

UPPER CRETACEOUS INTRAPLATE MAGMATIC EVENT IN THE NORTH-MINUSINSK DEPRESSION: PALEOMAGNETIC AND $^{40}\text{Ar}/^{39}\text{Ar}$ DATA

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First paleomagnetic and isotope-geochronological data on four basaltic volcanic pipes of the North-Minusinsk depression are reported. It is shown that the volcanic pipes appeared between 82 and 77 Ma ago. All *ChRM* directions of the pipe basanites are of reverse polarity. This fact is in agreement with the $^{40}\text{Ar}/^{39}\text{Ar}$ ages of the rocks (within the accuracy of the $^{40}\text{Ar}/^{39}\text{Ar}$ method). The revealed *ChRM* corresponds to the end of chron 33R of reverse polarity (according to the geomagnetic-polarity time scale). The paleomagnetic poles of the studied pipes differ from the APWP of Eurasia.

Volcanic pipes, basanite, Ar-Ar dating, paleomagnetism

INTRODUCTION

In the North-Minusinsk intermontane depression, volcanic pipes of basanites form a specific area of alkali-basaltoid volcanism. Many of these pipes are rich in mantle xenoliths — diverse garnet and spinel peridotites and pyroxenites [1–3]. They are clustered on the periphery of the Kop'evo arched uplift, at the flexures of northwestern strike on large faults (Fig. 1). Most of the pipes are made up of eruptive breccias in the marginal parts and massive basanites in the central part. The pipes often occur close to each other, forming groups (two or three pipes in a group). According to K-Ar dates, their formation proceeded over a long period — from 71 to 28 Ma ago [4]. The U-Pb age of the zircon from the Bele pipe (determined in the Geophysical Laboratory of the Carnegie Institute, US) is 77.9 Ma [2].

Most of paleomagnetic data on volcanic rocks in Siberia [5] disagree with the apparent polar wandering path (APWP) of the Eurasian plate [6] — the main curve for Late Mesozoic-Cenozoic reconstructions in Asia. This casts some doubt on the correctness of using the Eurasian APWP for Siberia. These contradictions can be resolved by obtaining new paleomagnetic and isotope data on the volcanic rocks of the framing of the Siberian craton, which developed in a stable tectonic regime, at least since the Early Mesozoic. In this context, complex paleomagnetic and Ar-Ar isotope studies of the volcanic pipes of the North-Minusinsk depression are of great interest. In this paper we present first paleomagnetic and geochronological data on basalts from four volcanic pipes of the depression.

INVESTIGATION TECHNIQUE AND RESULTS

For paleomagnetic studies, we took 42 samples of basalts of various magmatic phases from the Bele, Sestra, Kongarovskaya, and Borazhul'skaya pipes (Fig. 1). To measure characteristic remanent magnetization (*ChRM*), the samples were subjected to stepwise (17 steps) thermal demagnetization (at temperatures of up to 690° C) in the shielded furnace of the setup designed by V. P. Aparin (Institute of Physics, Krasnoyarsk) with the internal field of <10 nT and then were studied on a JR-4 spin-magnetometer. For analysis and presentation of paleomagnetic data, we used the software package compiled and kindly provided by Enkin [7]. To estimate the effect of anisotropy of magnetic susceptibility (*AMS*) on the distribution of the directions of remanent magnetization, the same samples were also studied on a KLY-2 kappa-bridge in the Paleomagnetic Laboratory of the East-Siberian Research Institute of Geology, Geophysics and Mineral Resources, Irkutsk.

