



THE UNIVERSITY *of* EDINBURGH

Edinburgh Research Explorer

Reassessment of the enigmatic Late Cretaceous theropod dinosaur, *Bagaraatan ostromi*

Citation for published version:

Słowiak-Morkovina, J, Brusatte, S & Szczygielski, T 2024, 'Reassessment of the enigmatic Late Cretaceous theropod dinosaur, *Bagaraatan ostromi*', *Zoological Journal of the Linnean Society*.
<https://doi.org/10.1093/zoolinnean/zlad169>

Digital Object Identifier (DOI):

[10.1093/zoolinnean/zlad169](https://doi.org/10.1093/zoolinnean/zlad169)

Link:

[Link to publication record in Edinburgh Research Explorer](#)

Document Version:

Peer reviewed version

Published In:

Zoological Journal of the Linnean Society

General rights

Copyright for the publications made accessible via the Edinburgh Research Explorer is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy

The University of Edinburgh has made every reasonable effort to ensure that Edinburgh Research Explorer content complies with UK legislation. If you believe that the public display of this file breaches copyright please contact openaccess@ed.ac.uk providing details, and we will remove access to the work immediately and investigate your claim.



1 **Reassessment of the enigmatic Late Cretaceous theropod**
2 **dinosaur, *Bagaraatan ostromi*.**

3
4 Justyna Słowiak-Morkovina^{1*}, Stephen L. Brusatte², Tomasz Szczygielski¹

5
6 ¹ Institute of Paleobiology, Polish Academy of Sciences, Warsaw, Poland.

7 ² School of GeoSciences, University of Edinburgh, Edinburgh, United Kingdom.

8
9 * Corresponding author: Justyna Słowiak-Morkovina¹

10 Twarda 51/55, Warsaw, 00-818, Poland

11 Email address: justyna.slowiak@twarda.pan.pl

12
13 Short running title: Reassessment of *Bagaraatan ostromi*.

14
15 **FUNDING**

16 This work was supported by the National Science Centre, Poland, grant no. 2019/35/B/NZ8/02292.
17 SLB's work on Nemegt theropods stems from his PhD at Columbia University and the American
18 Museum of Natural History, supervised by Mark Norell, whom he thanks for his friendship and
19 mentorship over the years. SLB was supported by a National Science Foundation Graduation
20 Research Fellowship, National Science Foundation Doctoral Dissertation Improvement Grant
21 (DEB 1110357), Columbia University, and American Museum of Natural History.

22
23 **AUTHORS' CONTRIBUTIONS**

24 JSM conceived the study, wrote the initial manuscript, prepared the 3D models and figures; SLB
25 performed the phylogenetics analyses, revised the manuscript; TS helped in the taxonomical
26 interpretation of the data, photographed the specimens, revised the manuscript. All authors
27 discussed the results and contributed to the final manuscript.

28
29 **ACKNOWLEDGEMENTS**

30 The presented material was collected during the Polish-Mongolian Paleontological Expeditions
31 organized by the Mongolian and Polish academies of sciences in the late 1960s and early 1970s.
32 This research was possible thanks to the work of all members of the expeditions, whom we would
33 like to acknowledge. We are grateful to Khishigjav Tsogtbaatar for the possibility to work on the
34 *Tarbosaurus* material housed in the Institute of Paleontology of the Mongolian Academy of
35 Sciences. JSM thanks Sanjaadash Ulziitseren, Damidansuren Idersaikhan, Zorig Enkhtaivan,
36 Chagnaadorj Bayardorj, and Bat-Erdene Erdenekhuyag for all their help during the research visit.
37 The manuscript benefited from input by Greg Funston and one anonymous reviewer. We thank
38 the Editor for processing the manuscript. We would like to thank Krzysztof Owocki for sharing
39 the thin section taken from the femur of ZPAL MgD-I/108 and Katarzyna Przestrzelska for the
40 accurate preparation of the caenagnathid vertebra. We also thank Boris Morkovin and Andrey

41 Podlesnov for sharing the photographs of *Avimimus portentosus* PIN 3907/1 and 3907/6. SLB
42 thanks Peter Makovicky for the discussion on *Bagaraatan* while doing his PhD work, and
43 acknowledges that he also independently came to the conclusion that the material represented a
44 chimera of multiple theropods. SLB also thanks Grzegorz Niedźwiedzki, Tomasz Sulej, Jerzy
45 Dzik, Magdalena Borsuk-Białynicka, and Zofia Kielan-Jaworowska for hosting him at the ZPAL
46 collections over the years, and for their friendship and hospitality. We thank Jakub Zalewski, who
47 prepared the life reconstruction of *Bagaraatan ostromi*.

48

49

50

51 **Reassessment of the enigmatic Late Cretaceous theropod**
52 **dinosaur, *Bagaraatan ostromi*.**
53

54 **ABSTRACT**

55 The Late Cretaceous *Bagaraatan ostromi*, described by Osmólska in 1996, is one of the most
56 enigmatic theropod dinosaurs. The holotype possesses a peculiar combination of features, which
57 Osmólska suggested were indicative of a primitive position among theropods that could not be
58 further resolved. Other researchers have argued point to affinities with either derived bird-like
59 coelurosaurs or tyrannosaurids. We here reanalyze all material collected by Osmólska, which
60 reveals it to be a chimaera of multiple theropod taxa. The femur, tibiotarsus, one pedal phalanx,
61 and most of the bones undescribed in Osmólska's paper are identified as Caenagnathidae indet.
62 The mandible, cervical vertebrae, pelvis, tail, and one pedal phalanx—which we consider the
63 holotype of *B. ostromi*—show tyrannosaurid affinities, which are here supported by phylogenetic
64 analyses. We find only two potentially unique diagnostic features of the *Bagaraatan* holotype:
65 double surangular foramina and a horizontal ridge on the lateral surface of the postacetabular
66 process of the ilium. Both, however, may be ontogenetically or intraspecifically variable, and thus
67 we conclude that the holotype of *B. ostromi* represents an indeterminate tyrannosaurid. The small
68 size of the holotype, and its possession of many features known to characterize juvenile
69 *Tyrannosaurus rex*, indicate that the skeleton belongs to a juvenile, which is one of the smallest
70 juvenile tyrannosaurids currently known.

71
72 **KEYWORDS** ontogeny, Tyrannosauridae, juvenile, revision, holotype designation, genus revision

73
74 **ABBREVIATIONS:** CMNH: Cleveland Museum of Natural History, Cleveland, Ohio, USA; LH:
75 Long Hao Institute of Geology and Paleontology in Hohhot, Inner Mongolia, China; MPC-D:
76 Mongolian Paleontological Center, Ulaanbaatar, Mongolia; PIN Paleontological Institute,
77 Moscow, Russia; ROM: Royal Ontario Museum, Toronto, Ontario, Canada; TMP: Royal Tyrell
78 Museum of Palaeontology, Drumheller, Canada; UALVP: University of Alberta Laboratory for
79 Vertebrate Paleontology, University of Alberta, Edmonton, Alberta; ZPAL Institute of
80 Paleobiology, Polish Academy of Sciences, Warsaw, Poland.

81
82 **INTRODUCTION**

83 In 1996, Halszka Osmólska described and named a new species of a theropod dinosaur,
84 *Bagaraatan ostromi*, based on a bone association collected in 1970 in the Nemegt Formation of
85 Mongolia by the Polish-Mongolian paleontological expeditions (ZPAL MgD-I/108). The
86 incomplete skeleton, estimated to belong to a moderately-sized carnivore that was 3.0-3.5 meters
87 long, included a partial mandible and the hind part of the body (pelvis, hind limb, and proximal
88 tail), and was described by Osmólska (1996) as showing a mosaic of features that made it
89 impossible to determine its relationship with other theropods. She pointed out similarities with
90 Dromaeosauridae (i.e., general structure of the mandible and slenderness of the hind limb), but
91 noticed that the presence of the pubic pelvis, short caudal prezygapophyses, and lack of ossified

92 caudal rods distinguishes it from dromaeosaurids. She also discussed affinity with tyrannosaurids,
93 due to the features of the mandible (i.e., shape and robustness of the anterior end, two glenoid
94 processes), but noted that the femoral trochanters are different in *B. ostromi* in contrast to
95 tyrannosaurids. Because of this unusual combination of features, Osmólska (1996) tentatively
96 considered *B. ostromi* to be a medium sized tetanuran with 'primitive' characteristics, and a
97 probable sister taxon to the Allosauridae and Coelurosauria. This placement, however, was not the
98 result of a phylogenetic analysis.

99 Later authors continued to be confused by the skeleton of *B. ostromi*. For example, Csiki and
100 Grigorescu (1998) noticed similarities in the hind limb structure between *B. ostromi* and theropod
101 hind limb material from the Hațeg Basin of Romania (*Bradycneme draculae* Harrison & Walker,
102 1975 and *Elopteryx nopcsai* Andrews, 1913), i.e., fusion of the tibia and proximal tarsals, presence
103 of a horizontal groove on the anterior surface of the astragalus, presence of a lateral tubercle on
104 the femoral lateral articular condyle, and the femoral head positioned above the greater and lesser
105 trochanter. *Br. draculae* and *E. nopcsai* were identified by Csiki and Grigorescu (1998) as a non-
106 coelurosaurian tetanuran and a maniraptoran, respectively. The authors proposed that those
107 species, together with *B. ostromi*, may represent a new clade of peculiar small theropods fairly
108 closely related to birds, also including the 'Iren Nor avimimid' PIN 2549/100 (Kurzanov, 1987;
109 Csiki & Grigorescu, 1998).

110 The idea that *B. ostromi* belonged to a clade of small, derived theropods was raised again with the
111 description of *Xinjiangovenator parvus* Rauhut & Xu, 2005, known from a partial articulated
112 hindlimb. This species was proposed as closely related to *B. ostromi*, forming a poorly known
113 Asian lineage of coelurosaurs (Rauhut & Xu, 2005). Subsequently, *Br. draculae* was identified as
114 an indeterminate representative of Maniraptora, *E. nopcsai* was recognized as a troodontid or a
115 non-ornithuromorph pygostylian bird (Naish & Dyke, 2004), the 'Iren Nor avimimid' was
116 revealed to be a troodontid (Currie & Peng, 1993), and *X. parvus* was placed in a polytomy with
117 other basal Coelurosauria (Choiniere *et al.*, 2010). Indeed, the earliest phylogenetic analyses in
118 which *B. ostromi* was included placed it as a sister taxon to the derived coelurosaurian clade
119 Maniraptoriformes (Holtz, 1998), or even within the Maniraptora (Rauhut, 2000; Rauhut *et al.*,
120 2010), quite closely related to birds.

121 Some authors, however, noted striking similarities between *B. ostromi* and tyrannosaurids. Holtz
122 (2004) claimed that the prominent and laterally expanded surangular shelf, reduced and broadened
123 retroarticular process, and the presence of a ventral flange on the ischial peduncle of the pubis are
124 shared between *B. ostromi* and tyrannosaurids. However, he also pointed out that this comparison
125 should be treated with caution due to the fragmentary nature of the *B. ostromi* holotype. Later, *B.*
126 *ostromi* was recovered as a basal tyrannosauroid in two phylogenetic analyses (Carr & Williamson,
127 2010; Loewen *et al.*, 2013). In the first analysis, it was found in a polytomy, together with
128 *Iliosuchus incognitus* Huene 1932, *Stokesosaurus clevelandi* Madsen, 1974, *Eotyrannus lengi* Hutt
129 *et al.*, 2001, *Aviatyrannis jurassica* Rauhut, 2003, and cf. *Alectrosaurus* sp. (see Carr &
130 Williamson, 2010). The second analysis (Loewen *et al.*, 2013) positioned *B. ostromi* together with
131 non-proceratosaurid tyrannosauroids closer to tyrannosaurids, i.e., *Dilong paradoxus* Xu *et al.*
132 2004, *E. lengi*, *Raptorex kriegsteini* Sereno *et al.*, 2009, and *Dryptosaurus aquilunguis* (Cope,

133 1866). Thus, for the last two decades, *B. ostromi* has often been presumed to be a tyrannosauroid
134 (Currie, 2003a; Choiniere *et al.*, 2010; Alifanov, 2012; Bell *et al.*, 2012; Dalman, 2013).
135 Recently, however, *B. ostromi* has been considered a chimera of tyrannosaurid and non-
136 tyrannosaurid bones (Brusatte, 2013; Brusatte & Carr, 2016; Napoli *et al.*, 2021), an intriguing
137 hypothesis that might explain the ‘mosaic’ of primitive and derived features noted by Osmólska
138 (1996). This idea has not yet been supported by careful description, comparisons, and
139 documentation of each bone of *B. ostromi*.
140 Here, we reassess the material of *B. ostromi* presented by Osmólska (1996). Although Osmólska
141 (1996) explicitly noted that there is no doubt that the bones of *B. ostromi* belonged to a single
142 individual, unpublished material catalogued under the same specimen number (ZPAL MgD-I/108)
143 indicates that the association was a multitaxic assemblage, thus putting the taxonomic identity of
144 individual bones into question. Thus, herein we redescribe, revise, and provide documentation of
145 all bones of the association, including the previously unpublished bones, and reassess the status of
146 *B. ostromi*. We indeed find that what Osmólska (1996) described as a single dinosaur skeleton is
147 actually a chimera of two taxa: an oviraptorosaur and bones belonging to a juvenile tyrannosaurid.
148 With this realization, we clarify the systematics of *B. ostromi* by designating an associated skeleton
149 in the assemblage as the holotype, discuss features that may support *B. ostromi* as a valid taxon,
150 but ultimately conclude that it is mostly likely is an indeterminate tyrannosaurid due to its juvenile
151 status, thus removing a genus and species from the roster of Nemegt theropods. The holotype
152 specimen becomes one of the smallest juvenile tyrannosaurids known, providing valuable
153 information on tyrannosaurid growth and ontogeny.

154 MATERIALS AND METHODS

155 Material

156 The holotype of *Bagaraatan ostromi*, ZPAL MgD-I/108, was found in 1970 in Northern Sary
157 (Nemegt Formation, Late Cretaceous) during the 7th Polish-Mongolian paleontological
158 expedition. The specimen was described as a partial skeleton including the mandible, incomplete
159 pelvis, incomplete left hindlimb, and proximal caudal vertebrae. According to Osmólska (1996),
160 the anterior part of the body of ZPAL MgD-I/108 was strongly weathered, thus not collected, but
161 the position of the mandible in the field indicated that it belongs to the same individual as the back
162 part of the body. In the field, in the area where the holotype of *B. ostromi* was found, several bones
163 were collected and catalogued under the same specimen number: two cervical and one caudal
164 vertebrae, manus phalanx II-1 and ungual II-3, proximal end of a rib, and a few indeterminate
165 bones. Despite that, Osmólska excluded those bones from the description of *B. ostromi*
166 (Osmólska’s personal notes: ‘Found together with *B. ostromi* but doubtful – not described’
167 [translation from Polish by the authors]). She preliminarily identified those bones as belonging to
168 indeterminate Oviraptorosauria. Unfortunately, no sketch or map of the arrangement of the bones
169 of *B. ostromi* was drafted and no photographs were taken before the excavation of the bones. Thus,
170 it is impossible to independently assess the position of the bones assigned to ZPAL MgD-I/108.
171 Herein, we assess all the bones found in the ZPAL MgD-I/108 assemblage, including the
172 undescribed fossils, some of which were used already in phylogenetic analyses (Loewen *et al.*,
173 2013).
174

175 To account for the multitaxic character of that composite specimen, we redefine ZPAL MgD-I/108
176 as a catalogue number. The mandible, being the first specimen described in detail, figured, and
177 referred to *B. ostromi* by Osmólska (1996), as well as the most autapomorphic bone in the
178 association, is here assigned the number ZPAL MgD-I/108. We also include the cervical and
179 caudal vertebrae and pelvis under this specimen number, as they were apparently found in
180 continuity with the mandible in the field, linked by the eroded remains of the vertebral column
181 (Osmólska, 1996: p. 3). The size, preservation, and general phylogenetic affinities of these bones
182 are also consistent with each other, and we consider them to belong to an associated skeleton,
183 which we refer as the holotype of the species *B. ostromi*. Two pedal phalanges were also found in
184 the assemblage; the size and taxonomic identity of the pedal phalanx IV-1 corresponds to ZPAL
185 MgD-I/108, and it is assigned to it. We exclude all the non-tyrannosaurid material from the
186 holotype of *B. ostromi* ZPAL MgD-I/108, and assign it the number ZPAL MgD-I/108/1.

187

188

Methods

189 The material was photographed using a Canon EOS M6 mark II camera. The fossils were also
190 digitalized using a Shining 3D EinScan Pro 2X 3D scanner fixed on a tripod with EinScan Pro 2X
191 Color Pack (texture scans), Ein-Turntable (alignment based on features), and EXScan Pro 3.2.0.2
192 software.

193 The anteroposterior diameter of the surangular foramen and the skull length in 38 tyrannosauroid
194 specimens of various body sizes (list in the supplementary material) was measured based on
195 photographs and 3D models or published data in ImageJ 1.53e. The analysis includes ten
196 individuals of *Tarbosaurus bataar* (Maleev, 1955), *Raptorex kriegsteini*, ten of *Gorgosaurus*
197 *libratus* Lambe, 1914, five of *Tyrannosaurus rex* Osborn, 1905, six of *Daspletosaurus* spp., and
198 one of *Alioramus altai* Brusatte et al., 2009, *Qianzhousaurus sinensis* Lu et al., 2014,
199 *Bistahieversor sealeyi* Carr & Williamson, 2010, *Teratophoneus curriei* Carr et al., 2011, and
200 *Lythronax argestes* Loewen et al., 2013, each. In the case of ‘*Shanshanosaurus huoyanshanensis*’
201 Dong, 1977 and *Gorgosaurus libratus* TMP 1994.12.155, the mandible length was taken instead
202 of the skull length due to lack of complete skulls. The mandible and skull length in *T. bataar* is
203 reported to be almost equal, ca. 1% of difference between in length between the lower jaw to the
204 length of the skull from premaxilla to occipital condyle (Maleev, 1974) and the skull and mandible
205 in tyrannosaurids grow isometrically (Currie, 2003b). Therefore, we included those individuals
206 due to their importance, as they represent small juveniles. *R. kriegsteini* is not included here within
207 *T. bataar*; although it was proposed that *Raptorex* is a juvenile of the latter species (Fowler *et al.*,
208 2023), recently it was once again suggested to be a valid taxon (Carr, 2023). *R. kriegsteini* still
209 requires a proper description in order to fully understand its affinities within the Tyrannosauroidea.
210 *Bagaraatan ostromi* ZPAL MgD-I/108 is included, however; the length of the mandible is
211 estimated to 30 cm based on the similarly sized specimen of *T. bataar* MPC-D 107/7 (Tsuihiji *et*
212 *al.*, 2011). Due to the presence of two surangular foramina in ZPAL MgD-I/108, that specimen is
213 represented on the plots by two points: one for the measurement of the posterior surangular
214 foramen alone, and the second for the measurement of the distance from the anterior margin of the
215 anterior surangular foramen to the posterior margin of the posterior surangular foramen. The
216 Pearson correlation coefficient was calculated in order to determine the linear dependence of the

217 skull length and the surangular foramen diameter. Then, a regression analysis was performed for
218 all tyrannosaurids and separately for the specimen groups of *Tarbosaurus*, *Gorgosaurus*,
219 *Tyrannosaurus*, and *Daspletosaurus*, to find the relationship between the size of the surangular
220 foramen and the skull length in order to determine possible allometries and quantify the
221 classification of the surangular foramen into imprecise size categories ('small', 'medium', and
222 'enlarged'). Although it is accepted that the small or absent surangular foramen is present in basal
223 Tyrannosauroida, and the enlarged fenestra (approximately 30% depth of the posterior end of the
224 surangular; Carr and Williamson 2010:204; Sereno et al. 2009:52) is present in the
225 Tyrannosauridae, the imprecise and inconsistent 'small', 'medium', and 'enlarged' categories are
226 still applied in the literature concerning tyrannosaurids (e.g., Tsuihiji *et al.*, 2011; Carr, 2020; Voris
227 *et al.*, 2021). All statistical analyses were conducted in PAST 4.03.

