



**HAL**  
open science

**Late Mesozoic topographic evolution of western  
Transbaikalia: evidence for rapid geodynamic changes  
from the Mongol-Okhotsk collision to widespread rifting**

A.V. Arzhannikova, E.I. I Demonterova, Marc Jolivet, S.G. Arzhannikov, E.A.  
A Mikheeva, A.V. V Ivanov, V.B. B Khubanov, L. A. Pavlova

► **To cite this version:**

A.V. Arzhannikova, E.I. I Demonterova, Marc Jolivet, S.G. Arzhannikov, E.A. A Mikheeva, et al..  
Late Mesozoic topographic evolution of western Transbaikalia: evidence for rapid geodynamic changes  
from the Mongol-Okhotsk collision to widespread rifting. *Geoscience Frontiers*, 2020, 11 (5), pp.1695-  
1709. 10.1016/j.gsf.2019.12.012 . insu-02458932

**HAL Id: insu-02458932**

**<https://insu.hal.science/insu-02458932>**

Submitted on 29 Jan 2020

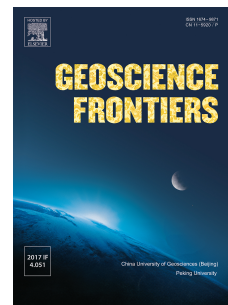
**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Journal Pre-proof

Late Mesozoic topographic evolution of western Transbaikalia: evidence for rapid geodynamic changes from the Mongol–Okhotsk collision to widespread rifting

A.V. Arzhannikova, E.I. Demonterova, M. Jolivet, S.G. Arzhannikov, E.A. Mikheeva, A.V. Ivanov, V.B. Khubanov, L.A. Pavlova



PII: S1674-9871(20)30028-1

DOI: <https://doi.org/10.1016/j.gsf.2019.12.012>

Reference: GSF 937

To appear in: *Geoscience Frontiers*

Received Date: 25 April 2019

Revised Date: 19 September 2019

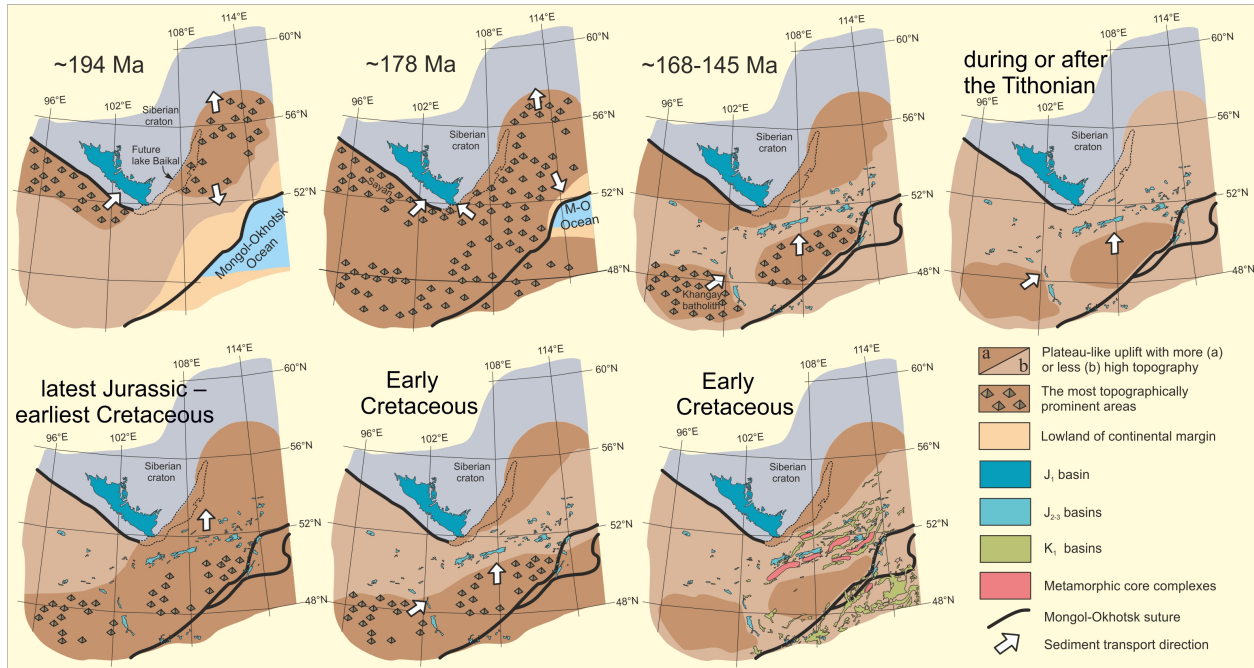
Accepted Date: 15 December 2019

Please cite this article as: Arzhannikova, A.V., Demonterova, E.I., Jolivet, M., Arzhannikov, S.G., Mikheeva, E.A., Ivanov, A.V., Khubanov, V.B., Pavlova, L.A., Late Mesozoic topographic evolution of western Transbaikalia: evidence for rapid geodynamic changes from the Mongol–Okhotsk collision to widespread rifting, *Geoscience Frontiers*, <https://doi.org/10.1016/j.gsf.2019.12.012>.

This is a PDF file of an article that has undergone enhancements after acceptance, such as the addition of a cover page and metadata, and formatting for readability, but it is not yet the definitive version of record. This version will undergo additional copyediting, typesetting and review before it is published in its final form, but we are providing this version to give early visibility of the article. Please note that, during the production process, errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

© 2020 China University of Geosciences (Beijing) and Peking University. Production and hosting by Elsevier B.V. All rights reserved.





1 **Late Mesozoic topographic evolution of western Transbaikalia: evidence for rapid**  
2 **geodynamic changes from the Mongol–Okhotsk collision to widespread rifting**

3  
4 **Arzhannikova A.V.<sup>a,\*</sup>, Demonterova E.I.<sup>a</sup>, Jolivet M.<sup>b</sup>, Arzhannikov S.G.<sup>a</sup>, Mikheeva E.A.<sup>a</sup>,**  
5 **Ivanov A.V.<sup>a</sup>, Khubanov V.B.<sup>c</sup>, Pavlova L.A.<sup>d</sup>**

6  
7 <sup>a</sup>Institute of the Earth's Crust, Russian Academy of Sciences, Siberian Branch, Irkutsk, Russia

8 <sup>b</sup>Laboratoire Géosciences Rennes, CNRS-UMR6118, Université de Rennes, Rennes, France

9 <sup>c</sup>Geological Institute, Russian Academy of Sciences, Siberian Branch, Ulan-Ude, Russia

10 <sup>d</sup>A.P. Vinogradov Institute of Geochemistry, Siberian Branch of the Russian Academy of Sciences, Irkutsk, Russia

11 \*Corresponding author. Arzhannikova Anastasia, [arzhan@crust.irk.ru](mailto:arzhan@crust.irk.ru)

12  
13 **Abstract**

14 The Mesozoic geodynamic evolution of Transbaikalia has been largely controlled by the  
15 scissors-like closure of the Mongol–Okhotsk Ocean that separated Siberia from Mongolia–North  
16 China continents. Following the oceanic closure, the tectonic evolution of that region was  
17 characterized by collisional uplift and subsequent extension that gave rise to the formation of  
18 metamorphic core complexes. This complex tectonic setting prevailed simultaneously between  
19 150 Ma and 110 Ma both in Transbaikalia, North Mongolia, and within the North China Craton.  
20 Published paleobotanical and paleontological data show that the oldest Mesozoic basins had  
21 formed in western Transbaikalia before the estimated age of extension onset. However no  
22 precise geochronological age is available for the onset of extension in Transbaikalia. The  
23 Tugny Basin, as probably the oldest Mesozoic basin in western Transbaikalia, is a key object to  
24 date the onset of extension and following changes in tectonic setting. In this study, U–Pb (LA-  
25 ICP-MS) dating of detrital zircons from three key Jurassic sediment formations of the Tugny  
26 Basin are used to identify the potential source areas of the sediments, understand the changes in  
27 sediment routing and provide insights on the topographic evolution of western Transbaikalia.

28 Our results show several significant changes in tectonic regime after the closure of the Mongol–  
29 Okhotsk Ocean. A wide uplifted plateau formed during the closure of the Mongol–Okhotsk Ocean,  
30 determining the Early Jurassic drainage system reaching the Angara–Vitim batholith to the north  
31 and shedding sediments to the continental margin to the South. The following collisional event at  
32 the end of the Early Jurassic led to the uplift of the collision zone, which partially inverted the  
33 drainage system toward the North. A strike-slip displacement induced by the oblique collision  
34 initiated some of the early Transbaikalian depressions, such as the Tugnuy Basin at about 168 Ma.  
35 A phase of basin inversion, marked by folding and erosion of the Upper Jurassic sediments, could  
36 correspond to the short-term collision event that took place during the latest Jurassic–earliest  
37 Cretaceous in the eastern Central Asian Orogenic Belt. The following inversion in tectonic regime  
38 from compression to extension is consistent with the mid-lower-crustal extension that led to the  
39 formation of the numerous metamorphic core complexes throughout northeastern continental Asia  
40 during the Early Cretaceous.

#### 41 **Keywords**

42 U–Pb detrital zircons dating, topographic evolution, Mongol–Okhotsk collision, Transbaikalia.

#### 44 **1. Introduction**

45 Transbaikalia is part of the Central Asian Orogenic Belt—one of the largest accretionary  
46 complexes of the Earth’s that developed southward from the Siberian Craton (Zonenshain et al.  
47 1990; Badarch et al., 2002; Bazhenov et al., 2016 et al.) (Fig. 1). A large-scale tectonic event  
48 therein was the closure of the Mongol–Okhotsk Ocean that extended between the Siberian and  
49 Mongolia–North China continents from central Mongolia to the west to the Sea of Okhotsk to  
50 the east (Zonenshain et al. 1990; Sengör and Natal’in, 1996; Yin and Nie, 1996; Zorin, 1999).  
51 The time of the closure of the Mongol–Okhotsk Ocean is subject to considerable discussion and  
52 estimates vary from the Permian to the Early Cretaceous (Nie et al., 1990; Zonenshain et al.  
53 1990; Nie, 1991; Yin and Nie, 1993, 1996; Kuzmin and Kravchinsky, 1996; Davis et al., 1998;

54 Halim et al., 1998; Zorin et al., 1998; Gordienko and Kuzmin, 1999; Zorin, 1999; Darby et al.,  
55 2001; Kravchinsky et al., 2002; Parfenov et al., 2003; Cogné et al., 2005; Metelkin et al., 2007;  
56 Metelkin et al., 2010; Donskaya et al., 2013; Van der Voo et al., 2015; Yang et al., 2015,  
57 Demonterova et al., 2017 and others.). Most of the geodynamic models imply a scissor-like  
58 closure of the ocean, the associated collision structures getting younger northeastward along the  
59 Mongol–Okhotsk suture zone (Zhao et al., 1990; Zonenshain et al., 1990; Scotese, 1991;  
60 Kravchinsky et al., 2002; Tomurtogoo et al., 2005; Metelkin et al., 2010). According to Nie et al.  
61 (1990), Nie (1991), Yin and Nie (1993, 1996) and Guan et al. (2018), the closure of the Mongol–  
62 Okhotsk Ocean occurred in the early Permian at its western termination in central Mongolia and  
63 in the latest Jurassic at its eastern termination near the Sea of Okhotsk. However, paleomagnetic  
64 data suggest that the final closure of the ocean near the Sea of Okhotsk did not occur until the  
65 Early Cretaceous (Kravchinsky et al., 2002; Metelkin et al., 2010).

66 The Mongol–Okhotsk suture zone is underlined by a laterally extensive accretionary  
67 wedge composed primarily of flysch (Parfenov et al., 2001). Geological evidence, such as a  
68 switch from marine flysch-type sediments to continental sediments indicate that the closure of  
69 the ocean in Transbaikalia occurred at the boundary between the Early and Middle Jurassic  
70 (Zorin, 1999). Subduction of the oceanic crust beneath the Siberian continent and the subsequent  
71 collision gave rise to significant crustal thickening, magmatism, thrusting and formation of the  
72 Mongol–Okhotsk belt, interpreted as a plateau-like uplift (Zorin, 1999). Further from the suture  
73 zone, it also induced compressive deformation and denudation on the edge of the Siberian Craton  
74 near the Altai–Sayan Mountains (De Grave and Van den haute, 2002; De Grave et al., 2008;  
75 2014) and the Baikal–Patom Upland (Van der Beek et al., 1996; Jolivet et al., 2009).  
76 Paleogeographic maps of the Verkhoyansk margin of North Asia show that the drainage system of  
77 the paleo-Lena River transported to the north detrital material from the Sayan region and the  
78 northern part of Transbaikalia (the Angara-Vitim batholite) from Pennsylvanian to Middle Jurassic  
79 times (Ershova et al., 2005; Prokopiev et al., 2008). U-Pb ages of detrital zircons collected from

80 sandstones of that age in the Verkhoyansk region show a significant increase in the Transbaikalian  
81 grains population in the Middle Jurassic deposits compared to the Middle–Upper Triassic  
82 sediments. The authors explain this shift towards the Angara-Vitim batholite provenance areas by  
83 the uplift and denudation of Transbaikalia due to the collision of the Amuria and North China  
84 blocks with Siberia (Prokopiev et al., 2008).

85 The Middle Jurassic growth of mountain ranges along the southern edge of the Siberian  
86 Craton is reflected in the increasing coarseness of sediments upward the section in the Irkutsk Basin  
87 along the southern edge of the Craton (Fig. 1B). According to (ISC USSR, 1981), three  
88 sedimentary formations (Fms.) are recognized in the Jurassic deposits of the Irkutsk Basin (from  
89 bottom to top)–Cheremkhovo, Prisayan and Kuda (Fig. 2). The lower two formations are  
90 composed of rhythmically inter-layered sandstones, siltstones and mudstones. Tuff and thin beds  
91 of coal are also found in the Cheremkhovo Fm. The uppermost Kuda Fm. is represented by  
92 alternating medium- to coarse-grained sandstones, gravelstones and conglomerates. U-Pb ages of  
93 volcanic zircons from tuffs inter-layered within the Cheremkhovo and Kuda Fms. are  $194.5\pm 2.6$   
94 Ma and  $178.3\pm 5.0$  Ma, respectively (Mikheeva, 2017). U-Pb detrital zircon ages and Sm-Nd data  
95 obtained from all the sedimentary succession of the Irkutsk Basin date the onset of erosion in  
96 Transbaikalia to the Early–Middle Jurassic boundary (during deposition of the Kuda Fm.)  
97 (Demonterova et al., 2017; Mikheeva et al., 2017).

98 The Present-day geomorphology of Transbaikalia is characterized by a series of NE-  
99 trending basins located northwest of the Mongol–Okhotsk suture (Fig. 1B). Geochronological data  
100 obtained from the volcanic rocks associated with the opening of the basins as well as paleomagnetic  
101 studies show that they formed during or immediately after the closure of the Mongol–Okhotsk  
102 Ocean (Gordienko and Klimuk, 1995; Gordienko et al., 1997; Kravchinsky et al., 2002; Cogné et  
103 al., 2005; Metelkin et al., 2007; Metelkin et al., 2010). Based on paleomagnetic data implying a  
104 left-lateral displacement along the Mongol–Okhotsk suture zone, several authors explained the  
105 formation of the Transbaikalia basins through pull-apart type extension along an oblique

106 continental convergence zone (Parfenov et al., 2001; Metelkin et al., 2004; Metelkin et al., 2010;  
107 Yang et al., 2015). Another model associates the formation of those basins with that of  
108 metamorphic core complexes, widely distributed both in Transbaikalia, North Mongolia, and  
109 within the North China Craton (Zheng et al., 1991; Sklyarov et al., 1997; Zorin et al. 1997; Zorin,  
110 1999; Donskaya et al., 2008; Daoudene et al., 2009, 2013, 2017; Wang et al., 2011, 2012). Tectonic  
111 exhumation of these metamorphic core complexes occurred simultaneously throughout northeastern  
112 continental Asia between 145 Ma and 110 Ma, with a peak at 130–125 Ma. The early mid–lower-  
113 crustal extension is dated to 150–145 Ma (U–Pb ages on zircons from synkinematic intrusions)  
114 (Wang et al., 2012; Daoudene et al., 2017). The spatio–temporal evolution of the Jurassic–  
115 Cretaceous granitoids and related intrusions in the Mongol–Okhotsk belt showed a transition  
116 from compressive crustal thickening due to the subduction/collision event related to the closure  
117 of the Mongol–Okhotsk Ocean during the Early Jurassic to extensional thinning of the  
118 continental crust in Late Jurassic–Early Cretaceous times (Wang et al., 2015).