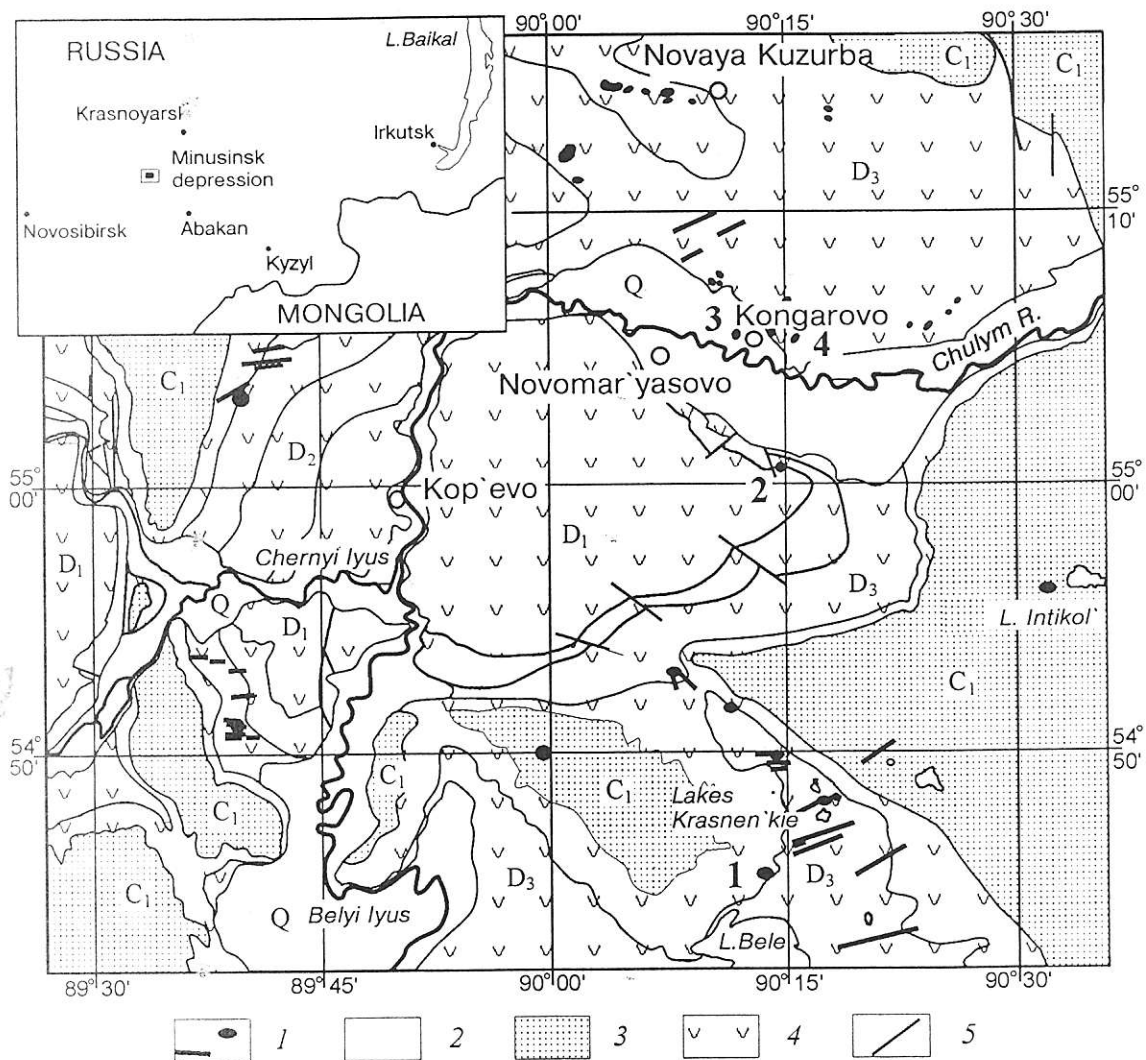


Fig. 1. Schematic geological structure of the Kop'evó dome in the North-Minusinsk depression (according to the Mingeo USSR Geological map, scale 1 : 200,000). 1 – Late Mesozoic volcanic pipes and Devonian basalt dikes; 2 – Quaternary deposits; 3 – Carboniferous deposits, sandstones, and siltstones; 4 – Devonian volcanosedimentary deposits; 5 – disjunctions. Volcanic pipes: 1 – Bele, 2 – Borazhul'skaya, 3 – Kongarovskaya, 4 – Sestra.

Data on AMS were processed by the software package compiled by F. Hrouda ("Geophysics", Brno, Czech Republic).