228 The distal end of the femur was historically cross-sectioned above the condyles, but the resulting
229 histological thin sections were never published. The section was taken using standard procedures
230 (Padian & Lamm, 2013) in the Institute of Paleobiology, Polish Academy of Sciences. The 100
231 and 50 μm ground sections were analyzed under normal and polarized light, including gypsum
232 wedge using a Nikon Eclipse LV100 POL polarizing microscope with a DS-Fil camera. The
233 pictures were combined together in NIS-Elements microscope imaging software. For the
234 description of bone histology we used standard terminology and definitions following Chinsamy-
235 Turan (2005) and Padian & Lamm (2013).

236 The amended holotype of *B. ostromi* (ZPAL MgD-I/108) was scored by us in two phylogenetic
237 datasets to assess its position among coelurosaurian theropods broadly and tyrannosauroids in
238 particular. First, it was added to the Theropod Working Group (TWiG) phylogenetic analysis
239 including a broad sample of 152 coelurosaurian theropods scored for 853 morphological characters
240 (Brusatte *et al.*, 2014). We analyzed the dataset in TNT 1.5 (Goloboff *et al.*, 2008) with *Allosaurus*
241 *fragilis* Marsh, 1877 as an outgroup. We began with a new technology search (with default
242 parameters for sectorial search, ratchet, tree drift, and tree fusion), which recovered a minimum
243 length tree in 10 replicates, in order to broadly sample tree space and identify major tree islands.
244 The returned most parsimonious trees were then subjected to a round of additional traditional
245 search (TBR) branch swapping, to more fully explore each tree island identified by the new
246 technology search. Second, to assess the position of the *B. ostromi* holotype among the
247 tyrannosauroids in particular, we scored it in a phylogenetic analysis including 31 tyrannosauroid
248 species (and four outgroups) and 366 characters (the Nesbitt *et al.*, 2019 version of the Brusatte &
249 Carr, 2016 dataset). The dataset was analyzed in TNT using the same parameters as above. For
250 both analyses, clade support was determined via Bremer supports and jackknife percentages.

251

252 SYSTEMATIC PALEONTOLOGY

253 DINOSAURIA OWEN, 1842; SAURISCHIA SEELEY, 1887; THEROPODA MARSH, 1881;
254 COELUROSAURIA HUENE, 1914; TYRANNOSAUROIDEA OSBORN, 1905; TYRANNOSAURIDAE
255 OSBORN, 1905; TYRANNOSAURIDAE INDET.

256

257 *Bagaraatan ostromi* Osmólska, 1996

258

259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299

Holotype

ZPAL MgD-I/108: incomplete right mandible (dentary, angular, surangular, prearticular, and articular), left and right incomplete ilia, nearly complete left pubis, partial right pubis, proximal end of left ischium, left pedal phalanx IV-1, 2 cervical vertebrae, 25 caudal vertebrae and 2 haemal arches.

Note on diagnostic characters

We provide a full diagnosis below, as we must first describe all of the bones of the *Bagaraatan* series before untangling which different taxa they belong to. However, we note here that this holotype individual can be referred to the Tyrannosauridae because of eight features: (1) presence of the dentary ‘chin’; (2) transition between the anterior and ventral edges of the dentary placed below the fourth alveolus; (3) dorsoventrally narrow Meckelian groove deeply inset into the medial side of the dentary; (4) extremely reduced retroarticular process of the articular; (5) prominent surangular shelf; (6) convex anterior margin of the pubis; (7) cervical vertebrae with a hypapophysis; (8) thick posterior centrodiapophyseal laminae.

Locality and age

Northern Sayr, Nemegt, Ömnögov, Mongolia; Nemegt Formation.

Description

Mandible

Only two fragments of the left mandible are preserved: the anterior part of the dentary with poorly preserved supradentary, and a piece that includes articulated posterior parts of the surangular, angular, and prearticular, and the incomplete articular.

Dentary

The dentary is slender in general outline and shows an anterior expansion in comparison to the midregion (28 mm deep at the third versus 25.5 mm deep at the ninth alveolus; Fig. 1–2), which is D-shaped in cross section. Also, the dentary is labiolingually expanded anteriorly: the anterior end is wide labiolingually (measuring 16.3 mm) in comparison to the posterior part of the preserved dentary (12.1 mm width; Fig. 1C). The anterior tip of the dentary is missing; however clearly it was positioned higher than the level of the tooth row (its preserved base is already dorsal relative to the rest of the bone; Fig. 1A-B). The anteroventral margin is relatively straight and strongly inclined posteroventrally, creating with the ventral margin of the dentary an angle of 135 degrees. This creates a distinct ‘chin’ (i.e., slightly protruding region at the place where the anteroventral and ventral margin meet) between the anterior and ventral surfaces, which is positioned underneath the third and fourth alveoli. The ‘chin’ underneath the fourth alveoli is commonly seen in juvenile tyrannosaurines (Carr 2020: character 117) and *Alioramus altai* (Brusatte *et al.*, 2012), but in adults the ‘chin’ is placed ahead of the fourth alveolus, like *Tarbosaurus bataar* (Fig. 3), and *Tyrannosaurus rex* (Brusatte and Carr, 2016: character 171). A low angle of the symphyseal region relative to the ventral margin is found in juvenile tyrannosaurids with narrow jaws, contrasting with the steeper rostroventral margin of deep-jawed

300 adult individuals, where the ‘chin’ migrates further anteriorly (Fig. 2-3; Carr & Williamson, 2004;
301 Carr, 2020).

302 The dorsal margin of the dentary is strongly concave in lateral view, even in the anterior part, a
303 feature of derived tyrannosaurids (Brusatte and Carr, 2016: character 177) that is also seen in
304 juveniles and subadults (Currie & Dong, 2001; Tsuihiji *et al.*, 2011; Brusatte *et al.*, 2012; Funston
305 *et al.*, 2020b). The ventral margin of the dentary is only very slightly convex (Fig. 1A-C, 2E-F).
306 The lateral surface is smooth; the neurovascular foramina pierce the bone along an anteroposterior
307 sulcus (i.e., dentary groove; Fig. 1A, 2E) 7.8 mm below the tooth row. The foramina are more
308 numerous in the anterior part of the dentary, close to the symphysis (Fig. 1F, 2B). The dentary
309 groove is an ontogenetically variable feature in tyrannosaurids, sharp and deep in juveniles and
310 shallow in mature individuals (Fig. 3; Brusatte *et al.*, 2016; Carr, 2020). On the ventral side of the
311 dentary, a second row of foramina, parallel to the ventral margin, is present. Anteriorly, those
312 foramina are larger and closely spaced; posteriorly, the foramina are smaller and widely spaced
313 (Fig. 1A, F, 2B, E).

314 The medial side of the dentary is smooth, with a deep and narrow groove that extends
315 anteroposteriorly between the interdental plates and the rest of the dentary (Fig. 1B, 2F). The
316 interdental plates are poorly preserved, but their triangular shape is visible in medial view. The
317 symphysis is elongated, aligned anterodorsally, and has a nearly smooth surface (bearing only
318 minute, very subtle striations). A ‘chin’ is present, as in other tyrannosaurids (Brusatte and Carr,
319 2016: character 172), including small juveniles (Funston *et al.*, 2020b) with the exception of
320 *Qianzhousaurus sinensis* (Lu *et al.*, 2014; Foster *et al.*, 2021). The ventral margin of the symphysis
321 ends below the fourth tooth alveolus, where a single anterior Meckelian foramen is present (Fig.
322 1B, 2F). The position is similar to that in *T. bataar* (e.g., ZPAL MgD-I/4, ZPAL MgD-I/175; Fig.
323 3) and other tyrannosaurids (Brusatte *et al.*, 2010; Funston *et al.*, 2020b), but in *A. altai* the foramen
324 is positioned further posteriorly, below the fifth tooth alveolus (Brusatte *et al.*, 2012). The anterior
325 Meckelian foramen is located anterior to the anterior end of the Meckelian groove, which is
326 shallower anteriorly and cuts deeper into the dentary posteriorly. The deep and sharp inset of the
327 Meckelian groove is a characteristic of tyrannosaurids and close relatives (Brusatte and Carr, 2016:
328 character 178), and is seen in small juveniles of *T. rex* (Carr, 2020) and other juvenile
329 tyrannosaurids (Funston *et al.*, 2020b). Anteriorly, the groove is positioned in the middle of the
330 medial surface of the dentary, but posteriorly, it is positioned in the upper third of the dorsoventral
331 height of the dentary. The distance between the Meckelian groove and the tooth row also shortens
332 posteriorly (from 13.25 mm anteriorly to 8 mm posteriorly). In dorsal view, the preserved part of
333 the dentary is straight (Fig. 1C, 2A), similar to *A. altai* (Brusatte *et al.*, 2012) and juvenile *T. bataar*
334 (Tsuihiji *et al.*, 2011).

335 The dentary shows eleven tooth alveoli. Nine dentary teeth are broken off, but nine complete tooth
336 alveoli are preserved, along with most of a tiny mesial-most alveolus at the front of the jaw, and
337 the anterior end of the 11th alveolus at the back. The preserved part of the first alveolus is
338 exceptionally small in comparison to other alveoli, whereas the second is larger than the first, but
339 still smaller than the remaining teeth, and with a circular outline (Fig. 1F, 2B; Table 1). This
340 indicates that the first two teeth in the jaw were smaller and more circular in cross section than the
341 remaining teeth, as is common in tyrannosauroids (Brusatte and Carr, 2016: character 175),

342 including small juveniles (Funston et al. 2020b). The alveoli posterior to the first two are elongated
343 mesiodistally, and have an eight-shaped outline in dorsal view (Fig. 1C, 2A). The labiolingual
344 width is the largest at the 3rd alveolar position and the anterior and posterior alveoli are narrower.
345 The anteroposterior length of the alveoli decreases anteriorly, so the 10th alveoli is the longest.
346 These alveoli indicate that the associated teeth are ziphodont, with labiolingual widths less than
347 60% mesiodistal lengths, as is the case in most theropods and juvenile tyrannosaurids, but differing
348 from the labiolingually widened incassate teeth of large adult tyrannosaurids (Brusatte and Carr,
349 2016: character 201).

350

351 Supradentary

352 As correctly noted by Osmólska (1996), only a small, poorly preserved splinter of the supradentary
353 is present in articulation, dorsal to the dentary and lingual to the interdental plates, at the level of
354 the fifth to the seventh tooth (Fig. 1B, 2F). Some uninformative, miniscule scraps of bone are also
355 present posteriorly. As preserved, the supradentary appears to be dorsoventrally narrow, covering
356 less than one fifth of the mandible height.

357

358 Splenial

359 We could not confirm the presence of a triangular, slightly hooked anterodorsally anterior part of
360 the splenial suggested by Osmólska (1996). The triangular element is most likely a cracked and
361 inset ventral bar of the dentary.

362

363 Surangular

364 Only the posterior part of the left surangular is preserved (Fig. 1A-E, 4). The surangular is a
365 generally thin, plate-like bone which expands labiolingually at the dorsal margin. Lateroventrally,
366 the surangular is covered by the flat and mediolaterally thin angular (Fig. 1A, 4A). The angular
367 ends very close to (only 4 mm below) the surangular foramen. In ventral view, the connection
368 between the surangular, articular, and prearticular is visible. The ventromedial edge of the
369 surangular contacts the prearticular. This contact is visible externally in the posterior part, but more
370 anteriorly the surangular is partly obscured by the angular – it continues only as a narrow splinter
371 along the posterior half of the preserved part of the angular. As preserved, the contacts between
372 the bones in that area appear split as a result of compaction, so their precise layout may be
373 displaced, and thus it is possible that in vivo the surangular was either not exposed from under the
374 angular, or that the exposure was slightly larger but now is obscured and/or partly eroded. In any
375 case, the deformation most likely was not substantial. The angular tightly covers the surangular,
376 so the margin between those bones is barely visible laterally, but well-marked ventrally.

377 The most conspicuous aspect of the surangular is the presence of two surangular foramina: one
378 smaller (2.3 x 1.5 mm) and positioned anterodorsally, and the second larger (diameter: 5.63 x 3.68
379 mm) and placed posteroventrally to the first one (Fig. 1A, 4A). Both are elongate, ovoid-shaped
380 rather than circular, with the long axes directed posterodorsally. The bone is extremely thin
381 between those foramina (Fig. 1E, 4F). This condition is different from most tyrannosaurids, where
382 a single surangular foramen is enlarged, such that its dorsoventral depth is more than 30% of the
383 depth of the surangular (Brusatte and Carr, 2016: character 179). This is the case in Nemegt

384 tyrannosaurids like alioramins (Brusatte *et al.*, 2009, 2012; Lu *et al.*, 2014), *T. bataar* (e.g., ZPAL
385 MgD-I/4, ZPAL MgD-I/31; Fig. 5), and the young juvenile *Raptorex* (Serenó *et al.*, 2009).
386 However, in some other juvenile tyrannosaurids there is a single surangular foramen but it is small
387 (Currie & Dong, 2001; Tsuihiji *et al.*, 2011), and it has been determined that the size of the foramen
388 changes during the ontogeny of *T. rex* (Carr 2020: character 126). Both surangular foramina in *B.*
389 *ostromi* are located in a fossa below the lateral surangular shelf. There is no pneumatic pocket
390 posterodorsal to the surangular foramen, whereas nearly all other tyrannosaurids have one
391 (Brusatte and Carr, 2016: character 183), although it is absent in some specimens of *T. bataar*
392 (e.g., ZPAL MgD-I/4 ZPAL MgD-I/31; Fig. 5, and MPC-D 107/7, Tsuihiji *et al.*, 2011). In *B.*
393 *ostromi*, the two foramina are separated by a laterally convex, lateroposterodorsally inclined,
394 dorsally thickening (up to about 5 mm), and gently posteroventrally bowed bar (Fig. 1A, 2A). The
395 bar buttresses the posterior part of the lateral surangular shelf.

396 There is a lateral surangular shelf above the foramina, close to the dorsal margin of the bone (Fig.
397 1A, E, 2A-B, F). Its lateral protrusion is not as prominent as in *A. altai* (Brusatte *et al.*, 2012) or
398 *T. bataar* (e.g., ZPAL MgD-I/4, ZPAL MgD-I/5, ZPAL MgD-I/31; Fig. 5), but the lateral
399 protrusion of the surangular shelf is subtle, as in some juvenile tyrannosaurids (Currie & Dong,
400 2001; Tsuihiji *et al.*, 2011; Foster *et al.*, 2021). In lateral view, the shelf extends straight
401 anteroposteriorly, paralleling the long axis of the mandible, as in tyrannosaurids, but differing from
402 the anteroventral or anterodorsal orientation in most other theropods (Brusatte and Carr, 2016:
403 character 182) The smooth surface of the adductor fossa dorsal to the shelf faces almost equally
404 dorsally and laterally. This is similar to both species of *Alioramus* (Kurzanov, 1976; Brusatte *et*
405 *al.*, 2012) and juvenile tyrannosaurids (Currie & Dong, 2001; Tsuihiji *et al.*, 2011), but differs
406 from the strongly laterally facing state in large adult tyrannosaurids (Brusatte and Carr, 2016:
407 character 184). In older *T. bataar* the fossa is just medial to the shelf, extends medioventrally, and
408 forms a depression (more pronounced in smaller specimens), but more medially the adductor fossa
409 curls up and faces strongly laterally (ZPAL MgD-I/31, ZPAL MgD-I/4, ZPAL MgD-I/5; Fig. 5).
410 The dorsally pointing posterior edge of the adductor fossa is more pronounced than in *A. altai*
411 (Brusatte *et al.*, 2012). There is a triangular fossa on the lateral surface of the surangular shelf
412 anteroventral to the glenoid, a distinguishing feature of derived tyrannosauroids (Brusatte and
413 Carr, 2016: character 185). The glenoid on the surangular (lateral glenoid socket of Osmólska,
414 1996) is a deep and anteroposteriorly narrow transverse concavity bound anteriorly and posteriorly
415 by dorsally extended processes (the preglenoid process and conelike process, respectively; Fig. 1,
416 4). This is similar to *A. altai* (Brusatte *et al.*, 2012) and juvenile *T. bataar* (Tsuihiji *et al.*, 2011);
417 in larger *T. bataar* the glenoid is anteroposteriorly wider (ZPAL MgD-I/4, ZPAL MgD-I/5, ZPAL
418 MgD-I/31; Fig. 5). Posteromedially to the glenoid fossa (lateral glenoid socket *sensu* Osmólska,
419 1996), in dorsal view, a deep and narrow fossa is present (medial glenoid socket *sensu* Osmólska,
420 1996). In *T. bataar*, the two glenoid fossae are not marked by the upraised lateral margin of the
421 surangular. Two glenoid depressions are present in that species, but similar in depth and separated
422 by a gradual elevation (e.g., ZPAL MgD-I/4). In *B. ostromi*, the medial glenoid is much deeper
423 than the lateral glenoid. There is a fossa on the lateral surface of the surangular, ventral to the
424 glenoid, as is seen in derived tyrannosauroids (Brusatte and Carr, 2016: character 186). This fossa
425 is smooth as in *A. altai* (Brusatte *et al.*, 2012), not rugose, as in in *T. bataar* (ZPAL MgD-I/4,

426 ZPAL MgD-I/5, ZPAL MgD-I/31). Distal to the glenoid, behind the posterior dorsal (conelike)
427 process, a second, groove-like concavity (cleft of Osmólska, 1996) is present bound posteriorly by
428 a small but well-defined dorsal projection, which continues medially as a sharp, distinct ridge (Fig.
429 1C, 4A). This feature occurs both in *A. altai* and *T. bataar*.

430 The retroarticular process of the surangular is tiny, corresponding to the small corresponding
431 process on the articular (Fig. 1A-B). This is a feature of tyrannosauroids (Brusatte et al., 2014:
432 character 76). This process is straight and slopes posteroventrally, similar to *A. altai* (Brusatte *et*
433 *al.*, 2012) and *Qianzhousaurus sinensis* (Lu *et al.*, 2014). In *T. bataar* (ZPAL MgD-I/4, ZPAL
434 MgD-I/5) it is oriented vertically. The medial hook process is nearly perpendicular to the
435 prearticular axis of the surangular and constitutes almost 50% of the width of the surangular.