119 The basins formed in association with metamorphic core complexes are assigned to the  
120 Early Cretaceous. However, in Transbaikalia, some basins, older than 150–145 Ma formed during  
121 the early stage of this widespread extension. For example, according to paleobotanical and  
122 paleontological data, the Tugnuy Basin in western Transbaikalia began to form in the Early  
123 Jurassic (Komarov et al., 1965; Leonov, 1983; Skoblo et al., 2001; Novikov, 2005; Qi and Wang,  
124 2008). No precise geochronological age is available for the onset of formation of the Tugnuy  
125 Basin, though, as probably the oldest Mesozoic basin in Transbaikalia, it is a key object to date  
126 the onset of extension in that region. According to (Novikov, 2005), four sedimentary formations  
127 are recognized in the Jurassic deposits of the Tugnuy Basin (from bottom to top)—Berezovskaya,  
128 Ichetuyskaya, Tugnuyskaya and Galgatayskaya (Fig. 3A, B). The conglomerates of the  
129 Berezovskaya Fm. in the Tugnuy Basin are sometimes not interpreted as basal but considered as a  
130 stratigraphic analogue of the Ichetuyskaya Fm. and referred to as the Sagannurskaya Fm. (Skoblo et  
131 al., 2001) (Fig. 3C). K–Ar dating on some volcanic rocks from the Ichetuyskaya Fm. collected

132 within the Tugnuy Basin yielded ages of  $145\pm 3$  Ma,  $150\pm 5$  Ma (Ivanov et al., 1995) and  
133  $154.5\pm 3.7$  Ma (Gordienko et al., 1997). Whole-rock Rb–Sr dating of the same rocks yielded  
134 similar ages of  $158\pm 8$  Ma (Gordienko et al., 1997). Finally, Arzhannikova et al. (2018) re-dated  
135 some of those volcanic rocks to  $167.7\pm 1.2$  Ma (Bajocian–Barthonian) using Ar–Ar analysis on  
136 whole rock. The question whether the Berezovskaya Fm. underlies the Ichetuyskaya Fm., or  
137 whether it represents a stratigraphic analogue, is crucial to constrain the onset of extension in  
138 Transbaikalia. If the Berezovskaya Fm. effectively underlies the Ichetuyskaya Fm., then  
139 extension initiated before  $\sim 168$  Ma.

140 In this study, we selected samples from three key formations of the Tugnuy Basin (from  
141 the basal Berezovskaya Fm., the Tugnuyskaya Fm. and the Galgatayskaya Fm.), and performed  
142 U–Pb (LA-ICP-MS) dating of detrital zircons. The U–Pb data are used to assess the still  
143 discussed age and stratigraphic position of the conglomerates of the Berezovskaya Fm. and to  
144 identify the potential source areas of the sediments. The results allow describing the Jurassic  
145 topographic evolution in the area of the Mongol–Okhotsk Ocean suture zone and bring new light  
146 on the peculiar geodynamic context that prevailed immediately after the collision.

147

## 148 **2. Late Paleozoic–Mesozoic history of Transbaikalia – North Mongolia**

149 As described above, the late Paleozoic–Mesozoic history of Transbaikalia–North  
150 Mongolia is largely linked to the closure of the Mongol–Okhotsk Ocean (Zorin et al., 1993;  
151 1994; Zorin, 1999; Gordienko, 2001; Donskaya et al., 2013). The most recent model, based on  
152 geochronological and geochemical data available on the late Paleozoic–Mesozoic subduction-  
153 related magmatic complexes north of the Mongol–Okhotsk suture in Transbaikalia and  
154 Mongolia, implies that subduction began in the Devonian, though the main peak of magmatic  
155 activity occurred during the Carboniferous–Late Triassic time interval (Donskaya et al., 2013).  
156 During that period, the emplacement of the voluminous granites of the Angara–Vitim batholith  
157 (C–P<sub>2</sub>) was followed by that of the alkaline granitoids and volcanic rocks of the Western



158 Transbaikalian belt ( $C_2$ – $P_2$ ), the calc-alkaline granitoids of the Khangay batholith ( $P_3$ – $T_1$ ) and the  
159 Khentey batholith ( $T_3$ ) near the Mongol–Okhotsk suture, and finally of the alkaline granitoids  
160 and bimodal lava series ( $T_3$ ) in the hinterland of the Mongolian–Transbaikalian volcano-plutonic  
161 belt (Fig. 4). Geochemical data show that the early Permian and Late Triassic alkaline granitoids  
162 of Transbaikalia are of  $A_2$ -type geochemical affinities, typical of active continental margins  
163 (Donskaya et al., 2013).

164 In the Jurassic, the magmatic activity significantly decreased. In western Transbaikalia  
165 only a few Jurassic granitoids are reported, spatially confined to metamorphic core complexes  
166 but preceding the tectonic exhumation of the cores. These granites are interpreted as marking the  
167 switch from subduction to collision following the closure of the Mongol–Okhotsk Ocean in  
168 Transbaikalia (Donskaya et al., 2013, 2016). The closure of the ocean in central Mongolia  
169 occurred earlier than in Transbaikalia, and most probably corresponds to the Late Triassic–Early  
170 Jurassic exhumation event recorded by low temperature thermochronology in the Gobi Altai and  
171 the Mongolian Altai (De Grave et al., 2007; Jolivet et al., 2007; Vassallo et al., 2007;). The  
172 Devonian and Carboniferous flysch-type sediments, widely distributed in the Khangay and  
173 Khentey areas, were involved in the collision, intensively folded and metamorphosed under  
174 greenschist facies (Zorin, 1999). Daoudene et al., (2017) showed that there is no structural or  
175 metamorphic evidence, such as thrusts and associated metamorphic jumps, to attest for the upper  
176 crust thrust beneath deeper units in eastern Mongolia. However, the geophysical data obtained  
177 from the upper half of the crust (Siberia–Central Mongolia and Baikal–Mongolia geophysical  
178 transects) indicate that part of the Siberian crust was thrust over the continental margin of the  
179 Mongolia–North China continent with an horizontal displacement of at least 150 km in Khangay  
180 (Zorin et al., 1993), and about 100 km in Khentey (Zorin et al., 1994). The collision-related  
181 thrusts verging towards the Siberian Craton are morphologically less pronounced. The most  
182 prominent features are considered to belong to the Angara thrust system, whose frontal part is  
183 situated 600 km north of the Mongol–Okhotsk suture on the edge of the Siberian Craton (see



184 location on Fig. 1B). The Precambrian basement of the craton therein was thrust over the Lower  
185 Jurassic continental sediments of the Irkutsk Basin. The maximum observed horizontal  
186 displacements on the Angara thrust nappe system are of 6–7 km (Sizykh, 2001), with folds and  
187 décollement layers affecting the sediments in the frontal part of the wedge. The structural  
188 features show displacements from south to north (Mazukabzov and Sizykh, 1987).

189         Crustal shortening driven by widespread collisional thrusting and abundant calc-alkaline  
190 magmatism gave rise to crustal thickening and formation of areas of elevated topography (Zorin,  
191 1999). Although Mesozoic crustal thickening in Eastern Mongolia and NE China is refuted by  
192 Daoudene et al. (2017), it is commonly accepted that the formation of metamorphic core  
193 complexes requires crustal thickening to at least 50 km (Buck, 1991). Based on correlation of  
194 seismic data (Egorokin et al., 1980; Puzyrev, 1981; Kozhevnikov et al., 1990) and gravity  
195 anomalies (Stepanov and Volkhonin, 1969; Zorin, 1971), a first crustal thickness map was  
196 generated for East Siberia and Mongolia (Zorin et al., 1990, 1999) (Fig. 5) showing that the  
197 average crustal thickness in Transbaikalia is 40–50 km. More recent crustal thickness maps  
198 based on deep seismic sounding and gravity data show the same result (Suvorov et al., 2002;  
199 Petit and Déverchère, 2006; Vinnik et al., 2017).

200         The main stage of the Middle–Upper Jurassic volcanic activity in Transbaikalia  
201 coincides in time with an early phase of tectonic extension and the formation of a series of NE-  
202 SW striking grabens, including the Tugnuy Basin (Fig. 1B). Intensive bimodal volcanism,  
203 including trachybasalt, trachyandesite, trachydacite and trachyrhyodacite lava flows, produced  
204 the volcanogenic material of the Ichetuyskaya Fm. Therein 90% belong to mafic and only 10%  
205 to felsic volcanic rocks. The geochemical composition of the basaltoids from the Ichetuyskaya  
206 Fm. corresponds to that of continental rift basalts (Gordienko et al., 1997).

207         A second volcanic stage occurred at the beginning of the Early Cretaceous. The volcanic  
208 activity extended towards the NE from North Mongolia to the Vitim Plateau, producing lava flows  
209 that formed numerous, up to 1000 m thick subalkaline basalts volcanic fields in western

210 Transbaikalia. This second volcanic stage was associated with the development of a new structural  
211 pattern characterized by a system of narrow grabens wherein most of the lava flows occurred  
212 (Ivanov et al., 1995). The formation of the Early Cretaceous grabens is still discussed. Daoudene et  
213 al. (2017) proposed that the extension was linked to changes in the direction of subduction of the  
214 Izanagi plate associated to an anomalously hot continental lithosphere. However, several other  
215 researchers consider that the formation of the grabens was associated to the tectonic exhumation of  
216 metamorphic core complexes as a result of extension in the overthickened crust (e.g. Zorin, 1999;  
217 Donskaya et al., 2008; Wang et al., 2011, 2012). The Early Cretaceous intra-plate basalts are  
218 geochemically similar to the Jurassic lavas of the main volcanic stage (Sklyarov et al., 1997,  
219 Donskaya et al., 2008, 2013). Tectonic exhumation of the metamorphic core complexes occurred  
220 simultaneously both in Transbaikalia–Mongolia and in the Northern China Craton.

221 The volcanic activity ended during the end of the Early Cretaceous. The lack of reliably  
222 dated Upper Cretaceous and Paleogene deposits in Transbaikalia suggests a period of tectonic  
223 quiescence (Logatchev et al., 1974). Though later, Logachev (1993) attributed the beginning of the  
224 Baikal rifting to the Early Cretaceous based on remnants of a few small basins and the great  
225 thickness of sediments in the Southern Baikal Basin. Ivanov et al. (2015) showed that alkaline  
226 volcanism initiated simultaneously with the Upper Cretaceous and Paleogene sedimentation.

227

### 228 **3. The Jurassic sedimentary deposits in the Tugnuy Basin**

229 The sedimentary deposits in the basins of Transbaikalia were studied intensively in the  
230 1950–1960s (e.g. Martinson, 1955; Kolesnikov, 1961, 1964). The data provided by these studies  
231 served as a scientific research basis for some more recent publications (Skoblo et al., 2001;  
232 Jolivet et al., 2017). However the ages of the various sediment formations, including those of the  
233 Tugnuy Basin, are still disputable (Arzhannikova et al., 2018 and references therein).

234 The Jurassic stratigraphy of the Tugnuy Basin, is summarized on Fig. 3A based on  
235 Novikov, (2005), Skoblo et al., (2001) and Jolivet et al., (2017). The base of the section is

236 represented by the 150 m to 1890 m thick Berezovskaya Fm. unconformably overlying the Upper  
237 Triassic volcanic rocks and Paleozoic basement. It is conformably overlain by the volcanic-  
238 sedimentary Ichetuyskaya Fm. up to 1000 m thick. Up-section, the Ichetuyskaya Fm. is overlain by  
239 the 150–240 m thick Tugnuyskaya Fm., either conformably or through an erosion surface. Finally,  
240 the Jurassic sequence ends with the up to 360 m thick Galgatayskaya Fm. Small, 100–300 m thick  
241 outcrops of Lower Cretaceous proximal alluvial fan deposits are confined to the edge of the Zagan  
242 Range (Fig. 3A). The nature of the boundary between the Cretaceous and Jurassic deposits is  
243 unknown. The Zagan Range is one of the better-known Lower Cretaceous metamorphic core  
244 complexes (Sklyarov et al., 1994, 1997; Donskaya et al., 2008, 2013). The accumulation of the  
245 Lower Cretaceous sediments near the edge of the Tugnuy Basin could be related to tectonic  
246 exposure of the core complex.

247 According to Skoblo et al. (2001), the conglomerate deposits of the Berezovskaya Fm.  
248 belong to the Sagannurskaya Fm., a stratigraphic analog of the Ichetuyskaya Fm. (Fig. 3C).  
249 Following these authors, the Jurassic sedimentation in West Transbaikalia initiated with the  
250 deposition of the Pliensbachian to Aalenian Ichetuyskaya and Sagannurskaya Fms., separated  
251 from the basement by an erosion surface. The Aalenian-Bathonian Tugnuyskaya Fm.  
252 conformably overlies the Ichetuyskaya and Sagannurskaya deposits. Finally, the presumably  
253 Oxfordian-Tithonian Galgatayskaya Fm. deposits are separated from the underlying  
254 Tugnuyskaya Fm. by an erosion surface (Skoblo et al., 2001) (Fig. 3C). All these ages were  
255 estimated based on macro-flora and pollen assemblages. Since the volcanic rocks from the  
256 Ichetuyskaya Fm. have been dated to late Middle Jurassic–late Late Jurassic using K-Ar, Rb-Sr  
257 and Ar-Ar methods (Ivanov et al., 1995; Gordienko et al., 1997; Arzhannikova et al., 2018), all  
258 the overlying deposits presented above were formed during or after the Tithonian.

259 Samples for detrital zircons U-Pb analysis were collected from two locations in the  
260 Tugnuy Basin, in order to cover the Berezovskaya, Tugnuyskaya and Galgatayskaya Fms. (Fig.  
261 3A). The Berezovskaya Fm. is exposed in the Berezovskaya section (51°06,065'N; 107°57,929'E)

262 (Fig. 6A). The deposits are composed of poorly sorted pebble to boulder (up to 0.5 m)  
263 conglomerates. The clasts are moderately rounded, in a matrix formed by gravels and coarse  
264 sandstones. The coarse conglomerates are inter-layered with thin beds of poorly sorted medium-  
265 grained sandstones and gravel-conglomerates, both containing loose pebbles. The lithology of the  
266 pebbles is dominated by pink and light-gray granites with few mafic and felsic effusive rocks (Fig.  
267 6B). Sample Tug-17-8 was collected from a medium-grained sandstone layer (Fig. 6A). A thin  
268 section shows that the polymict sandstone is composed of poorly sorted minerals (quartz,  
269 plagioclase, kaolinized feldspar and rare muscovite) and rock fragments (quartzite, felsic and  
270 intermediate type of volcanic rocks and granite). The clasts are characterized by varying degrees  
271 of roundness, from poor to good. The cement that binds the clasts is made of clay rich-in-iron  
272 oxide. These sediments are interpreted as deposited in a braided river to proximal alluvial fan  
273 environments. The lithology of the pebbles is dominated by pink and light-gray granites with few  
274 mafic and felsic effusive rocks (Fig. 5B). The unit is tectonically disturbed, bedding plunges NW at  
275 30°. Numerous fractures disrupt the conglomerates, some of them with a meter to several meters  
276 offset (Fig. 6C).

277         Samples from the Tugnuyskaya and Galgatayskaya Fms. were taken from the Tugnuy  
278 coal mine (51°18,690'N, 108°31,426'E). The Tugnuyskaya Fm. is represented by a sequence  
279 including 4 groups of economic humic coal beds showing considerable variations in thickness and  
280 affected by folds with N–S striking axes. The undeformed Galgatayskaya Fm. unconformably  
281 overlies the Tugnuyskaya Fm. through an erosion surface. The sediment sequence is composed of  
282 red sandstones and gravel conglomerates, only exposed in the upper part of the quarry (Fig. 7A–D).  
283 Samples were collected along two sections.

284         The first, 12 m thick section in the lower part of the quarry (Fig. 8) is characteristic of  
285 most of the Tugnuyskaya Fm. coal-bearing sequence excavated in the mine. The deposits are  
286 composed of rhythmically inter-layered, well-sorted light-gray medium-grained sandstones,  
287 dark-gray siltstones, yellow coarse-grained to gravel sandstones, and thin beds of coal. Medium-

288 — grained sandstones are well rounded while coarser-grained ones are less rounded. This facies  
289 assemblage is interpreted as representing distal alluvial plain deposits including river and lake  
290 environments. The sample Tug-14-3 was collected from a medium-grained sandstone layer (Fig.  
291 8A). It consists of small- to medium-grained polymict sandstone, similar in mineral composition  
292 to sample Tug-17-8. However, in contrast, it is well-sorted, has clay cement and mineral grains  
293 are well-rounded.