During the thermal demagnetization of the samples, we revealed two differently oriented magnetization components: low- and high-temperature (*ChRM*). The former is of normal polarity and disintegrates at temperatures less than 370–400° C. Its direction in general coincides with the direction of the geomagnetic field at the sampling locality; therefore, this component is interpreted as viscous magnetization. For some samples, the temperature spectra of *ChRM* overlap those of the low-temperature component. At the initial stage of demagnetization, the combined direction of these components either "scatters" over the stereogram or is distributed along the arc of the large circle between the directions of the geomagnetic field and *ChRM*.

High-temperature component *ChRM* is determined in the range from 400 to 600°C and is of reverse polarity (Fig. 2, a, b). In each pipe, the single directions of *ChRM* form compact groups; their average directions coincide rather well in all pipes (Fig. 2, c–g).

Four samples from the Bele pipe have one more direction different from both the low-temperature

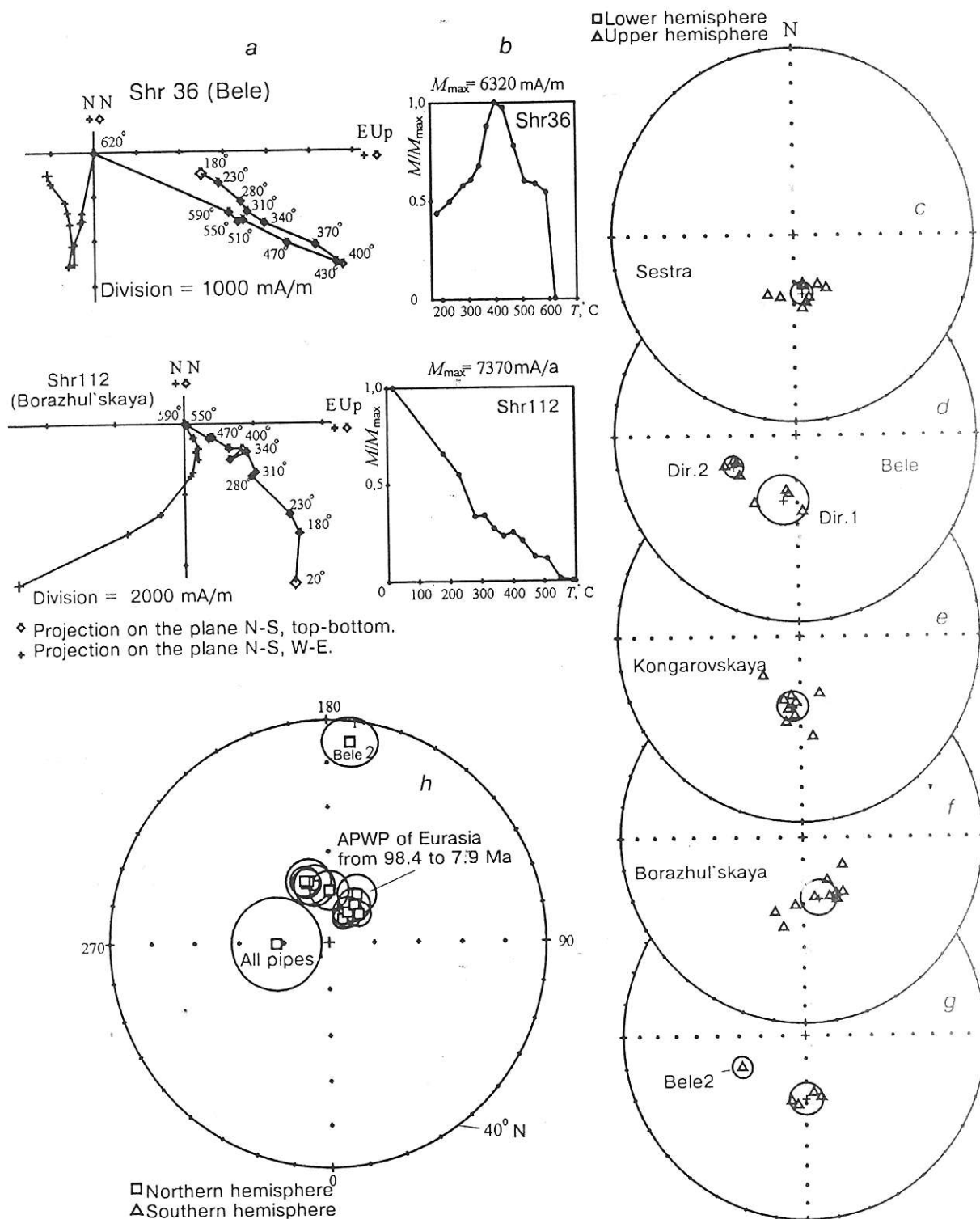


Fig. 2. Results of paleomagnetic studies. *a* – Typical Zijderveld diagrams, *b* – curves of magnetization disintegration on thermal demagnetization of the samples; distribution of the *ChRM* directions in volcanic pipes: *c* – Sestra, *d* – Bele, *e* – Kongarovskaya, *f* – Borazhul'skaya; *g* – distribution of the average directions; *h* – position of the paleomagnetic poles of the pipes and the APWP of Eurasia [6].

Table 1
Paleomagnetic Data on the Volcanic Pipes of the Minusinsk Depression