436

437 Angular

438 Only the left posterior part of the angular is preserved (Fig. 1D, 4A, C). It is plate-like, laterally
439 convex, securely sutured, and tightly covers the surangular. Its margins are marked in the lateral
440 view by a shallow groove historically marked with a pen, making the exact observation difficult
441 (Fig. 1A, 4A). The dorsal margin of the posterior plate of the angular is convex below the anterior
442 of the two surangular foramina and concave below the distal margin of the posterior foramen,
443 where the dorsoventral height of the angular decreases posteriorly. The distance between the
444 dorsal margin of the angular and ventral margin of the posterior surangular foramen is short,
445 measures 4.2 mm The posterior margin is convex, pointing slightly upwards, and the ventral
446 margin is straight and contacts the surangular posteriorly and prearticular anteriorly. The posterior
447 tip of the angular is not complete. The preserved posterior end of the angular extends past the level
448 of the posterior margin of the posterior surangular foramen.

449

450 Prearticular

451 The posterior process of the left prearticular is preserved, and tightly articulated with articular
452 posteriorly, angular ventrally, and surangular dorsally, laterally, and posteroventrally (Fig. 1B-E,
453 4C-D). The posteromedial tip of the prearticular is broken off. The preserved part of the
454 prearticular is medially concave in ventral view. The ventral margin between the prearticular,
455 angular (anteriorly), and surangular (posteriorly) runs sigmoidally in ventral view, and only
456 posteriorly the margin between the bones curves medially (note that the bones are slightly split
457 along the ventral surface of the mandible, but that does not seem to distort their general layout).
458 The articular, surangular, and angular are tightly articulated with the prearticular. The prearticular
459 is not fused to the surangular and articular, similar to juvenile *Tarbosaurus* (Currie & Dong, 2001;
460 Tsuihiji *et al.*, 2011) and *A. altai* (Brusatte *et al.*, 2012) and in contrast to large *T. bataar* (ZPAL
461 MgD-I/4, ZPAL MgD-I/5)The posteroventral margin of the prearticular is pointed downwards
462 (similar to *A. altai*), while in *T. bataar* it is oriented posteriorly. The distal concave margin
463 contacting the articular is shallower than in *T. bataar*.

464

465 Articular

466 The articular is almost complete, lacking only the ventromedial part. It is tightly articulated with
467 the prearticular anteromedially and contacts the surangular laterally. The posterior surface is

468 smooth, gently concave, and elliptic, over twice as tall as it is wide. The retroarticular process is
469 extremely reduced (Fig. 1, 4D-E), as in all Tyrannosauroida, but differing from the much larger
470 processes in dromaeosaurids and other theropods (Brusatte *et al.*, 2014: character 76). The
471 attachment site for the jaw muscles on the articular is mediolaterally narrower than the glenoid
472 articular surface, and there is a very narrow non-articular region between the glenoid and the
473 muscle attachment. Both features are characteristic of most tyrannosauroids, but not other
474 theropods (Rauhut *et al.* 2010; Brusatte and Carr, 2016: characters 189, 190).

475

476 Antarticular

477 We could not confirm the presence of a separate antarticular suggested by Osmólska (1996). As
478 preserved, the structure in question is a cracked medial edge of the surangular.

479

480

480 *Postcranial skeleton*

481 Cervical vertebrae

482 Two incomplete amphiplatyan cervical vertebrae are preserved (Fig. 6). They are similar in
483 structure and size: the anteroposterior length of the anterior cervical centrum (Fig. 6A-F) measures
484 35.8 mm, and the posterior cervical centrum (Fig. 6G-L) measures 36.5 mm. The articular surfaces
485 of the centrum are oval, slightly concave, and shallow dorsoventrally. The height to width ratio of
486 the centra is 0.7 and 0.6 for the anterior and posterior cervical vertebra, respectively. The centra
487 are concave laterally, and thicken close to the parapophyses, which are oval in lateral view and
488 directed laterally (Fig. 6B, H). On the lateral sides of the centra, pleurocoels (lateral pneumatic
489 fossae) are present. Above the pleurocoels, the posterior centrodiapophyseal laminae are thick and
490 laterally offset, and demarcate a deep infradiapophyseal fossa anteriorly, as in all tyrannosaurids,
491 but differing from the thinner laminae of more basal tyrannosauroids (Brusatte and Carr, 2016:
492 character 213). Sutures between the centra and neural arches are open. Small, eroded
493 hypapophyses on the anterior region of the ventral surface of the cervical vertebrae are present, as
494 in tyrannosaurids and close relatives (Brusatte and Carr, 2016: character 214), including juveniles
495 such as the *A. altai* holotype (Brusatte *et al.*, 2013).

496 The cervical vertebrae are similar to the mid- or posterior cervical vertebrae of the juvenile
497 tyrannosaurid '*Shanshanosaurus huoyanshanensis*', as both exhibit flat ventral surfaces of the
498 centrum, which are also narrow-waisted, biconcave, and with a large, and single pleurocoel on the
499 lateral side (Currie & Dong, 2001).

500

501 Caudal vertebrae

502 Twenty-one caudal vertebrae were found in articulation (Fig. 7-14). Four distal caudal vertebrae
503 and two haemal arches were also found (Fig. 14-15), but cannot be fitted to the articulated tail.
504 The first preserved caudal is taller dorsoventrally than long (Fig. 7A-F; Table 2), whereas the
505 second is roughly equal in height and length (Fig. 7G-L), and all successive centra are longer than
506 tall (Fig. 8-14; Table 2). The transverse processes disappear starting from the 15th preserved caudal
507 (Fig. 12M-R). In *T. bataar* (ZPAL MgD-I/4, ZPAL MgD-I/175, and ZPAL MgD-I/177) the height
508 of the centrum is similar to its length in the 5th caudal vertebrae, and the transverse processes
509 disappear starting from the 18th caudal vertebra. Thus, we estimate that the preserved articulated

510 part of the tail ZPAL MgD-I/108 represents the 4th to 24th caudal vertebrae. Moreover, in the first
511 preserved caudal, the transverse processes are oriented posteriorly (Fig. 7A-F), which is a typical
512 condition of the proximal caudal vertebrae of tyrannosaurids.

513 The neural arches of the caudal vertebrae in ZPAL MgD-I/108 are co-ossified with the centra in
514 all bones, but the remnant of the suture is visible in the proximal centra, up to the 18th caudal (Fig.
515 12M-R). This suture is also present in the proximal caudal vertebrae of other tyrannosaurids,
516 including *T. bataar*, and also in some other theropods like ornithomimids (e.g., *Gallimimus*
517 *bullatus* Osmólska et al., 1972 ZPAL MgD-I/94).

518 The caudal centra are all amphicoelous; only the first preserved caudal of ZPAL MgD-I/108 is
519 somewhat concave anteriorly and flat posteriorly (Fig. 7A-F). In both *T. bataar* (ZPAL MgD-I/4,
520 ZPAL MgD-I/175, and ZPAL MgD-I/177) and *T. rex* (Brochu, 2003), the caudal vertebrae are
521 amphicoelous, and the first four centra are somewhat concave anteriorly. This supports the
522 identification of the first preserved caudal of ZPAL MgD-I/108 as the 4th caudal vertebra (Fig. 7A-
523 F). The lateral surfaces of the centra do not have any pleurocoels or other pneumatic features, and
524 on the ventral surfaces there are no ridges (Fig. 7-14). The articular surfaces for the hemal arches
525 are present at the posteroventral end of the centra; these are well-visible, and similar in shape as
526 in *T. bataar* (e.g., ZPAL MgD-I/175).

527 The neural arches are generally incomplete. The robust and rectangular neural spines of the
528 proximal caudal vertebrae lack their dorsal ends, but even as preserved they project beyond the
529 level of the posterior limit of the respective centra, as in most other tyrannosaurids (Brusatte and
530 Carr, 2016: character 229). The ontogenetic component to this character was noticed by Carr
531 (2020), in *T. rex* the spinous processes of the caudal vertebrae do not extend behind the level of
532 the posterior edge of the centrum, as in juvenile *T. bataar* (Tsuihiji et al., 2011) and apparently the
533 *Raptorex* holotype (Sereno et al., 2009). In adult *T. rex* the spinous process of the caudal vertebrae
534 extend posterior to the centrum (Carr, 2020), as it is also in *T. bataar* (ZPAL MgD-I/3, ZPAL
535 MgD-I/175). The neural spines of ZPAL MgD-I/108 are inclined posteriorly along the tail, similar
536 to *A. altai* (Brusatte et al., 2012) and *Qianzhousaurus sinensis* (Lu et al., 2014), and in contrast to
537 *T. bataar*, in which the neural spines project more vertically (ZPAL MgD-I/4, ZPAL MgD-I/175,
538 and ZPAL MgD-I/177). Further distally, the neural spines become stronger inclined posteriorly,
539 and from the 16th caudal vertebrae they become short dorsoventrally and elongated
540 anteroposteriorly (Fig. 12-14). The dorsal expansion present on the posterodorsal end of the neural
541 spine in other tyrannosaurids (Brusatte et al., 2012) is not preserved in *B. ostromi*, and thus its
542 presence cannot be confirmed.

543 The transverse processes are mostly incomplete in the caudal series of *B. ostromi*. Proximal caudal
544 vertebrae have anteroposteriorly long and dorsoventrally thin distally narrowing transverse
545 processes. From the 9th caudal vertebra onwards, the transverse processes are still thin and flat,
546 and directed laterally. Then, the 15th caudal vertebra shows reduced transverse process, much
547 shorter and narrow anteroposteriorly. The 16th and 17th caudal vertebrae have minute transverse
548 processes, and the 18th and further caudal vertebrae lack the transverse processes (Fig. 12-14). On
549 the anteroventral surface of each transverse process, where the process meets the prezygapophysis,
550 there are two laminae that define a deep, triangular concavity. This is present in most other
551 tyrannosaurids, including juvenile specimens like the *A. altai* holotype (Brusatte et al., 2012), but

552 absent in more basal tyrannosauroids and other theropods (Brusatte and Carr, 2016: character 231).
553 A triangular depression was noticed in *A. altai* (Brusatte *et al.*, 2012) at the region where the
554 transverse process meets the neural spine, but in *B. ostromi* it is proportionally wider and
555 shallower. In *T. bataar*, the depression is rather broad and shallow, regardless of the animals' size
556 (ZPAL MgD-I/3, ZPAL MgD-I/4, ZPAL MgD-I/175); however, the depth and width of the
557 depression depend on the preservation: in the caudal vertebrae of *T. bataar* ZPAL MgD-I/3, the
558 depression is narrow and deep on the left side and shallow and wide on the right side. The depth
559 and breadth of the fossa is best explained by taphonomic deformation, and thus its taxonomical
560 value is limited.

561 The prezygapophyses of the proximal caudal vertebrae are positioned more vertically than in *T.*
562 *bataar* (ZPAL MgD-I/3, ZPAL MgD-I/4, ZPAL MgD-I/175) and *A. altai* (Brusatte *et al.*, 2012).
563 Further distally, the prezygapophyses point more anteriorly, and from the 17th caudal onwards,
564 they are longer and project even more anteriorly (Fig. 12-14). The surface and shape of the articular
565 surfaces of the prezygapophyses is not visible due to their tight articulation with the
566 postzygapophyses or damage. The postzygapophyses are positioned behind the centrum and their
567 articular surfaces face lateroventrally, more laterally than in *T. bataar* (ZPAL MgD-I/3, ZPAL
568 MgD-I/4, ZPAL MgD-I/175) and *A. altai* (Brusatte *et al.*, 2012).

569 Due to the close articulation between the caudal vertebrae, the hypantrum between the
570 prezygapophyses is not visible. The hyposphene between the postzygapophyses is large and
571 rectangular in *B. ostromi*, similar to *T. bataar* (ZPAL MgD-I/3, ZPAL MgD-I/4, ZPAL MgD-
572 I/175), and in contrast to the delicate hyposphene found in *A. altai* (Brusatte *et al.*, 2012).

573

574 Iliia

575 The ilia are incomplete; the left and right ventral postacetabular processes, part of left proximal
576 preacetabular process, and apparently two fragments of the dorsal edge of the left ilium blade are
577 preserved (Fig. 16). Osmólska (1996) mentioned (but did not illustrate) a thin bone fragment found
578 some distance from the remainder of the pelvis, with an even natural dorsal edge and dense,
579 perpendicular striations on one of the surfaces, which she interpreted as the dorsal edge of the
580 ilium. The material catalogued under ZPAL MgD-I/108 includes two fragments fitting that
581 description (Fig. 16K-N). Given the presence of other dinosaur species in the association and lack
582 of articulation with the remainder of the skeleton, their affinity to *B. ostromi* is uncertain, although
583 possible.

584 The base of the preacetabular process was positioned above the pubic peduncle, as marked by the
585 attachment site of the *M. iliofemoralis internus*, the cuppedicus fossa (Fig. 16A-B), characteristic
586 for tyrannosaurids and other tetanurans (Hutchinson, 2001; Carrano & Hutchinson, 2002).
587 Dorsally, the cuppedicus fossa is a wide and slightly concave area, which curls down laterally and
588 forms the ventral margin of the preacetabular process. The dorsal margin of the preserved element
589 of the preacetabular blade is crushed diagenetically. Above the ventral margin of the preacetabular
590 blade, a depression is present.

591 Above the acetabulum, on the lateral surface of the right iliac blade (Fig. 16G-J) an eroded linear
592 ridge is present (Fig. 16I). This structure is present in all tyrannosauroids, including the juvenile
593 MPC-D 107/7 (Tsuihiji *et al.* 2011), but excluding *Raptorex kriegsteini* and *Qianzhousaurus*

594 *sinensis* (Lu *et al.*, 2014; Brusatte and Carr, 2016: character 258). Possibly, the absence of this
595 feature in the latter two may reflect an individual or growth variation.

596 The right postacetabular process is taphonomically compressed mediolaterally, and its pubic
597 peduncle and the supraacetabular crest are eroded (Fig. 16C-F). The ischial peduncle is robust, and
598 the acetabular surface is flat. Distally, the ischial peduncle is laterally, ventrally, and medially
599 surrounded by a shallow depression. Further posteriorly from the ischial peduncle, ventrally, a
600 large and deep brevis fossa is present. It is concave, wide mediolaterally, and gradually widens
601 posteriorly: from 11 mm anteriorly to 28 mm distally. Such widening occurs also in *A. altai*
602 (Brusatte *et al.*, 2012). There is no foramen at the base of this fossa, as in *T. bataar* (ZPAL MgD-
603 I/4), but the foramen is present in *A. altai* (Brusatte *et al.*, 2012). The medial and lateral walls of
604 the brevis fossa are formed by the medial and lateral flanges of the postacetabular process. The
605 lateral flange is thicker than the medial flange, as in *T. bataar* (ZPAL MgD-I/3) and *A. altai*
606 (Brusatte *et al.*, 2012). The brevis fossa is visible in lateral view only anteriorly; further posteriorly
607 it is concealed by the lateral flange of the postacetabular process. Above the beginning of the brevis
608 fossa, the lateral flange of the postacetabular process continues dorsally as a dorsal, ca. 24 mm
609 long crest described by Osmólska (1996), surrounded by anterior and posterior depressions.

610 On the medial surface of the right ilium of ZPAL MgD-I/108, parts of three sacral ribs are present:
611 one above the acetabulum, the second above the pubic peduncle, and the last positioned on the
612 medial flange (Fig. 16C-J). Due to the position of the sacral ribs, we agree with Osmólska (1996)
613 that they belong to the third to fifth sacral vertebra. If so, the laterally exposed brevis fossa
614 terminates posteriorly at the level of the anterior part of the fifth sacral vertebra.

615

616 Pubes

617 The left pubis (proximal part and shaft preserved) is more complete than the right (where only the
618 proximal part is preserved; Fig. 17). The articulation facet for the ilium is preserved in the left
619 pubis (Fig. 17A-E). The contact with the pubic peduncle of the ilium is clear: the lateral margin is
620 laterally extended with a rugose surface. In dorsal view, the pubic portion of the acetabulum is
621 wider transversely, but shorter anteroposteriorly, than the ischial part. Below the acetabulum, the
622 pubis narrows medialolaterally and forms a thin plate. The pubic tuberosity is incomplete, but it is
623 present as a distinct convex structure as in many tyrannosauroids, including juveniles such as the
624 *Raptorex* holotype, but it does not have the highly rugose form of large subadult and adult
625 tyrannosaurids like *T. bataar* (ZPAL MgD-I/3, ZPAL MgD-I/5) (Brusatte and Carr, 2016:
626 character 270). In *B. ostromi*, the tubercle is essentially level with the obturator notch, as in
627 tyrannosaurids (Brusatte and Carr, 2016: character 271). Ventral to the pubic tuberosity and the
628 articulation surface with the ischium, the pubis narrows anteroposteriorly and slightly widens
629 transversely. Here, the main shaft of the pubis is anteriorly concave when seen in lateral view (Fig.
630 17A), as in tyrannosaurids generally, but differing from the straighter condition in the juvenile
631 *Raptorex* holotype (Brusatte and Carr, 2016: character 269). On the posteromedial surface of the
632 bone, the beginning of the pubic apron is preserved: a sigmoidal crest running along the medial
633 surface of the pubic shaft (Fig. 17B, D-E). Its shape is similar to *T. bataar* (ZPAL MgD-I/175).
634 The medial surface of the pubic apron is missing. The pubic shaft is circular in cross section,
635 starting from the region where the pubic apron appears, and remains circular until the end of the

636 preserved part of the pubis (although the lateral surface of the pubic shaft is missing). In distal
637 view, the proximal part of the pubis (above the shaft) is less bowed laterally than in *T. bataar*
638 (ZPAL MgD-I/3, ZPAL MgD-I/175). This, however, can be accounted for the twice larger size
639 (ca. 7 m in length) of these two subadult individuals of *T. bataar* than *B. ostromi*.

640

641 Ischium

642 Only the proximalmost left ischial plate including the peduncles is preserved (Fig. 17A-D). The
643 articular surface of the pubic peduncle is tightly articulated with the ischial peduncle of the pubis.
644 The pubic peduncle is separated from the ischial peduncle by an elliptic concavity. In dorsal view,
645 the concavity is walled laterally by a wide and low margin (5 mm wide mediolaterally in the
646 narrowest place), which expands anteriorly and posteriorly until reaching the peduncle margins,
647 forming an hourglass-shaped margin (Fig. 17C). Medially, the concavity is walled by a straight,
648 mediolaterally thin, and dorsally extended, lamina, which is also present in other tyrannosaurids.
649 The articular surface of the pubic peduncle is 26 mm tall proximodistally, and 20 mm wide
650 mediolaterally. The lateral surface of the preserved part of the proximal ischium is concave,
651 whereas the medial surface is only slightly concave. The articular surface of the iliac peduncle is
652 31 mm wide mediolaterally, and 23.5 long anteroposteriorly. The lateral margin of the iliac
653 peduncle is strongly extended laterally. In dorsal view, it is elliptical, and has a concave articular
654 surface with the ischial peduncle of the ilium, similar to other tyrannosaurids (Brusatte, Carr &
655 Norell, 2012).