294         The second, 27 m thick section is located in the upper part of the quarry and contains  
295 the contact between the Tugnuyskaya and Galgatayskaya Fms. (Fig. 9). The lower part of the  
296 section (0–15 m) corresponds to the Tugnuyskaya Fm. It consists of parallel layers of light-gray  
297 medium- and coarse-grained sandstones with intercalations of thin beds of dark-gray siltstones  
298 and coal, again interpreted as distal alluvial plain deposits. These are unconformably overlain by  
299 deposits of the Galgatayskaya Fm. (15–24 m) represented by intercalated red-yellow medium- to  
300 coarse-grained and gravel sandstones with moderately rounded grains characteristic of proximal  
301 alluvial plain to distal alluvial fan deposits. The red color suggests a warm, semi-arid climate  
302 contrasting with the more humid climate prevailing during deposition of the Tugnuyskaya Fm.  
303 (Martinson, 1988). Sample Tug-14-2 was collected from a medium-grained sandstone layer of the  
304 Galgatayskaya Fm. (Fig. 9A). The composition of the sample is virtually identical to that of  
305 sample Tug-17-8 with minor differences in the cement composition, which is shifted towards  
306 iron oxide composition. The uppermost deposits (24–27 m) consist of unsorted Quaternary alluvial  
307 sediments.

308

#### 309                 **4. Detrital zircon analysis and results**

310         Detrital zircons were extracted using an electromagnetic separator and heavy liquids. For  
311 each sample, more than 100 zircons crystals were mounted without selection based on size  
312 (analyzed crystal size vary between 60  $\mu\text{m}$  and 180  $\mu\text{m}$ ) or morphology. U–Pb analysis was  
313 performed using and ICP-MS Element XR (ThermoFisher Scientific) coupled to an UP-213 laser

314 (New Wave). The instrumental parameters and measurement technique are described in  
315 (Khubanov et al., 2016; Buyantuev et al., 2017). The 91500 (1065 Ma) (Wiedenbeck et al.,  
316 1995), Plešovice (337 Ma) (Slama et al., 2008) and GJ-1 (608.5 Ma) (Jackson et al., 2004)  
317 zircons were used as external standards. Relative errors in the measurement for isotope ratios in  
318 the reference standards varied within ranges of 1%–2.3% for  $^{208}\text{Pb}/^{232}\text{Th}$ , 2.1%–2.6% for  
319  $^{207}\text{Pb}/^{206}\text{Pb}$ , 1.1%–2.6% for  $^{206}\text{Pb}/^{238}\text{U}$  and 2%–2.5% for  $^{207}\text{Pb}/^{235}\text{U}$ . The measurement data were  
320 processed using the GLITTER (Griffin et al., 2008) and ISOPLOT (Ludwig, 2003) software. The  
321 interpretation only considered the data with <10% discordance. The age data histogram and  
322 probability curves for each sample were plotted from  $^{206}\text{Pb}/^{238}\text{U}$  with  $2\sigma$  error bars (Fig. 10;  
323 samples Tug-14-2, Tug-14-3 and Tug-17-8 in Suppl. Material). Backscattered electron imaging  
324 (BSE) was used to infer zoning and internal structures of the zircon grains as well as the  
325 occurrence of mineral inclusions (Fig. 11).

326 In general, zircon U–Pb ages from the Tugnuy Basin deposits indicate upper Paleozoic  
327 and Mesozoic source rocks. Detrital zircons from the Berezovskaya Fm. (sample Tug-17-8 in  
328 Suppl. Material) are transparent, pale yellow to yellow, and contain no more than 5% of  
329 fractured grains. Most of the grains are isometric (~35%), short-prismatic (~35%), prismatic  
330 (~20%), and some of them are long-prismatic (~10%), most of them are of volcanic affinity. One  
331 hundred twelve concordant zircon grains provided U–Pb dates distributed in the following  
332 populations: 154–174 Ma (38% of grains), 190–237 Ma (35% of grains), 241–275 Ma (17% of  
333 grains), and 288–325 Ma (11% of grains). A few additional single grains with ages of 400 Ma  
334 and 1524 Ma have been obtained but they do not represent statistically reliable populations (3%  
335 or more) and are not considered for discussion.

336 Detrital zircons from the Tugnuyskaya Fm. (sample Tug-14-3 in Suppl. Material) are  
337 colorless, pale yellow and very seldom yellow. The grains are isometric (~50%), prismatic  
338 (~30%) or short-prismatic (~20%). The grains are transparent, with almost no fractures (no more  
339 than 5%). One hundred ten U–Pb zircon dates were obtained, distributed in the following

Journal Pre-proof  
340 populations: 168–177 Ma (3% of grains), 197–270 Ma (91% of grains) and 280–305 Ma (6% of  
341 grains).

342 Detrital zircons from the Galgatayskaya Fm. (sample Tug-14-2 in Suppl. Material), are  
343 yellow to pale yellow, less often colorless (~10%). Most of the grains are isometric (~50%) or  
344 prismatic (~30%) but some are short-prismatic (~17%) or single long-prismatic (~3%). Fractured  
345 grains (predominantly yellow and pale yellow) make up about 20% of the total. One hundred  
346 seven U-Pb zircon dates were obtained with age populations of 162–173 Ma (6% of grains),  
347 194–230 Ma (74% of grains) and 233–256 Ma (20% of grains).

348

## 349 **5. Discussion**

### 350 **5.1. Provenance of detrital zircons**

351 Based on the distribution of the detrital zircon U-Pb ages and the sediment facies and  
352 depositional environment we discuss the source area for each formation as well as the  
353 topographic evolution of the region surrounding the Tugnuy Basin. The potential sediment  
354 source areas have been distinguished based on the geochronological data available in Siberia,  
355 North Mongolia and Central Mongolia (Fig. 4).

356 Based on detrital zircon provenance analysis (Prokopiev et al., 2008; Demonterova et al.,  
357 2017; Mikheeva et al., 2017), the topographic evolution of Western Transbaikalia during the Early  
358 Jurassic resulted from compressive deformation and denudation on the edge of the Siberian  
359 Craton near the Sayan Mountains and the Angara-Vitim batholite area (Fig. 12A) and from the  
360 onset of erosion in Western Transbaikalia by ~178 Ma (Fig. 12B). The compressive stress field  
361 caused by the Mongol–Okhotsk collision was rapidly inverted; leading to continental rifting  
362 which onset age corresponds to the age of the oldest deposits in the Tugnuy Basin.

363 In the lowest Berezovskaya Fm. (sample Tug-17-8, Fig. 10A), the main zircon ages  
364 ranging from 154 Ma to 170 Ma correspond to the age of volcanic rocks of the Ichetuyskaya Fm.  
365 (145–168 Ma), widespread within the basin (Ivanov et al., 1995, Gordienko et al., 1997;



366 Arzhannikova et al., 2018). The occurrence of mafic volcanic fragments and the preservation of  
367 long-prismatic magmatic zircons of “Ichetuyskaya” age in conglomerates and sandstones of the  
368 Berezovskaya Fm. indicate that the latter does not underlie the Ichetuyskaya Fm. but was  
369 deposited simultaneously at least during the latest stage of the Ichetuyskaya volcanism.  
370 However, the groundmass of pebbles in the Berezovskaya Fm. conglomerates corresponds to  
371 felsic magmatic rocks; the percentage of granitoid pebbles (80%) remains unchanged along the  
372 investigated cross-section. This is also typical of the other sections logged in the conglomerates  
373 of the Berezovskaya Fm. (Skoblo et al., 2001), indicating a continuous erosion of the granitoid  
374 provinces. The age peaks of 210–235 Ma and 245–270 Ma correspond to the erosion of the  
375 southern magmatic provinces including the Mongolian-Transbaikalian belt, the Northern  
376 Mongolian belt, the Khentey batholith, and the Khangay batholith. Only the Onon province  
377 farther to the east seems not to be represented (Fig. 4). As proposed by Donskaya et al., (2013),  
378 some of these belts presented relatively high relief that could explain the coarse material  
379 transported to the Transbaikalian basins (Fig. 12C). The more restricted zircon ages ranging from  
380 290 Ma to 315 Ma only correspond to the Angara–Vitim batholith situated to the north of the  
381 Tugny Basin. As indicated by the significant occurrence of late Carboniferous–early Permian  
382 detrital zircon U-Pb ages in the Lower–Middle Jurassic deposits of the Verkhoyansk margin and  
383 Irkutsk Basin, the Angara-Vitim batholith area was also an uplifted region at the Early–Middle  
384 Jurassic boundary (Prokopiev et al., 2008; Demonterova et al., 2017; Mikheeva, 2017) (Fig.  
385 12B). However, the occurrence of age peaks corresponding to sources both to the north and  
386 south of the Transbaikal province in a single sample suggest sediment recycling from previous  
387 deposits (Yang et al., 2013). The large amount of granitoid fragments derived from the southern  
388 provinces, associated to the short transport distance suggested by the alluvial fan depositional  
389 environment advocates for a river system flowing from the south and mainly eroding the  
390 basement. Nonetheless, as the Berezovskaya Fm. corresponds to the onset of extension, the  
391 previously existing cover sequence, containing zircons derived from sources to the north was



392 probably still preserved and participated to the clastic material source (Fig. 12C). The presence  
393 of detrital zircons with ages typical of the Angara-Vitim batholith south of the Tugnuy Basin  
394 further implies that a river system sourced in the Angara-Vitim area had reached this region prior  
395 to Middle Jurassic times (Fig. 12A). This South-directed drainage system seems to have been at  
396 least partially inverted during the Middle Jurassic (Fig. 12C). This is consistent with the  
397 southward shift in the zircon sources observed by Prokopiev et al. (2008) in the late Lower to  
398 Middle Jurassic deposits of the paleo-Lena River System.

399         The distal alluvial plain to lacustrine, coal-bearing facies of the Tugnuyskaya Fm.,  
400 suggests that by that time, Transbaikalia was already a tectonically quiet area with a flat, poorly  
401 dissected topography mainly characterized by wide alluvial valleys (Butova, 1963; this work).  
402 Volcanism had ceased by that time (Donskaya et al., 2013), and the volcanic deposits were  
403 already largely overlain by younger clastic sediments. We suppose that for this reason we do not  
404 observe zircon age population corresponding to the Ichetuyskaya Fm. time-span in the  
405 Tugnuyskaya Fm. Sample Tug-14-3 is characterized by a major population of zircons issued  
406 from the southern provinces (200–260 Ma, Fig. 10B), which indicates that erosion in the uplifted  
407 areas to the south still continued (Fig. 12D). This is consistent with the occurrence of a few  
408 Jurassic (170–180 Ma) and late Carboniferous–early Permian (280–305 Ma) ages (Fig. 10B)  
409 most probably representing, like in sample Tug-17-8 (Berezovskaya Fm.) recycling of previous  
410 deposits. Finally, this result supports the idea that the Berezovskaya and Tugnuyskaya Fms.  
411 correspond to a single, continuous topographic and erosional stage: the lower proportions of  
412 Jurassic and late Paleozoic zircon ages observed in sample Tug-14-3 compared to sample Tug-  
413 17-8 indicate a deepening of the erosion level associated with the progressive removal of the  
414 previously existing sediment cover in the southern provinces.

415         The tectonic deformation (folding) observed in the Tugnuyskaya Fm. deposits and the  
416 unconformable erosional contact with the overlying Galgatayskaya Fm. indicate an episode of  
417 compression and erosion in the Tugnuy Basin area (Fig. 12E). The roughly N–S folds axes imply

418 E–W compression coherent with the contemporaneous collision-related compressive  
419 deformations described in the eastern part of the Mongol–Okhotsk suture zone, east of  
420 Transbaikalia. Based on geophysical studies, the results of Shevchenko et al. (2011) and  
421 Didenko et al. (2013) showed multiple thrusting on the Aldan–Stanovoy craton where the South  
422 Aldan Jurassic coal basin was partly overthrust by metamorphic rocks. Yang et al. (2015)  
423 described Upper Jurassic–Lower Cretaceous folding and erosion in some basins of Mongolia and  
424 North China. They related this compression phase, enclosed between two episodes of extension,  
425 to a short-term collision event lasting about 10 million years during the latest Jurassic–earliest  
426 Cretaceous in the eastern Central Asian Orogenic Belt. The folding of the Tugnuyskaya Fm. can  
427 be a response to this collision event in the central part of the Mongol–Okhotsk fold belt.

428 The compression and erosion phase was followed by the deposition of the  
429 Galgatayskaya Fm. terminating the Tugnuy sequence. The upward coarsening of the deposits  
430 and the progressive shift toward more proximal depositional environments suggest a renewed  
431 relief building associated with an increasing rate of basin subsidence (Fig. 12F). The zircon U–Pb  
432 age distribution again shows a small peak of recycled Jurassic volcanic zircons (160–170 Ma)  
433 and two main peaks corresponding to sources in the magmatic provinces of North Mongolia  
434 (210–230 Ma and 242–256 Ma) (Fig. 10C). The absence of upper Paleozoic zircons suggests that  
435 most of the previously deposited sediment cover containing those zircons had been removed by  
436 Middle–Late Jurassic times.

437 Finally, by Early Cretaceous time, further extension led to the tectonic exhumation of  
438 metamorphic core complexes and the formation of the Lower Cretaceous grabens widespread in  
439 Transbaikalia and North Mongolia (Sklyarov et al., 1997, Donskaya et al., 2008, 2013) (Fig.  
440 12G).

## 441 **5.2. Formation mechanism of the Jurassic basins in Transbaikalia**

442 Based on detrital U–Pb zircon geochronology data and sediment analysis presented  
443 above, extension in the Tugnuy Basin started around 168 Ma, participating to the initial

444 degradation of the post-collision relief in the Transbaikal region. This is ~10–12 million years  
445 later than the latest Early Jurassic age proposed for the onset of the collision-related topography  
446 in Transbaikalia (Demonterova et al., 2017; Mikheeva et al., 2017; Mikheeva, 2017). However, the  
447 Tugny Basin initiated earlier than the mid–lower-crustal extension that led to the tectonic  
448 exhumation of the Lower Cretaceous metamorphic core complexes in Southeast Siberia and  
449 North Mongolia (Donskaya et al., 2008; Wang et al., 2012; Daoudene et al., 2017). In that respect,  
450 the model relating the formation of the Transbaikalian basins to post-collisional collapse of the  
451 thickened continental crust, can only explain the evolution of the Lower Cretaceous basins  
452 widespread in Transbaikalia, North Mongolia and within the North China Craton (Zheng et al.,  
453 1991; Sklyarov et al., 1997, Zorin et al. 1997; Zorin, 1999; Donskaya et al., 2008; Wang et al.,  
454 2011, 2012). The formation of the Jurassic basins, however, seems to have had a more local  
455 character, and their spatial location is often unrelated to any metamorphic complex.

456         The Jurassic evolution of the Tugny Basin can be divided in three stages. Following  
457 the Bathonian initiation of the basin, the deposition of the at least 1 km thick volcano-  
458 sedimentary deposits of the Berezovskaya/Ichetuyskaya and Tugnyuskaya Fms. shows a  
459 generally retrograding trend from coarse, proximal alluvial fan deposits to sandy, coal bearing  
460 alluvial plain and lacustrine deposits. This retrogradation trend suggests a decrease in subsidence  
461 rate and thus in tectonic extension rate. In the latest Jurassic–earliest Cretaceous, the basin was  
462 affected by E–W compression leading to basin inversion and erosion of the Tugnyuskaya Fm.  
463 Renewed extension in Early Cretaceous finally allowed the deposition of the prograding  
464 Galgatayskaya Fm.

