Paleomagnetism of the early carboniferous thickness of Tuva

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Paleomagnetic studies of the early Carboniferous strata of Tuva have been carried out. As a result of the component analysis, post-folding secondary and pre-folding, probably close to the primary components of magnetization, were identified in them. Coordinates of the paleomagnetic pole for the Lower Carboniferous of Tuva: $\Phi = 53.8°$N, $\Lambda = 141.7°$ E, $A95 = 9.6°$. The lower Carboniferous strata of Tuva were formed at high latitudes: 51–70.5°N. The Tuva block as a whole did not experience significant rotations relative to Siberia in the Phanerozoic. Nevertheless, in the Late Devonian in the territory of Tuva, shear deformations and rotations of rocks in the horizontal plane took place. *KEYWORDS:* Magnetization; paleolatitude; tectonic alignment; declination; inclination.

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Introduction

Early Carboniferous geological strata of Tuva are an element of the Central Asian Fold Belt (CAFB). The CAFB structures from the south build up the Siberian platform. The folded base of the CAFB in Tuva was formed as a result of accretion processes in the late Cambrian–early Ordovician. As a result of the tectonic implacement of Precambrian and Cambrian terranes, the so-called "Caledonides" CAFB were formed. Caledonian structures are widespread in Tuva, Mongolia, Kazakhstan and other regions [*Berzin and Kungurtsev,* 1996; *Belichenko et al.,* 1994; *Dobretsov et al.,* 2003; *Gordienko et al.,* 2007; *Kazansky,* 2002; *Kovalenko,* 2017a, 2017b;*Kovalenko and Chernov,* 2008; *Kovalenko and Petrov,* 2017; *Kovalenko et al.,* 1996, 2016; *Metelkin,* 2012, and others]. After the completion of accretion processes, a sedimentary, sometimes volcanogenic-sedimentary cover began to accumulate on the Caledonides of the CAFB, part of which are the Early Carboniferous strata of Tuva. Despite the fact that active accretionary processes in Tuva were completed after the formation of the Caledonids, numerous structural unconformities are distinguished in the post-Caledonian cover. They indicate that the rocks also experienced deformations at this time. In a number of works [for example, *Buslov,* 2011], it is assumed that some deformations were associated with shears, which were active in various parts of the CAFB throughout the Paleozoic. Shear movements could lead to rotations of geological blocks in the plane of the layers. Such rotations can only be detected by the paleomagnetic method. Elucidation of the patterns of rotation of geological blocks in the geological structure of Tuva is one of the tasks of paleomagnetic studies, the results of which are presented in this article.

Besides, since the early Carboniferous strata of Tuva accumulated on the structural extension of the Siberian continent, paleomagnetic data on them can be used to refine the apparent polar wander paths (APWP) of Siberia. APWP curves are key paleomagnetic characteristics necessary for calculating the kinematic parameters of the Earth's geological blocks and global reconstruction. For the Siberian craton, several APWP curves were pro-

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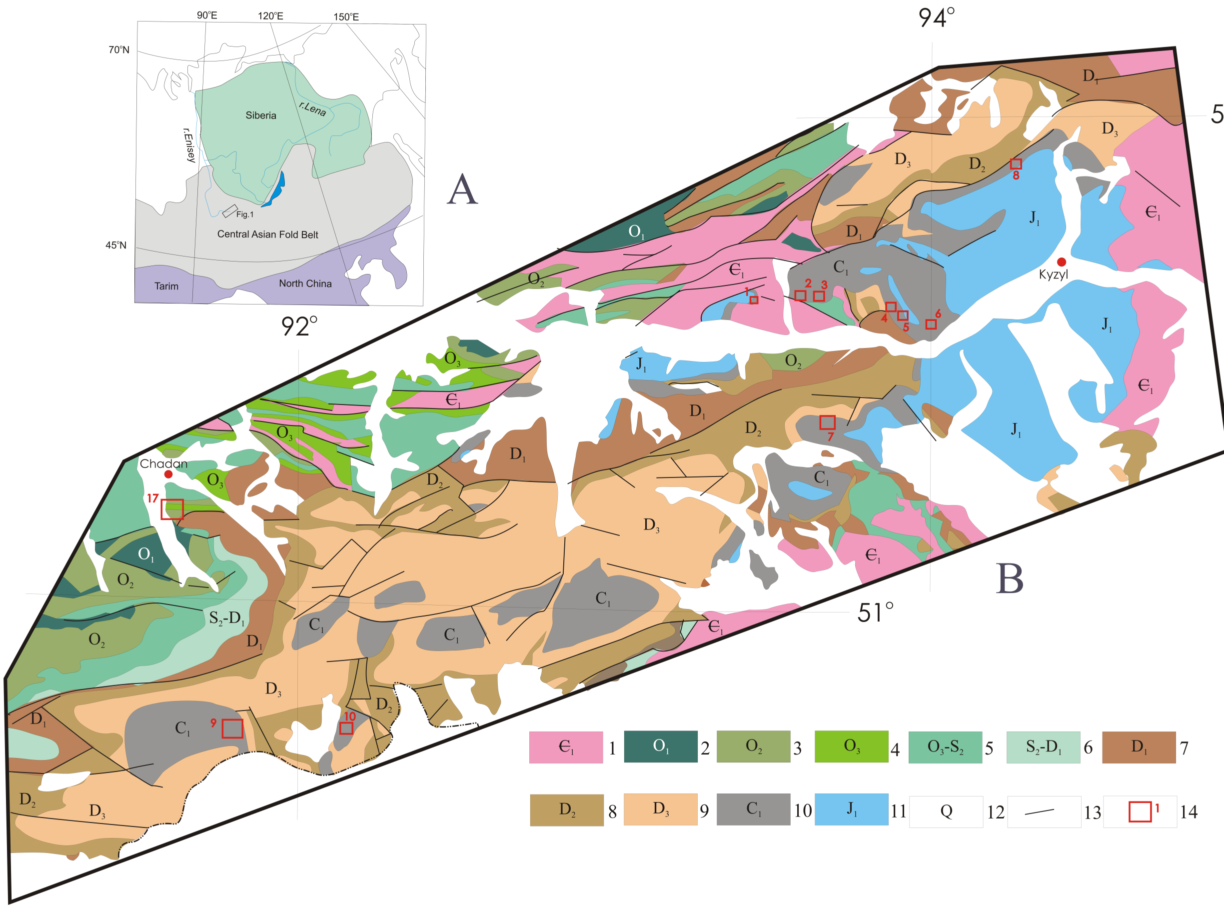


Figure 1. A. The main tectonic elements of Asia. Location of the work area. B. Scheme of the geological structure of the Tuva trough. 1–12 – rock complexes: 1 – Early Cambrian, 2 – Early Ordovician, 3 – Middle Ordovician, 4 – Late Ordovician, 5 – Late Ordovician–Middle Silurian, 6 – Middle Silurian-Early Devonian, 7 – Early Devonian, 8 – Middle Devonian, 9 – Late Devonian, 10 – Early Carboniferous, 11 – Early Jurassic, 12 – Quaternary, 13 – faults, 14 – sampled sections with numbers.

posed at different times [*Metelkin,* 2012; *Pavlov,* 2016; *Pechersky and Didenko,* 1995; *Smethurst et al.,* 1998; *Torsvik et al.,* 2012]. Each of the subsequent curves substantially refines the previous APWP curves. Nevertheless, even the most recent APWP curve for Siberia [*Pavlov,* 2016] for many periods of the Phanerozoic is based on single paleomagnetic determinations that require confirmation. This article provides a new paleomagnetic data that can be used to refine the Early Carboniferous paleomagnetic pole of Siberia [*Pavlov,* 2016].

The Main Geological Elements of Tuva

Sedimentary and volcanogenic-sedimentary strata of the Phanerozoic post-Caledonian cover of Tuva overlap complexly deformed Caledonian structures with a sharp angular unconformity. The Caledonides of Tuva unite the tectonically superposed Precambrian and Early Paleozoic strata of the Tuva-Mongolian massif, fragments of the Vendian ophiolite association and Cambrian volcanogenic-sedimentary complexes. The Tuva-Mongolian massif includes several tectonic blocks. The Naryn, Morensky and Erzinsky blocks of sedimentary and igneous rocks, metamorphosed under the amphibolite–granulite conditions, are distinguished. The strata were deformed and metamorphosed in the Early Cambrian (536±6 Ma) and at the Cambrian-Ordovician boundary (497 ± 4, 489 ± 3 Ma) [*Salnikova et al.,* 2001]. Fragments of ophiolites are represented by rocks of the lower part of the layered complex and a dike complex. U-Pb age from plagiogranites of the Agardag zone shows 570 ± 1.7 Ma [*Pfander and Kroner,* 2004; *Pfander et al.,* 2001]. Cambrian volcanic-sedimentary complexes with olistostromes are considered as fragments of suprasubduction systems [*Berzin and Kungurtsev,* 1996, etc.]. For limestones, there are early Cambrian age determinations from archaeocyates and other species of flora and fauna [for example, *Nedra,* 1958, 1961, 1966; *VSEGEI,* 1963]. The period of accretionary Caledonian deformations is estimated by the age of the post-accretionary Kaachem batholith – 485 Ma [*Rudnev et al.,* 2015; *Sugorakova,* 2007] and proceeded in the Late Cambrian. At this time, molasse strata formed in the lower part of the post-Caledonian cover. In the modern geological structure of Tuva, the strata of the post-Caledonian cover are mainly exposed within the Central Tuva trough (Figure 1). As a result of geological survey, the strata of the Central Tuvinsky trough were stratigraphically dissected in sufficient detail to geological stages. The sequence of strata accumulation and their relationship has been reliably established. Sedimentary strata were dated by assemblages of fossil flora and fauna. The Early Devonian volcanic strata in Tuva have not been dated by the absolute geochronology methods, but dated by the U-Pb method in Khakassia [*Vorontsov,* 2015]. Molasse sediments of the Ordovician age [*Nedra,* 1958, 1961] overlie the Caledonian structures with sharp unconformity. They are composed of members of red and gray conglomerates, gravelstones, sandstones, limestones and siltstones. The Silurian strata overlie molasse strata without visible unconformity. They are represented by sandstones, siltstones, conglomerates, gravelstones and limestones [*Nedra,* 1958, 1961]. Devonian rocks overlap Silurian rocks with unconformity. The Lower Devonian strata include tuffs, tuff breccias, lava flows and subvolcanic bodies of basic, intermediate and felsic composition, limestones, sandstones, siltstones, conglomerates and gravelstones [*Nedra,* 1958, 1961, 1966; *VSEGEI,* 1963]. The Middle and Upper Devonian strata are composed of red-colored sandstones, siltstones, conglomerates, gravelstones, gray-colored marls, limestones and, less often, volcanic rocks of basic and intermediate composition. Lower Carboniferous strata with unconformity overlie the Devonian and older complexes [*Nedra,* 1958, 1961, 1966; *VSEGEI,* 1963]. The strata include variegated and red-colored members of conglomerates, sandstones, siltstones, mudstones. Middle and Upper Jurassic rocks unconformably overlap more and more ancient rock complexes. The strata are composed of gray-colored conglomerates, sandstones, siltstones, coals [*Nedra,* 1966; *VSEGEI,* 1963].

The Ordovician, Silurian and Devonian strata are deformed to varying degrees, crumpled into folds and broken into blocks by faults. The Early Carboniferous strata in many areas lie flat (dip angles up to 10°), in some – steep, and the Jurassic strata are slightly deformed and mostly lie almost horizontally.

Objects of Paleomagnetic Research

The Lower Carboniferous strata of the Central Tuva trough were sampled for paleomagnetic analysis in central and southern Tuva (Figure 1). In the south of Tuva, they are subdivided from bottom to top into the Suglughem, Herbes, Baytag, Ekiotug, and Aktal formations [*Nedra,* 1958, 1961]. The Suglukhem and Herbes formations were assigned to the Tournaisian stage based on the finds of ichthyofauna (Strepsodus siberiacus, Rhizodopsis savenkovi Obr., Acanthodes sp., Ganolepis sp., Cycloptychius sp.) and plants (Pteridorachis f. modica Radcz). Baitag, Ekiotug and Aktal formations – to the Visean stage based on the finds of flora (Arctodendron Kidstoni, Pteridorachis f. modica Radcz., Protolepidodendron megaphyllum Rodct., Angarodendron sp., A. tetragonum aff. Kidstonii Nath., Tomiodendron schmalhauseni (Chache) Radcz.).

Samples for paleomagnetic studies were taken from two sections from thin-bedded sandstones, siltstones, and mudstones of the Suglughem, Herbes, and Baytag formations. A total of 57 samples were taken from the Lower Carboniferous strata. All samples in the sections were taken from different stratigraphic levels.

In the central part of Tuva (Figure 1), the Lower Carboniferous strata are divided into the Suglugkhem, Kyzylgirin, Herbes formations of the Tournaisian stage and the Baytag, Ekiottug, and Aktal formations of the Visean stage [1966; *VSEGEI,* 1963]. The strata are assigned to the first of them on the basis of fish (Strepsodus siberiacus Chab, Rhizodopsis Savencovi Obr., Acanthodes ex gr. Lopatni Rohon) and plants (Lepidodendron Schmalhauseni chachl., Knorria sp., Archaeopteris sp., Pteridorhachis sp., Archaeopteris fissilis Schzalhauseni). The second – based on the fish (Rhabdoderma sp ind., Gonatodus, Elonichydae sp., Polaeniscoidei far) and plants (Pteridorachis f. modica megaphyllum sp., Angarodendron, Bothrodendron, Arctodendron aff. Kidstoni Nath, Knorria (Arctodendron), Knorria (Bothrodendron), Cordoiles).

Samples for paleomagnetic studies were taken from gray, purple, and red-colored thin-bedded sandstones, siltstones, and mudstones mainly of the Baytag, Ekiottug, and Aktal formations. A total of 389 samples were taken from eight sections. All samples in the sections were taken from different stratigraphic levels.

Paleomagnetic Method

The treatment of paleomagnetic samples was carried out in the paleomagnetic laboratory of IGEM RAS. Two cubes with an edge of 1 or 2 cm were cut from each sample, depending on the value of the magnetic susceptibility of the sample. Each cube was subjected to thermal demagnetization in the temperature range 20–680°C. Thermal demagnetization was carried out in a heater protected by permalloy screens. The earth's magnetic field in the screens was compensated up to 10–15 nT. Most of the cubes were heated 12–16 times. The measurement of the magnitude and direction of the magnetization of the samples was carried out on a JR-6 magnetometer. A component analysis of magnetization was carried out on the Zijderveld diagrams [*Kirschvink,* 1980; *Zijderveld,* 1967]. The average directions of the selected magnetization components were calculated for two cubes. The components of the magnetization of the samples were analyzed on a sphere in geographic (GS) and stratigraphic (SS) coordinate systems [*Khramov et al.,* 1982; *McFadden and Jones,* 1981; *Shipunov,* 1995], computer programs created by R. J. Enkin.

Results of Paleomagnetic Studies

In ten sampled sections of early Carboniferous rocks of Tuva (Figure 1), either one or two, rarely three components of magnetization are distinguished (Figure 2). One-component magnetization is retained in magnetite-containing rocks up to the Curie point of magnetite, in red flowers – up to the Curie point of hematite. In samples with multicomponent magnetization, the low-temperature component (LT) is released in the temperature range from 20 to 300–460°C, and the high-temperature component of magnetization (HT) is released in the range from 300 to 580°C, in the samples of red rocks – up to 660°C. The vectors of one-component magnetization are randomly distributed in all sections. The genesis of this magnetization is unknown. The low-temperature components of the magnetization of the early Carboniferous rocks on the sphere are either grouped around the direction of the Cenozoic magnetic field of the Earth in the Tuva region, or distributed along a great circle from the direction of the present-day field to the direction of high-temperature magnetization, or distributed randomly (Figure 3, Table 1). Apparently, this component of the magnetization is of a viscous origin. The high-temperature components of the magnetization of the lower Carboniferous rocks in different sections form groups of vectors with different polarities. The scatter of directions in these groups depends on the number of samples with one-component chaotic magnetization from these sections. In sections 1, 6, 7, only one-component chaotic magnetization was identified (Figure 1). In sections 2, 3, 4, one-component chaotic magnetization was detected in 40–60% of the samples. The directions of high-temperature magnetization in these sections are characterized by a large scatter (Figure 3). These sections were excluded from the analysis. In sections 5, 8, 10, no one-component chaotic magnetization was found. The directions of high-temperature components of magnetization in these sections are characterized by acceptable accuracy (Figure 3). In section 9, only 6 samples with one-component magnetization were identified. They have been removed. The directions of the high-temperature components of the magnetization in section 9 are well grouped (Figure 3). Thus, for further analysis, we used the high-temperature HT magnetization of sections 5, 8, 9, 10. Judging by the temperatures of destruction of the HT magnetization, its carriers, apparently, are magnetite and hematite.

Fold test carried out by the method of comparison of mean directions [*Khramov et al.,* 1982; *McFadden and Jones,* 1981; *Shipunov,* 1995] showed that the average directions of the HT-components

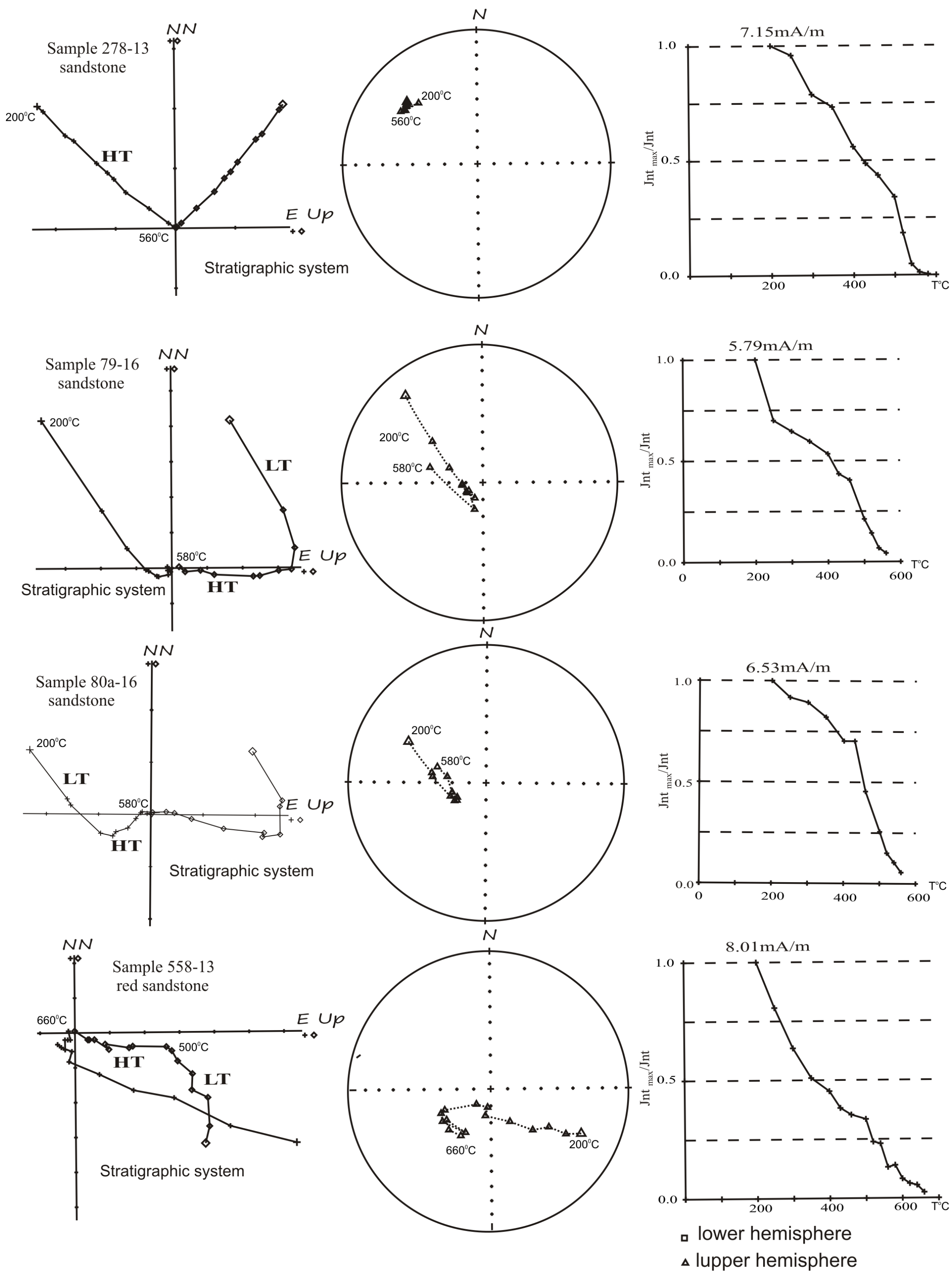


Figure 2. Results of thermal demagnetization of Early Carboniferous rock samples. HT, LT are high temperature and low temperature magnetization components. $Jnt_{\max}/Jnt-$ the ratio of the maximum remanent magnetization of the sample to the magnetization of the sample after different stages of thermal cleaning.

Table 1. Average Directions of the Magnetization Components of the Paleozoic Strata of Tuva

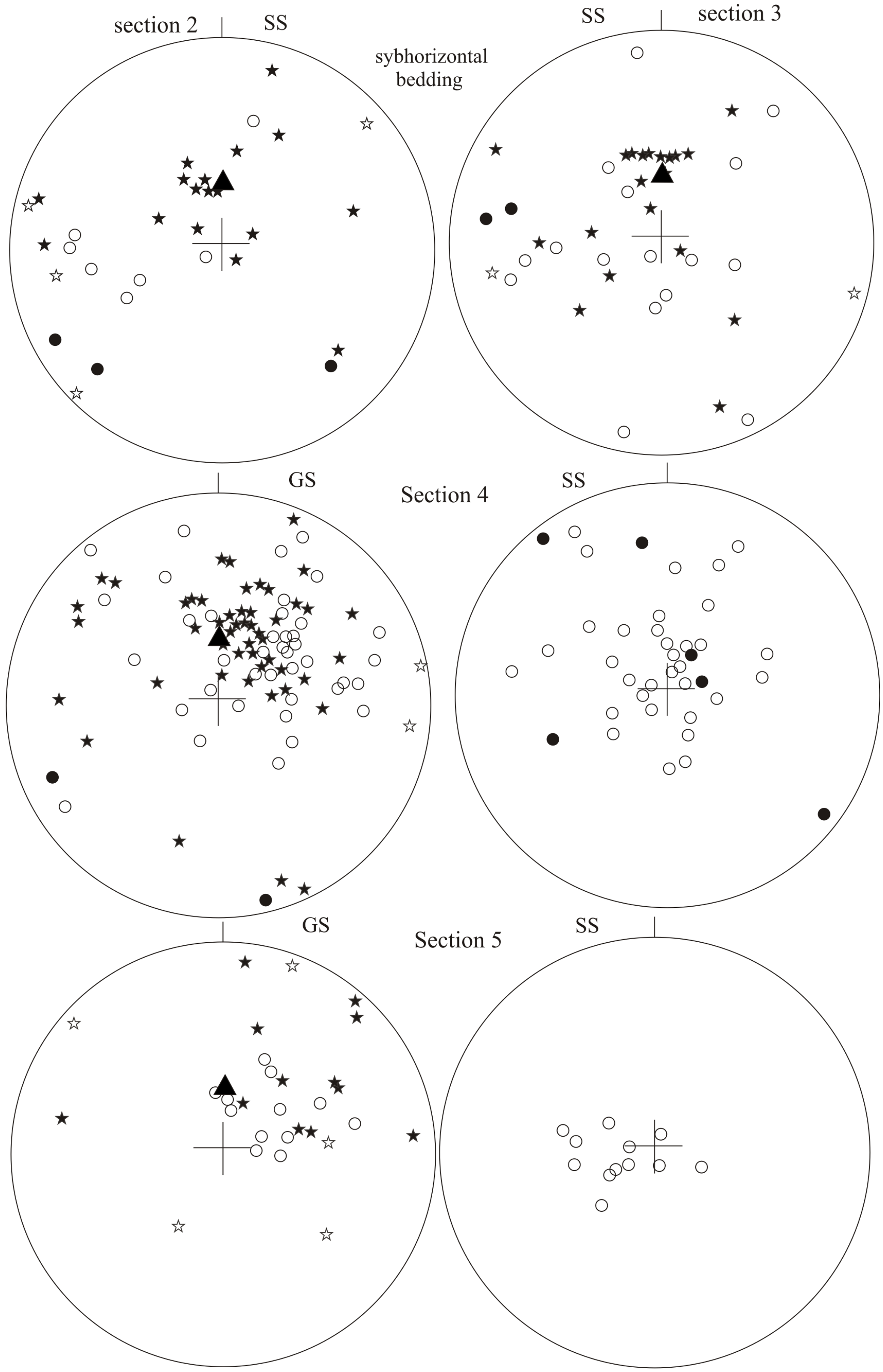
Magnetization components, sections	N	D_g,°	I_g,°	K_g	α_g,°	D_s,°	I_s,°	K_s	α_s,°
Middle Devonian									
D2	8	152	−26	4	25	90	−45	5	22
D3	38	147	−60	11	7	60	−34	8	8
D4R	36	64	−42	6	10	352	−46	6	9
D4N	8	207	47	6	20	174	23	10	16
D5	19	333	−30	6	14	334	−42	5.5	14
Average D2+D3	46	148	−55	7.5	7.5	64	−36	7	8
Average D4N+D4R+D5	63	32	−47	3.5	9	347	−42	6	7.3
Early Carboniferous									
HT 9	25	238	−53	8	10	238	−79	9	9.5
HT 5	12	53	−64	19	9	267	−75	19	9
HT 8	35	154	−8	8	8	222	−71	6.5	9
HT 10	29	295	−35	26	5	262	−75	27	5
Fold test results (average comparison)									
HT 9+5+8+10	101	214	−61	2	9.5	242	−75	10	4
$F_{cr} = 2.46$		$F_g = 108$				$F_s = 1.57$			
HT 5+8+10	76	193	−64	1.8	12	243	−74	10	5
$F_{cr} = 2.74$		$F_g = 165$				$F_s = 2.1$			

Notes: N – number of vectors involved in calculations, D° – declination of magnetization, I° – inclination of magnetization, K – the precision parameter, α° – the radius that the mean direction lies within 95% confidence. The letters g and s respectively denote geographic (g) and stratigraphic (s) coordinates. HT 5–HT 10 are high-temperature magnetization components isolated in 5–10 sections (Figure 1, Figure 3, Figure 4). Directions D2–D5 are taken from the work [*Kovalenko and Lobanov,* 2018a]. F is a statistical parameter used to compare averages. F_{cr}, F_g, F_s – the critical value of the parameter F and the value of this parameter in geographic and stratigraphic coordinates *McFadden and Jones,* 1981; *Shipunov,* 1995].