656

657 Pedal phalanx

658 The left phalanx IV-1 is 33 mm long (Fig. 18), its length to width ratio is 1.5. The proximal articular
659 surface is wider (22 mm) than tall (19 mm; unlike in for *T. bataar*, where the proportions are
660 opposite: ZPAL MgD-I/29; ZPAL MgD-I/175; ZPAL MgD-I/206), however, the dorsal and
661 plantolateral margins of the phalanx are incomplete. The proximal articular surface is concave, in
662 a similar manner to *T. baatar* individuals. The medial margin of the articular surface is slightly
663 concave, and the opposite lateral margin is convex. In the dorsal and planar view the phalanx IV-
664 1 of ZPAL MgD-I/108 is rectangular, only slightly narrowed in the middle. In the lateral and
665 medial view, the phalanx is triangular in overall shape, clearly narrows (stronger on the lateral than
666 medial side) just before the distal condyles. In dorsal view, a supracondylar basin is present, just
667 behind the slightly elevated margin of the distal articular surface. The supracondylar basin is only
668 slightly wider mediolaterally than long proximodistally (the length to width ratio is 0.8; in *T.*
669 *bataar* specimens the basin is much wider than long, the ratio is ca. 0.4) and in comparison to *T.*
670 *bataar* individuals the basin is shallower. The lateral condyle is smaller than the medial condyle,
671 and the lateral ligament pit is shallower in comparison to the medial one as in all *T. bataar*
672 individuals studied (ZPAL MgD-I/3; ZPAL MgD-I/4; ZPAL MgD-I/5; ZPAL MgD-I/29; ZPAL
673 MgD-I/175; ZPAL MgD-I/206; ZPAL MgD-I/331). The distal margin of the medial condyle is
674 circular, its dorsal end do not form a pointed posteriorly tip, as young *T. bataar* (ZPAL MgD-I/29),
675 but in contrast to larger individuals (ZPAL MgD-I/3; ZPAL MgD-I/4; ZPAL MgD-I/5; ZPAL
676 MgD-I/175; ZPAL MgD-I/206; ZPAL MgD-I/331), where the tip is present. In dorsal view, the
677 distal margin of the medial condyle is pointing anteromedially. The medial condyle is higher

678 plantodorsally and wider medialolaterally than the lateral condyle. The distal condyles are
679 separated by a cleft (which is acute and narrower in comparison to *T. bataar* individuals) along
680 the entire articular surface. The rounded margin of the lateral condyle in lateral view is not
681 complete on the plantar side. On the dorsal side, the margin of the articulation surface is smooth,
682 only slightly lifted up. In larger individuals of *T. bataar* the dorsal end of the articular surface in
683 lateral view is clearly demarcated.

684 The pedal phalanx IV-1 of young *T. bataar* ZPAL MgD-I/29 shows the same length to width ratio
685 as ZPAL MgD-I/108. In subadults of *T. bataar* the ratio is 1.3 (e.g., ZPAL MgD-I/175), and in
686 adults it is 1.2 (e.g., ZPAL MgD-I/206). Despite the fact that the phalanx IV-1 of *B. ostromi* is
687 slender than in subadult and adult *T. bataar*, it is short and wide, as is typical for tyrannosaurids,
688 in contrast to elongated and slender pedal phalanges of ornithomimids (length to width ratio is 1.7
689 for *G. bullatus* ZPAL MgD-I/94), caenagnathids (length to width ratio is 2.1 for *Elmisaurus rarus*
690 ZPAL MgD-I/98), or troodontids (length to width ratio is 1.7 for *Borogovia gracilicrus* ZPAL
691 MgD-I/174).

692

693 OVIRAPTOROSAURIA BARSBOLD 1976; CAENAGNATHOIDEA STENBERG, 1940; CAENAGNATHIDAE
694 STENBERG, 1940

695

696

Referred material

697 ZPAL MgD-I/108/1: Left manus phalanx II-1, manus ungual I-2, proximal and distal ends of the
698 left femur, tibiotarsus, and rib.

699

700

Note on diagnostic characters

701 We provide full details below, as we must first describe all of the bones of the *Bagaraatan* original
702 series before untangling which different taxa they belong to. However, we note here that this set
703 of bones can be referred to Caenagnathidae because of: (1) the presence of lateral pleurocoels in
704 the proximal caudal centra; (2) lesser and greater trochanters in contact; (3) clearly demarcated
705 accessory trochanter; (4) gracile and straight shape of the manual phalanx.

706

707

Locality and age

708 Northern Sayr, Nemegt, Ömnögov, Mongolia; Nemegt Formation.

709

710

Description

711 Caudal vertebrae

712 The centrum of one caudal vertebra is preserved (Fig. 19A-F). It is 28 mm long, 19.5 mm tall, and
713 23 mm wide (the height to width ratio of the centrum is 0.8). The centrum is oval, only slightly
714 compressed dorsoventrally. Laterally, the centrum bears one pleurocoel (pneumatic foramen) on
715 each side. The presence of lateral pleurocoels in the caudal vertebrae is a synapomorphy of
716 Caenagnathoidea (Lamanna *et al.*, 2014). The centrum is only slightly concave laterally. Ventrally,
717 two parallel ridges extend along the centrum, as in *Elmisaurus rarus* (specimen MPC-D 100/119
718 ‘*Nomingia gobiensis*’ Barsbold *et al.*, 2000).

719

720 Ribs

721 Only a proximal part of a dorsal rib is preserved; the rib is broken at the tuberculum (Fig. 19G-H).
722 The capitulum is bulbous. Behind the slightly convex articular surface no depression is present, in
723 contrast to tyrannosaurids (*T. bataar* e.g., ZPAL MgD-I/3, ZPAL MgD-I/4, ZPAL MgD-I/175 and
724 *A. altai* see Brusatte *et al.*, 2012). Also, in contrast to the latter, the tuberculum is enlarged. Because
725 the capitulum and tuberculum are at a similar level, the rib likely comes from the posterior part of
726 the ribcage. The overall shape of the preserved part of the rib corresponds to the morphology in
727 caenagnathids (e.g., Caenagnathidae indet. ZPAL MgD-I/99).

728

729 Manus phalanx II-1.

730 The left phalanx is straight and elongated, measuring 76.6 mm (Fig. 19O-T). The proximal
731 articular surface is taller (18 mm) than wide (16 mm) and divided by a low ridge, which is narrow
732 dorsally and wide ventrally. On both sides of the ridge, the articular surfaces are teardrop-shaped
733 and strongly concave. The distal medial condyle (13.5 mm high) is smaller than the lateral one
734 (15.4 mm high) and separated by a deep and narrow furrow. The medial ligament pit is shallower
735 than the lateral ligament pit. The width of the distal end is 15 mm; the length to width ratio of the
736 phalanx is 4.7.

737 The gracile and straight shape of the manus phalanx II-1 of ZPAL MgD-I/108/1 is the same as in
738 *E. rarus* ZPAL MgD-I/98, although the phalanx of ZPAL MgD-I/108/1 is larger. The length of
739 manus phalanx II-1 of ZPAL MgD-I/98 is 66 mm, the proximal width 14 mm, and the distal width
740 12 mm (the length to width ratio is 4.7, same as for ZPAL MgD-I/108/1). The manus phalanx II-
741 1 of ZPAL MgD-I/108/1 shares also with *E. rarus* slightly downturned distal condyle and
742 expanded articular surfaces of the distal condyles. Other theropods known from the Nemegt
743 Formation, i.e., tyrannosaurids (*T. bataar*, e.g., ZPAL MgD-I/3, ZPAL MgD-I/4), ornithomimids
744 (*G. bullatus*, cast of MPC-D 100/11; *Deinocheirus mirificus* Osmólska & Roniewicz, 1970, cast of
745 MPC-D 100/18), avimimids (alvarezsaurids (*Mononykus olecranus* (Perle *et al.*, 1994)), and
746 oviraptorids (e.g., *Oksoko avarsan* (Funston *et al.*, 2020a), *Nemegtomaia barsboldi* Lu *et al.*, 2005
747 (Fanti *et al.*, 2012)) do not have manual phalanges that are so straight, slender, and elongated.

748

749 Manus ungual II-3

750 The ungual is elongated (54 mm in length), curved, and very narrow, and the proximal articular
751 surface is 13 mm wide (Fig. 19I-N). The ungual lacks only the distal tip. The proximal articular
752 surface is oval (longer dorsoventrally than mediolaterally). A vertical ridge, which is dorsally and
753 ventrally expanded but constricted in the middle section, extends across the middle of the articular
754 surface. The articular surfaces on both sides of the ridge are strongly concave. The dorsal edge of
755 the articular surface forms a robust dorsal lip, surrounded by a depression. A ventral process is
756 present on the ventral edge of the articular surface. The articular surface is separated by a notch
757 from the ventrodistally located enlarged flexor tubercle. Laterally and medially, the collateral
758 groove extends along the entire ungual, starting from the area above the flexor tubercle.

759 The manus ungual II-3 is not known in *E. rarus*, however, the presence of the distinctive dorsal
760 lip indicates, that the ungual corresponds to the manual unguals of Caenagnathidae. Comparison
761 with the manual unguals of an North American caenagnathid *Chiropstenotes pergracillis* Gilmore,

1924, CMN 2367 (Funston, 2020) the ungual of ZPAL MgD-I/108/1 is less curved than the phalanges I-2 and III-4, but more straight, similar to II-3. Moreover, the proximal articulation is offset and the flexor tubercle is distally positioned and smaller in contrast to unguals I-2 and III-4, which further supports its identification as II-3 of a caenagnathid. Other theropods known from the Nemegt Formation, i.e., tyrannosaurids (*T. bataar*, e.g., ZPAL MgD-I/3, ZPAL MgD-I/4), ornithomimids (*G. bullatus*, cast of MPC-D 100/11; *D. mirificus*, cast of MPC-D 100/18), alvarezsaurids (*M. olecranus* (Perle *et al.*, 1994)), and oviraptorids (*O. avarsan* (Funston *et al.*, 2020a), *N. barsboldi* (Fanti *et al.*, 2012)) do not have such enlarged, curved, and transversely narrow manual unguals with an enlarged flexor tubercle distinctly separated from the ventral process and distinctive dorsal lip.

772

773 Femur

774 Two parts of the left femur are preserved: the proximal and distal end; most of the shaft is missing, so the length of the femur is unknown (Fig. 20). The circumference of the shaft portions preserved with the distal and proximal parts is 105 mm. Osmólska (1996) hypothesized that ca. 80–90 mm of the shaft is missing, adding up to a total femur length of 310–320 mm.

778 The proximal part of the femur (Fig. 20A-E) is narrower lateromedially than longer anteroposteriorly. In dorsal view, the femur is L-shaped. The posterior part of the greater trochanter is connected to the femoral head that projects mediodistally, and the anterior part of the greater trochanter is widened anteriorly. In anterior view, the femoral head is positioned higher than the greater trochanter and they are separated by a broad, shallow depression. The surface of the rounded femoral head is rugose. In posterior view, a wide groove for the capital ligament is present on the femoral head. In medial view, the femoral head is ovoid, and its posterodorsal margin is wider than the anteroventral end. The neck is narrower anteroposteriorly than the head; and the ventral margin of the head is directed downward before connecting to the neck. The neck extends upward from the greater trochanter, which is wider lateromedially than the lesser trochanter. The lesser trochanter is almond-shaped in anterior view. The dorsal margin of the femoral trochanters in lateral view is arched; the small, anteriorly positioned lesser trochanter is separated by a shallow groove from the much anteroposteriorly longer greater trochanter. On the lateral surface of the proximal part of the femur, the separation between the lesser and greater trochanter is marked by a shallow and short groove. Below the lesser trochanter, the accessory trochanter (anterior crest *sensu* Osmólska, 1996) is present. It is slightly expanded anteriorly and extends along the preserved part of the proximal shaft. The accessory trochanter keeps a consistent lateromedial width along the preserved proximal part of the shaft. A posterior tubercle is present below the greater trochanter, well visible in anterior and posterior views.

797 The distal end of the femur is now longitudinally shorter than described by Osmólska (1996), because it has since been thin sectioned. At that time, it measured 105 mm; now, only the distalmost part of the femur including both condyles is present, measuring 52 mm (Fig. 20F-J). The medial condyle is bigger than the lateral condyle, but the lateral condyle extends further distally than the medial condyle. The condyles are distally separated by a deep but narrow notch (the popliteal fossa). Anteriorly and distally, the condyles are separated by shallower and wider depressions (the extensor grooves). The medial condyle is convex with a slightly rugose surface.

804 The lateral condyle bears an elevation on its distal surface. The tibiofibular crest extends
805 posteromedially. In lateral view, the tibiofibular crest is axe-shaped, and projects further
806 posteriorly than the medial condyle.

807 The accessory trochanter appeared in Tetanurae as a branch of the distal base of the lesser
808 trochanter and it was reduced in Eumaniraptora. The accessory trochanter is smaller in basal
809 Tetanurae, Carnosauria, basal Coelurosauria, Tyrannosauridae, and Ornithomimosauria, than in
810 *Caudipteryx* spp., *Microvenator celer* Ostrom, 1970, Caenagnathidae, and some Oviraptoridae
811 (Hutchinson, 2001). The accessory trochanter of the femur of ZPAL MgD-I/108/1 is clearly
812 demarcated from the lesser trochanter and forms a dorsoventral flange, comparable as seen in
813 Caenagnathidae, e.g., *E. rarus* ZPAL MgD-I/98, *Anzu wyliei* Lamanna *et al.*, 2014, or *Ch.*
814 *pergracilis* (Currie & Russell, 1987). The lesser and greater trochanters are in contact as in all
815 Caenagnathoidea (Lamanna *et al.*, 2014). The proximal end of the femur further resembles the
816 femur of *E. rarus* ZPAL MgD-I/98 in possessing a cylindrical head positioned higher than the
817 greater trochanter and separated by a depression, which is wider in the larger (ontogenetically
818 older, as indicated by the difference in size between those specimens) ZPAL MgD-I/108/1. Such
819 an embayment is also present in other Caenagnathidae, e.g., *A. wyliei* (see Lamanna *et al.*, 2014),
820 *E. rarus* (see Barsbold *et al.*, 2000), or *Ch. pergracilis* (see Currie & Russell, 1987). A wide groove
821 on the posterior surface of the femoral head for the capital ligament is present in both *E. rarus*
822 ZPAL MgD-I/98 and MgD-I/108/1. Also, similar to Caenagnathidae, the lateral condyle of the
823 femur ZPAL MgD-I/108/1 is positioned more distally than the medial condyle, and the tibiofibular
824 crest is well demarcated (*A. wyliei* (see Lamanna *et al.*, 2014), *E. rarus* (see Barsbold *et al.*, 2000),
825 or *Ch. Pergracilis* (see Currie & Russell, 1987)). The extensor groove is distinct, but shallow,
826 consistent with *E. rarus* (see Barsbold *et al.*, 2000). The proximal and distal ends of the femur
827 ZPAL MgD-I/108/1 are of similar size to the measurements in *E. rarus* (see Barsbold *et al.*, 2000),
828 so the probable length of the whole bone was similar, ca. 285 mm.

829

830 Bone microstructure of femur.

831 A histological section of the distal part of the shaft, above the condyles, shows a large marrow
832 cavity and thin (ca. 2 mm) cortex (Fig. 20K-L). The external part of the cortex (half of its thickness)
833 is built of parallel-fibered bone with scattered secondary osteons. The vascularization is laminar,
834 and growth marks are absent. In the section no definite primary osteons were seen, although the
835 external cortex is poorly preserved, possibly obscuring their presence. The inner cortex is sharply
836 demarcated from the external cortex and built of densely packed secondary osteons: up to 4
837 generations are present. Close to the marrow cavity, resorption cavities are present, surrounded by
838 a thick layer of lamellar bone (up to 0.3 mm). The marrow cavity is surrounded by a thinner layer
839 of lamellar bone (0.15 mm) and filled by slender and elongated bony trabeculae.

840 The section shows features typical for the metaphyses of long bones: extensive secondary
841 remodeling, lack of growth marks, numerous resorption cavities. Thus, due to the lack of any
842 growth record in the section, it is not possible to estimate the growth ratio.

843 The bone microstructure of the femur in caenagnathids is unknown. Thus far, bone histology of
844 the tibiae of cf. *Anzu wyliei* (ROM 65884) and Caenagnathidae indet. (UALVP 57349) have been
845 described (Funston & Currie, 2018; Cullen *et al.*, 2021). Both, however, represent young

846 individuals, as indicated by their predominant fibrolamellar bone, high vascularity, and limited
847 secondary remodeling (none in UALVP 57349 and up to 30% of cortex in OMVP 65884). The
848 predominance of fibrolamellar bone and high vascularity are also seen in the cortices of the femora
849 and fibulae of the oviraptorid *Oksoko avarsan*, regardless of their ontogenetic age (Funston *et al.*,
850 2020). Even in the large-bodied cf. *A. wyliei* (ROM 65884), the section from the tibia revealed a
851 predominately primary tissue with generally high vascularity and limited secondary remodeling
852 (Cullen *et al.*, 2021). As can be noticed, the section taken from ZPAL MgD-I/108/1 is different
853 from the Caenagnathoidea described before, and it is explained as a result of its sectioning at the
854 metaphysis, and not diaphysis as it is usually done.

855

856 Tibiotarsus

857 The left tibiotarsus is complete and measures 380 mm (Fig. 21A-F). The bone is slender, slightly
858 bowed laterally (possibly taphonomically exaggerated), and the distal fibula is fused to the distal
859 tibia and calcaneum (Fig. 21A-C). The shaft is elliptical in cross section (circumference: 95 mm)
860 and is compressed anteroposteriorly, possibly as an effect of taphonomical crushing. Proximally,
861 the tibia expands anteriorly and slightly mediolaterally; its anteroposterior depth is 47.5 mm and
862 mediolateral width is 59.2 mm. Distally, where the tibia is fused with the astragalocalcaneum
863 distally and the fibula laterally, the tibia expands mediolaterally and measures 57.3 mm.

864 The cnemial crest condyle (cranial cnemial crest *sensu* Osmólska, 1996) is robust, laterally
865 deflected, and short in anterior view, comprising only ca. 15% of the maximum proximodistal
866 tibiotarsus length. The fibular condyle (lateral cnemial crest *sensu* Osmólska, 1996) is also robust,
867 slightly curved anteriorly, and shorter mediolaterally and dorsoventrally than the cnemial crest.
868 Between the cnemial crest and fibular condyle, a deep and posteriorly curved incisura tibialis is
869 present (Fig. 21A-E). The medial proximal condyle of the tibiotarsus is long anteroposteriorly;
870 anteriorly it is smoothly connected with the cnemial crest, and posteriorly it is separated from the
871 fibular condyle by a triangular cleft. The posteromedial edge of the medial proximal condyle of
872 the tibiotarsus is posteriorly extended. Below the fibular condyle, the fibular crest is present. It is
873 tall dorsoventrally, ca. 20% of the tibiotarsus length. The crest gets wider mediolaterally and
874 deflects anteriorly; however, the crest is not strongly pronounced. The distal end of the crest is
875 rectangular.