465         Such a long-term deformation pattern, with the simultaneous or alternating occurrence  
466 of short-term compression and extension phases, is typical of basins forming along large shear  
467 zones. For example, the Tunka Basin in the southwestern flank of the Baikal rift (see location on  
468 Fig. 1B), which began to subside during late Oligocene and accumulated about 3 km of sediment  
469 in a regionally transtensive tectonic setting (Sherman et al., 1973; Mazilov et al., 1993), was

470 locally inverted during the late Pleistocene–Holocene (Larroque et al., 2001; Arjannikova et al.,  
471 2004; Arzhannikova et al., 2005; Shchetnikov, 2017; Ritz et al., 2018). To a larger scale, a similar  
472 deformation pattern, associating contemporaneous extension and compression along a large-  
473 scale strike-slip system has been put forward to explain the Cenozoic evolution of the Baikal rift  
474 –the Transbaikalian system (Jolivet et al., 2013). Paleomagnetic data obtained from the Mesozoic  
475 deposits of Southeast Siberia and North Mongolia evidence left-lateral strike-slip motion along  
476 the Mongol–Okhotsk suture zone during and after the collision due to clockwise rotation of the  
477 Siberian continent (Parfenov et al., 2001; Metelkin et al., 2004; Metelkin et al., 2010). Yang et  
478 al. (2015) proposed that this major left-lateral strike-slip motion triggered the gravitational collapse  
479 of the thickened upper crust, leading to the development of rift basins. The oblique closure of the  
480 Mongol–Okhotsk Ocean has been put forward to explain the simultaneous formation of  
481 compressional structures along the edge of the Siberian Craton and that of extensional structures  
482 in Transbaikalia (Jolivet et al., 2017). However, as indicated in the introduction, newly obtained  
483 data show that compression and positive relief building in Transbaikalia began about 12 million  
484 years earlier than extension (Demonterova et al., 2017; Mikheeva, 2017; this work). The basin  
485 formation in Transbaikalia as the extension along strike-slip fault systems seems probable,  
486 though it relates only to the Jurassic basins. Finally, the Cretaceous basins widespread  
487 throughout northeastern continental Asia are tightly related in space and time with metamorphic  
488 core complexes and correspond to an extensional mechanism not limited to the Mongol–Okhotsk  
489 suture zone. To the east, the Mongol–Okhotsk oceanic plate was directly connected to the  
490 Farallon plate itself separated from the Izanagi plate to the south. By Late Jurassic, the Farallon  
491 plate had completely subducted, replaced by the Izanagi plate moving northwestward and  
492 connected to the Pacific plate to the south (Cogné et al., 2005; Daoudene et al., 2017). It is  
493 largely admitted that this widespread extension phase is related both to collisional uplift collapse  
494 and far-field effects of the Cretaceous Pacific and the Izanagi plate subduction processes (Zheng  
495 et al., 1991; Sklyarov et al., 1997; Zorin et al. 1997; Zorin, 1999; Donskaya et al., 2008; Wang et al.,

496 2011, 2012; Daoudene et al., 2017). This last event was superimposed to the more local, Jurassic  
497 extension in Transbaikalia similarly to the Cenozoic superimposition of the Baikal system to the  
498 Mesozoic Transbaikal basins (Jolivet et al., 2013).

499

## 500 **6. Conclusions**

501 The Jurassic-Lower Cretaceous sedimentary and topographic evolution of Transbaikalia  
502 provides key information on the rapid change in tectonic setting between the final closure of the  
503 Mongol–Okhotsk Ocean and the onset of the continental-scale extension in northeastern Asia.

504 A wide uplifted plateau reaching the southern edge of the Siberian craton by ~178 Ma  
505 characterized the topography that resulted from the closure of the Mongol–Okhotsk Ocean at the  
506 end of the Early Jurassic. The main sediment sources in Transbaikalia were the exhumed granitic  
507 batholiths of North Mongolia and Transbaikalia. Sedimentation occurred in a wide area including  
508 Transbaikalia, the Irkutsk Basin and the Verkhoyansk margin. Nonetheless, while this topography  
509 was evolving, strike-slip displacement induced by the oblique closure of the Mongol–Okhotsk  
510 Ocean initiated some of the Transbaikalian depressions, such as the Tugnuy Basin at about 168 Ma,  
511 associated to igneous activity. Our results on detrital zircon geochronology of the Tugnuy Basin  
512 sediments together with published  $^{40}\text{Ar}/^{39}\text{Ar}$  data on volcanic rocks clearly demonstrate that the  
513 Berezovskaya Fm. was deposited simultaneously with the Ichetuyskaya Fm. during the final stage  
514 of volcanic activity from Kimmeridgian to Tithonian. They contain material partially recycled from  
515 a previous vast Lower Jurassic drainage system reaching the Angara-Vitim batholith to the north  
516 and shedding sediments to the continental margin of the Mongol–Okhotsk Ocean in Early Jurassic.  
517 The collisional event at the end of the Early Jurassic led to the uplift of the continental margin,  
518 which partially inverted the drainage system toward the North. The main zircon age populations in  
519 the Berezovskaya and Tugnuyskaya Fms. correspond to the erosion of the southern (North  
520 Mongolian) granite batholites. A phase of basin inversion marked by folding of the Tugnuyskaya

521 Fm., could correspond to the short-term collision event that took place during the latest Jurassic–  
522 earliest Cretaceous in the eastern Central Asian Orogenic Belt (Yang et al., 2015).

523 The following inversion in tectonic regime from compression to extension occurred in  
524 Transbaikalia in Early Cretaceous. This is consistent with the crustal extension that led to the  
525 formation of the numerous metamorphic core complexes throughout northeastern continental Asia  
526 during the Early Cretaceous. We propose that this extension was driven by a combination between  
527 the Mongol–Okhotsk orogenic collapse and the far field effects of the paleo-Pacific–Izanagi plate  
528 subduction to the east. A pattern similar to the combination between the India-Asia collision and  
529 Pacific subduction stress fields opening the Cenozoic Baikal rift system.

530

531 **Acknowledgments:** The study was supported by grants from the Russian Foundation for Basic  
532 Research (Grant No. 17-05-00191 and PICS No. 13-05-91052–CNRS-4881). Detrital zircons  
533 were extracted from the bulk sample and prepared for U-Pb analysis at the Centre for  
534 Geodynamics and Geochronology of the Institute of the Earth’s Crust SB RAS (Irkutsk, Russia).  
535 The BSE images of detrital zircons were obtained at the Centre of isotope-geochemical studies at  
536 the A.P. Vinogradov Institute of Geochemistry, SB RAS (Irkutsk, Russia). U-Pb isotope analysis  
537 of zircons was made at the “Analytical center of mineralogical, geochemical and isotope Studies”  
538 at the Geological Institute, SB RAS (Ulan-Ude, Russia).

539

#### 540 **References**

541 Arjannikova, A., Larroque, C., Ritz, J.-F., Déverchère, J., Stéphan, J.-F., Arjannikov, S.,  
542 San'kov, V., 2004. Geometry and kinematics of recent deformation in the Mondy-Tunka  
543 area (south-westernmost Baikal rift zone, Mongolia-Siberia). *Terra Nova* 16, 5, 265-  
544 272.

- 545 Arzhannikova, A.V., Arzhannikov, S.G., Semenov, R.M. Chipizubov, A.V., 2005.  
546 Morphotectonics and Late Pleistocene - Holocene deformations in the Tunka system of  
547 basins (Baikal rift, Siberia). *Zeitschrift fur Geomorphologie* 49, 4, 485-494.
- 548 Arzhannikova, A.V., Frolov, A.O., Arzhannikov, S.G., Demonterova, E.I., Ivanov, A.V., Jolivet,  
549 M., Rubtsova, M.N. and Dorozhko, A.L., 2018. On correlation between the Jurassic  
550 deposits of the Irkutsk basin and Southwestern Transbaikalia from the paleobotanical  
551 and geochronological data. *Russian Geology and Geophysics* 59, 6, 773-791.
- 552 Badarch, G., Cunningham, W.D., Brian, F.W., 2002. A new terrane subdivision for Mongolia:  
553 implication for the Phanerozoic crustal growth of Central Asia. *Journal of Asian Earth*  
554 *Sciences* 21, 87-110.
- 555 Bazhenov, M.L. Kozlovsky, A.M., Yarmolyuk, V.V., Fedorova, N.M., Meert, J.G., 2016. Late  
556 Paleozoic paleomagnetism of South Mongolia: Exploring relationships between Siberia,  
557 Mongolia and North China. *Gondwana Research* 40, 124–141.
- 558 Buck, W.R., 1991. Models of continental lithospheric extension. *J. Geophys. Res.* 96, 20161-  
559 20178.
- 560 Butova, E.P., 1963. Lithological-facial characteristics of coal-bearing strata and coal  
561 accumulation conditions. In: Karpov, N. F. and Nefedyeva, L. P. (Eds.), *History of the*  
562 *upper Mesozoic coal accumulation in the Buryat ASSR and southeastern Lena basin.*  
563 *Proceedings of the Coal Geology Laboratory. Issue XVIII. Izd-vo Akademii nauk*  
564 *SSSR, Moscow-Leningrad, pp. 85-115 (in Russian).*
- 565 Buyantuev, M. D., Khubanov, V. B. and Vrublevskaya, T. T., 2017. U-Pb LA-ICP-MS dating of  
566 zircons from subvolcanics of the bimodal dyke series of the Western Transbaikalia:  
567 technique, and evidence of the Late Paleozoic extension of the crust. *Geodynamics &*  
568 *Tectonophysics* 8(2), 369-384 (in Russian).
- 569 Cogné, J.-P., Kravchinsky, V.A., Halim, N. Hankard, F., 2005. Late Jurassic-early Cretaceous  
570 closure of the Mongol-Okhotsk Ocean demonstrated by new Mesozoic palaeomagnetic

- 571 results from Trans-Baikal area (SE Siberia). *Geophysical Journal International* 163,  
572 813-832.
- 573 Daoudene, Y., Gapais, D., Cogné, J-P. Ruffet, G., 2017. Late Mesozoic continental extension in  
574 northeast Asia – Relationship to plate kinematics. *BSGF-Earth Sciences Bulletin* 188, 1-  
575 2, 10.
- 576 Daoudene, Y., Gapais, D., Ledru, P., Cocherie, A., Hocquet, S. Donskaya, T.V., 2009. The  
577 Ereendavaa Range (northeastern Mongolia): an additional argument for Mesozoic  
578 extension throughout eastern Asia. In: W.J., Xiao, A., Kröner and B., Windley (Eds.),  
579 Geodynamic evolution of Central Asia in the Paleozoic and Mesozoic. *International*  
580 *Journal of Earth Science* 98(6), 1381-1393.
- 581 Daoudene, Y., Ruffet, G., Cocherie, A., Ledru, P. Gapais, D., 2013. Timing of exhumation of the  
582 Ereendavaa metamorphic core complex (northeastern Mongolia) – U-Pb and  $^{40}\text{Ar}/^{39}\text{Ar}$   
583 constraints. *Journal of Asian Earth Sciences* 62, 98-116.
- 584 Darby, B.J., Davis, G.A., and Zheng, Y., 2001. Structural evolution of the southwestern Daqing  
585 Shan, Yinshan belt, Inner Mongolia, China. In: Hendrix, M.S., Davis, G.A. (Eds.),  
586 Paleozoic and Mesozoic tectonic evolution of central Asia: From continental assembly  
587 to intracontinental deformation. Boulder, Colorado, Geological Society of America  
588 Memoir 194.
- 589 Davis, G.A., Wang, Cong, Zheng, Yadong, Zhang, Jinjiang, Zhang, Changhou, and Gehrels, G.E.,  
590 1998. The enigmatic Yinshan fold-and-thrust belt of northern China: New views on its  
591 intraplate contractional styles. *Geology* 26, 43-46.



- 592 De Grave, J., Buslov, M.M., Van den haute, P., 2007. Distant effects of India–Eurasia  
593 convergence and Mesozoic intracontinental deformation in Central Asia: Constraints from  
594 apatite fission-track thermochronology. *Journal of Asian Earth Sciences* 29, 188–204.
- 595 De Grave, J., De Pelsmaeker, E., Zhimulev, F.I., Glorie, S., Buslov, M.M., Van den haute, P.,  
596 2014. Meso-Cenozoic building of the northern Central Asian Orogenic Belt:  
597 Thermotectonic history of the Tuva region. *Tectonophysics* 621, 44–59.
- 598 De Grave, J. Van den Haute, P., 2002. Denudation and cooling of the lake Teletskoye region in  
599 the Altai Mountains (South Siberia) as revealed by apatite fission-track  
600 thermochronology. *Tectonophysics* 349, 145-159.
- 601 De Grave, J., Van den Haute, P., Buslov, M.M., Dehandschutter, B. Glorie, S., 2008. Apatite  
602 fission-track thermochronology applied to the Chulyshman Plateau, Siberian Altai  
603 Region. *Radiation Measurements* 43, 38-42.
- 604 Demonterova, E.I., Ivanov, A.V., Mikheeva, E.A., Arzhannikova, A.V., Frolov, A.O.,  
605 Arzhannikov, S.G., Bryanskiy, N.V., Pavlova, L.A., 2017. Early to Middle Jurassic  
606 history of the southern Siberian continent (Transbaikalia) recorded in sediments of the  
607 Siberian Craton: Sm-Nd and U-Pb provenance study. *BSGF-Earth Sciences Bulletin*  
608 188, 1-2, 8.
- 609 Decisions of the III Interdepartmental Regional Stratigraphic Conference on the Mesozoic and  
610 Cenozoic of Central Siberia, 1981. ISC USSR, Novosibirsk, 91 pp. (in Russian).
- 611 Didenko, A.N., Efimov, A.S., Nelyubov, P.A., Sal'nikov, A.S., Starosel'tsev, V.S., Shevchenko,  
612 B.F., Goroshko, M.V., Gur'yanov V.A., V.A., Zamozhnyaya, N.G., 2013. Structure and  
613 evolution of the Earth's crust in the region of junction of the Central Asian Fold Belt  
614 and the Siberian Platform: Skovorodino–Tommot profile. *Russian Geology and*  
615 *Geophysics* 54, 10, 1236–1249.
- 616 Donskaya, T.V., Gladkochub, D.P., Mazukabzov, A.M., Ivanov, A.V., 2013. Late Paleozoic-  
617 Mesozoic subduction-related magmatism at the southern margin of the Siberian

- 618 continent and the 150 million-year history of the Mongol-Okhotsk Ocean. *Journal of*  
619 *Asian Earth Sciences* 62, 79-97.
- 620 Donskaya, T.V., Gladkochub, D.P., Mazukabzov, A.M., Wang, T., Guo, L.,  
621 Rodionov, N.V., Demonterova, E.I., 2016. Mesozoic granitoids in the structure of the  
622 Bezymyanni metamorphic-core complex (western Transbaikalia). *Russian Geology*  
623 *and Geophysics* 57, 1591–1605.
- 624 Donskaya, V., Windley, B.F., Mazukabzov, A.M., Kröner, A., Sklyarov, E.V., Gladkochub,  
625 D.P., Ponomarchuk, V.A., Badarch, G., Reichow, M.K., Hegner, E., 2008. Age and  
626 evolution of late Mesozoic metamorphic core complexes in southern Siberia and  
627 northern Mongolia. *Journal of the Geological Society* 165, 405–421.
- 628 Egorkin, A.V., Chernikov, N.M., Danilova, Ye.G., Shcheglova, L.V., 1980. A regional profile  
629 across the northern Asian continent (in Russian). In: Zverev, S.M., Kosminskaya, I.P.  
630 (Eds.), *Seismic Models of the Lithosphere of Major Geological Units on the USSR*  
631 *Territory*. Nauka, Moscow, pp. 61–67.
- 632 Ershova, V.B., Prokopiev, A.V., Khudoley, A.K., 2015. Integrated provenance analysis of  
633 Carboniferous deposits from Northeastern Siberia: Implication for the Late Paleozoic  
634 history of the Arctic. *Journal of Asian Earth Sciences* 109, 38-49. doi:  
635 <http://dx.doi.org/10.1016/j.jseaes.2015.04.046>
- 636 Gordienko, I.V., 2001. Geodynamic evolution of the Central-Asian and Mongol-Okhotsk fold  
637 belts and formation of the endogenic deposits. *Geosciences Journal* 5, 3, 233-241.
- 638 Gordienko, I.V. and Klimuk, V.S., 1995. Bimodal volcanism of the Tugnuyskaya rift depression,  
639 Transbaikalia. *Geologiya i Geofizika (Russian Geology and Geophysics)* 36, 5, 23-37  
640 (in Russian).
- 641 Gordienko, I. V. and Kuz'min, M. I., 1999. Geodynamics and metallogeny of the Mongolo-  
642 Transbaikalian region. *Geologiya i Geofizika (Russian Geology and Geophysics)* 40,  
643 11, 1545-1562 (in Russian).