Pipe	φN	λE	n/N	Average direction (reverse polarity)					Coordinates of pole (northern pole)			
				<i>Dec</i>	<i>Inc</i>	<i>K</i>	$\alpha 95$	<i>Plat</i>	<i>Lat.</i>	<i>Lon.</i>	<i>dp</i>	<i>dm</i>
Direction I												
Borazhul'skaya	55.02	90.23	10/10	165.7	-62.0	37.3	8.0	-43.4	75.1	314.7	9.7	12.4
Bele	54.75	90.25	4/13	192.7	-60.5	68.2	11.2	-41.5	74.3	232.8	13.0	17.0
Kongarovskaya	55.10	90.18	9/9	186.6	-59.1	58.2	6.8	-39.9	74.2	251.4	7.6	10.2
Sestra	55.08	90.26	10/10	172.2	-64.7	97	4.9	-46.6	80.2	303.5	6.3	7.9
Average direction			4	179.8	-62.0	160.7	7.3	-43.2	78.3	271.0	8.8	11.3
Direction II												
Bele	54.75	90.25	4/13	244.3	-58.2	407.4	4.6	-38.9	45	173.2	5	6.8

component and *ChRM* in the samples from the other pipes (Table 1). The nature of this anomalous component is yet to be studied; perhaps, this component is related to some additional ejection phase or rotation of the block on explosion.

The *AMS* of the pipe basalts is small, and the shape of the *AMS* ellipsoids varies from sample to sample (Fig. 3, *a*). The correlations between the parameters of shape (*T*) and total anisotropy (*Pj*) shown in the figure are typical of basaltic rocks [13]. As seen from Fig. 3, *b*, the directions of the axes of the *AMS* ellipsoids are distributed chaotically, which indicates that there are no currents and magnetic difference in potentials after the formation of magnetization and the sample shape has no effect on the direction of magnetization. Thus, the detected magnetization component is close to the initial one.

Isotope-geochronological studies were performed by the ^{40}Ar - ^{39}Ar method on the MI1201 V mass

