between the calculated value of B_{anc} from the true in this case does not exceed 4%.
2. The position of the paleomagnetic pole ($Plat = 66^\circ \pm 4^\circ$, $Plong = 266^\circ \pm 5^\circ$) determined from the NRM of samples K17-3, K17-6, and K17-7, confirms that the studied lava flow belongs to the historical eruption of 1827.
3. Based on the results of determining the coordinates of the paleopole ($Plat = 83^\circ \pm 3^\circ$, $Plong = 254^\circ \pm 21^\circ$) and the $VDM = (7.7 \pm 0.8) 10^{22} A \cdot m^2$, it was concluded that the lava flow from which samples K17-8, K17-9 K19-11 and K19-12 were taken, refers to one of the largest eruptions of the Avachinsky volcano, which occurred 5000-5500 years ago.
4. The significant difference in the direction of the NRM of the sample from the Gorely volcano (K17-13) from the direction of the modern field in the sampling area and the high value of $VADM = (9.7 \pm 0.2) 10^{22} A \cdot m^2$ can be due to the "Sterno-Etrussia" geomagnetic excursion (2.7 thousand years ago).

This work was supported by the Russian Foundation for Basic Research,
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Open questions

- ▶ Is the "Sterno-Etrussia" geomagnetic excursion (2.7 thousand years ago) , which has not yet been discovered in the igneous rocks of Kamchatka, really recorded in the NRM of sample K17-13 from Gorely volcano?
- ▶ What are the direction of paleointensity and coordinates of the paleomagnetic pole, determined from the NRM of sample K17-5 from the Avachinsky volcano (the age of lava is about 30-50 thousand years)?

Thank you for attention!