- 644 Gordienko, I.V., Klimuk, V.S., Ivanov, V.G. and Posokhov, V.F., 1997. New data on  
645 composition and age of bimodal volcanic series of the Tugnui riftogenic depression,  
646 Trans-Baikal Region. *Doklady Earth Sciences* 353, 2, 273-276.
- 647 Griffin, W.L., Powell, W.J., Pearson, N.J., O'Reilly, S.Y., 2008. In: Sylvester, P.J. (Ed.), *Laser*  
648 *Ablation ICP-MS in the Earth Sciences*. Mineralogical association of Canada short  
649 course series 40, 204–207.
- 650 Guan, Q.-B., Liu, Z.-H., Wang, B., Wang, X., Wang, X.-An., Shi, Q. Chen, Y.-S., 2018. Middle  
651 Jurassic–Early Cretaceous tectonic evolution of the Bayanhusuo area, southern Great  
652 Xing'an Range, NE China: constraints from zircon U–Pb geochronological and  
653 geochemical data of volcanic and subvolcanic rocks. *International Geology Review* 60,  
654 15, 1883-1905.
- 655 Halim, N., Kravchinsky, V., Gilder, S., et al., 1998. Palaeomagnetic study from the Mongol-  
656 Okhotsk region: rotated Early Cretaceous volcanics and remagnetized Mesozoic  
657 sediments. *Earth and Planetary Science Letters* 159, 133-145.
- 658 Ivanov, A.V., Demonterova, E.I., He, H.Y., Perepelov, A.B., Travin, A.V., Lebedev, V.A., 2015.  
659 Volcanism in the Baikal rift: 40 years of active-versus-passive model discussion. *Earth-*  
660 *Science Reviews* 148, 18-43. doi: 10.1016/j.earscirev.2015.05.011.
- 661 Ivanov, V.G., Yarmolyuk, V.V and Smirnov, V.N., 1995. New data on the age of volcanism  
662 evidence in West-Zabaikalian Late Mesozoic-Cenozoic volcanic domain. *Doklady*  
663 *Earth Sciences* 345, 5, 648-652 (in Russian).
- 664 Jackson, S.E., Pearson, N.J., Griffin, W.L. and Belousova, E.A., 2004. The application of laser  
665 ablation-inductively coupled plasma-mass spectrometry to in situ U–Pb zircon geochro-  
666 nology. *Chemical Geology* 211, 47-69.
- 667 Jolivet, M., Arzhannikov, S., Chauvet, A., Arzhannikova, A., Vassallo, R., Kulagina, N.,  
668 Akulova, V., 2013. Accomodating large-scale intracontinental extension and

- 669 compression in a single stress-field: A key example from the Baikal Rift System.  
670 Gondwana Research 24, 3-4, 918-935. Doi: 10.1016/j.gr.2012.07.017
- 671 Jolivet, M., De Boisgrollier, T., Petit, C., Fournier, M., Sankov, V.A., Ringenbach, J.-C., Byzov,  
672 L., Miroshnichenko, A.I., Kovalenko, S.N. & Anisimova, S.V., 2009. How old is the  
673 Baikal Rift Zone? Insight from apatite fission track thermochronology. *Tectonics* 28,  
674 Tc3008. Doi: 10.1029/2008tc002404.
- 675 Jolivet, M., Arzhannikova, A., Frolov, A., Arzhannikov, S., Kulagina, N., Akulova, V., Vassallo,  
676 R., 2017. Late Jurassic – Early Cretaceous paleoenvironment evolution of the  
677 Transbaikalian basins (SE Siberia): implications for the Mongol-Okhotsk orogeny. *BSGF-*  
678 *Earth Sciences Bulletin* 188, 1-2, 9. DOI: 10.1051/bsgf/2017010
- 679 Jolivet, M., Ritz, J.-F., Vassallo, R., Larroque, C., Braucher, R., Todbileg, M., Chauvet, A., Sue,  
680 C., Arnaud, N., De Vicente, R., Arzhannikova, A., Arzhannikov, S., 2007. Mongolian  
681 summits: An uplifted, flat, old but still preserved erosion surface. *Geology* 35, 10, 871–  
682 874.
- 683 Khubanov, V.B., Buyantuev, M.D. and Tsygankov, A.A., 2016. U-Pb dating of zircons from  
684 PZ(3)-MZ igneous complexes of Transbaikalia by sector-field mass spectrometry with  
685 laser sampling: technique and comparison with SHRIMP. *Russian Geology and*  
686 *Geophysics* 57, 1, 190-205.
- 687 Kolesnikov, Ch. M., 1961. Continental Mesozoic stratigraphy of the Buryat ASSR (West  
688 Transbaikalia). *Izvestiya Akademii Nauk SSSR, Seriya Geologicheskaya (Izvestiya of*  
689 *the Academy of Sciences of the U.S.S.R., Geological Series)* 4, 59-73 (in Russian).
- 690 Kolesnikov, Ch.K., 1964. Continental Mesozoic stratigraphy of Transbaikalia. In: Martinson, G.  
691 G. (Ed.), *Stratigraphy and paleontology of the Mesozoic and Cenozoic deposits in East*  
692 *Siberia and the Far East. Proceeding of the Limnologic Institute, Vol. 4.* Nauka,  
693 Moscow-Leningrad, pp. 5-138 (in Russian).

- 694 Komarov, Yu.V., Kiselev, A.I., Lyamina, N.A. Skoblo, V.M., 1965. Middle Jurassic effusive  
695 rocks of the Southwest Transbaikaliya. In: Afanasyev, G.D. and Belov, I.V. (Eds.),  
696 Petrography of East Siberia. Nauka, Moscow, pp. 295-314 (in Russian).
- 697 Kozhevnikov, V.M., Antonova, L.M., Yanovskaya, T.B., 1990. Horizontal inhomogeneity of the  
698 crust and upper mantle of the Asian continent, from Rg-wave data. *Fiz. Zemli* 3, 3–11  
699 (in Russian).
- 700 Kravchinsky, V.A., Cogné, J.P., Harbert, W.P., Kuzmin, M.I., 2002. Evolution of the Mongol–  
701 Okhotsk Ocean as constrained by new palaeomagnetic data from the Mongol–Okhotsk  
702 suture zone, Siberia. *Geophysical Journal International* 148, 34–57.
- 703 Kuzmin, M.I, and Kravchinsky, V.A., 1996. First paleomagnetic data for Mongol-Okhotsk fold  
704 belt. *Geologiya i Geofizika (Russian Geology and Geophysics)* 37, 1, 54-62 (in  
705 Russian).
- 706 Larroque, C., Ritz, J.F., Stéphan, J.F., Sankov, V., Arjannikova, A., Calais, E., Deverchere, J. et  
707 Loncke, L., 2001. Interaction compression-extension a la limite Mongolie-Siberie:  
708 analyse preliminaire des deformations recentes et actuelles dans le bassin de Tunka.  
709 *C.R. Acad.Sci. Paris, Sciences de la Terre et des planetes (Earth and Planetary sciences)*  
710 332, 177-184.
- 711 Leonov, Yu.G. (Ed.), 1983. Mesozoic tectonics and magmatism of East Asia (correlation  
712 between time of manifestation of tectonic movements and magmatism). Nauka,  
713 Moscow, 230 pp. (in Russian).
- 714 Logachev, N.A., 2003. History and geodynamics of the Baikal Rift. *Geologia i Geofizika*  
715 (Russian Geology and Geophysics) 44, 391-406 (in Russian).
- 716 Logachev, N. A., Antoshchenko-Olenev, I. V., Bazarov, D. B., Galkin, V. I., Goldyrev, G. S.,  
717 Endrikhinsky, A. S., Zolotarev, A. G., Sizikov, A. M. and Ufimtsev, G. F., 1974. The  
718 history of the relief formation in Siberia and the Far East. Uplands of Pribaikalia and  
719 Transbaikalia. Nauka, Moscow, 359 pp. (in Russian).

- Journal Pre-proof
- 720 Ludwig, K.R., 2003. User's Manual for Isoplot 3.00: A Geochronological Toolkit for Microsoft  
721 Excel. Berkeley Geochronology Center. Spec. Publ. 4, 74 p.
- 722 Martinson, G. G., 1955. On continental Mesozoic stratigraphy of Transbaikalia. Doklady Earth  
723 Sciences 105, 2, 355-338 (in Russian).
- 724 Martinson, G. G. (Ed.), 1988. Late Mesozoic and Cenozoic lake history. Nauka, Leningrad, 286  
725 pp. (in Russian).
- 726 Mazilov, V. N., Kashik, S. A. and Lomonosova, T. K., 1993. Oligocene sediments in the Tunka  
727 basin (Baikal rift zone). Geologiya i Geofizika (Russian Geology and Geophysics) 34,  
728 8, 81–88 (in Russian).
- 729 Mazukabzov, A. M. and Sizykh, V. I., 1987. Nappe slice structure of the Western Baykal Area.  
730 Geotectonics 21, 3, 265-268.
- 731 Metelkin, D.V., Vernikovskiy, V.A., Kazansky, A.Y., and Wingate, M.T.D., 2010. Late  
732 Mesozoic tectonics of Central Asia based on paleomagnetic evidence. Gondwana  
733 Research 18, 400-419.
- 734 Metelkin, D. V., Gordienko, I. V. and Klimuk, V. S., 2007. Paleomagnetism of Upper Jurassic  
735 basalts from Transbaikalia: new data on the time of closure of the Mongol-Okhotsk  
736 Ocean and Mesozoic intraplate tectonics of Central Asia. Russian Geology and  
737 Geophysics 48, 10, 825-834.
- 738 Metelkin, D. V., Gordienko, I. V. and Zhao, X., 2004. Paleomagnetism of Early Cretaceous  
739 volcanic rocks from Transbaikalia: argument for Mesozoic strike-slip motions in  
740 Central Asian structure. Russian Geology and Geophysics 45, 12, 1349-1363.
- 741 Mikheeva, E.A., Demonterova, E.I., Frolov, A.O., Arzhannikova, A.V., Arzhannikov, S.G.,  
742 Cherkashina, T.Yu., Ivanov, A.V., 2017. Provenance Change in the Irkutsk Coal Basin  
743 during the Early and Middle Jurassic: Geochemical and Sm-Nd Isotope Evidence.  
744 Stratigraphy and Geological Correlation 25, 4, 363–384.

- 745 Mikheeva, E. A., 2017. Age limits, correlation and source areas of the Jurassic sediments in the  
746 Irkutsk basin. Synopsis of the PhD thesis, IEC SB RAS, 16 pp. (in Russian).
- 747 Nie, S., 1991. Paleoclimatic and paleomagnetic constraints on the Paleozoic Reconstructions of  
748 south China, north China and Tarim. *Tectonophysics* 196, 279–308.
- 749 Nie, S., Rowley, D.B., Ziegler, A.M., 1990. Constraints on the location of Asian microcontinents  
750 in Paleo-Tethys during Late Palaeozoic. In: McKerrow, W.S., Scotese, C.R. (Eds.),  
751 Palaeozoic Palaeogeography and Biogeography. *Geol. Soc. Mem. Am.* 12, 12397–  
752 12409.
- 753 Novikov, V.A. (Ed.), 2005. Geological map 1:200 000, Selenga series, sheet M-48-XII.  
754 VSEGEI, St.-Peterburg.
- 755 Parfenov, L.M., Berzin, N.A., Khanchuk, A.I., Badarch, G., Belichenko, V.G., Bulgatov, A.N.,  
756 Dril', S.I., Kirillova, G.L., Kuzmin, M.I., Nockleberg, W., Prokopyev, A.V., Timofeev,  
757 V.F., Tomurtogoo, O. and Yan, X., 2003. A model for the formation of orogenic belts in  
758 Central and NE Asia. *Russian Journal of Pacific Geology* 22, 6, 7–41.
- 759 Parfenov, L.M., Popeko, L.I., Tomurtogoo, O., 2001. Problems of tectonics of the Mongol-  
760 Okhotsk orogenic belt. *Russian Journal of Pacific Geology* 16, 797–830.
- 761 Petit, C., Déverchère, J., 2006. Structure and evolution of the Baikal rift: A synthesis.  
762 *Geochemistry, Geophysics, Geosystems* 7, 11. doi: 10.1029/2006GC001265.
- 763 Prokopyev, A.V., Toro, J., Miller, E.L., Gehrels, G.E., 2008. The paleo-Lena River - 200 m.y. of  
764 transcontinental zircon transport in Siberia. *Geology* 36, 9, 699-702.
- 765 Puzyrev, N.N. (Ed.), 1981. The Interior of Baikal from Seismic Data. Nauka, Novosibirsk, 105  
766 pp. (in Russian).
- 767 Qi, X., & Wang, Z. (Eds.), 2008. Geological map of Central Asia and adjacent areas 1:2500000.  
768 Geological Publishing House, Beijing (in Chinese).
- 769 Ritz, J.-F., Arzhannikova, A., Vassallo, R., Arzhannikov, S., Larroque, C., Michelot,  
770 J.-L., & Massault, M., 2018. Characterizing the present-day activity of the Tunka and

- 771 Sayan faults within their relay zone (western Baikal rift system, Russia). *Tectonics* 37,  
772 5, 1376-1392.
- 773 Scotese, C.R., 1991. Jurassic and Cretaceous plate tectonic reconstruction. *Palaeogeography,*  
774 *Palaeoclimatology, Palaeoecology* 87, 493–501.
- 775 Sengör, A.M.C., Natal'in, B.A., 1996. Paleotectonics of Asia: fragments of a synthesis. In: Yin,  
776 A., Harrison, T.M. (Eds.), *The Tectonics of Asia*. Cambridge Univ. Press, New York,  
777 pp. 486–640.
- 778 Shchetnikov, A.A., 2017. Morphotectonic inversion in the Tunka rift basin (southwestern Baikal  
779 region). *Russian Geology and Geophysics* 58, 778–786.
- 780 Sherman, S.I., Medvedev, M.E., Ruzhich, V.V., Kiselev, A.I. and Shmotov, A.P., 1973.  
781 *Tectonics and volcanism of the southwestern Baikal rift zone*. Nauka, Novosibirsk, 135  
782 pp. (in Russian).
- 783 Shevchenko, B.F., Goroshko, M.V., Didenko, A.N., Gur'yanov, V.A., Starosel'tsev, V.S., &  
784 Sal'nikov, A.S., 2011. The junction of the eastern Central Asian Fold Belt and the  
785 Siberian Platform: deep structure and Mesozoic tectonics and geodynamics. *Russian*  
786 *Geology and Geophysics* 52, 12, 1672–1679. doi:10.1016/j.rgg.2011.11.008
- 787 Sizykh, V.I., 2001. *Overthrust-thrust tectonics of the margins of ancient platforms*. Publishing  
788 house of SB RAS, Branch “Geo”, Novosibirsk, 153 pp. (in Russian).
- 789 Sklyarov, E.V., Mazukabzov, A.M. & Mel'nikov, A.I. 1997. *Metamorphic core complexes of the*  
790 *Cordilleran type*. SPC UIGGM Siberian Branch of the RAS, Novosibirsk, 176 p. (in  
791 Russian).
- 792 Sklyarov, E.V., Mazukabzov, A.M., Donskaya, T.V., Doronina, N.A. & Shafeev, A.A., 1994.  
793 *Metamorphic core complexes of the Zagan Range (Transbaikalia)*. *Doklady Earth*  
794 *Sciences* 339, 83–86.



- 795 Skoblo, V. M., Lyamina, N. A., Rudnev, A. F. and Luzina, I. V., 2001. Continental upper  
796 Mesozoic of Pribaikalia and Transbaikalia (stratigraphy, sedimentation conditions,  
797 correlations). Izd-vo SB RAS, Novosibirsk, 332 pp. (in Russian).
- 798 Sláma, J., Košler, J., Condon, D.J., Crowley, J.L., Gerdes, A., Hanchar, J.M., Horstwood,  
799 M.S.A., Morris, G.A., Nasdala, L., Norberg, N., Schaltegger, U., Schoene, B., Tubrett,  
800 M.N., Whitehouse, M.J., 2008. Plesovice zircon - A new natural reference material for  
801 U-Pb and Hf isotopic microanalysis. *Chem. Geol.* 249, 1–35.
- 802 Stepanov, P.P., Volkhonin, V.S., 1969. Present framework and deep structure of the crust in  
803 Mongolia, from geophysical evidence. *Sov. Geol.* 5, 47–63 (in Russian).
- 804 Suvorov, V.D., Mishenkina, Z.M., Petrick, G.V., Sheludko, I.F., Seleznev, V.S. Solovyov, V.M.,  
805 2002. Structure of the crust in the Baikal Rift Zone and adjacent areas from Deep Seismic  
806 Sounding data. *Tectonophysics* 351, 61-74.
- 807 Tomurtogoo, O., Windley, B.F., Kroner, A., Badarch, G., and Liu, D.Y., 2005. Zircon age and  
808 occurrence of the Adaatsag ophiolite and Muron shear zone, central Mongolia:  
809 Constraints on the evolution of the Mongol-Okhotsk ocean, suture and orogeny. *Journal*  
810 *of the Geological Society* 162, 197–229.
- 811 Van Der Beek, P., Delvaux, D., Andriessen, P.A.M. & Levi, K.G., 1996. Early Cretaceous  
812 denudation related to convergent tectonics in the Baikal Region, SE Siberia. *Journal of*  
813 *the Geological Society of London* 153, 515-523.
- 814 Van der Voo, R., van Hinsbergen, D.J.J., Domeier, M., Spakman, W., and Torsvik, T.H., 2015.  
815 Latest Jurassic–earliest Cretaceous closure of the Mongol-Okhotsk Ocean: A  
816 paleomagnetic and seismological-tomographic analysis. In Anderson, T.H., Didenko,  
817 A.N., Johnson, C.L., Khanchuk, A.I., and MacDonald, J.H., Jr. (Eds.), *Late Jurassic*  
818 *Margin of Laurasia - A Record of Faulting Accommodating Plate Rotation*. Geological  
819 Society of America Special Paper 513, 1–18. doi:10.1130/2015.2513(19).