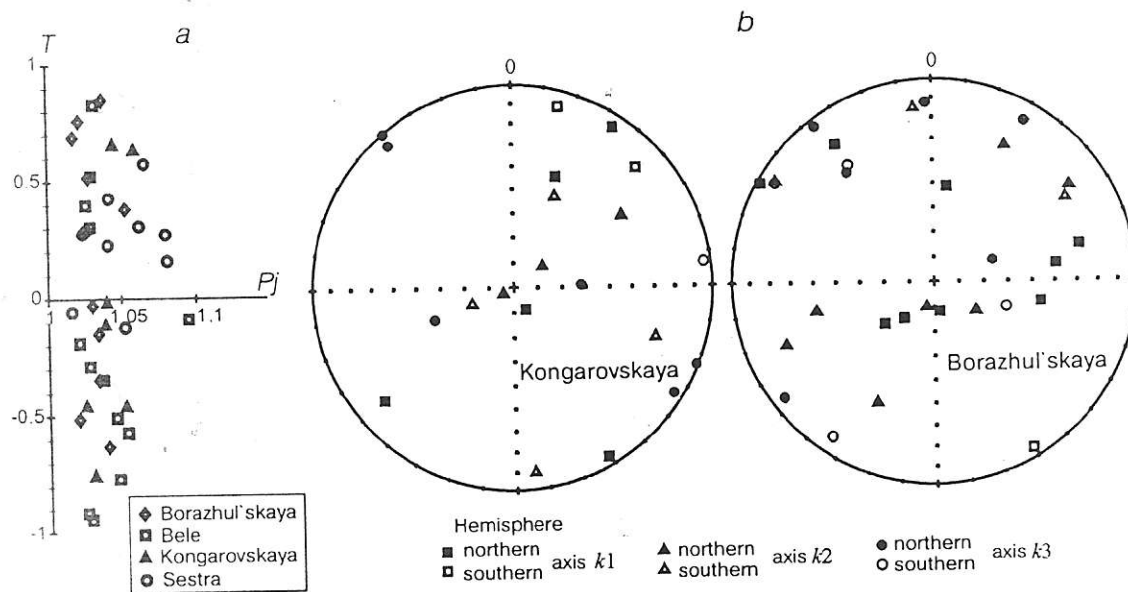


Fig. 3. Results of *AMS* measurements. *a* – Correlation between the shape of the *AMS* ellipsoids (*T*) and anisotropy (*Pj*); *b* – directions of the axes of the *AMS* ellipsoids in basanites from the Borazhul'skaya and Kongarovskaya volcanic pipes (in geographic coordinates). Axes of the *AMS* ellipsoids: *k1* – maximum, *k2* – intermediate, *k3* – minimum.

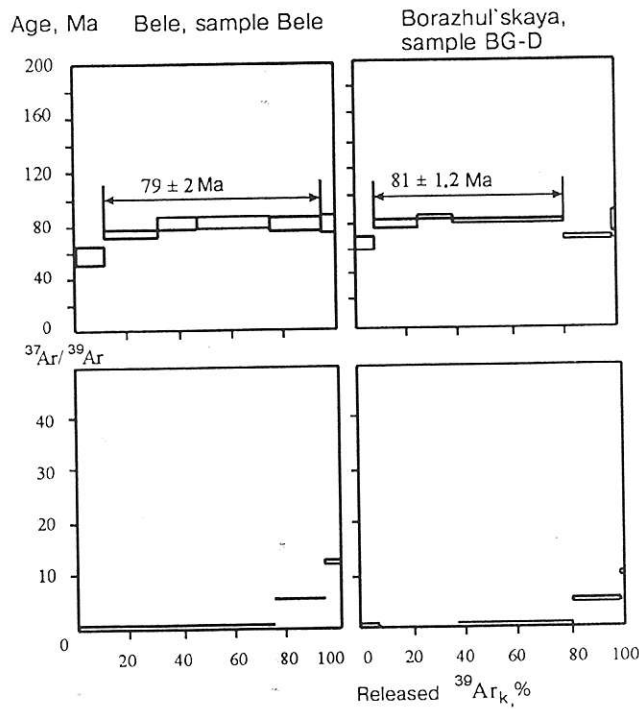


Fig. 4. Typical Ar-Ar spectra for basanites.

spectrometer with the use of a double-vacuum furnace with a molybdenum crucible [8]. The blank sample contained as little as $(1-2) \cdot 10^{-13}$ mole ^{40}Ar . The age of basanites was calculated by the plateau method according to generally accepted criteria [9]. Figure 4 shows their typical Ar-Ar spectra with a well-pronounced 3-4-step plateau. Sample BG-671 is a sanidine megacryst; its age is in good agreement with the age of the parent rock (Table 2, BG-1).