of the magnetization of the rocks of these sections are statistically equal in the SS and differ in the GS (Table 1). Ks/Kg = 5. The synfolding test also showed that the magnetization of these sections is prefolding. The maximum grouping of vectors of the HT-component is formed at 100% straightening of the fold: $N = 4$, $D = 66°$, $I = 76°$, $K = 155$, $\alpha 95 = 7.2°$. We also analyzed HT magnetization at the site level. The sites were combined from 4 to 8 samples from fragments of sections with similar attitudes (Table 2). Kg/Ks = 13.7. The fold test performed by the method of comparison of means [*McFadden and Jones,* 1981; *Shipunov,* 1995] for six sites with the highest precision parameter of HT-magnetization (K) – positive (Table 2). Thus, we believe that on the basis of fold tests, a pre-folding high-temperature magnetization of the early Carboniferous sections is close to the primary.

Discussion

The coordinates of the Early Carboniferous paleomagnetic pole were calculated: $\Phi = 55°$ N, $\Lambda = 138°$ E, A95 = 7° for all four sections, $\Phi = 55.5°$ N, $\Lambda = 138.5°$ E, A95 = 7° over three sections. According to the sites, the coordinates of the paleomagnetic pole: $\Phi = 53.8°$ N, $\Lambda = 141.7°$ E, A95 = 9.6°.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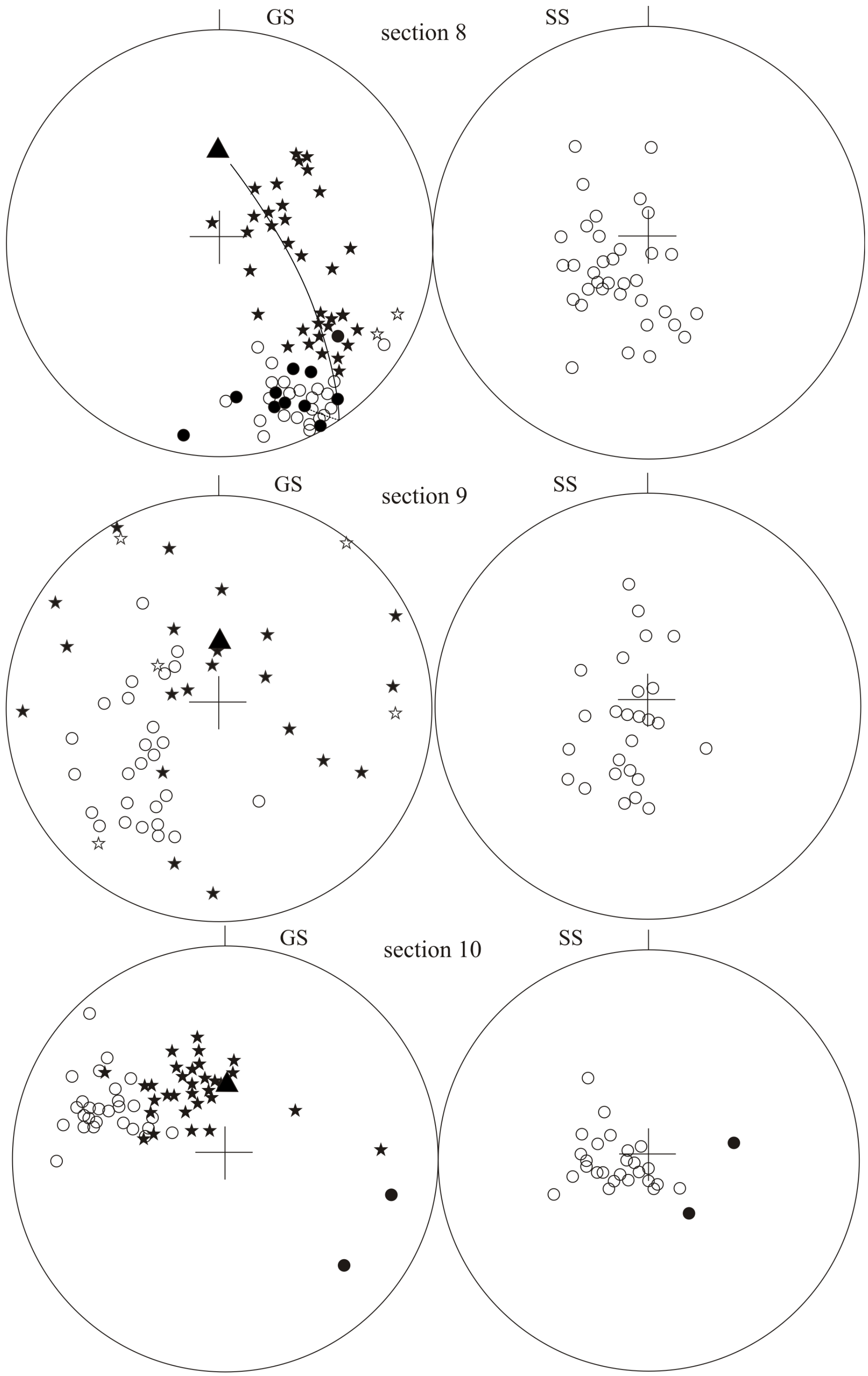

Figure 3. Distribution of unit vectors of magnetization in the Early Carboniferous sections. Circles – directions of HT components of magnetization, asterisks – directions of LT components of magnetization. Filled and open characters are normal and reverse polarity, respectively. The triangle is the Cenozoic direction of the magnetic field in the Tuva region.

Table 2. Average Directions of the Magnetization Components of Sites of the Paleozoic Strata of Tuva

Sites	N	D_g,°	I_g,°	K_g	α_g,°	D_s,°	I_s,°	K_s	α_s,°
Early Carboniferous									
1	7/7	157	−7	31	10	215	−63	31	10
2	7/7	152	−12	26	10	228	−68	26	10
3	6/6	152	−2	10	18	196	−65	8	20
4	4/4	171	−6	11	21	228	−49	11	21
5	6/6	155	−5	8	20	233	−80	8	20
6	4/4	143	−21	11	21	347	−69	11	21
7	8/8	301	−31	27	10	276	−76	27	10
8	7/7	293	−34	51	7	249	−74	51	7
9	6/6	285	−34	31	10	255	−68	31	10
10	7/7	295	−43	18	13	257	−81	18	13
11	6/6	52	−63	26	11	252	−72	26	11
12	6/6	56	−65	13	16	287	−77	15	15
13	6/7	236	−43	7	22	237	−68	7	22
14	5/5	262	−55	9	20	282	−80	9	21
15	7/7	223	−52	9	17	194	−76	13	15
16	7/8	240	−57	6	21	280	−82	7	20
Average	**16**	**202**	**−58**	**2**	**23**	**243**	**−75**	**34**	**6**
Fold test results (average comparison)									
$1+2+7+8+9+11$	41	245	−65	1.9	15.7	242.6	−71	26	4.3
$F_{cr} = 2.34$			$F_g = 90$				$F_s = 2.3$		

An analysis of the inclinations of high-temperature magnetization showed that the Early Carboniferous strata were formed at high latitudes: 55–62–69°N (minimum–average–maximum paleolatitude) in four sections, 54–62–70°N in three sections.

Comparison of our data with the Early Carboniferous poles of Siberia published in [*Pavlov,* 2016] showed that in the Early Carboniferous the studied geological strata were in the structure of Siberia: $F = 1.8° \pm 4.5°$ (4 sections), $F = 2.8° \pm 5.1°$ (3 sections) (F is the difference between the expected and calculated inclinations of magnetization [*Beck,* 1980; *Demarest,* 1983]).

The declination of the HT magnetization component of the Early Carboniferous rocks differs from the declination of the magnetization calculated from the paleomagnetic poles for Siberia: $R = -80 \pm 18.7$ (4 sections), $R = -79 \pm 20.2$ (3 sections) (R is the difference between the calculated and expected declinations of magnetization [*Beck,* 1980; *Demarest,* 1983]).

How can these differences be explained? The investigated Early Carboniferous sections are separated from each other by 300–400 km. The coincidence in the SS of the directions of the HT-components of the magnetization of the Early Carboniferous sections shows that after the Early Carboniferous in Tuva there were no local deformations that could lead to rotation of strata in the horizontal plane. This is also evidenced by the flat (from 0 to 20°) occurrence of the majority of early Carbonaceous thicknesses in Tuva. That is, in this case, paleomagnetic data for the Early Carboniferous can be extended to a large geological block within Tuva, including at least the entire Tuva trough, and, most likely, most of Tuva (Tuva block). Could this block rotate relative to Siberia?

Paleomagnetic poles calculated from Ordovician and undeformed horizontally lying Middle Devonian rocks of Tuva [*Kovalenko and Lobanov,* 2018a; *Kovalenko et al.,* 2021], showed good convergence with the same age paleomagnetic poles of Siberia –

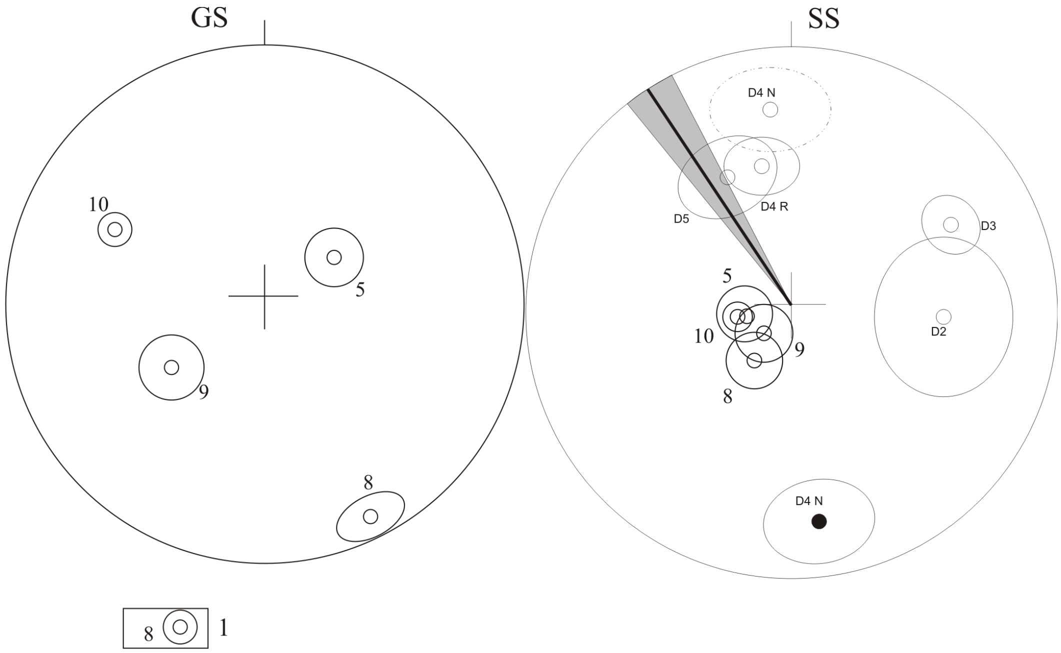

Figure 4. Distributions of average directions of magnetization with confidence circles of early Carboniferous and Middle Devonian sections. Circles are the average directions of magnetization for individual sections. Filled and open characters are normal and reverse polarity, respectively. The gray segment is the "expected" declination of magnetization with confidence angles calculated from the Early-Middle Devonian paleomagnetic pole of Siberia [*Pavlov,* 2016].

for Tremadoc: $F = 3.5° \pm 11.2°$, $R = 5.2° \pm 11.5°$, for the Middle Devonian: $F = 10.6 \pm 12.5$, $R = 5.5 \pm 17.5$ [*Beck,* 1980; *Demarest,* 1983]. Hence it follows that the Tuva block as a whole has not rotated relative to Siberia since the Ordovician time. The Early Carboniferous paleomagnetic pole of Siberia was calculated from thirteen magmatic bodies of the Emyaksin Formation in the Vilyui River valley [*Pavlov,* 2016]. The primary magnetization is justified by the presence of directions of different polarity. Possibly, there were local rotations of a small block in the Vilyui River basin in Siberia, from which the paleomagnetic pole was calculated [*Pavlov,* 2016]. In addition, it cannot be completely ruled out that the studied magmatic bodies of the Vilyui River valley are subvolcanic. Then the difference in declinations may be due to inaccuracy in determining their primary bedding elements.

The difference in declinations can also be explained if we assume that the early Carboniferous strata of Tuva were remagnetized at a later time. Comparison with the late Carboniferous-Permian paleomagnetic poles of Siberia [*Pavlov,* 2016] showed that the differences in the declinations of the magnetization directions measured in Tuva and the "expected" Siberian directions of magnetization persist up to 250 Ma, up to the Permian-Triassic boundary. For the paleomagnetic pole 315 Ma – $R = -45 \pm 17$, $F = -13 \pm 6$, for the paleomagnetic pole 290 Ma – $R = -41 \pm 17$, $F = 0 \pm 4.5$. But the early Carboniferous pole of Tuva statistically coincides with the pole of 250 Ma of Siberia – $R = 0 \pm 14$, $F = -3.2 \pm 3.9$. If the assumption that the early Carboniferous rocks of Tuva were remagnetized 250 Ma ago at the Permian-Triassic boundary is correct, then the strata should have been remagnetized in an undeformed state, and deformed after remagnetization. The assumption of the remagnetization of rocks is questionable, since the secondary components of the magnetization of reverse polarity close to the direction 4+5+6+7 (Table 1) are absent in the older strata of Tuva in all sections of different ages that we studied [*Kovalenko,* 2017a; *Kovalenko and Lobanov,* 2018a, 2018b]. In [*Bachtadse et al.,* 2000], the secondary magnetization component of reverse polarity was revealed only in one section of the Late Silurian rocks of Tuva and, most likely, it is associated with the intrusion of the Middle Devonian intrusion several kilometers from the section. In addition, in the early Carboniferous sections of Tuva 5, 8, 9, 10 there are insignificant magnetization directions of direct polarity. The predominantly reverse polarity of the magnetization in the Early Carboniferous sections of Tuva corresponds to the reverse polarity magnetization revealed in the Late Devonian–Early Carboniferous rocks of Siberia [*Kravchinsky et al.,* 2002] and Mongolia [*Bazhenov et al.,* 2016]. The primary magnetization of the early Carboniferous rocks of Tuva is also supported by the regular change in the directions of magnetization from the Early Carboniferous sequences with steep inclinations to the Late Devonian ones with gentle inclinations [*Kovalenko et al.,* 2020].

It is important to note that the Middle Devonian rocks studied in [*Kovalenko and Lobanov,* 2018a] are characterized by a wide scatter in declination (Figure 4). One group of directions (D4N, D4R, D5) is close to the expected direction calculated from the Early-Middle Devonian pole of Siberia [*Pavlov,* 2016]. The second group of directions (D2, D3) sharply differs from it in declination. That is, strata with the directions of magnetization D2, D3 are rotated in the horizontal plane relative to Siberia clockwise at an angle of more than 90°. The strata of both groups are territorially separated and separated by young faults [*Kovalenko and Lobanov,* 2018a]. Apparently, such rotations were associated with shear displacements. Since the Middle Devonian strata are overlain by Early Carboniferous strata that are slightly deformed and not rotated in the horizontal plane, the time of shear deformations can be estimated as Late Devonian.

Conclusion

1. In the Lower Carboniferous strata of Tuva, post-folding secondary and pre-folding, probably close to the primary components of magnetization, are distinguished.
2. Coordinates of the paleomagnetic pole for the Lower Carboniferous of Tuva: $\Phi = 53.8°$N, $\Lambda = 141.7°$E, A95 = 9.6°. The Early Carboniferous strata of Tuva accumulated at high latitudes: 51–70.5°N.
3. The Tuva block as a whole did not experience significant rotations relative to Siberia in the Phanerozoic. Nevertheless, in the Late Devonian in the territory of Tuva, shear deformations and rotations of rocks in the horizontal plane took place.

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