- 820 Vassallo, R., Ritz, J-F., Braucher, R., Jolivet, M., Carretier, S., Larroque, C., Chauvet, A., Sue,  
821 C., Todbileg, M., Bourles, D., Arzhannikova A., and Arzhannikov S., 2007.  
822 Transpressional tectonics and stream terraces of the Gobi-Altay, Mongolia. *Tectonics*  
823 26, TC5013, 1-24. doi: 10.1029/2006TC002081.
- 824 Vinnik, L.P., Oreshin, S.I., Tsydypova, L.R., Mordvinova, V.V., Kobelev, M.M., Khritova,  
825 M.A., Tubanov, T.A., 2017. Crust and mantle of the Baikal rift zone from P- and S-  
826 wave receiver functions. *Geodynamics&Tectonophysics* 8, 695-709. Doi: 10.5800/GT-  
827 2017-8-4-0313.
- 828 Wang, T., Guo, L., Zhang, L., Yang, Q., Zhang, J., Tong, Y., Ye, K., 2015. Timing and evolution  
829 of Jurassic-Cretaceous granitoid magmatisms in the Mongol-Okhotsk belt and adjacent  
830 areas, NE Asia: Implications for transition from contractional crustal thickening to  
831 extensional thinning and geodynamic settings. *J. Asian Earth Sci.* 97, 365-392.
- 832 Wang, T., Guo, L., Zheng, Y., Donskaya, T., Gladkochub, D., Zeng, L., Li, J., Wang, Y.,  
833 Mazukabzov, A., 2012. Timing and processes of late Mesozoic mid-lower-crustal  
834 extension in continental NE Asia and implications for the tectonic setting of the  
835 destruction of the North China Craton: Mainly constrained by zircon U-Pb ages from  
836 metamorphic core complexes. *Lithos* 154, 315-345.
- 837 Wang, T., Zheng, Y.D., Zhang, J.J., Zeng, L.S., Donskaya, T.V., Guo, L., Li, J.B., 2011. Pattern  
838 and kinematic polarity of late Mesozoic extension in continental NE Asia: perspectives  
839 from metamorphic core complexes. *Tectonics* 30, TC6007. [http://dx.doi.org/  
840 10.1029/2011TC002896](http://dx.doi.org/10.1029/2011TC002896).
- 841 Wiedenbeck, M., Allé, P., Corfu, F., Griffin, W.L., Meier, M., Oberli, F., van Quadt, A.,  
842 Roddick, J.C., Spiegel, W., 1995. Three natural zircon standards for U-Th-Pb, Lu-Hf,  
843 trace element and REE analyses. *Geostandards Newsletter* 19, 1–23.
- 844 Yang, W., Jolivet M., Dupont-Nivet G., Guo Z., Zhang Z., and Zhang Z., 2013, Source to sink  
845 relations between the Tian Shan and Junggar Basin (northwest China) from Late

- 846 Palaeozoic to Quaternary: evidence from detrital U-Pb zircon geochronology. *Basin*  
847 *Research* 25, 219-240.
- 848 Yang, Y.-T., Guo, Z.-X., Song, C.-C., Li, X.-B., He, S., 2015. A short-lived but significant  
849 Mongol – Okhotsk collisional orogeny in latest Jurassic – earliest Cretaceous.  
850 *Gondwana Research* 28, 1096-1116.
- 851 Yarmolyuk, V.V., Kovalenko, V.I., Sal'nikova, E.B., Budnikov, S.V., Kovach, V.P., Kotov,  
852 A.B., Ponomarchuk, V.A., 2002. Tectono-magmatic zoning, magma sources, and  
853 geodynamic of the Early Mesozoic Mongolia–Transbaikal province. *Geotectonics* 36, 4,  
854 293–311.
- 855 Yarmolyuk, V. V., Kozlovsky, A. M., Savatenkov, V.M., Kovach, V.P., Kozakov, I.K., Kotov,  
856 A.B., Lebedev, V.I. and Eenjin, G., 2016. Composition, Sources, and Geodynamic  
857 Nature of Giant Batholiths in Central Asia: Evidence from the Geochemistry and Nd  
858 Isotopic Characteristics of Granitoids in the Khangai Zonal Magmatic Area. *Petrology*  
859 24, 5, 433–461.
- 860 Yin, A., and Nie, S., 1996. A Phanerozoic plinstatic reconstruction of China and its neighbouring  
861 regions. In: Yin, A and Harrison, T.M. (Eds.), *The tectonic evolution of Asia*. Cambridge  
862 University Press, Cambridge, pp. 442-485.
- 863 Yin, A., and Nie, S., 1993. An indentation model for North and South China collision and the  
864 development of the Tan Lu and Honam fault systems, eastern Asia. *Tectonics* 12, 801–  
865 813.
- 866 Zhao, X., Coe, R.S., Zhou, Y.X., Wu, H.R., Wang, J., 1990. New palaeomagnetic results from  
867 northern China: collision and suturing with Siberia and Kazakhstan. *Tectonophysics*  
868 181, 43–81.
- 869 Zheng, Y., Wang, S. & Wang, Y., 1991. An enormous thrust nappe and extensional metamorphic  
870 core complex in Sino-Mongolian boundary area. *Science in China, ser. B*, 34, 1145-  
871 1152.

- 872 Zonenshain, L.P., Kuzmin, M.I. & Natapov, L.M., 1990. Geology of the USSR:  
873 A Plate Tectonic Synthesis. American Geophysical Union, Geodynamics Series, 21, 242  
874 pp.
- 875 Zorin, Y.A., Belichenko, V.G., Turutanov, E.K., Kozhevnikov, V.M., Ruzhentsev, S.V.,  
876 Dergunov, A.B., Filippova, I.B., Tomurtogoo, O., Arvisbaatar, N., Bayasgalan, T.,  
877 Biambaa, C., Khosbayar, P., 1993. The Siberia–Central Mongolia transect.  
878 *Tectonophysics* 225, 361–378.
- 879 Zorin, Y.A., Belichenko, V.G., Turutanov, E.K., Mordvinova, V.V., Khosbayar, P., Tomurtogoo,  
880 O., Arvisbaatar, N., Gao, S., Davis, P., 1994. The Baikal–Mongolia transect. *Russian*  
881 *Geol. Geophys.* 7–8, 94–110.
- 882 Zorin, Y.A., Novoselova, M.R., Turutanov, E.K., Kozhevnikov, V.M., 1990. Structure of the  
883 lithosphere in the Mongolia–Siberian mountainous province. *J. Geodyn.* 11, 327–342.
- 884 Zorin, Yu.A. 1999. Geodynamics of the western part of the Mongolia–Okhotsk  
885 collisional belt, Trans-Baikal region (Russia) and Mongolia. *Tectonophysics* 306, 33–  
886 56.
- 887 Zorin, Yu.A., 1971. Recent Structure and Isostasy in the Baikal rift Zone and Adjacent  
888 Territories. Nauka, Moscow, 167 pp. (in Russian).
- 889 Zorin, Yu.A., Belichenko, V.G., Turutanov, E.Kh., Kozhevnikov, V.M., Sklyarov, E.V.,  
890 Tomurtogoo, O., Khosbayar, P., Arvisbaatar, N. and Byambaa, Ch., 1998. Terranes in  
891 East Mongolia and Central Transbaikalia and evolution of the Okhotsk-Mongolian fold  
892 belt. *Russian Geology and Geophysics* 39, 1, 11-25.
- 893 Zorin, Yu.A., Sklyarov, E.V., Mazukabzov, A.M. & Belichenko, V.G. 1997.  
894 Metamorphic core complexes and Early Cretaceous rifting in the Trans-Baikal region.  
895 *Russian Geology and Geophysics* 38, 1574–1584.

896

897 **Figure captions**

898 Fig. 1. (A) Location of Transbaikalia on the map of Asia; (B) geological setting of Transbaikalia  
899 and adjacent areas (Qi and Wang, 2008; Jolivet et al., 2013; Yarmolyuk et al., 2016). 1–  
900 Siberian craton, 2–Lakes, 3–Jurassic basins (TGB–Tugny Basin), 4–Cretaceous basins,  
901 5–Cenozoic basins (TNB–Tunka Basin), 6–Cretaceous and Tertiary volcanic fields, 7–  
902 Metamorphic core complexes, 8–Granitoid batholiths, 9–Mongol-Okhotsk suture zone  
903 (M-O S), 10–Angara thrust location, 11–Main Cenozoic faults.

904 Fig. 2. Lithology of the Jurassic deposits of the Irkutsk Basin (after Mikheeva et al., 2017).

905 Fig. 3. (A) Simplified geological map of the Tugny Basin and surrounding area (after Novikov,  
906 2005; Jolivet et al., 2017); (B,C) Triassic–Jurassic stratigraphic section in the Tugny  
907 Basin: B–after Novikov (2005), C–after Skoblo et al. (2001).

908 Fig. 4. Distribution of the Late Paleozoic–Early Mesozoic granitoid batholiths and volcano-  
909 plutonic belts of Transbaikalia (Russia) and northern and central Mongolia. The figure  
910 is modified after (Donskaya et al., 2013) with data from (Zorin, 1999; Parfenov et al.,  
911 2001; Yarmolyuk et al., 2002; Demonterova et al., 2017).

912 Fig. 5. Crustal thickness of East Siberia and Mongolia (modified after Zorin, 1999).

913 Fig. 6. (A) Berezovskaya sedimentary section. Red triangle–U-Pb Zircon sample; (B) photo of  
914 conglomerates; (C) photo of deformed conglomerates with offset of several meters (the  
915 rupture is shown by yellow triangles).

916 Fig. 7 The folded coal-bearing strata of the Tugnyuskaya Fm. exposed in the Tugny coal mine,  
917 overlain by the undeformed Galgatayskaya Fm. deposits. The yellow triangles indicate  
918 the unconformity between the two formations.

919 Fig. 8. (A) Sedimentary section of Tugnyuskaya Fm. in sampling site. Red triangle–U-Pb Zircon  
920 sample; (B) photo of the logged section.

921 Fig. 9. (A) Sedimentary section of Galgatayskaya and Tugnyuskaya Fms. in their contact zone.  
922 Red triangle–U-Pb Zircon sample; (B) photo of the cross-section. The yellow triangles  
923 indicate the unconformity between the two formations.

924 Fig. 10. Histograms coupled with probability density plot (black curve) and U-Pb concordia  
925 diagrams for zircons from the (A) Berezovskaya, (B) Tugnuyskaya and (C)  
926 Galgatayskaya Fms, n–number of data.

927 Fig. 11. BSE images of some representative igneous zircons from the Berezovskaya,  
928 Tugnuyskaya and Galgatayskaya Fms. The white circles indicate the locations of the  
929 laser ablation spots.

930 Fig. 12. Schematic paleogeographic reconstruction of Transbaikalia and North Mongolia during  
931 the Early Jurassic–Early Cretaceous. (A) Onset of sediment deposition in the Irkutsk  
932 Basin (~194 Ma). (B) Final period of deposition in the Irkutsk Basin (~178 Ma); the  
933 compressive stress field was caused by the Mongol-Okhotsk collision. (C)  
934 “Ichetuyskaya/Berezovskaya” period (~168–145 Ma). onset of continental rifting. (D)  
935 “Tugnuyskaya tectonically quiet period (during or after the Tithonian). (E) Erosional  
936 phase in Western Transbaikalia (latest Jurassic–earliest Cretaceous) related to a short-  
937 term collision event (Yang et al., 2015). (F) “Galgatayskaya” period (Early Cretaceous),  
938 increasing of basin subsidence. (G) “Metamorphic core complexes” period (Early  
939 Cretaceous).

940

941 **Supplementary Items:**

942 Sample Tug-14-2. Results of U–Pb isotope studies of detrital zircons from sediments of the  
943 Galgatayskaya Fm., the Tugnuy Basin, western Transbaikalia.

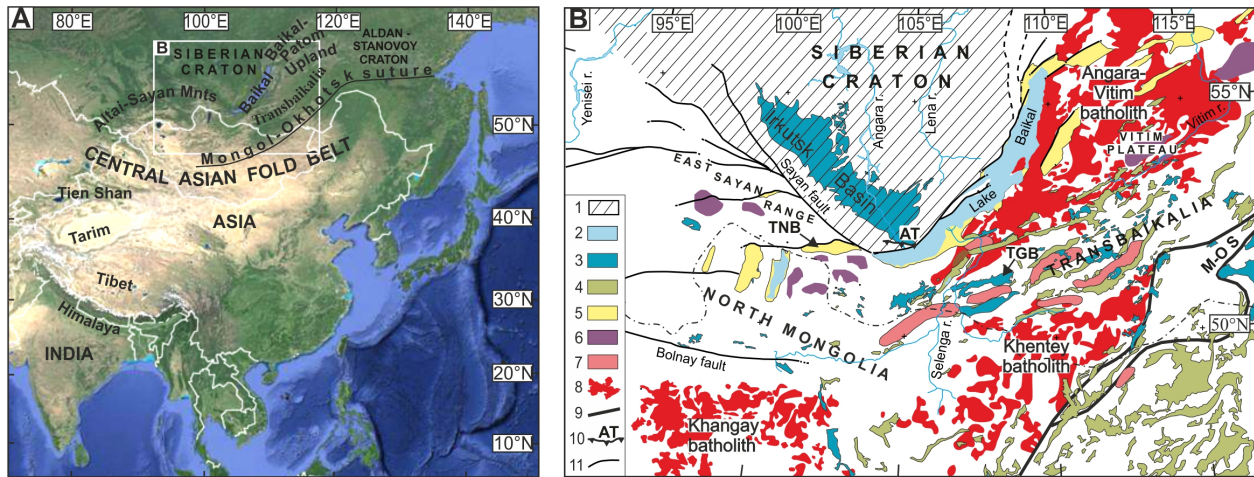
944 Sample Tug-14-3. Results of U–Pb isotope studies of detrital zircons from sediments of the  
945 Tugnuyskaya Fm., the Tugnuy Basin, western Transbaikalia.

946 Sample Tug-17-8. Results of U–Pb isotope studies of detrital zircons from sediments of the  
947 Berezovskaya Fm., the Tugnuy Basin, western Transbaikalia.