Table 2 presents ^{40}Ar - ^{39}Ar dates for the volcanic pipes of the Minusinsk depression. The age of the pipes (determined with a high degree of accuracy over all samples) is about 80 Ma.

DISCUSSION

The discordance between our Ar-Ar dates and K-Ar dates in [4] is probably related to the specific features of the samples, because the minerals in most basanites are often altered and subjected to secondary

Table 2
Generalized ^{40}Ar - ^{39}Ar Dates for the Volcanic Pipes of the North-Minusinsk Depression
and Their Comparison with K-Ar and ^{206}Pb - ^{238}U Dates

Pipe	$^{40}\text{Ar}/^{39}\text{Ar}$ dates		K-Ar age, Ma [4]	$^{206}\text{Pb}/^{238}\text{U}$ age, Ma [2]
	Sample	Age, Ma		
Bele	Bele	79 ± 2	62 ± 3	77.9^{**}
Kongarovskaya	KG-2	74 ± 5.5	45 ± 2	
	BG-D	81 ± 1.2		
Borazhul'skaya	BG-1	77 ± 2.1	49 ± 3	
	BG-671*	77 ± 5		

* Sanidine megacryst.
** Zircon concentrate.

Table 3

**Difference between the Established Directions of Magnetization in the Pipes
and the Expected Directions Calculated from the Coordinates of the Pole Dated at 81 Ma [6]**

Pipe	ΔI	ΔD
Borazhul'skaya	4.5 ± 6.4	$34.4 \pm 8.8^*$
Bele	6.1 ± 8.6	7.3 ± 11.5
Kongarovskaya	$8.1 \pm 5.6^*$	$13.5 \pm 7.4^*$
Sestra	1.4 ± 4.4	$27.9 \pm 6.4^*$
Average direction	4.5 ± 5.9	$20.3 \pm 8.5^*$

Note. The differences with a confidence interval along the magnetic inclination (ΔI) and the magnetic declination (ΔD).

* Significant differences.

thermal processes. Stepwise heating in Ar-Ar studies permits separation of epimagmatic gas fractions from initial minerals. Therefore, the rock age is determined from the plateaus in Ar-Ar spectra. Since K-Ar dating is based on measuring the integral amount of gas released from the sample, the K-Ar age may be underestimated. Our dates agree well with the ^{206}Pb - ^{238}U age obtained from zircon (Table 2), which supports their correctness.

If the studied pipes are of the same age as those in [4], their rocks should have both normal and reverse types of magnetization, because their K-Ar dates fall in the ranges of both normal and reverse polarities of the ancient field. But we have established only reverse magnetization for all pipes; its average directions coincide in all samples within the confidence intervals (Fig. 2, g). This may indicate that all pipes formed almost at the same time, which agrees with their ^{40}Ar - ^{39}Ar ages (within the accuracy of the ^{40}Ar - ^{39}Ar method). The revealed reverse magnetization of the pipes corresponds to the end of chron 33R of reverse polarity (according to the geomagnetic-polarity time scale [10, 12]).

Our paleomagnetic data are inconsistent with the APWP of Eurasia [6] (Table 1; Fig. 2, h). Since the confidence intervals of the poles do not overlap, the difference in data is of fundamental importance. The obtained and expected *ChRM* directions (calculated from the coordinates of the pole dated at 81 Ma [6]) along the magnetic inclination differ little, whereas their difference along the magnetic declination is rather great (Table 3). Thus, our paleomagnetic data rule out a significant lateral transfer of the study region relative to stable Eurasia but imply rotation of the pipes at least 12° counter-clockwise. The scales and causes of this post-Cretaceous rotation are yet to be elucidated. Probably, this rotation is typical only of the Minusinsk depressions. But many Cretaceous and Cenozoic paleomagnetic directions in the rocks of Prebaikalia and Gorny Altai [11] also suggest a counter-clockwise rotation of blocks relative to the APWP of Eurasia, which is referred to as "stable Asia". The same discordance in paleomagnetic data for all pipes is not random; it may characterize the real movements of the Siberian block within Eurasia. In addition, the kinematics of these movements agrees with the supposed movement of the Siberian continent relative to the East-European continent along the Uralian structures, which was caused by the collision of the Indian subcontinent with Asia [14].