876 The fibula is fused to the lateral side of the distal end of the tibia, along the distal ca. 23% of the
877 tibiotarsus length (Fig. 21A-C). The distal end of the fibula is partly fused with the calcaneum.
878 The outline of the distal part of the fibula is marked and distinguishable against the remaining
879 bones. The suture between the astragalocalcaneum and distal tibia are clearer in anterior than
880 posterior view; however, that may be a matter of preservation. No suture is visible between the
881 astragalus and calcaneum. The calcaneum shows a lateral depression (lateral epicondylar
882 depression), below the suture with the fibula. The preserved, incomplete ascending process of the
883 astragalus extends along 7.5% of the of the tibiotarsus length. In anterior view, it has subtriangular
884 pointed medial and lateral processes, separated by a deep depression. At the base of the ascending
885 process, a shallow median depression is present, above which a low, mediolaterally extended ridge
886 is located (Fig. 21A).

887 A proper tibiotarsus—in which the tibia is fused to the proximal tarsals—is recognized in three
888 non-avian maniraptoran taxa: Alvarezsauridae, Troodontidae, and Avimimididae. Both
889 alvarezsaurids known from the Nemegt Formation (*Mononykus olecranus* Perle et al., 1993 and
890 *Nemegtomykus citus* Lee et al., 2019) have a proximodistally short fibula, which does not reach
891 even the midshaft of the tibiotarsus (Perle et al., 1994; Lee et al., 2019). The presence of a
892 tibiotarsus in the troodontids known from the Nemegt Formation is variable. In the larger species
893 *Zanabazar junior* (Barsbold, 1974), the astagalocalcaneum is not fused to the tibia (Norell et al.,
894 2009), while in the smaller *Borogovia gracilicrus* Osmólska, 1987, a tibiotarsus is present
895 (Osmólska, 1987; Cau & Madzia, 2021). The hindlimb is unknown in the third troodontid from
896 the Nemegt Formation, *Tochisaurus nemegtensis* Kurzanov & Osmólska, 1991. Only a fragment
897 of proximal right fibula of *Bo. gracilicrus* is preserved, but the distal end of the tibiotarsus does
898 not show any signs of fusion with the distal fibula, as in other Troodontidae e.g., Gao et al. (2012).
899 Oviraptoridae and Caenagnathidae show a fused astragalus and calcaneum, but not to the tibia
900 (Currie et al., 2016). Finally, a fused tibiotarsus including the distal end of the fibula is an
901 autapomorphy of *Avimimus* spp. (Kurzanov, 1981; Funston et al., 2018).
902 However, ZPAL MgD-I/108/1 would be an exceptionally large representative of *Avimimus*; the
903 largest reported tibiotarsus of *A. nemegtensis* MPC-D 102/92 measures 282 mm (Funston et al.,
904 2016), and in *A. portentosus* PIN 3907/1 it is 257 mm long (Kurzanov, 1981), whereas ZPAL
905 MgD-I/108/1 measures 380 mm, similar to *E. rarus* MPC-D 100/119 i.e., 355 mm. The
906 histological sections of the Iren Dabasu avimimids, revealed that the largest sectioned specimens
907 were already adults (Funston et al., 2019). Moreover, three features of the tibia are shared for
908 ZPAL MgD-I/108/1 and *E. rarus*: (1) the medial proximal condyle is more protruded dorsally than
909 in *Avimimus* spp.; (2) the fibular crest is longer and its distal end is rectangular, not arcuate as in
910 *Avimimus* spp.; and (3) the medial malleolus protrudes further medially than in *Avimimus* spp.

911

912 Fibula

913 The left fibula is complete, measuring 340 mm. The distal end is partially fused to the calcaneum,
914 and laterally fused to the tibia, along ca. 33% of the fibula's length. It is similar to *Avimimus*
915 *portentosus*, in which the fibula is fused to the tibia along 1/3 of its length (Kurzanov, 1981). The
916 proximal anteroposterior length of the fibula is 47.1 mm. The proximal end of the fibula is
917 triangular in the lateromedial aspect, only slightly concave medially in dorsal view (Fig. 21G-K),
918 similar to *E. rarus* (MPC-D 100/119; Barsbold et al., 2000), and in contrast to rectangular proximal
919 end in *Avimimus* spp. (Kurzanov, 1981; Funston et al., 2016). Distal to the expanded proximal
920 end, the fibula narrows anteroposteriorly. On the medial surface is a long (74.2 mm, about 22% of
921 total length) fusiform attachment for the fibular crest of the tibia. At this level, on the anterior
922 surface of the fibula, an elliptical iliofibularis tubercle is present. Distally, the fibula strongly
923 narrows anteroposteriorly and has a triangular cross section along ca. 65% of its total length.

924 Despite the distal part of fibula fused with the tibia in a similar manner to *Avimimus* spp. the
925 proximal end of the fibula is more triangular, as in MPC-D 100/119 (Barsbold et al., 2000), than
926 rectangular, as seen in *Avimimus* spp.

927

928 Pedal phalanx

929 The left phalanx II-2 is 35 mm long (Fig. 19U-A') and its length to width ratio is 2. The proximal
930 articular surface is triangular in posterior view, and can be divided into lateral and medial teardrop-
931 shaped concave articular surfaces, separated from each other by a smooth ridge running in the
932 middle of the proximal articular surface. In the lateral and medial view the proximal articular
933 surface is strongly concave, the plantar margin extends backward, and the lip-shaped dorsal margin
934 (extensor tubercle) is elevated dorsally, and directed posteriorly. The distal articular surface is
935 composed of lateral condyle and slightly shorter plantodorsally medial condyle, which are
936 separated by a concavity, which is shallow dorsally, but gets deeper along the articular surface to
937 its end on the plantar side. In anterior view, the lateral condyle extends downwards, than the medial
938 condyle. The ligament pits are well marked on the both sides of the phalanx, the lateral ligament
939 pit is elongated anteroposteriorly, and the medial ligament pit is circular.

940 The phalanx II-2 is similar to the corresponding phalanx of *E. rarus* (ZPAL MgD-I/98; length to
941 width ratio: 2.1), especially in the structure of the proximal articular surface, i.e., two teardrop-
942 shaped surfaces separated by a ridge, and the lip-like extensor tubercle. The phalanx II-2 in other
943 theropods from the Nemegt formation differs from the one of ZPAL MgD-I/108/1. This phalanx
944 in *G. bullatus* (ZPAL MgD-I/94) is compressed (the length to width ratio is 1.4), and the extensor
945 tubercle is less pronounced than in ZPAL MgD-I/108/1. The phalanx II-2 is even more compressed
946 in *B. gracilicrus* (ZPAL MgD-I/174; the length to width ratio is 1.2). The proximal articular surface
947 in *T. bataar* (ZPAL MgD-I/3, ZPAL MgD-I/4, ZPAL MgD-I/29, ZPAL MgD-I/175) is wider than
948 long, in contrast to *E. rarus*, *G. bullatus*, and ZPAL MgD-I/108/1. The length to width ratio of the
949 phalanx II-2 in *T. bataar* is 1.5-1.6, depending on the ontogenetical age.

950

951 SIZE OF THE SURANGULAR FORAMEN IN TYRANNOSAURIDS

952 The Pearson correlation coefficient for the measurements of the anteroposterior length of the
953 posterior surangular foramen and skull length is high and statistically significant (0.85653;
954 $p=0.0001$), indicating that the anteroposterior diameter of the surangular foramen is dependent on
955 the skull length in tyrannosaurids (Fig. 22A). The regression analysis for all specimens and taxa
956 included shows a negative slope and a high correlation coefficient (slope: 1.32; $R^2=0.8$; $p=0.0001$),
957 and the same is true even when juveniles are excluded (slope: 1.2; $R^2=0.68$; $p=0.001$). The same
958 is true for *Tarbosaurus bataar* (slope: 0.04; $R^2=0.78$; $p=0.0005$), *Tyrannosaurus rex* (slope: 0.03;
959 $R^2=0.94$; $p<0.1$), *Gorgosaurus libratus* (slope: 0.05; $R^2=0.76$; $p<0.01$), and *Daspletosaurus* spp.
960 (slope: 0.08; $R^2=0.88$; $p<0.01$; Fig. 22B). This indicates a negative allometry, so the size of the
961 surangular foramen decreases during ontogeny in those tyrannosaurid species. This trend was
962 reported previously for *T. rex* (Carr, 2020). Our analysis does not find the surangular foramen of
963 *Bistahieversor sealeyi*, *Daspletosaurus* spp., *Teratophoneus curriei*, *Qianzhousaurus sinensis*, and
964 *A. altai* as enlarged in comparison to other tyrannosaurids. Also, the surangular foramen of *T.*
965 *bataar* is not smaller than in other tyrannosaurids as reported previously (Tsuihiji et al., 2011;
966 Voris et al., 2021).

967

968

PHYLOGENETIC ANALYSIS

969 The parsimony analysis of the larger, inclusive dataset of coelurosaurian phylogeny (based on
970 Brusatte et al., 2014) resulted in 10 000 most parsimonious trees (the memory limit in TNT) of

971 3361 steps (CI=0.322, RI=0.777). The strict consensus tree (Fig. 23) places *Bagaraatan ostromi*
972 among tyrannosauroids, as the sister taxon to the clade *Dryptosaurus aquilunguis* +
973 Tyrannosauridae. *B. ostromi* shares seven synapomorphies with tyrannosauroids or major
974 inclusive clades: (1) extremely reduced retroarticular process of the articular; (2) pubic tubercle
975 forming a convexity on the anterior margin of the pubis; (3) mediolateral width of the jaw muscle
976 attachment site of the articular equal to glenoid width (*Dilong paradoxus* + Tyrannosauridae);
977 surangular shelf (4) prominent and (5) not overhanging the surangular foramen, which abuts the
978 shelf (*Eotyrannus lengi* + Tyrannosauridae); (6) cervical vertebrae with hypapophysis
979 (*Xiongguanlong baimoensis* Li *et al.*, 2010 + Tyrannosauridae); and (7) thick laterally offset
980 posterior centrodiapophyseal laminae, which demarcates a deep infradiapophyseal fossa anteriorly
981 in the anterior-middle cervical vertebrae (*B. ostromi* + Tyrannosauridae). These results strongly
982 support the tyrannosauroid affinity of the *B. ostromi* holotype. The exact position of *B. ostromi*
983 outside of Tyrannosauridae, however, may be an artefact of the immature status of the specimen.
984 Because of the robust tyrannosauroid affinities of the *B. ostromi* holotype, its more precise
985 relationships within Tyrannosauroidea are better tested with a phylogenetic dataset designed to
986 assess tyrannosauroid ingroup relationships. Thus, when we included it in the tyrannosauroid
987 dataset of Brusatte and Carr (2016), we found 40 most parsimonious trees (769 steps, CI=0.553,
988 RI=0.812). The strict consensus tree (Fig. 24) places *B. ostromi* within a polytomy of derived
989 tyrannosauroids (with *Bistahieversor sealeyi*, *Qianzhousaurus sinensis*, *Alioramus* spp., and
990 *Appalachiosaurus montgomeriensis*, Albertosaurinae, and Tyrannosaurinae), which indicates that
991 it is either a member of Tyrannosauridae or a very close relative. Among the synapomorphies of
992 Tyrannosauroidea found also in *B. ostromi* are: (1) cervical vertebrae with hypapophysis; and (2)
993 thin, sharp, and deeply inset Mackelian groove on the dentary. The synapomorphies of
994 Tyrannosauridae (or a slightly more inclusive clade, depending on the resolution of the polytomy)
995 present in *B. ostromi* are: (1) transitional point between the ventral and anterior margins of the
996 dentary positioned below the 4th alveolus; (2) the presence of a dentary ‘chin’. Finally, the presence
997 of a small surangular foramen is found to be an autapomorphy of *B. ostromi*, a reversal from the
998 enlarged condition in closely related taxa.
999 Because of the juvenile nature of the specimen (see below), we interpret these results as strong
1000 support for the tyrannosaurid (or near-tyrannosaurid) affinities of *B. ostromi*, but do not put much
1001 stock into its exact position on the tree, because juveniles often fall out more basally than adults
1002 in phylogenetic analysis (Tschopp *et al.*, 2015).

1003 1004 DISCUSSION

1005 The *Bagaraatan* assemblage ZPAL MgD-I/108

1006 It will remain unknown why Osmólska (1996) refrained from even mentioning some of the
1007 remaining bones found together with what she considered to be *Bagaraatan ostromi*. Our complete
1008 reanalysis of the material collected and catalogued together revealed that ZPAL MgD-I/108 is not
1009 a single individual, but an assemblage of two different non-avian dinosaurs, in which only one
1010 individual was partly articulated. The presence of an oviraptorosaurian in the chimaera explains
1011 why some previous phylogenetic analyses found *B. ostromi* related with Maniraptora (Holtz, 1998;
1012 Rauhut, 2000; Rauhut *et al.*, 2010).

1013 Osmólska (1996) did remove most bones of the Caenagnathidae indet. found as part of ZPAL
1014 MgD-I/108 from what she considered to be *B. ostromi*, possibly due to the fact that 15 years earlier
1015 (Osmólska, 1981) she described a caenagnathid from the Nemegt Formation, *Elmisaurus rarus*
1016 with characteristic elongated manual phalanges. The caenagnathid bones from the assemblage
1017 which she did not exclude from the description of *B. ostromi* are: the femur, tibiotarsus, and pedal
1018 phalanx II-2 (ZPAL MgD-I/108/1). The femur of the holotype of *E. rarus* is incomplete—e.g., the
1019 accessory trochanter is missing—and thus Osmólska possibly missed the similarities in the
1020 structure of the proximal end of the femur of *E. rarus* and the specimen she considered to be *B.*
1021 *ostromi*. The femur of ZPAL MgD-I/108/1 definitely does not belong to a tyrannosaurid due to the
1022 presence of a: (1) clearly demarcated anterior trochanter, which is proximodistally long; (2) saddle-
1023 like proximal margin of the femur; (3) lateral condyle positioned more distally than the medial
1024 condyle, and (4) tibiofibular crest well demarcated. Body size of the individual ZPAL MgD-
1025 I/108/1 was similar to *E. rarus* (see Barsbold *et al.*, 2000). The identification of the tibiotarsus is
1026 more problematic. The fusion of the astragalocalcaneum with the tibia and the fusion of the distal
1027 end of fibula to the tibia should unambiguously indicate a representative of Avimimidae
1028 (Kurzanov, 1981; Funston *et al.*, 2018). However, the large (for an avimimid) size of the
1029 tibiotarsus, and the morphological features of the tibia and fibula are more reminiscent of the
1030 Caenagnathidae. In the latter taxon, the fusion usually occurs between the astragalus and
1031 calcaneum and less often between the distal tarsals and metatarsals (as proposed by Currie *et al.*,
1032 2016 in mature individuals). There are two caenagnathids thus far known in which the astragalus
1033 fused with the tibia (Atkins-Weltman *et al.* in review). Therefore, given the large size of the
1034 individual, a caenagnathid-like general morphology of the tibia and fibula, and the general
1035 tendency towards the fusion of the bones among the heel joint in the Caenagnathoidae, we decided
1036 to recognize the tibiotarsus as belonging to an senile or/and atypical (in the terms of bone fusion)
1037 caenagnathid. The size of the tibiotarsus fits to the remaining bones of ZPAL MgD-I/108/1, thus
1038 they likely belonged to a single individual. Finally, the pes phalanx II-2, as described above,
1039 matches the general morphology seen in the caenagnathids. Thus, the hind limb bones that
1040 Osmólska (1996) originally considered a part of *B. ostromi* could not have been found in
1041 articulation with each other, nor with the tyrannosauroid skeleton that we designate as the amended
1042 holotype of *B. ostromi*. Two species of caenagnathids were known from the Nemegt Formation of
1043 Mongolia: *E. rarus* and ‘*N. gobiensis*’; however, the validity of the latter was recently called into
1044 question (Funston *et al.*, 2018, 2021), implying that only one caenagnathid lived in the Nemegt
1045 Formation: *E. rarus*, thus the specimen ZPAL MgD-I/108/1 is most likely a representative of that
1046 species.

1047 Finally, the mandible, axial skeleton, and pelvis of the *B. ostromi* material was found in
1048 articulation, as noted by Osmólska (1996; Fig. 25). This specimen, ZPAL MgD-I/108, is here
1049 designated as the holotype of *B. ostromi* and is referred to Tyrannosauridae indet. due to the
1050 presence of numerous diagnostic features, including a dentary ‘chin’ and the position of the
1051 transition between the anterior and ventral edges of the dentary below the fourth alveolus (Fig. 1).
1052 Those features were considered synapomorphies of *Bistahieversor sealeyi* + *Appalachiosaurus*
1053 *montgomeriensis* + Tyrannosauridae (Brusatte *et al.*, 2010; Brusatte and Carr, 2016) and appear
1054 early in the ontogeny of tyrannosaurids (Funston *et al.*, 2020b). The dorsoventrally narrow

1055 Meckelian groove deeply inset into the medial side of the dentary is a tyrannosauroid
1056 synapomorphy, also present already in hatchlings (Funston *et al.*, 2020b). The extremely reduced
1057 retroarticular process of the articular and prominent surangular shelf present in *B. ostromi* are also
1058 typical for tyrannosauroids (Brusatte *et al.*, 2014). The features of the postcranial skeleton, such
1059 as the convexity on the anterior margin of the pubis (present in all Tyrannosauroidea), cervical
1060 vertebrae with a hypapophysis (present in *Xiongguanlong baimoensis* + Tyrannosauroidea) and
1061 thick posterior centrodiapophyseal laminae (present in *Dryptosaurus aquilunguis* +
1062 Tyrannosauroidea) further support the close affinities of this associated holotype skeleton of *B.*
1063 *ostromi* with tyrannosaurids.

1064 Only three clearly valid tyrannosaurid species are currently known from the Nemegt Formation in
1065 Mongolia: the large-bodied, common *Tarbosaurus bataar*, and the much smaller and uncommon
1066 long-snouted *Alioramus remotus* and *Alioramus altai*. Another potentially valid taxon, *Raptorex*
1067 *kriegsteini* (Serenó *et al.*, 2009; Carr 2023), also most likely comes from the Nemegt Formation
1068 (Fowler *et al.* 2011), but as its holotype is a very small juvenile, its taxonomic status is difficult to
1069 determine and awaits full description of the material. *B. ostromi* is much smaller than all of them
1070 (*Raptorex* notwithstanding), with an estimated body length not larger than 3 m, vs 10 m in *T.*
1071 *bataar* and 5–6 m in the known subadult skeletons of *Alioramus* spp., which admittedly may have
1072 been larger as adults (Brusatte *et al.*, 2009, 2012). The size of *Bagaratan*'s mandible is slightly
1073 larger than those of '*Shanshanosaurus huoyanshanensis*', which was once considered a valid
1074 species from the Chinese Subashi Formation (contemporary to the Nemegt Formation; Wan *et al.*,
1075 2007), but is now regarded a juvenile tyrannosaurid (Currie and Dong, 2001). The *B. ostromi*
1076 mandible, however, is similar in size and general structure to the mandible of the juvenile *T. bataar*
1077 MPC-D 107/7 described by Tsuihiji *et al.*, (2011). This raises a question: does *B. ostromi* represent
1078 a juvenile of one of the already known Nemegt tyrannosaurid species?

1079

1080 *Is Bagaraatan ostromi a valid taxon?*

1081 Osmólska (1996) listed eight diagnostic features for *Bagaraatan ostromi*: (1) two surangular
1082 foramina (also considered by Holtz (2004) an autapomorphy of *B. ostromi*); (2) articular with an
1083 oblique posterior surface and a short retroarticular surface; (3) caudal vertebrae with thin-walled
1084 centra; (4) hyposphene-hypantrum articulations in at least the first 16 caudal vertebrae (also listed
1085 by Holtz (2004) as an autapomorphy of *B. ostromi*); (5) prezygapophyses in proximal caudal
1086 vertebrae with ridges on the lateral surfaces; (6) ilium with two deep depressions; (7) femur with
1087 the anterior trochanter (anterior crest *sensu* Osmólska); and (8) tibia and fibula fused distally. The
1088 status of those features is shortly discussed below. Because we have now reidentified the hindlimb
1089 bones as belonging to other non-tyrannosaurid taxa, those features regarding the hind limb were
1090 discussed above, so they will be omitted in this section.

1091 The ilium with a distinct ridge on the lateral surface of the postacetabular process, demarcated
1092 anteriorly, medially, and posteriorly by depressions, is striking (Fig. 16). It occurs symmetrically
1093 on both ilia, and better preserved on the left, which is less compressed. Such ridges are not found
1094 in other theropods, to our knowledge, and are not present in juvenile *Tarbosaurus bataar* (MPC-
1095 D 107/7) nor the other tyrannosaurid juvenile, *Raptorex kriegsteini* (Serenó *et al.*, 2009).
1096 Therefore, they may be a diagnostic feature of *B. ostromi*.

1097 The ridges on the lateral surfaces of the prezygapophyses are found also in the proximal caudal
1098 vertebrae of *Tyrannosaurus rex*, running from the anterior margin of the transverse process to the
1099 prezygapopysis (Brochu, 2003). Similar ridges on the prezygapophyses of anterior caudal
1100 vertebrae are also present in *T. bataar* (ZPAL MgD-I/176). Osmólska (1996) did not quantify how
1101 thin-walled the caudal vertebrae centra of *B. ostromi* are in comparison to other theropods. We do
1102 not recognize any clear difference between the centrum thickness of *B. ostromi* and other
1103 theropods. The stout hyposphene-hypantrum articulations in at least the first 16 caudal vertebrae
1104 was considered an autapomorphy of *B. ostromi* by Osmólska (1996) and Holtz (2004). The
1105 presence of the hyposphene-hypantrum articulation is seen in many archosaurs, is strongly
1106 correlated with body size and is often present already at a young age, before the articulation is
1107 necessary to support the large mass of the fully-grown animal (Stefanic & Nesbitt, 2019). The
1108 hyposphene-hypantrum articulations are common in theropods, and for instance, are present in the
1109 caudal vertebrae of medium-sized *T. bataar* (ZPAL MgD-I/176). The oblique posterior surface
1110 and short retroarticular surface of the articular, also listed by Osmólska (1996), are tyrannosauroid
1111 synapomorphies (Brusatte *et al.*, 2014).

1112 The presence of two surangular foramina and the ridge on the lateral surface of the postacetabular
1113 process of ilium seem to be only two features listed by Osmólska (1996) which distinguish *B.*
1114 *ostromi* from other tyrannosaurids. The two surangular foramina were also later listed by Holtz
1115 (2004) as unique for *B. ostromi* in comparison to other theropods (Currie *et al.*, 2003). There is
1116 some confusion in the literature about the size of the surangular foramen in tyrannosauroids, and
1117 its phylogenetic significance and ontogenetic and individual variation. In their phylogenetic
1118 dataset of tyrannosauroids, Brusatte and Carr (2016) used a character which simply divided the
1119 size of the foramen into two states: those with a dorsoventral depth less than or greater than 30%
1120 of the depth of the posterior end of the surangular. This was based on earlier characters used by
1121 Sereno *et al.* (2009, Carr and Williamson (2010), and Brusatte *et al.* (2010). The enlarged condition
1122 was found to be synapomorphic of a clade consisting of *Dryptosaurus* + Tyrannosauridae, whereas
1123 the primitive smaller foramen is seen in more basal tyrannosauroids like *Suskityrannus*,
1124 *Eotyrannus*, *Dilong*, and proceratosaurids.

1125 Other authors, however, have considered the foramen differently. The size of the surangular
1126 foramen in tyrannosaurids was divided into moderate (*Gorgosaurus libratus*, *Albertosaurus*
1127 *sarcophagus* Osborn, 1905, *T. rex*, and *T. bataar*) or enlarged (*Bistahieversor sealeyi*,
1128 *Daspletosaurus* spp., *Teratophoneus curriei*, *Thanatotheristes degrootorum* Voris *et al.*, 2020,
1129 *Qianzhousaurus sinensis*, and *Alioramus altai*) states by Voris *et al.*, (2021). However, the
1130 surangular foramen in *T. rex* and *Albertosaurus sarcophagus* used to be also classified as smaller
1131 than in other tyrannosaurids (Carr & Williamson, 2004). Other authors reported that the surangular
1132 foramen in *T. bataar* is smaller than in other tyrannosaurids and invariant during ontogeny
1133 (Tsuihiji *et al.*, 2011; Voris *et al.*, 2021). Also, the surangular foramen in ‘*Shanshanosaurus*
1134 *huoyanshanensis*’ was described as large (Currie & Dong, 2001), but later as small (Tsuihiji *et al.*,
1135 2011). For *T. rex*, the size of the surangular foramen was first reported as increasing (Carr, 1999),
1136 but later as decreasing in size, through ontogeny (Carr, 2020).

1137 Because of this confusion, we built a dataset to examine the size of foramina in a quantitative
1138 context. In tyrannosaurids the mandible, skull, and femur growth are isometric, and are related to

1139 the body size of the individual (Currie, 2003b). Thus, we assessed the relationship between the
1140 size of the surangular foramen and skull length (as a proxy for body size). Our results (Fig. 22)
1141 show that in all taxa the size of the surangular foramen decreases during ontogeny (negative
1142 allometry), and is strongly correlated with the length of the skull. Thus, e.g., *A. altai* (IGM
1143 100/1844) and the similarly sized *G. libratus* (TMP 1991.36.500) have surangular foramina of
1144 proportionally the same size. Although the surangular foramen-skull length correlation is
1145 statistically significant, variability in surangular foramen size is also apparent, especially in *G.*
1146 *libratus* and *T. bataar*; for which the data are less fitted to the trend than for the other species
1147 ($R^2=0.76-0.78$, vs. $R^2>0.88-0.94$ in *Daspletosaurus* spp., and *T. rex* ; Fig. 22). Indeed, although
1148 the surangular foramen is rather enlarged in *Tarbosaurus* individuals (as in other tyrannosaurids;
1149 Fig. 22) bigger than MPC-D 100/66 (skull length: 45 cm), few exceptions were found within the
1150 hypodigm. The surangular foramen of the medium-sized specimen MPC-D 107/14 is exceptionally
1151 small in comparison to other *T. bataar* individuals of similar size (e.g., ZPAL MgD-I/3; MPC-D
1152 107/5; Fig. 5). Moreover, a specimen larger than the listed above, MPC-D 100/60, shows
1153 asymmetrical surangular foramina: the left one is smaller (anteroposterior length: 23 mm) and the
1154 right one is larger (anteroposterior length: 40 mm). The smaller surangular foramen of the left
1155 mandible can be noticed as an outlier in the Figure 22. So, apparently, there was some variability
1156 in the timing of the surangular foramen enlargement, at least in *T. bataar*. The size of the
1157 surangular foramen in *B. ostromi*, regardless if measured for the single (posterior only) or double
1158 (posterior + anterior) foramina, falls into the overall variability of surangular size in the
1159 tyrannosaurids generally and *T. bataar* specifically. The position of the surangular foramen in
1160 ‘*Shanshanosaurus*’ and *T. bataar* MPC-D 107/7 is similar to the position of the posterior opening
1161 in the surangular of *Bagaraatan* and those individuals cluster together on the plot. In turn, if the
1162 length of the area of both surangular foramina was measured for *B. ostromi*, it clusters with
1163 *Raptorex kriegsteni*, the surangular foramen of which was previously reported as ‘enlarged’
1164 (Fowler *et al.*, 2011).

1165 What might explain the strange double set of foramina in *Bagaraatan*? The bone between the
1166 anterior and posterior surangular foramina in *B. ostromi* is very thin, and the relative position of
1167 this area and both foramina matches the surangular foramen of *Raptorex kriegsteni* and *T. bataar*
1168 (ZPAL MgD-I/31). The surangular in tyrannosaurids during the early years of life was invaded by
1169 a pneumatic diverticulum (Gold *et al.*, 2013), which pneumatized the bone and formed the enlarged
1170 surangular foramen, bordered by a pneumatic pocket posterodorsal to it. Because more basal
1171 tyrannosauroids have a small foramen without a pneumatic pocket, it is not clear if there was any
1172 pneumatic diverticulum in this region in these species. Due to the fact that pneumatic diverticula
1173 induce bone resorption when they contact bone (Bremer, 1940; Witmer, 1997; Wedel, 2007), we
1174 propose that the mandible of *B. ostromi* exhibits local bone resorption induced by the pneumatic
1175 diverticula, that would explain the extremely thin bone between the anterior and posterior foramen.
1176 We hypothesize that if the pneumatization process continued slightly longer, the two foramina
1177 might have merged into a single large foramen, which is the common condition in *Dryptosaurus*
1178 + Tyrannosauridae (Brusatte and Carr, 2016). This proposal is supported by the fact that the
1179 posterior surangular foramen in *B. ostromi* is similar in length and positioned in a similar place as
1180 in the smaller ‘*Shanshanosaurus*’ and *T. bataar* MPC-D 107/7 (skull length about 29 cm)

1181 specimens. Furthermore, the area of the surangular containing the posterior and anterior surangular
1182 foramina, and the thinned bone between them, matches the length and position of the surangular
1183 foramen in *Raptorex* (skull length about 30 cm). Therefore, *B. ostromi* (also ca. 30 cm long skull)
1184 possibly captures the precise moment of ongoing bone resorption and perforation due to the
1185 pneumatic diverticulum. This process likely occurred early in ontogeny, in specimens 2–3 m long,
1186 which were probably 2–3 years old at the time of death (as indicated for *T. bataar* MPC-D 107/7
1187 by Tsuihiji *et al.* (2011)). Apparently around this growth stage the pneumatic diverticulum invaded
1188 the bone, and thus variability in the size, shape, and even number of foramina is to be expected.

1189

1190 Juvenile Tyrannosauridae indet.

1191 Due to its small body size and similarity to other juvenile tyrannosaurid specimens from the
1192 Nemegt, it is likely that *Bagaraatan ostromi* is a juvenile tyrannosaurid. We tested this hypothesis
1193 further by determining if *B. ostromi* shows juvenile features that have been well documented in
1194 *Tyrannosaurus rex*, whose ontogenetic osteological changes have been chronicled in detail by Carr
1195 (2020). We recognized that *B. ostromi* shows 22 juvenile, and only 5 adult mandible features found
1196 in *T. rex* by Carr (2020). Four out of the 22 juvenile features were found only in early juveniles,
1197 and the remaining eighteen in late juveniles.

1198 The mandible characters recognized both in *B. ostromi* and juveniles of *T. rex* are: (1) increasing
1199 posteriorly size of the first three alveoli of the dentary; (2) shallow dentary in lateral view; (3)
1200 shallow coronoid region of the surangular; (4) no ridge delimiting the caudoventral fossa of the
1201 angular caudal process; (5) first two dentary alveoli much smaller than the latter alveoli; (6) 8th
1202 tooth is the mesiodistally longest in the dentary; (7) the alveoli decreasing posteriorly in
1203 mesiodistal length from the sixth to seventh alveolus; (8) single large pit median to the Meckelian
1204 fossa; (9) low angle of the ‘chin’; (10) lightly textured ‘chin’ region; (11) distance of the
1205 ventralmost dentary foramen from the dorsal margin of the dentary to the total height of the bone
1206 greater than 40%; (12) the lateral extension of the surangular shelf horizontal; (13) surangular shelf
1207 not slanted; (14) small surangular foramen; (15) caudal extent of the coronoid process declining
1208 before it reaches the glenoid; (16) presence of an embayment on the caudal margin of the
1209 surangular foramen; (17) cleft between the caudal glenoid process dorsoventrally short and
1210 shallow; (18) caudal end of the surangular shelf fading below the glenoid region; (19) lateral scar
1211 on the surangular present; (20) caudal glenoid process as tall as the rostral process; (21) lateral
1212 scar on the surangular rugose and shallow; (22) dorsal orientation of the anterior glenoid foramen
1213 (Carr, 2020).

1214 The prevalence of features shared by *B. ostromi* with juvenile *T. rex* supports the identification of
1215 *B. ostromi* as a young tyrannosaurid. The less numerous adult *T. rex* features (Carr, 2020) found
1216 in *B. ostromi* are listed below, with comments regarding variability within *Tarbosaurus bataar*.
1217 (1) The second dentary tooth is more than 75% of the mesiodistal length of the third dentary tooth.
1218 The proportions between the first three dentary teeth in *T. bataar* seem to be variable. In the
1219 subadult ZPAL MgD-I/175, the second dentary tooth is less than 75% of the mesiodistal length of
1220 the third dentary tooth, and in the adults (ZPAL MgD-I/5) it is between 70–78%. (2) The combined
1221 mesiodistal lengths of the first two alveoli of the dentary are greater than the mesiodistal length of
1222 the third alveolus, as in all examined individuals of *T. bataar* (subadults ZPAL MgD-I/45, ZPAL

1223 MgD-I/46, ZPAL MgD-I/175; and adults ZPAL MgD-I/4, ZPAL MgD-I/5; Table 1). However,
1224 the difference in all *T. bataar* specimens is greater (ca. 4 cm) than in *B. ostromi* (1 cm). (3) Lack
1225 of the deviation in the ‘chin’ region, which is not recognized in any examined *T. bataar* specimen
1226 (ZPAL MgD-I/45, ZPAL MgD-I/46, ZPAL MgD-I/175, ZPAL MgD-I/4, ZPAL MgD-I/5), nor it
1227 has been described in juvenile *T. bataar* MPC-D 107/7 (Tsuihiji *et al.*, 2011). (4) The caudal
1228 surangular foramen is positioned far anteriorly to the glenoid, as in all *T. bataar* individuals (ZPAL
1229 MgD-I/4, ZPAL MgD-I/5, ZPAL MgD-I/31) including the juvenile MPC-D 107/7 (Tsuihiji *et al.*,
1230 2011). (5) Short and deep glenoid fossa in adult *T. rex* and *B. ostromi*. A shallow and long glenoid
1231 fossa can be recognized in ‘*Shanshanosaurus huoyanshanensis*’ see (Currie & Dong, 2001), but
1232 already in the slightly larger MPC-D 107/7 and *B. ostromi*, as well as young and adult *T. bataar*
1233 (ZPAL MgD-I/4, ZPAL MgD-I/5 ZPAL MgD-I/31), it is narrow and deep. Those features possibly
1234 indicate some species-dependent variability, similar to the proportion of the antorbital fenestra,
1235 which does not shorten as much during the ontogeny of *T. bataar* as it does in *T. rex* (Tsuihiji *et*
1236 *al.*, 2011).

1237 As it is clear that the *B. ostromi* holotype belongs to a juvenile tyrannosaurid, the question
1238 becomes: can we identify which species it belonged to? We can first make comparisons to the
1239 other Nemegt tyrannosaurids: *T. bataar* and *Alioramus* spp. The mandible of *B. ostromi* is
1240 generally similar to juvenile *T. bataar* or putative juveniles of that species like ‘*S.*
1241 *huoyanshanensis*’ and *Raptorex kriegsteni* see (Currie & Dong, 2001; Sereno *et al.*, 2009; Fowler
1242 *et al.*, 2011; Tsuihiji *et al.*, 2011). The dentary is straight in the dorsal and ventral view, shallow,
1243 slender, thickens and tapers dorsally at the anterior end. *B. ostromi*, similarly to MPC-D 107/7 ,
1244 but in contrast to *T. bataar* specimens and *A. altai*, does not show any pneumatic pocket behind
1245 the surangular foramen (Tsuihiji *et al.*, 2011; Brusatte *et al.*, 2012). The cervical vertebrae of *B.*
1246 *ostromi* strongly resemble the middle or posterior cervical vertebrae of ‘*S. huoyanshanensis*’. They
1247 share the posterodorsal rather than dorsal inclination of the neural spines, and less flexed centra
1248 than in adult, large tyrannosaurids (Currie & Zhiming, 2001). The fusion of some bones occurred
1249 early in the ontogeny of tyrannosaurids, e.g., the juvenile *T. bataar* has already fused nasals
1250 (Tsuihiji *et al.*, 2011). However, the articular remains unfused with the surangular in *B. ostromi*,
1251 similar to ‘*S. huoyanshanensis*’, juvenile *T. bataar* (MPC-D 107/7), and *A. altai* (see Brusatte *et*
1252 *al.*; 2012). In contrast, in *Raptorex* and larger *T. bataar* individuals the articular is fused to the
1253 surangular. Moreover, early in ontogeny partial fusion of the pelvis was reported in *Raptorex* (see
1254 Fowler *et al.*, 2011), and young *T. rex* (BMR P2002.4.1, ‘Jane’; Larson & Parrish, 2013). On the
1255 other hand, the pelvic bones are unfused in *B. ostromi*, juvenile *T. bataar* (MPC-D 107/7), and
1256 subadult *A. altai* (see Brusatte *et al.*, 2012) However, an early fusion of the cranial sutures may
1257 not necessarily be associated with an early fusion of postcrania, since these functional units could
1258 be subjected to developmental plasticity or separate evolutionary pressure depending on the
1259 ecology and preferred or available diet. The coossification of postcranial sutures and fusion
1260 between bones among tyrannosaurids require further study. However, due to their high variability,
1261 also in juveniles, we do not find them as a adequate indicator for growth stage in tyrannosaurids.
1262 We can more thoroughly compare *B. ostromi* to young juvenile *T. bataar*, because no young
1263 juveniles of *Alioramus* spp. are known thus far. Due to the fact that both tyrannosaurids occur in
1264 the Nemegt Formation and *B. ostromi* lacks diagnostic features of either *Alioramus* spp. (see

1265 Brusatte *et al.*, 2012) or *T. bataar* (see Hurum & Sabath, 2003) which is mostly due to the
1266 fragmentary nature of the holotype skeleton, we cannot assign ZPAL MgD-108/1 to any particular
1267 species. Some subtle features suggest that *B. ostromi* may be a juvenile of *T. bataar*: e.g., (1)
1268 already strongly expanded anterior end of the dentary, (2) ‘chin’ well demarcated, (3) lack of the
1269 pneumatic pocket next to the surangular foramen. However, because those features may potentially
1270 be a result of intraspecific variability or be more widespread among juvenile tyrannosaurids than
1271 currently suspected, we cannot clearly determine whether *B. ostromi* is a juvenile of *T. bataar* or
1272 *Alioramus* spp. Thus, we consider *B. ostromi* to be an indeterminate juvenile representative of the
1273 Tyrannosauridae. This assessment may be modified in the future, when more juvenile individuals
1274 of tyrannosaurid taxa are known (particularly young individuals of *Alioramus* spp.) and the growth
1275 series and variability at early life stages are better understood.

1276 1277 CONCLUSIONS

1278 The enigmatic theropod described by Osmólska (1996) from the Late Cretaceous Nemegt
1279 Formation of Mongolia, *Bagaraatan ostromi*, is a chimaera of two non-avian dinosaurs. First, the
1280 femur, tibiotarsus, and pedal phalanx II-2 together with several other bones not described by
1281 Osmólska but catalogued under the same specimen number (manus phalanges, caudal vertebrae,
1282 and rib) are referred here to the Caenagnathidae. Second, the mandible, axial skeleton, pelvis, and
1283 pedal phalanx IV-1—which together form an associated skeleton—are considered here as the
1284 holotype of *B. ostromi* and identified as Tyrannosauridae indet. (Fig. 25). Due to the presence of
1285 numerous juvenile features, which are seen in young individuals of *Tyrannosaurus rex*, and many
1286 shared similarities with juvenile *Tarbosaurus bataar* and putative representative of that species
1287 (‘*Shanshanosaurus*’) we propose that *B. ostromi* is a juvenile tyrannosaurid. There are two features
1288 distinguishing *B. ostromi* from other tyrannosaurids: the ridge separating two depressions on the
1289 lateral surface of the postacetabular process and the presence of a double surangular foramen. The
1290 latter we interpret as a result of ongoing bone resorption due to the entrance of the pneumatic
1291 diverticulum into the surangular. Three (or four) previously known tyrannosaurids co-occur in the
1292 Nemegt Formation: *T. bataar*, *Alioramus altai*, and *A. remotus* (and maybe *R. kriegsteni*), and the
1293 morphology of the mandible suggest that *B. ostromi* is most similar to juvenile *T. bataar*. However,
1294 due to the lack of diagnostic features in the preserved material, which would clearly indicate its
1295 taxonomic identity, and the confounding issues of individual and ontogenetic variation in
1296 tyrannosaurids, we simply conclude at the moment that *Bagaraatan* is a juvenile tyrannosaurid, of
1297 uncertain species placement. Yet, we do not elect to formally sink *B. ostromi* as a name, because
1298 we have identified some potentially diagnostic features at the species level, and because
1299 tyrannosaurid specimens are commonly found in the Nemegt Formation, meaning that future
1300 discoveries should help clarify this taxonomic issue.

1301 1302 COMPETING INTERESTS

1303 The authors declare that they have no competing interests.

1304
1305

REFERENCES

- 1306
1307 **Alifanov VR. 2012.** Suborder Theropoda. In: Kurochin EN, In: Lopatin A V., eds. *Fossil*
1308 *vertebrates of Russia and adjacent countries. Part 2: Fossil reptiles and birds.* Moscow: CEOS,
1309 169–240.
- 1310 **Andrews CW. 1913.** On some bird remains from the Upper Cretaceous of Transylvania.
1311 *Geological Magazine* 5: 193–196.
- 1312 **Atkins-Weltman; K.L.; Simon; J.D.; Woodward; H.N.; Funston; G.F.; Snively; E.R.**
1313 Accepted pending minor revisions. A new oviraptorosaur (Dinosauria: Theropoda) from the end-
1314 Maastrichtian Hell Creek Formation of North America. *PLoS ONE* manuscript no PONE-D-23-
1315 20976 [Resubmitted July 5; 2023].
- 1316 **Barsbold R. 1974.** Saurornithoididae, a new family of small theropod dinosaurs from Central
1317 Asia and North America. *Palaeontologia Polonica* 30: 5–22.
- 1318 **Barsbold R, Osmólska H, Watabe M, Curte PJ, Tsogtbaatar K. 2000.** A new oviraptorosaur
1319 (Dinosauria , Theropoda) from Mongolia: the first dinosaur with a pygostyle. *Acta Geologica*
1320 *Polonica* 45: 97–106.
- 1321 **Bell P, Currie PJ, Lee YN. 2012.** Tyrannosaur feeding traces on *Deinocheirus* (Theropoda:?
1322 Ornithomimosauria) remains from the Nemegt Formation (Late Cretaceous), Mongolia.
1323 *Cretaceous Research* 37: 186–190.
- 1324 **Bremer JL. 1940.** The pneumatization of the humerus in common fowl and the associated
1325 activity of theelin. *Anatomical Record* 77: 197–211.
- 1326 **Brochu CA. 2003.** Osteology of *Tyrannosaurus rex*: insights from a nearly complete skeleton
1327 and high-resolution computed tomographic analysis of the skull. *Journal of Vertebrate*
1328 *Paleontology* 22: 1–138.
- 1329 **Brusatte SL. 2013.** The Phylogeny of Basal Coelurosaurian Theropods (Archosauria:
1330 Dinosauria) and Patterns of Morphological Evolution during the Dinosaur-Bird Transition.
1331 Unpublished PhD Dissertation, Columbia University, New York.
- 1332 **Brusatte SL, Carr TD. 2016.** The phylogeny and evolutionary history of tyrannosauroid
1333 dinosaurs. *Scientific Reports* 6: 1–8.
- 1334 **Brusatte SL, Carr TD, Erickson GM, Bever GS, Norell MA. 2009.** A long-snouted,
1335 multihorned tyrannosaurid from the Late Cretaceous of Mongolia. *Proceedings of the National*
1336 *Academy of Sciences of the United States of America* 106: 17261–17266.
- 1337 **Brusatte SL, Carr TD, Norell MA. 2012.** The osteology of *Alioramus*, a gracile and long-
1338 snouted tyrannosaurid (Dinosauria: Theropoda) from the Late Cretaceous of Mongolia. *Bulletin*
1339 *of the American Museum of Natural History* 366: 1–197.
- 1340 **Brusatte SL, Carr TD, Williamson TE, Holtz TR, Hone DWE, Williams SA. 2016.** Dentary
1341 groove morphology does not distinguish ‘ *Nanotyrannus* ’ as a valid taxon of tyrannosauroid
1342 dinosaur . Comment on : “ Distribution of the dentary groove of theropod dinosaurs :
1343 Implications for theropod phylogeny and the validity of the genu. *Cretaceous Research* 65: 232–
1344 237.
- 1345 **Brusatte SL, Lloyd GT, Wang SC, Norell MA. 2014.** Gradual assembly of avian body plan
1346 culminated in rapid rates of evolution across the dinosaur-bird transition. *Current Biology* 24:
1347 2386–2392.
- 1348 **Brusatte SL, Norell MA, Carr TD, Erickson GM, Hutchinson JR, Balanoff AM, Bever GS,**
1349 **Choiniere JN, Makovicky PJ, Xu X. 2010.** Tyrannosaur paleobiology: new research on ancient
1350 exemplar organisms. *Science* 329: 1481–1485.
- 1351 **Carr TD. 1999.** Craniofacial ontogeny in Tyrannosauridae (Dinosauria, Coelurosauria). *Journal*
1352 *of Vertebrate Paleontology* 19: 497–520.
- 1353 **Carr TD. 2020.** A high-resolution growth series of *Tyrannosaurus rex* obtained from multiple

1354 lines of evidence. *PeerJ* 8: e9192.

1355 **Carr TD. 2023.** A reappraisal of tyrannosauroid fossils from the Iren Dabasu Formation
1356 (Coniacian–Campanian); Inner Mongolia; People’s Republic of China. *Journal of Vertebrate*
1357 *Paleontology* e2199817.

1358 **Carr TD, Williamson TE. 2004.** Diversity of late Maastrichtian Tyrannosauridae (Dinosauria:
1359 Theropoda) from western North America. *Zoological Journal of the Linnean Society* 142: 479–
1360 523.

1361 **Carr TD, Williamson TE. 2010.** *Bistahieversor sealeyi*, gen. et sp. nov., a new tyrannosauroid
1362 from New Mexico and the origin of deep snouts in Tyrannosauroidea. *Journal of Vertebrate*
1363 *Paleontology* 30: 1–16.

1364 **Carr TD, Williamson TE, Britt BB, Stadtman K. 2011.** Evidence for high taxonomic and
1365 morphologic tyrannosaurid diversity in the Late Cretaceous (Late Campanian) of the American
1366 Southwest and a new short-skulled tyrannosaurid from the Kaiparowits formation of Utah.
1367 *Naturwissenschaften* 98: 241–246.

1368 **Carrano MT, Hutchinson JR. 2002.** Pelvic and hindlimb musculature of *Tyrannosaurus rex*
1369 (Dinosauria: Theropoda). *Journal of Morphology* 253: 207–228.

1370 **Cau A, Madzia D. 2021.** The phylogenetic affinities and morphological peculiarities of the bird-
1371 like dinosaur *Borogovia gracilicrus* from the Upper Cretaceous of Mongolia. *PeerJ* 9: e12640.

1372 **Chinsamy-Turan, A. 2005.** *The microstructure of dinosaur bone*. Johns Hopkins University
1373 Press, 1-216.

1374 **Choiniere JN, Clark JM, Forster CA, Xu X. 2010.** A basal coelurosaur (Dinosauria:
1375 Theropoda) from the Late Jurassic (Oxfordian) of the Shishugou Formation in Wucuiwan,
1376 People’s Republic of China. *Journal of Vertebrate Paleontology* 30: 1773–1793.

1377 **Cope ED. 1866.** Discovery of a gigantic dinosaur in the Cretaceous of New Jersey. *Proceedings*
1378 *of the Academy of Natural Sciences of Philadelphia* 18: 275–279.

1379 **Csiki Z, Grigorescu D. 1998.** Small theropods from the Late Cretaceous of the Hateg basin
1380 (Western Romania) an unexpected diversity at the top of the food chain. *Oryctos* 1: 87–104.

1381 **Cullen TM, Simon DJ, Benner EKC, Evans DC. 2021.** Morphology and osteohistology of a
1382 large-bodied caenagnathid (Theropoda, Oviraptorosauria) from the Hell Creek Formation
1383 (Montana): implications for size-based classifications and growth reconstruction in theropods.
1384 *Papers in Palaeontology* 7: 751–767.

1385 **Currie PJ. 2003a.** Theropods from the Cretaceous of Mongolia. In: Benton MJ, In: Shishkin
1386 MA, In: Unwin DM, In: Kurochkin EN, eds. *The Age of Dinosaurs in Russia and Mongolia*.
1387 Cambridge: Cambridge University Press, 434–455.

1388 **Currie PJ. 2003b.** Allometric growth in tyrannosaurids (Dinosauria: Theropoda) from the Upper
1389 Cretaceous of North America and Asia. *Canadian Journal of Earth Sciences* 40: 651–665.

1390 **Currie PJ, Dong ZM. 2001.** New information on *Shanshanosaurus huoyanshanensis*, a juvenile
1391 tyrannosaurid (Theropoda, Dinosauria) from the Late Cretaceous of China. *Canadian Journal of*
1392 *Earth Sciences* 38: 1729–1737.

1393 **Currie PJ, Funston GF, Osmólska H. 2016.** New specimens of the crested theropod dinosaur
1394 *Elmisaurus rarus* from Mongolia. *Acta Palaeontologica Polonica* 61: 143–157.

1395 **Currie PJ, Hurum JH, Sabath K. 2003.** Skull structure and evolution in tyrannosaurid
1396 dinosaurs. *Acta Palaeontologica Polonica* 48: 227–234.

1397 **Currie PJ, Peng JH. 1993.** A juvenile specimen of *Saurornithoides mongoliensis* from the
1398 Upper Cretaceous of Northern China. *Canadian Journal of Earth Sciences* 30: 2224–2230.

1399 **Currie J, Russell DA. 1987.** Osteology and relationships of *Chirostenotes pergracilis*
1400 (Saurischia, Theropoda) from the Judith River (Oldman) Formation of Alberta, Canada.
1401 *Canadian Journal of Earth Sciences* 25: 972–986.

1402 **Dalman SG. 2013.** New Examples of *Tyrannosaurus rex* from the Lance Formation of
1403 Wyoming, United States. *Bulletin of the Peabody Museum of Natural History* 54: 241–254.
1404 **Dong Z. 1977.** On the dinosaurian remains from Turpan, Xinjiang. *Vertebrata Palasiatica* 15:
1405 59–66.
1406 **Fanti F, Currie PJ, Badamgarav D. 2012.** New Specimens of *Nemegtomaia* from the
1407 Baruungoyot and Nemegt Formations (Late Cretaceous) of Mongolia. *PLoS ONE* 7: e31330.
1408 **Foster W, Brusatte SL, Carr TD, Williamson TE, Yi L, Lü J. 2021.** The cranial anatomy of
1409 the long-snouted tyrannosaurid dinosaur *Qianzhousaurus sinensis* from the Upper Cretaceous of
1410 China. *Journal of Vertebrate Paleontology* 41: e1999251.
1411 **Fowler DW, Woodward HN, Freedman EA, Larson PL, Horner JR. 2011.** Reanalysis of
1412 *Raptorex kriegsteini*; a juvenile tyrannosaurid dinosaur from Mongolia. *PLoS ONE* 6: e21376.
1413 **Funston GF. 2020.** Caenagnathids of the Dinosaur Park Formation (Campanian) of Alberta,
1414 Canada: anatomy, osteo-histology, taxonomy, and evolution. *Vertebrate Anatomy Morphology*
1415 *Palaeontology* 8: 105–153.
1416 **Funston GF, Chinzorig T, Tsogtbaatar K, Kobayashi Y, Sullivan C, Currie PJ,**
1417 **Tsogtbaatar K, Kobayashi Y, Sullivan C, Pj C. 2020a.** A new two-fingered dinosaur sheds
1418 light on the radiation of Oviraptorosauria. *Royal Society Open Science* 7: 201184.
1419 **Funston GF, Currie PJ. 2018.** A small caenagnathid tibia from the Horseshoe Canyon
1420 Formation (Maastrichtian): Implications for growth and lifestyle in oviraptorosaurs. *Cretaceous*
1421 *Research* 92: 220–230.
1422 **Funston GF, Currie PJ, Eberth DA, Ryan MJ, Ch T, Badamgarav D, Longrich NR. 2016.**
1423 The first oviraptorosaur (Dinosauria: Theropoda) bonebed: evidence of gregarious behaviour in a
1424 maniraptoran theropod. *Scientific reports* 6: 1–13.
1425 **Funston GF, Currie PJ, Tsogtbaatar C, Khishigjav T. 2021.** A partial oviraptorosaur skeleton
1426 suggests low caenagnathid diversity in the Late Cretaceous Nemegt Formation of Mongolia.
1427 *PLoS ONE* 16: e0254564.
1428 **Funston GF, Mendonca SE, Currie PJ, Barsbold R. 2018.** Oviraptorosaur anatomy , diversity
1429 and ecology in the Nemegt Basin. *Palaeogeography, Palaeoclimatology, Palaeoecology* 494:
1430 101–120.
1431 **Funston GF, Powers MJ, Whitebone A, Brusatte SL, Scannella JB, Horner JR, Currie PJ.**
1432 **2020b.** Baby tyrannosaurid bones and teeth from the Late Cretaceous of western North
1433 America.pdf. *Canadian Journal of Earth Sciences* 58: 756–777.
1434 **Gao C, Morschhauser EM, Varricchio DJ, Liu J, Zhao B. 2012.** A second soundly sleeping
1435 dragon: new anatomical details of the Chinese troodontid *Mei long* with implications for
1436 phylogeny and taphonomy. *PLoS ONE* 7: e45203.
1437 **Gilmore CW. 1924.** A new coelurid dinosaur from the Belly River Cretaceous of AlberT.
1438 *Canada Department of Mines Geological Survey Bulletin (Geological Series)* 38: 1–12.
1439 **Gold MEL, Brusatte SL, Norell MA. 2013.** The cranial pneumatic sinuses of the tyrannosaurid
1440 *Alioramus* (Dinosauria: Theropoda) and the evolution of cranial pneumaticity in theropod
1441 dinosaurs. *American Museum Novitates* 3790: 1–46.
1442 **Goloboff P, Farris S, Nixon K. 2008.** TNT, a free programm for phylogenetic analysis.
1443 *Cladistics* 24: 774–786.
1444 **Harrison CJO, Walker CA. 1975.** The Bradycnemidae, a new family of owls from the Upper
1445 Cretaceous of Romania. *Palaeontology* 18: 563–570.
1446 **Holtz TR. 1998.** A new phylogeny of the carnivorous dinosaurs. *GALIA - Ecological Perspectives*
1447 *on Science and Society* 15: 5–61.
1448 **Holtz TRJ. 2004.** Tyrannosauroida. In: Weishampel DB,, In: Dodson P,, In: Osmólska H, eds.
1449 *The Dinosauria*. Berkeley: University of California Press, .

1450 **Huene F v. 1932.** Die fossile Reptil-Ordnung Saurischia, ihre Entwicklung und Geschichte.
1451 *Monographien zur Geologie und Palaeontologie, series 1* 4: 1–361.

1452 **Hurum JH, Sabath K. 2003.** Giant theropod dinosaurs from Asia and North America: Skulls of
1453 *Tarbosaurus bataar* and *Tyrannosaurus rex* compared. *Acta Palaeontologica Polonica* 48: 161–
1454 190.

1455 **Hutchinson JR. 2001.** The evolution of femoral osteology and soft tissues on the line to extant
1456 birds The evolution of femoral osteology and soft tissues on the line to extant birds (Neornithes).
1457 *Zoological Journal of the Linnean Society* 131: 169–197.

1458 **Hutt S, Naish D, Martill DM, Barker MJ, Newbery P. 2001.** A preliminary account of a new
1459 tyrannosauroid theropod from the Wessex Formation (Early Cretaceous) of Southern England.
1460 *Cretaceous Research* 22: 227–242.

1461 **Kurzanov SM. 1976.** A New Carnosaur from the Late Cretaceous of Nogon-Tsav, Mongolia. In:
1462 Kramarenko et al., ed. *Paleontology and Biostratigraphy of Mongolia. The Joint Soviet-*
1463 *Mongolian Paleontological Expedition, Transactions.*93-104.

1464 **Kurzanov SM. 1981.** An unusual theropod from the Upper Cretaceous of Mongolia. *Fossil*
1465 *Vertebrates of Mongolia. Joint Soviet-Mongolian Paleontological Expedition.*39–49.

1466 **Kurzanov SM. 1987.** Avimimidae and the problem of the origin of birds. *Trudy Sowmectnoj*
1467 *Cobwetchko-Mongolckoj Paleontologičeckoj Ekspedicii* 31: 1–92.

1468 **Kurzanov SM, Osmólska H. 1991.** *Tochisaurus nemegtensis* gen. et sp. n., a new troodontid
1469 (Dinosauria, Theropoda) from Mongolia. *Acta Palaeontologica Polonica* 36: 69–76.

1470 **Lamanna MC, Sues HD, Schachner ER, Lyson TR. 2014.** A new large-bodied
1471 oviraptorosaurian theropod dinosaur from the Latest Cretaceous of Western North America.
1472 *PLoS ONE* 9: e92022.

1473 **Lambe LM. 1914.** On the fore-limb of a carnivorous dinosaur from the Belly River Formation
1474 of Alberta, and a new genus of Ceratopsia from the same horizon, with remarks on the
1475 integument of some Cretaceous herbivorous dinosaurs. *Ottawa Naturalist* 27: 129–135.

1476 **Larson P, Parrish JM. 2013.** The case for *Nanotyrannus*. *Tyrannosaurid paleobiology.*15–53.

1477 **Lee S, Park J young, Lee Y nam, Kim S hwan, Lü J. 2019.** A new alvarezsaurid dinosaur
1478 from the Nemegt Formation of Mongolia. *Scientific Reports* 9: 15493.

1479 **Li D, Norell MA, Gao K qin, Smith ND, Makovicky PJ. 2010.** A longirostrine tyrannosauroid
1480 from the Early Cretaceous of China. : 183–190.

1481 **Loewen MA, Irmis RB, Sertich JJW, Currie PJ, Sampson SD. 2013.** Tyrant dinosaur
1482 evolution tracks the rise and fall of late Cretaceous oceans. *PLoS ONE* 8: e79420.

1483 **Lu J, Tomida Y, Azuma Y, Dong Z. 2005.** *Nemegtomaia* gen. nov., a replacement name for the
1484 oviraptorosaurian dinosaur *Nemegtia* Lü et al. 2004, a preoccupied name. *Bulletin of the*
1485 *National Science Museum, Tokyo, Series C* 31: 51.

1486 **Lu J, Yi L, Brusatte SL, Yang L, Li H, Chen L. 2014.** A new clade of Asian Late Cretaceous
1487 long-snouted tyrannosaurids. *Nature Communications* 5: 3788.

1488 **Madsen JH. 1974.** A new theropod dinosaur from the Upper Jurassic of Utah. *Journal of*
1489 *Paleontology* 48: 27–31.

1490 **Maleev EA. 1955.** Giant carnivorous dinosaurs of Mongolia. *Doklady Akademii Nauk SSSR* 104:
1491 634–637.

1492 **Maleev EA. 1974.** Gigantic carnosaurs of the family Tyrannosauridae. *he Joint Soviet-*
1493 *Mongolian Paleontological Expedition Transactions* 1: 132–191.

1494 **Naish D, Dyke GJ. 2004.** *Heptasteornis* was no ornithomimid, troodontid, dromaeosaurid or
1495 owl: the first alvarezsaurid (Dinosauria: Theropoda) from Europe. *Neues Jahrbuch für Geologie*
1496 *und Paläontologie - Monatshefte* 7: 385–401.

1497 **Napoli JG, Ruebenstahl AA, Turner AH, Norell MA. 2021.** A New Dromaeosaurid

1498 (Dinosauria: Coelurosauria) from Khulsan, Central Mongolia. *American Midland Naturalist*
1499 3982: 1–48.

1500 **Nesbitt S, RK DJ, Loewen M, Brusatte S, Smith N, Turner A, Kirkland J, McDonald A,**
1501 **Wolfe D. 2019.** A mid-Cretaceous tyrannosauroid and the origin of North American end-
1502 Cretaceous dinosaur assemblages. *Nature Ecology & Evolution* 3: 892–899.

1503 **Norell MA, Makovicky PJ, Bever GS, Balanoff AM, Clark JM, Barsbold R, Rowe TB.**
1504 **2009.** A review of the Mongolian Cretaceous dinosaur *Saurornithoides*. *American Museum*
1505 *Novitates* 3654: 1–63.

1506 **Osborn HF. 1905.** *Tyrannosaurus* and other Cretaceous carnivorous dinosaurs. *Bulletin of the*
1507 *AMNH* 21: 259–265.

1508 **Osmólska H. 1981.** Coossified tarsometatarsi in theropod dinosaurs and their bearing on the
1509 problem of bird origins. *Paleontologia Polonica* 42: 79–95.

1510 **Osmólska H. 1987.** *Borogovia gracilicrus* gen. et sp. n., a new troodontid dinosaur from the
1511 Late Cretaceous of Mongolia. *Acta Palaeontologica Polonica* 32: 133–150.

1512 **Osmólska H. 1996.** An unusual theropod dinosaur from the Late Cretaceous Nemegt Formation
1513 of Mongolia. *Acta Palaeontologica Polonica* 41: 1–38.

1514 **Osmólska H, Roniewicz E. 1970.** Deinocheiridae, a new family of theropod dinosaurs.
1515 *Palaentologica Polonica* 21: 5–19.

1516 **Osmólska H, Roniewicz E, Barsbold R. 1972.** A new dinosaur, *Gallimimus bullatus* n. gen., n.
1517 sp. (Ornithomimidae) from the Upper Cretaceous of Mongolia". *Palaentologia Polonica* 27:
1518 103–143.

1519 **Ostrom JH. 1970.** Stratigraphy and paleontology of the Cloverly Formation (Lower Cretaceous)
1520 of the Bighorn Basin area, Wyoming and Montana. *Bulletin of the Peabody Museum of Natural*
1521 *History* 35: 1–356.

1522 **Padian K, Lamm ET. 2013.** *Bone Histology of Fossil Tetrapods*. Berkeley, Los Angeles,
1523 California: University of California Press.

1524 **Perle A, Chiappe LM, Barsbold R, Clarke JM, Norell MA. 1994.** Skeletal morphology of
1525 *Mononykus olecranus* (Theropoda: Avialae) from the Late Cretaceous of Mongolia. *American*
1526 *Museum Novitates*: 1–29.

1527 **Perle A, Norell MA, Chiappe LM, Clark JM. 1993.** Flightless bird from the Cretaceous of
1528 Mongolia. *Nature* 362: 623–626.

1529 **Rauhut OWM. 2000.** The interrelationships and evolution of basal theropods (Dinosauria,
1530 Saurischia). Unpublished thesis, University of Bristol.

1531 **Rauhut OWM. 2003.** A tyrannosauroid dinosaur from the Upper Jurassic of Portugal.
1532 *Palaentologia* 46: 903–910.

1533 **Rauhut OWM, Milner AC, Moore-Fay S. 2010.** Cranial osteology and phylogenetic position
1534 of the theropod dinosaur *Proceratosaurus bradleyi* (Woodward, 1910) from the Middle Jurassic
1535 of England. *Zoological Journal of the Linnean Society* 158: 155–195.

1536 **Rauhut OWM, Xu X. 2005.** The small theropod dinosaurs *Tugulusaurus* and *Phaedrolosaurus*
1537 from the Early Cretaceous of Xinjiang, China. *Journal of Vertebrate Paleontology* 25: 107–118.

1538 **Sereno PC, Tan L, Brusatte SL, Kriegerstein HJ, Zhao X, Cloward K. 2009.** Tyrannosaurid
1539 skeletal design first evolved at small body size. *Science* 326: 418–423.

1540 **Stefanic CM, Nesbitt SJ. 2019.** The evolution and role of the hyposphene-hypantrum
1541 articulation in Archosauria: phylogeny, size and/or mechanics? *Royal Society Open Science* 6: 1–
1542 27.

1543 **Tschopp E, Mateus O, Benson RB. 2015.** A specimen-level phylogenetic analysis and
1544 taxonomic revision of Diplodocidae (Dinosauria, Sauropoda). *PeerJ*, 3, e857.

1545 **Tsuihiji T, Watabe M, Tsogtbaatar K, Tsubamoto T, Barsbold R, Suzuki S, Lee AH,**

- 1546 **Ridgely RC, Kawahara Y, Witmer LM. 2011.** Cranial osteology of a juvenile specimen of
 1547 *Tarbosaurus bataar* (Theropoda, Tyrannosauridae) from the Nemegt Formation (Upper
 1548 Cretaceous) of Bugin Tsav, Mongolia. *Journal of Vertebrate Paleontology* 31: 497–517.
- 1549 **Voris JT, Therrien F, Zelenitsky DK, Brown CM. 2020.** A new tyrannosaurine
 1550 (Theropoda: Tyrannosauridae) from the Campanian Foremost Formation of Alberta, Canada,
 1551 provides insight into the evolution and biogeography of tyrannosaurids. *Cretaceous Research*
 1552 110: 104388.
- 1553 **Voris JT, Zelenitsky DK, Therrien F, Ridgely RC, Currie PJ, Witmer LM. 2021.** Two
 1554 exceptionally preserved juvenile specimens of *Gorgosaurus libratus* (Tyrannosauridae,
 1555 Albertosaurinae) provide new insight into the timing of ontogenetic changes in tyrannosaurids.
 1556 *Journal of Vertebrate Paleontology* 41: 1–21.
- 1557 **Wan X, Chen P, Wei M. 2007.** The Cretaceous System in China. *Acta Geologica Sinica* 81:
 1558 957–983.
- 1559 **Wedel M. 2007.** Postcranial pneumaticity in dinosaurs and the origin of the avian lung.
 1560 Unpublished thesis, University of California.
- 1561 **Witmer LM. 1997.** The Evolution of the Antorbital Cavity of Archosaurs: A Study in Soft-
 1562 Tissue Reconstruction in the Fossil Record with an Analysis of the Function of
 1563 Pneumaticity. *Journal of Vertebrate Paleontology*, 17: 1–76.
- 1564 **Xu X, Norell MA, Kuang X, Wang X, Zhao Q, Jia C. 2004.** Basal tyrannosauroids from China
 1565 and evidence for protofeathers in tyrannosauroids. *Nature* 431: 680–684.

1566
 1567 FIGURES

1568 Figure 1. Mandible of *Bagaraatan ostromi* ZPAL MgD-I/108 in lateral (A); medial (B); dorsal
 1569 (C); and posterior (D) view. E; the preserved part distal part of the mandible in anterior view. F;
 1570 dentary in anterior view.

1571
 1572 Figure 2. Details of the dentary of *Bagaraatan ostromi* ZPAL MgD-I/108 in dorsal (A); anterior
 1573 (B); posterior (C); ventral (D); lateral (E); and medial (F) view.

1574
 1575 Figure 3. Comparison of *Bagaraatan ostromi* (A–B) and *Tarbosaurus bataar* (C–J) dentaries. A–
 1576 B; ZPAL MgD-I/108 in medial (A); and lateral (B) view. C–D; ZPAL MgD-I/75 in medial (C);
 1577 and lateral (D) view. E–F; ZPAL MgD-I/175 in medial (E); and lateral (F) view. G–H; ZPAL
 1578 MgD-I/4 in medial (G); and lateral (H) view. I–J; ZPAL MgD-I/5 in medial (I); and lateral (J)
 1579 view. Note the anterior margin of the dentary is steepens with ontogeny and the dentary becomes
 1580 taller dorsoventrally. The ‘chin’ is distinct and the anterior end of the dentary is expanded through
 1581 the ontogeny.

1582
 1583 Figure 4. Details of the posterior mandible of *Bagaraatan ostromi* ZPAL MgD-I/108 in lateral
 1584 (A); dorsal (B); ventral (C); medial (D); posterior (E); and anterior (F) view.

1585
 1586 Figure 5. Comparison of *Bagaraatan ostromi* (A) and *Tarbosaurus bataar* (B–E) distal end of the
 1587 mandible in lateral view. A; ZPAL MgD-I/108. B; ZPAL MgD-I/31. C; ZPAL MgD-I/3. D; MPC-
 1588 D 107/14. E; ZPAL MgD-I/4. F; ZPAL MgD-I/5. Note the exceptionally small surangular foramen
 1589 in the medium-sized individual MPC-D 107/14 (D) in comparison to similar-sized ZPAL MgD-
 1590 I/3 (C). Asterisks indicate the posterior surangular foramen. Note, that the placement of the double

1591 surangular foramina in *B. ostromi* is similar to the enlarged posterior surangular foramen in *T.*
1592 *bataar*. During ontogeny, the surangular shelf is facing more laterally and the glenoid gets longer
1593 anteroposteriorly.

1594
1595 Figure 6. Cervical vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; anterior cervical
1596 vertebrae in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1597 view. G–L; posterior cervical vertebrae in anterior (G); left lateral (H); posterior (I); right lateral
1598 (J); dorsal (K); and ventral (L) view.

1599
1600 Figure 7. Anterior caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 4th caudal
1601 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1602 view. G–L; 5th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1603 (K); and ventral (L) view.

1604
1605 Figure 8. Anterior caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 6th caudal
1606 vertebra anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1607 view. G–L; 7th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1608 (K); and ventral (L) view.

1609
1610 Figure 9. Anterior caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 8th caudal
1611 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1612 view. G–L; 9th–10th caudal vertebrae in anterior (G); posterior (H); dorsal (I); left lateral (J); right
1613 lateral (K); and ventral (L) view.

1614
1615 Figure 10. Middle caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 11th caudal
1616 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1617 view. G–L; 12th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1618 (K); and ventral (L) view.

1619
1620 Figure 11. Middle caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 13th caudal
1621 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1622 view. G–L; 14th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1623 (K); and ventral (L) view. M–R; 15th caudal vertebra in anterior (M); left lateral (N); posterior (O);
1624 right lateral (P); dorsal (Q); and ventral (R) view.

1625
1626 Figure 12. Middle caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 16th caudal
1627 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1628 view. G–L; 17th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1629 (K); and ventral (L) view. M–R; 18th caudal vertebra in anterior (M); left lateral (N); posterior (O);
1630 right lateral (P); dorsal (Q); and ventral (R) view.

1631

1632 Figure 13. Posterior caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 19th caudal
1633 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1634 view. G–L; 20th caudal vertebra in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1635 (K); and ventral (L) view. M–R; 21st–23th caudal vertebrae in anterior (M); left lateral (N); dorsal
1636 (O); ventral (P); posterior (Q); and right lateral (R) view.

1637
1638 Figure 14. Posterior caudal vertebrae of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; 24th caudal
1639 vertebra in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1640 view. G–L; indeterminate posterior caudal vertebra in anterior (G); left lateral (H); posterior (I);
1641 right lateral (J); dorsal (K); and ventral (L) view. G–L; indeterminate posterior caudal vertebra in
1642 anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal (K); and ventral (L) view. M–R;
1643 indeterminate posterior caudal vertebra in anterior (M); left lateral (N); posterior (O); right lateral
1644 (P); dorsal (Q); and ventral (R) view. S–Y; indeterminate posterior caudal vertebra in anterior (S);
1645 left lateral (T); posterior (U); right lateral (W); dorsal (X); and ventral (Y) view. Z–E’;
1646 indeterminate posterior caudal vertebra in anterior (Z); left lateral (A’); posterior (B’); right lateral
1647 (C’); dorsal (D’); and ventral (E’) view.

1648
1649 Figure 15. Two incomplete haemal arches of *Bagaraatan ostromi* ZPAL MgD-I/108. A–F; Haemal
1650 arch A in anterior (A); left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F)
1651 view. G–L; Haemal arch B in anterior (G); left lateral (H); posterior (I); right lateral (J); dorsal
1652 (K); and ventral (L) view.

1653
1654 Figure 16. Ilium of *Bagaraatan ostromi* ZPAL MgD-I/108. A–B; fragment of left preacetabular
1655 process in lateral (A) and medial (B) view. C–F; left postacetabular process in lateral (C); medial
1656 (D); dorsal (E); and ventral (F) view. G–J; right postacetabular process in dorsal (G); ventral (H);
1657 lateral (I); and medial (J) view. K–N; two fragments of ilium blade in lateral (K; M) and medial
1658 (L; N) view.

1659
1660 Figure 17. Pubes of *Bagaraatan ostromi* ZPAL MgD-I/108. A–E; left pubis with proximal end of
1661 the ischium in lateral (A); medial (B); dorsal (C); posterior (D); and anterior (E) view. F–G; right
1662 pubis in lateral (F) and medial (G) view.

1663
1664 Figure 18. Left pes phalanx IV-1 of *Bagaraatan ostromi* ZPAL MgD-I/108 in dorsal (A); lateral
1665 (B); anterior (C); plantar (D); medial (E); and posterior (F) view.

1666
1667 Figure 19. Various bones of Caenagnathidae indet. ZPAL MgD-I/108/1. A–F; caudal vertebra in
1668 (A) anterior; left lateral (B); posterior (C); right lateral (D); dorsal (E); and ventral (F) view. G–
1669 H; proximal part of dorsal rib. I–N; manus ungual II-3 in dorsal (I); medial (J); ventral (K);
1670 lateral (L); anterior (M); and posterior (N) view. O–T; left manus phalanx II-1 in medial (O);
1671 ventral (P); lateral (Q); dorsal (R); anterior (M); and posterior (N) view. U–A’; left pedal phalanx
1672 II-2 in medial (U); ventral (W); lateral (X); dorsal (Y); anterior (Z); and posterior (A’) view.

1673

1674 Figure 20. Left femur of Caenagnathidae indet. ZPAL MgD-I/108/1. A–E; proximal end of the
1675 femur in anterior (A); lateral (B); posterior (C); medial (D); and dorsal (E) view. F–J; distal end
1676 of the femur in anterior (F); lateral (G); posterior (H); medial (I); and ventral (J) view. K–L; thin
1677 section of the femoral cortex under polarized light. Red arrows indicate secondary osteons; green
1678 arrows point resorption cavities; yellow arrows indicate lamellar bone; and purple arrows point
1679 parallel-fibered bone.

1680
1681 Figure 21. Left tibiotarsus of Caenagnathidae indet. ZPAL MgD-I/108/1. A–F; tibiotarsus in
1682 anterior (A); lateral (B); posterior (C); medial (D); dorsal (E); and ventral (F) view. G–K; proximal
1683 fibula in dorsal (G); anterior (H); lateral (I); posterior (J); and medial (K).

1684
1685 Figure 22. Plots showing the relationship between the anteroposterior length of the surangular
1686 foramen to the skull length (as a proxy of body size) in tyrannosaurids. *Bagaraatan ostromi*
1687 measured for the single (posterior only) or double (posterior + anterior) foramina. A; regression
1688 analysis including specimens shows a negative slope and a high correlation coefficient. B;
1689 regression analysis for specific taxa shows the same trend. No small-medium-large size of the
1690 surangular foramen distinction can be noticed in the tyrannosaurids.

1691
1692 Figure 23. Strict consensus tree of the Theropod Working Group (TWiG; Brusatte *et al.*; 2014)
1693 phylogenetic analysis, *Bagaraatan ostromi* ZPAL MgD-I/108 is found as basal tyrannosauroid.

1694
1695 Figure 24. Strict consensus tree of the tyrannosaurid phylogeny (the Nesbitt *et al.*; 2019 version
1696 of the Brusatte & Carr, 2016 dataset), *Bagaraatan ostromi* ZPAL MgD-I/108 is placed in a
1697 polytomy within tyrannosaurids.

1698
1699 Figure 25. Reconstruction of *Bagaraatan ostromi* ZPAL MgD-I/108 including only
1700 tyrannosaurid bones found in the assemblage and life reconstruction of the dinosaur by Jakub
1701 Zalewski.

1702
1703 TABLES

1704 Tab. 1. Measurements of the tooth alveoli (anteroposterior length to labiolingual width) in dorsal
1705 view [mm].

1706
1707 Table 2. Measurements of the caudal vertebrae [mm]. * – incomplete.

1708
1709