Formation	Index	Lithology	Thickness (m)
Kuda	J <sub>2</sub> kd <sub>2</sub>		20-70
	J <sub>2</sub> kd <sub>1</sub>		40-75
Prisayan	J <sub>2</sub> ps <sub>2</sub>		55-120
	J <sub>1</sub> ps <sub>1</sub>		55-100
Cheremkhovo	J <sub>1</sub> čr <sub>3</sub>		25-130
	J <sub>1</sub> čr <sub>2</sub>		20-145
	J <sub>1</sub> čr <sub>1</sub>		10-160

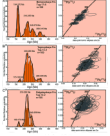
- tuff  
 coal deposits  
 calcareous sediments  
 mudstone  
 siltstone  
 sandstone  
 gravelstone  
 conglomerate



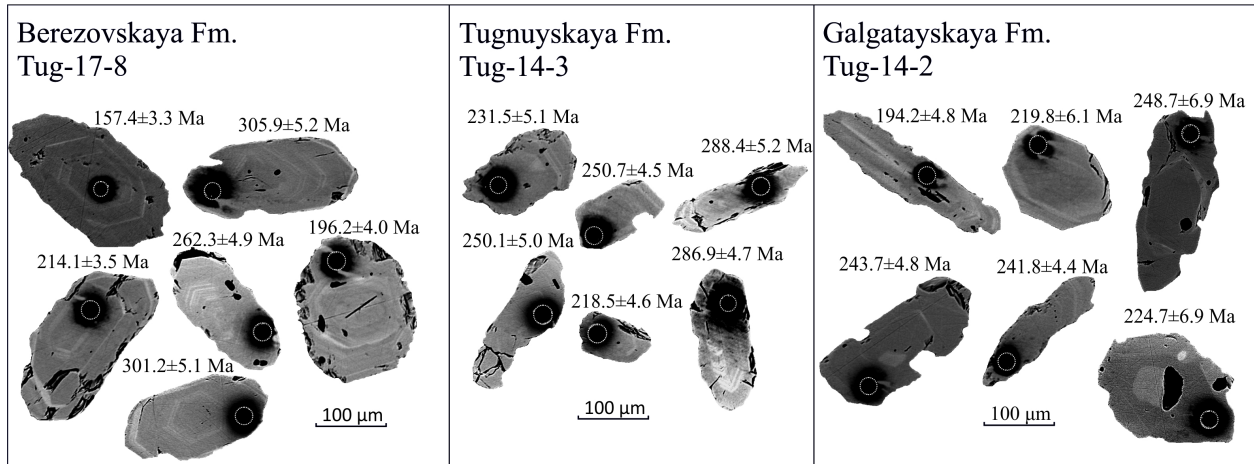


Arzhannikova et al., Fig. 1.

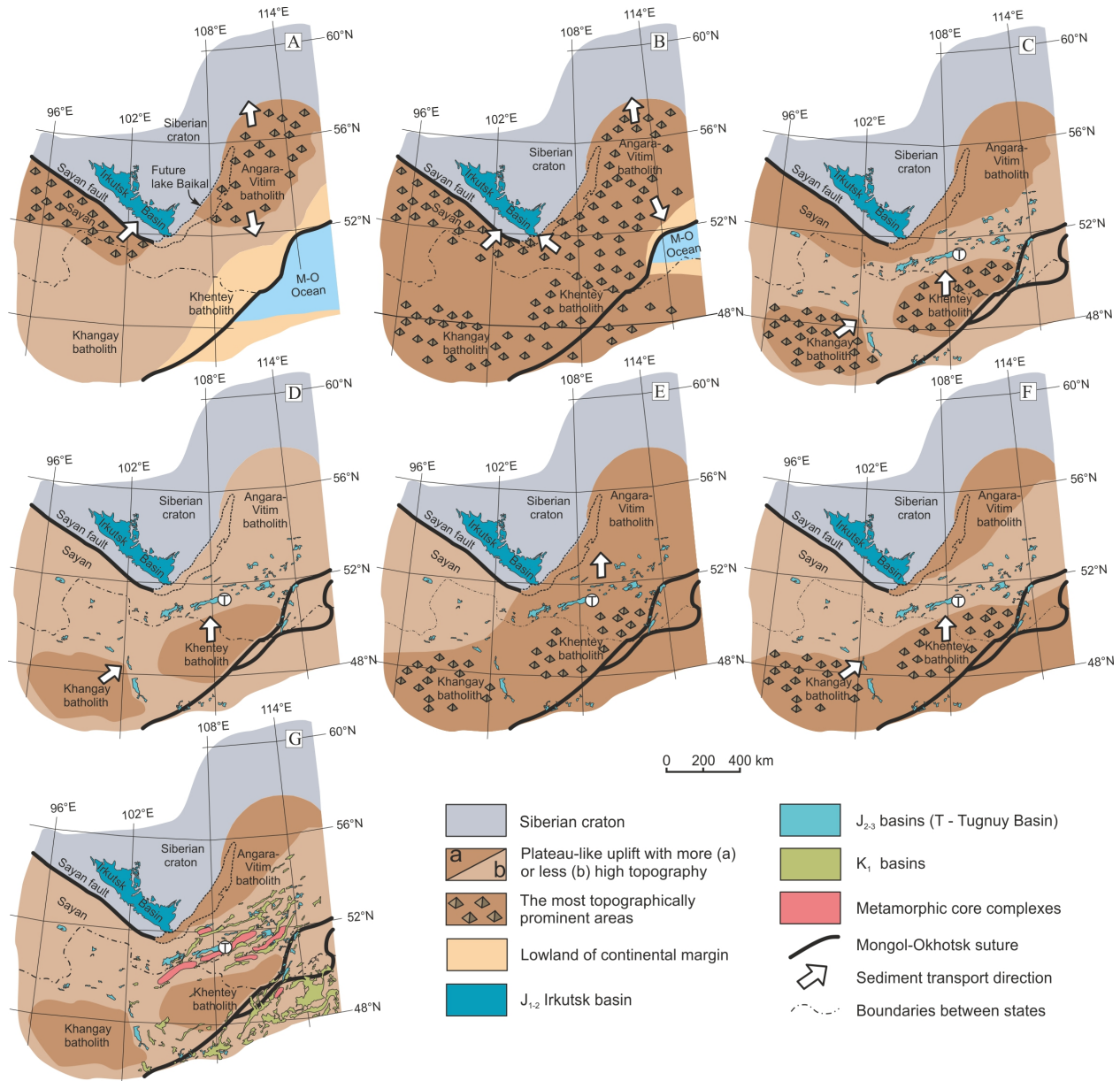




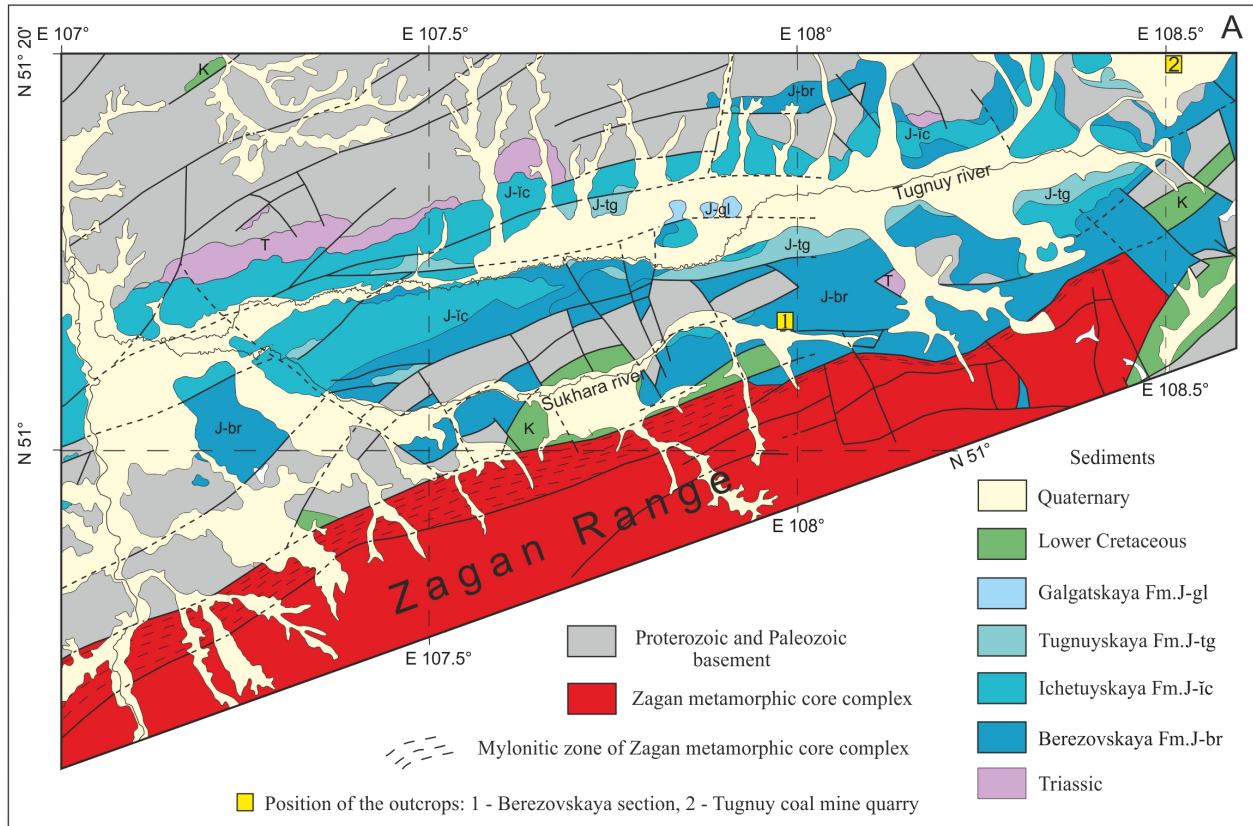
Journal Pre-proof



Arzhannikova et al., Fig. 11.



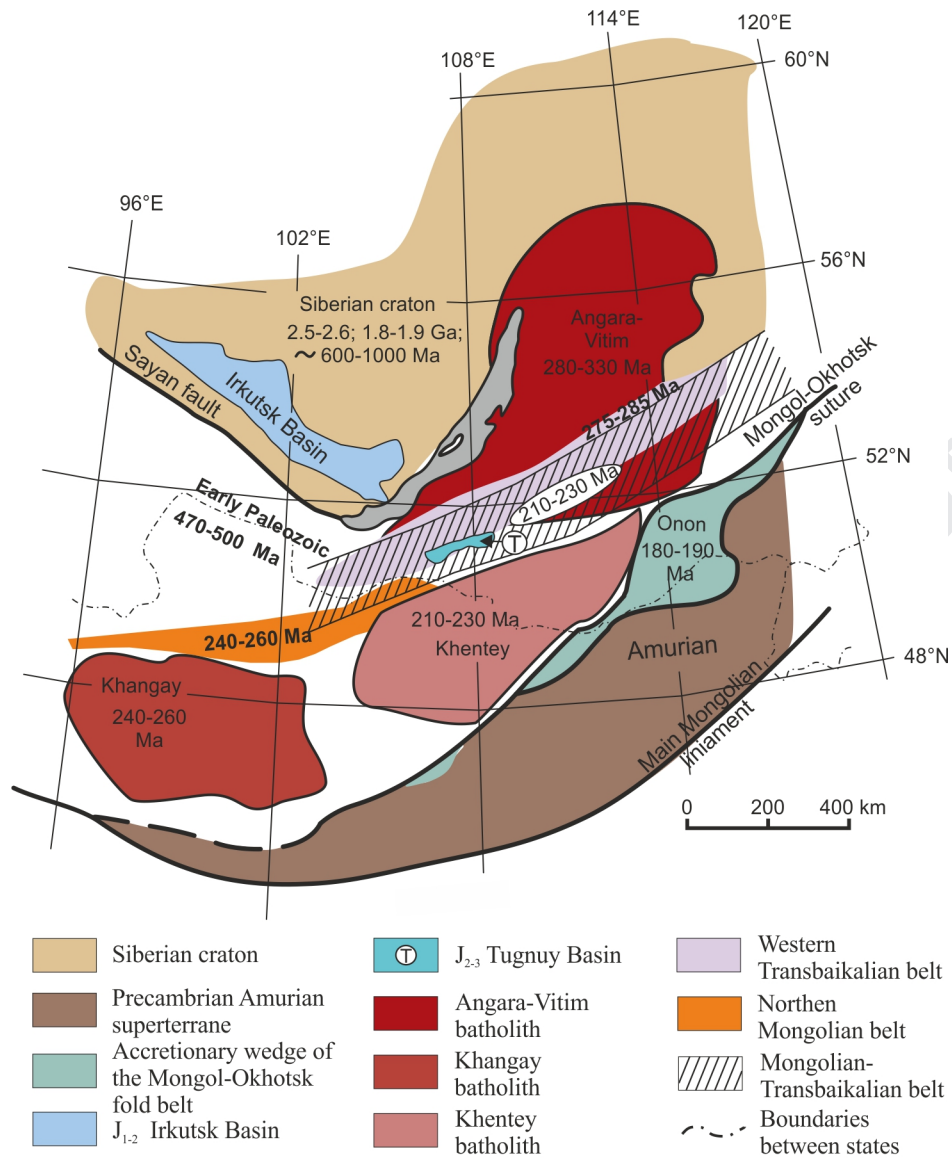
Arzhannikova et al., Fig. 12.



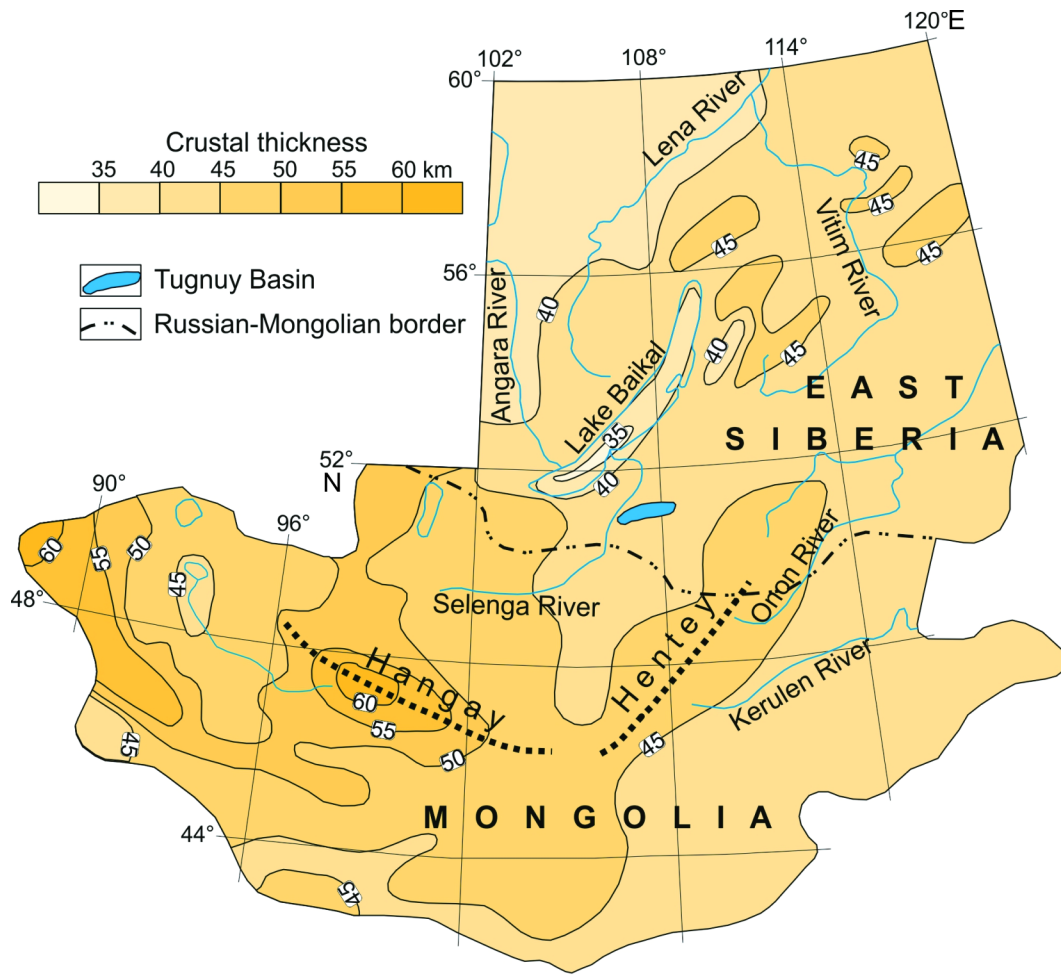
System	Series	Symbol	Lithology	Thic. (m)	Formation
JURASSIC	UPPER	J <sub>1</sub> gl		0-360	Galgatskaya Formation. Conglomerates, gravelites, sandstones, siltstone interlayers containing <i>Turgniscus reissi</i> Jakov., <i>Timiriasevia galgataica</i> Scob., <i>Sphaerostheria</i> sp. Pollen grains – <i>Classopolis</i> sp., and others.
	MIDDLE	J <sub>1</sub> tg		150-240	Tugnuykaya Formation. Rhythmical alternation of sandstones, siltstones, less often conglomerates, argillites and coal beds. Fauna – <i>Subcardinia sibirensis</i> , <i>S. jenisseica</i> , <i>S. lankoviensis</i> , <i>Timiriasevia tugnuica</i> , <i>Pseudestheria galgataica</i> ; flora – <i>Cladophlebis sulcutensis</i> , <i>Raphaelia diamensis</i> , <i>Thinnfeldia</i> sp., <i>Czeranowskia rigida</i>
	LOWER-MIDDLE	J <sub>1-2</sub> ic		>1000	Ichetuyskaya Formation. At the base - ignimbrites, caked tuffs, clastolavas of trachyrhyodacites and trachydacites, horizons of volcanic glasses, conglomerates, sandstones and siltstones. Upper - trachybasalts, basaltic trachyandesites, less often trachyandezites, trachytes and their tuffs, interlayered with conglomerates, sandstones and siltstones. Insects – <i>Mesolectroides</i> - <i>Dinosamarura</i> ; flora – <i>Heilungia iczetujensis</i> Vachr. et Srebr.
	LOWER	J <sub>1</sub> br		150-1890	Berezovskaya Formation. Conglomerates, sandstones, siltstones, less often argillite interlayers. Flora – <i>Czeranowskia rigida</i> Heer; spores – <i>Cyathidites</i> - <i>Leiotriletes</i> , <i>Osmundacidites</i> , <i>Stereis-porites</i> sp.; pollen grains – <i>Ginkgo</i> sp., <i>Pseudopicea variabiliformis</i> (Mai.) Bolch., <i>P. rotundiformis</i> (Mai.) Bolch., <i>Classopolis</i> sp., and others.
TRIASSIC	MIDDLE-UPPER	T <sub>2-3</sub> cb		1000-1070	Chernoyarovskaya Formation. Trachybasalts, basaltic trachyandesites, tuff conglomerates, tuff sandstones and tuff siltstones with fossils: <i>Cladophlebis</i> sp. (aff. <i>Kirjamkensis</i> Prun.), <i>C. sp.</i> (cf. <i>Lobifolia taymurensis</i> Mogutch.), <i>Yuccites</i> sp., <i>Carpolithes cf. cinitus</i> Natch.