CONCLUSIONS

From the studies performed we have drawn the following conclusions:

1. The studied volcanic pipes of the North-Minusinsk depression formed in a shorter period than was assumed in [4]. The narrow age range of volcanism and the large area of its manifestation permit us to treat this period as an important reference point of the Late Cretaceous tectonic and magmatic activities in Asia. The Ar-Ar dates obtained, concordant with the Pb-U dates in [2] and our paleomagnetic data, show that all the pipes formed 82–77 Ma ago.

2. The revealed reverse magnetization of the pipes (which is in agreement with the ^{40}Ar - ^{39}Ar dates) corresponds to the end of chron 33R of reverse polarity (according to the geomagnetic-polarity time scale [10, 12]). The obtained paleomagnetic data differ greatly from the APWP of "stable Eurasia" [6]. This discordance

is likely related to the counter-clockwise rotation of the pipe-bearing structure (which calls for serious geological substantiation); otherwise, it casts doubt on the possibility of using the APWP of "stable Eurasia" for geodynamic reconstructions in Siberia.

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REFERENCES

- [1] *Deep-seated xenoliths and the upper mantle* [in Russian], Novosibirsk, 1975.
- [2] N. V. Sobolev, V. V. Kepezhinskas, Yu. I. Ovchinnikov, and N. P. Pokhilenko, in: *Field Guidebook of the International Symposium "Continental Lithosphere: Composition and Deep-Seated Processes"* [in Russian], Novosibirsk, 1988.
- [3] I. V. Ashchepkov, V. V. Kepezhinskas, V. G. Mal'kovets, and Yu. I. Ovchinnikov, *Mantle xenoliths from the Mezo-Cenozoic volcanic pipes of Khakassia: Field Guide Book 6th Int. Kimb. Conf.*, Novosibirsk, 1995.
- [4] V. S. Zubkov, V. N. Smirnov, G. S. Plyusnin, et al., *Dokl. AN SSSR*, vol. 307, p. 1466, 1989.
- [5] *Materials of the World Data Bank* [in Russian], Moscow, 1984.
- [6] J. Besse and V. Courtillot, *J. Geophys. Res.*, vol. 96, p. 4029, 1991.
- [7] R. J. Enkin, *A computer program package for analysis and presentation of paleomagnetic data*, *Pacific Geosci. Cent., Geol. Sur. Canada*, 1994.
- [8] V. A. Ponomarchuk, Yu. N. Lebedev, A. V. Travin, et al., *Application of fine magnetic-separation technology in K-Ar, ⁴⁰Ar-³⁹Ar, and Rb-Sr methods of rock and mineral dating*, *Geologiya i Geofizika* (Russian Geology and Geophysics), vol. 39, no. 1, p. 55 (52), 1998.
- [9] R. J. Feck, J. F. Sutter, and D. H. Elliot, *Geochim. Cosmochim. Acta*, vol. 41, p. 15, 1977.
- [10] W. B. Harland, R. L. Armstrong, A. V. Cox, et al., in: *A geologic time scale*, Cambridge, 1989.
- [11] J. C. Thomas, A. Yu. Kazansky, R. Lanza, and N. N. Semakov, in: *Continental rift tectonics and evolution of sedimentary basins: Abst. of INTAS Int. Workshop*, Novosibirsk, p. 70, 1996.
- [12] S. C. Cande and D. V. Kent, *J. Geophys. Res.*, vol. 97, p. 13917, 1992.
- [13] D. H. Tarling and F. Hrouda, *The magnetic anisotropy of rocks*, London, 1993.
- [14] S. A. Gilder, X. Zhao, R. S. Coe, et al., *J. Geophys. Res.*, vol. 101, p. 22015, 1996.

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