System	Series	Stage	Formation
JURASSIC	UPPER	Tithonian	Galgatskaya
		Kimmeridgian	
		Oxfordian	
	MIDDLE	Callovian	Tugnuykaya
		Bathonian	
		Bajocian	
		Aalenian	
	LOWER	Toarcian	Ichetuyskaya / Sagannurskaya
Pliensbachian		Hettangian	
Sinemurian			

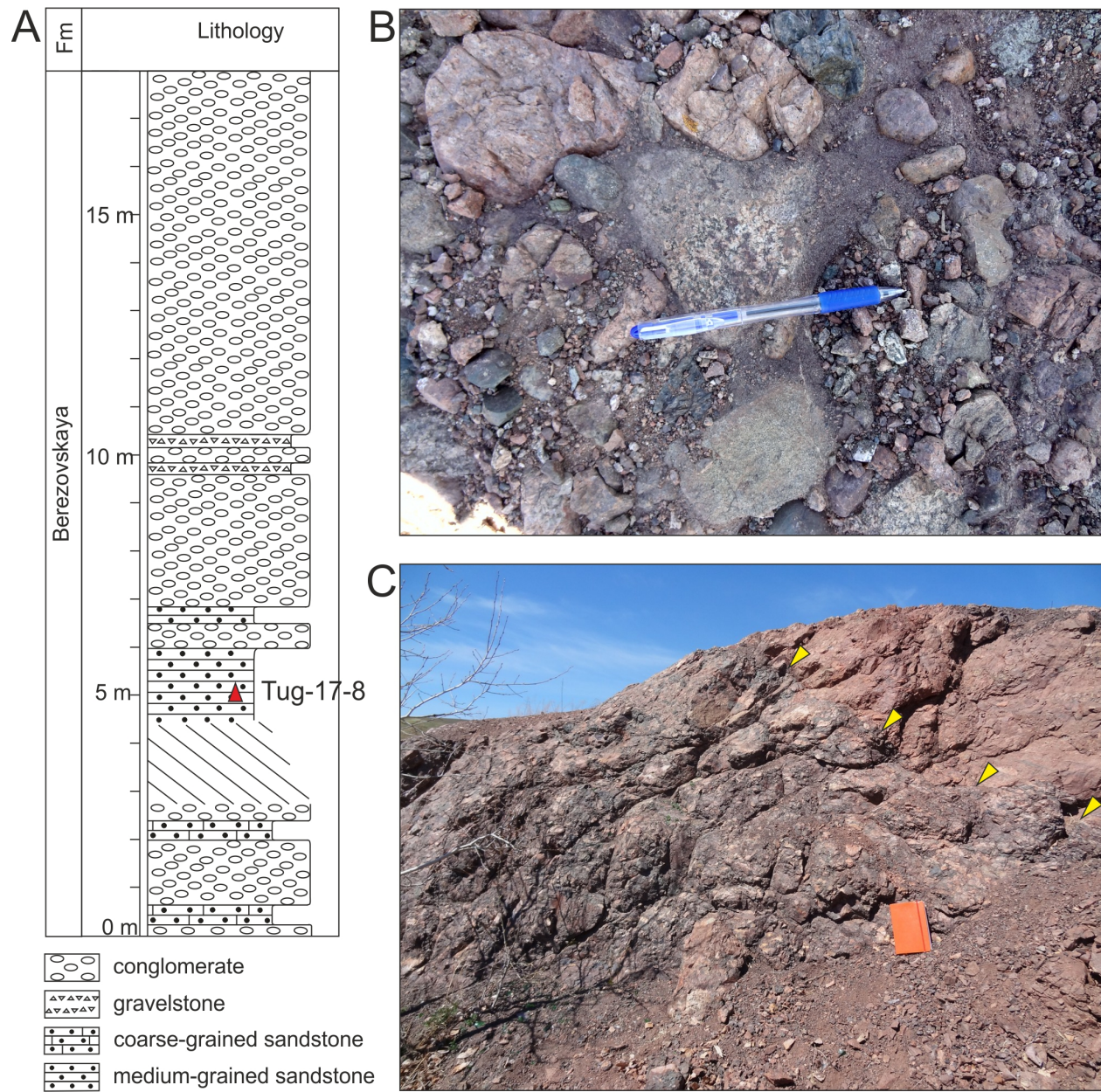
Arzhannikova et al., Fig. 3.



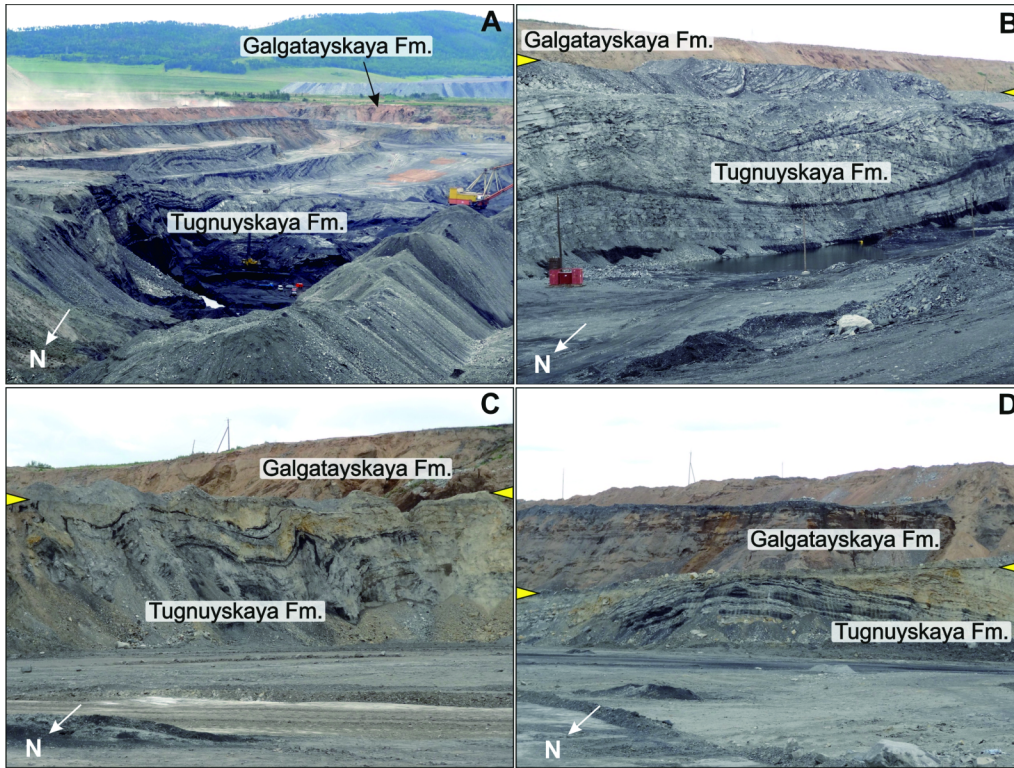
Arzhannikova et al., Fig. 4.



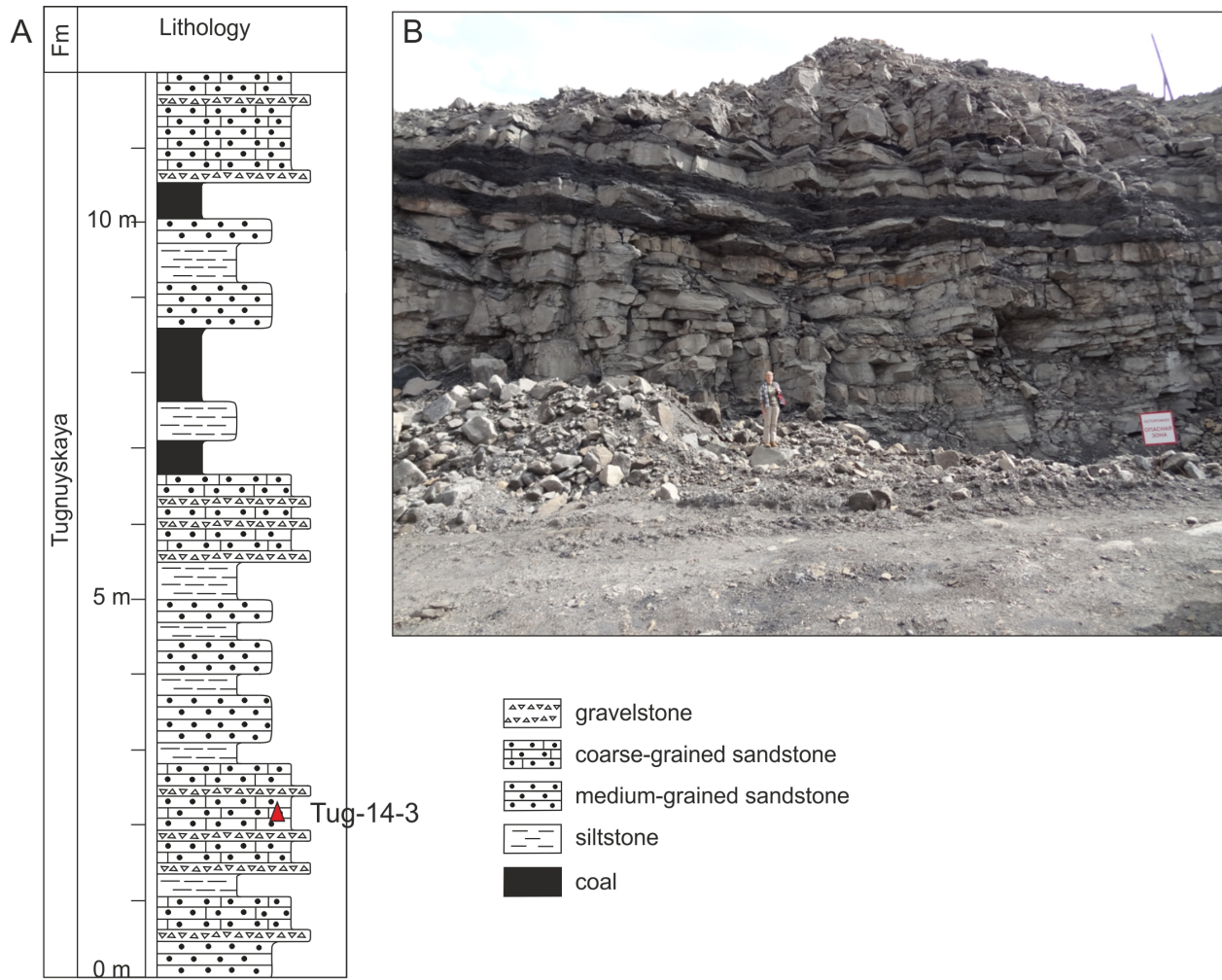




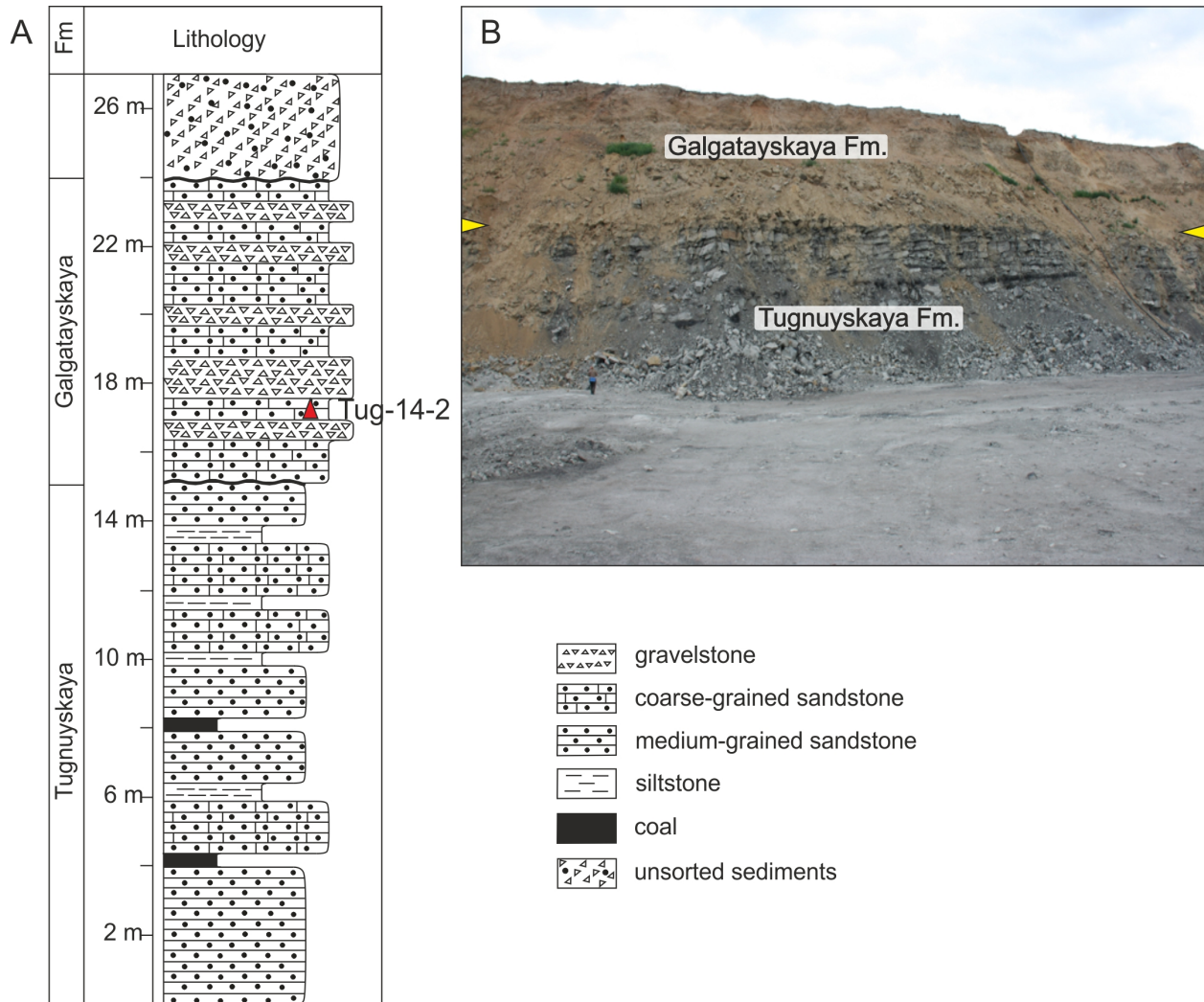
Arzhannikova et al., Fig. 6.







Arzhannikova et al., Fig. 8.



Arzhannikova et al., Fig. 9.

**Research highlights**

- Topographic evolution of Transbaikalia controlled by the Mongol–Okhotsk collision
- Changes in tectonic regime in Transbaikalia occurred between 180 Ma and 110 Ma
- U–Pb dating of detrital zircons shows inversion of the drainage system

Journal Pre-proof

**Declaration of interests**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: