Supplementary information for 'Palaeopolar marine reptiles from the Early Jurassic of Siberia'

by Nikolay G. Zverkov, Dmitry V. Grigoriev & Igor. G. Danilov

Extended comparative description of materials from the Early Jurassic of Siberia

Preliminary remark. This text represents an initial version of the description of materials. It was reduced in the main text during the revision process, therefore some parts of the description and some photographs overlap with those provided in the main text.

Ichthyosauria

The specimen **ZIN PH 24/211** is a partial rostrum of a large ichthyosaurian with its structure revealed by transverse breakages (Fig. S1a). Partial premaxillae, dentaries and splenials could be identified; however, these are too fragmentary for an adequate description. The teeth are robust and large. The largest preserved tooth is 60 mm high apicobasally, although incompletely preserved (Fig 3a11). The crowns are broken in all preserved teeth, however, their impressions in matrix allow providing taxonomically informative observations. The crowns were textured by shallow and widely spaced apicobasal ridges at the base. The whole enamel was ornamented by fine striations, unlike those robust wrinkles in *Suevoleviathan* Maisch, 1998 (Maxwell, 2018). The root shows a great number of striations formed by plications of the dentine (plicidentine). Most importantly is the presence of at least one carina that could be observed from the impression (Fig S1a13) and its presence is also supported by the keeled cross-sectional shape of the pulp cavity filled with calcite (Fig S1a12). *Temnodontosaurus* Lydekker, 1889 is the only known genus of post-Triassic ichthyosaurians that evolved carinate morphology of the tooth crown, known for three of its species, namely *T. platyodon*, *T. trigonodon* and *T. eurycephalus* (McGowan, 1974; McGowan, 1996; McGowan & Motani, 2003; Martin et al., 2012). Thus, we refer ZIN PH 24/211 to as *Temnodontosaurus* sp. The ammonites reported as collected with this specimen and originally identified as "*Dactylioceras gracile*" and "*D. athleticum*" (information from the label; Kirina, 1966) allow the referral to *Dactylioceras commune* Ammonite Biozone of the lower Toarcian (Kutygin & Knyazev, 2000; Knyazev et al., 2003; Surygin et al., 2011).

Two large ichthyosaurian vertebrae are present in the collection: a caudal centrum **ZIN PH 4/211** (Fig. S1b) is 123 mm in maximum diameter and origins from the *Harpoceras falciferum* zone of the outcrop 18 at Vilyuy River; a probably presacral (uncertain because of poor preservation) centrum **ZIN PH**

2/213 (Fig. S1c) is 130 mm in maximum diameter, it comes from the upper Pliensbachian–Toarcian of the Udzha River basin. These vertebrae further support the presence of large ichthyosaurians in the late Early Jurassic of Eastern Siberia. However, their taxonomic identification is equivocal due to the existence of not only *Temnodontosaurus* but also large leptonectids in the Early Jurassic (e.g. McGowan & Motani, 2003). Therefore, we refer the specimens to as Neoichthyosauria indet.

The specimen **ZIN PH 89/211** is a fragmentary humerus lacking the proximal part and the ulnar facet (Fig. S1d). The proximodistal length as preserved is 95 mm (the reconstructed length would be 13–14 cm), the anteroposterior width of the radial facet is 52 mm; hence the humerus belonged to a moderately large ichthyosaurian. The preserved radial facet is dorsoventrally compressed and tapered anteriorly (Fig. S1d4). Anterior to it, a prominent leading edge tuberosity is present (Fig. S1d2). The posterior portion of the humerus is markedly compressed (Fig. S1d3). Judging from the preserved part, the deltopectoral crest and the dorsal process were relatively well pronounced (Fig. S1d3), thus it is more likely that the specimen represents a thunnosaurian ichthyosaurian, rather than a more basal neoichthyosaurian, in which the trochanters are poorly developed (e.g. Johnson, 1979; McGowan & Motani, 2003). Among the Toarcian thunnosaurians *Stenopterygius uniter* von Huene, 1931 is relatively large, having a humerus exceeding 12 cm in some specimens (Maxwell, 2012). However, this is not a substantial enough reason for taxonomic referral of ZIN PH 89/211, and thus we refer the specimen to as Thunnosauria indet.

ZIN PH 2/211 is a partial skeleton of a small ichthyosaurian originating from the lowermost Toarcian of the outcrop 9, Markha River. This is the only bone association in the collection that undoubtedly represents a single individual. The specimen comprises some fragments of the dermatocranium, one tooth, partially articulated vertebral column, partial coracoid and nearly complete left femur. The preserved portion of the dermatocranium (Fig. S2a) is interpreted as a frontal region with partially exposed nasal, prefrontal, frontal, postfrontal and parietal. If this interpretation is correct, we observe no contact of the prefrontal and frontal, characteristic of basal thunnosaurians (Motani, 2005; Maxwell et al., 2012a, Marek et al., 2015). This condition makes ZIN PH 2/211 more similar to basal neoichthyosaurians as well as to ophthalmosaurids. The preserved tooth has a relatively stout conical crown (basal diameter to apicobasal length ratio = 0.55). The enamel ornamentation is weak and composed of rare striations. The root is only slightly wider than the basal crown, it bears plications, characteristic of non-ophthalmosaurid neoichthyosaurians (Maxwell et al., 2012b).

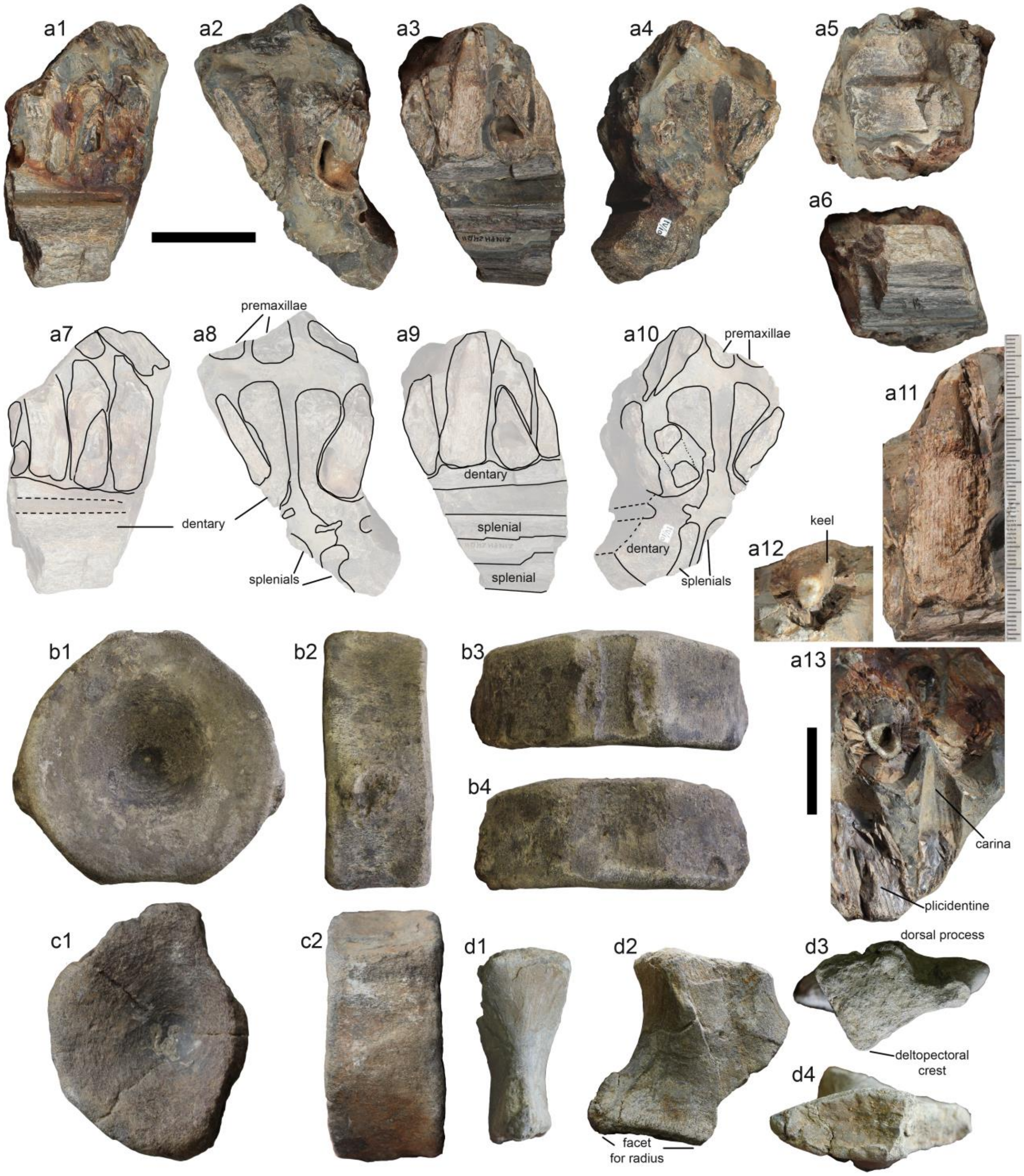

Fig. S1. Remains of large ichthyosaurians from the Pliensbachian–Toarcian of Eastern Siberia. (a) Fragmental rostrum of *Temnodontosaurus* sp. ZIN PH 24/211 in right lateral (a1, a7), posterior (a2, a8), left lateral (a3, a9), anterior (a4, a10), dorsal (a5) and ventral (a6) views, and its teeth (a11 – a13). (b) Neoichthyosauria indet. caudal centrum ZIN PH 4/211 in articular (b1), lateral (b2), dorsal (b3) and ventral (b4) views. (c) Neoichthyosauria indet. presacral centrum ZIN PH 2/213 in articular (c1) and dorsal (c2) views. (d) Neoichthyosauria indet. fragmental humerus ZIN PH 89/211 in anterior (d1), ventral (d2), proximal (d3) and distal (d4) views. Scale bars represent 50 mm for a1–10 and b–d; 20 mm for a11-a13.

The available vertebral centra of ZIN PH 2/211 are from presacral and caudal regions. The anteriormost preserved presacral centrum has diapophyses separated from the neural arch facet and parapophyses confluent with the anterior edge of the centrum (Fig. S2c). In lateral view, the apophyses are located approximately at the mid-height of the centrum equidistantly to dorsal and ventral margins. The ventral surface of the centrum is slightly tapered (Fig. S2c4). The posterior presacral centra have apophyses closely located to each other and shifted to the ventral edge of the centrum (Fig. S2d). The preserved caudal centra are available for all regions of the tail, including the postflexural region. The preflexural centra have circular articular surfaces (Fig. S2e, f, g) and the single circular fib facet located on the mid-height of the centrum. The postflexural centra are slightly mediolaterally compressed and lacking chevron facets (Fig. S2i).

The coracoid of ZIN PH 2/211 is markedly elongated (preserved anteroposterior length to mediolateral width ratio = 1.4). The anteromedial process of the coracoid is relatively poorly developed (Fig. S2k1). The anterior notch was likely small and narrow. Based on preserved part, the posterolateral notch is likely absent, or it was extremely reduced. Among moderate-sized Early Jurassic ichthyosaurians, this condition is characteristic of *Stenopterygius* (e.g. Johnson, 1979; Maisch & Matzke, 2000). The intercoracoidal facet is lenticular in outline with its dorsoventral thickness increasing anteriorly (Fig. S2k2). Judging from the angle between the intercoracoidal surface and the dorsal surface it could be suggested that the angle between the articulated coracoids was close to 170.

Several available distal limb elements are all hexagonal in dorsal/ventral outline.

The left femur is nearly completely preserved. It is oriented based on criteria of Maxwell et al. (2012c). The femur is markedly proximodistally elongated and slender. The distal end is not strongly anteroposteriorly expanded, unlike that distal femoral blade in basal neoichthyosaurians (see e.g. Fischer et al., 2016, character 83; Moon, 2019, character 269). The shaft is straight, unlike that curved in *Ichthyosaurus* (Massare & Lomax, 2019). The dorsal and ventral processes are weak, compared to those of ophthalmosaurids (e.g. Maxwell et al., 2012c). There is a decrease in dorsoventral width between the tibial and fibular facets (Fig. S2l5).

In summary, the combination of features (weak ornamentation of the crown; absence of chevron facets in the postflexural centra; elongated coracoids with relatively short anteromedial process, narrow anterior notch and reduced posterior notch; hexagonal phalanxes; slender and straight femur with minor distal expansion), in our opinion, allows the referral of ZIN PH 2/211 to *Stenopterygius* (see Johnson, 1979; Maisch & Matzke, 2000; McGowan & Motani, 2003; Maisch, 2008; Maxwell et al., 2012a).

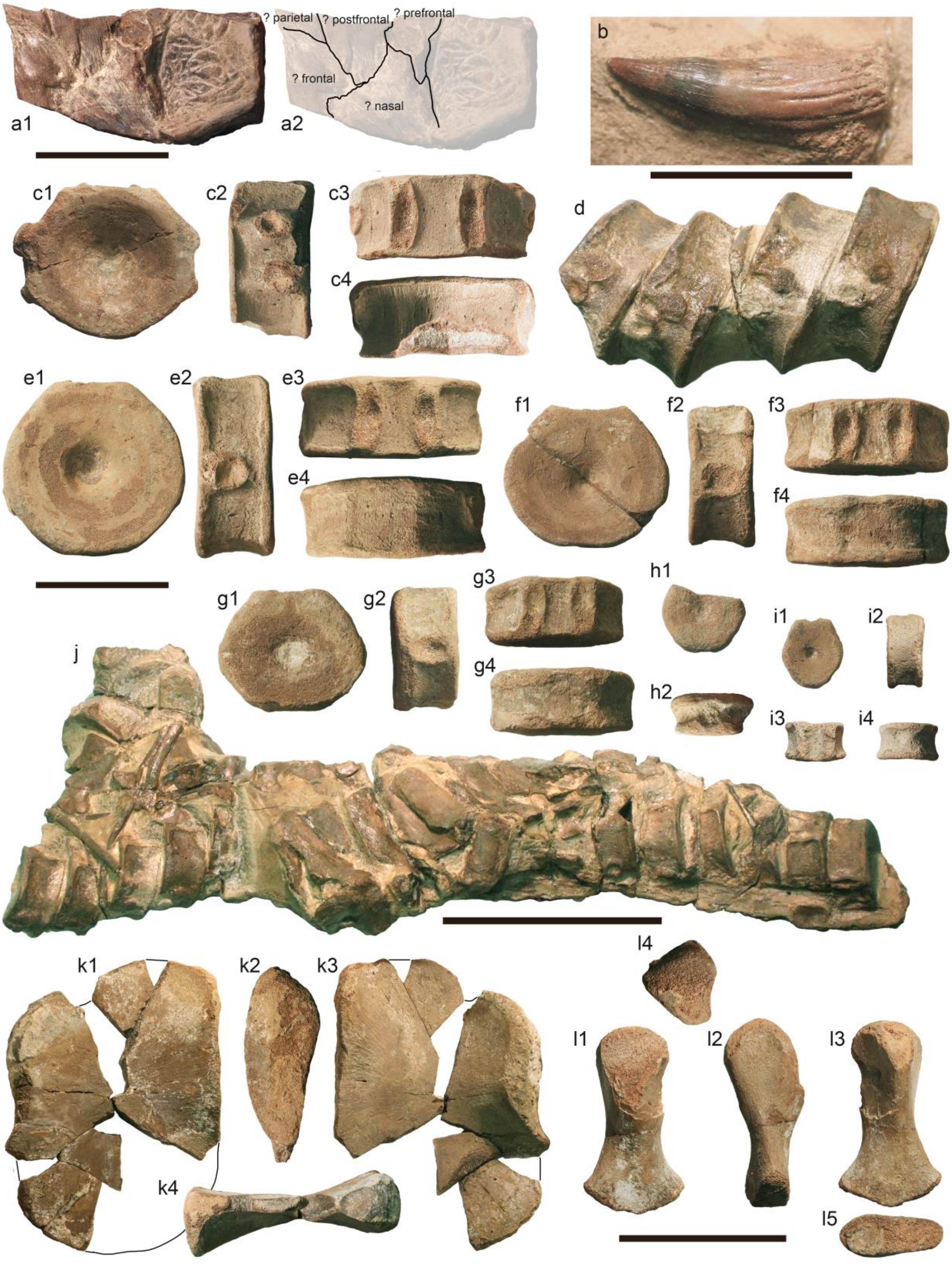

Figure S2. Remains of a small ichthyosaurian ZIN PH 2/211 here referred to as *Stenopterygius* sp. from the lower Toarcian of the Markha River. (a) Partial frontal region of the skull and its interpretation (a2). (b) Isolated tooth. (c) Middle presacral (dorsal) centrum in articular (c1), right lateral (c2), dorsal (c3) and ventral (c4) views. (d) A series of four articulated posterior presacral centra in lateral view. (e–i) caudal centra from anteriormost to posterior most; for (e)–(i) numbers indicate the following views: 1, articular view; 2, lateral view; 3, dorsal view; 4, ventral view. (j) Partially articulated vertebral column, neural arches and ribs. (k) Left coracoid in dorsal (k1), medial (k2), ventral (k3) and anterior (k4) views; the line shows the reconstructed outline of the element. (l) Right femur in dorsal (l1), anterior (l2), ventral (l3), proximal (l4) and distal (l5) views. Scale bars represent 3 cm for (a), (c)–(i), 1 cm for (b), 10 cm for (j) and 5 cm for (k)–(l).

The specimen **ZIN PH 39/211** is the distal portion of the femur that is in its size and morphology well consistent with the femur of ZIN PH 2/211 (see description above).

A number of specimens are isolated vertebral centra belonging to moderate and small ichthyosaurians (Tab. S1). These all are identified as Neoichthyosauria indet. based primarily on the temporal setting (all post-Triassic ichthyosaurians are known to belong to Neoichthyosauria) and also on bicipital rib articulations in the presacral centra and on the marked anteroposterior shortening of the centra relative to their width and height (e.g. Maisch, 2010; Moon, 2019).

The specimens **ZIN PH 3/211**, **118/211** and **1/213**, are presacral vertebrae that in their size and preservation are highly similar to the above described ZIN PH 2/211 and likely belong to the same or closely related taxon.

ZIN PH 30/211 is an atlas-axis complex. The atlas and axis are completely fused with preservation of the suture forming a ridge. The atlas is anteroposteriorly longer than the axis. In the articular view, the element is somewhat heart-shaped, tapering ventrally (Fig. S3a1). The neural canal is wide, with convex lateral edges (Fig. S3a3), unlike those parallel or concave in other available centra. There are no marked ventral facets for the intercentra. Considering a good fusion of atlas and axis as well as lack of marked intercentral facet between the two elements the specimen is likely represents a baracromian ichthyosaurian (NGZ pes. obs. on the phylogenetic distribution of this feature from the relevant literature).

ZIN PH 19/211 (Fig. S3b) is anterior presacral centrum (“cervical” according to some interpretations; see e.g. McGowan & Motani, 2003; however, here we inclined to reduce the usage of the term “cervical” for the poorly regionalized presacral series of ichthyosaurians), its articular face is circular in outline, the diapophysis is fused to the neural arch facet and parapophysis fused to the anterior edge of the centrum and located on the centrum mid-height.

The neural canal is relatively wide, with nearly parallel lateral edges (Fig. S3b3). The ventral surface bears a poorly pronounced ventral keel (Fig. S3b4).

ZIN PH 76/211 (Fig. S3c) is anterior presacral (“cervical”) centrum that differs from the above described ZIN PH 19/211 in smaller size and absence of the ventral keel.

ZIN PH 63/211 (Fig. S3d) is a posterior presacral (posterior dorsal) centrum. Its articular face is ovoid in outline, slightly constricting dorsally. The rib facets are closely located to each other and shifted to the ventral edge of the centrum (Fig. S3d2). The neural canal has parallel lateral edges (Fig. S3b3).

Figure S3. Remains of moderate and small ichthyosaurians referable to Neoichthyosauria from the Early Jurassic (all except for [g] are Toarcian in age) of Eastern Siberia. (a) Atlas-axis complex, ZIN PH 30/211. (b) Anterior presacral centrum, ZIN PH 19/211. (c) Anterior presacral centrum, ZIN PH 76/211. (d) Posterior presacral centrum, ZIN PH 63/211. (e) Anterior caudal centrum, ZIN PH 88/211. (f) Middle preflexural caudal centrum, ZIN PH 53/211[partim]. (g) ZIN PH 1/212, Caudal centrum from the Hettangian–Sinemurian of Cape Tumul, mouth of the River Olenyok. (h) Presacral centrum of a very small individual, ZIN PH 61/211. For (a)–(h) numbers indicate the following views: 1, anterior view; 2, lateral view; 3, dorsal view; 4, ventral view; 5, posterior view. (*i*) Left humerus, SPbU VZ R Ip 27, in ventral (i1), anterior (i2), dorsal (i3), posterior (i4), proximal (i5) and distal (i6) views. (j) isolated tooth SPbU VZ R Ip 30. Scale bars represent 5 cm for (a)–(i) and 5 mm for (j).

ZIN PH 88/211 (Fig. S3e) is an anterior caudal centrum with ovoid in outline articular face and a single circular rib facet located in the ventral third of the centrum height (Fig. S3e2). The neural canal has convex lateral edges being somewhat hourglass-shaped (Fig. S3e3).

ZIN PH 53/211[partim] is a middle preflexural caudal centrum (Fig. S3f). It has circular articular face and the single circular rib facet. It is very short anteroposteriorly (length to width ratio = 0.3). The neural canal is narrow and hourglass-shaped (Fig. S3f3).

The specimen **SPbU VZ R Ip27** (Fig. S3i) is a complete right humerus 8 cm long. It has an isometric proximal end with poorly developed dorsal process and deltopectoral crest. The humeral shaft is slender and the distal end is dorsoventrally compressed and markedly anteroposteriorly expanded. There are two distal facets for the radius and ulna, both are equal in dorsoventral width, but the anteroposterior width of the ulnar facet is slightly longer than that of the radial facet. Anterodistal edge of the humerus forms a leading edge tuberosity (Fig. S3i). Considering the poorly developed humeral processes and the greatly expanded and compressed distal end, the specimen is likely belong to a non-barachromian neoichthyosaurian. Here we refer SPbU VZ R Ip27 to as Neoichthyosauria indet. Although the specimen was collected by T.I. Kirina, the precise data on its locality and stratigraphic position are nowadays missing. Judging from its preservation (strongly phosphatised dense dark bone with well-preserved surface retaining light-grey silty matrix on articular surfaces; in the Pliensbachian deposits of the Vilyuy River basin, the remains are brown and poorly separated from the surrounding concretions), it is more likely Toarcian in age.

Plesiosauria

The specimens **ZIN PH 48/211, 85/211, 86/211, 93/211, 110/211** and **SPbU VZ R Sp22c, SPbU VZ R Sp36** (Fig. S4) are the cervical vertebrae with articulated neural arches and ribs lacking any visible trace of a suture (criterion of maturity *sensu* Brown, 1981; although in most of these specimens the neural arches and ribs are largely broken). The centra are mediolaterally wider than they are long anteroposteriorly and high dorsoventrally (W > L > H). The articular surfaces are slightly concave, giving the centrum a platycoelous condition. The anterior surfaces bear a distinct U-shaped or V-shaped notochordal pit (e.g. Fig. S4e1, f1, g1), whereas on the posterior surface the notochordal pit is less pronounced as a horizontal scar (Fig. S4c4) or a circular depression (Fig. S4f4, g4). There are concentric grooves on articular surfaces, especially marked in their peripheral region. We suggest that these structures can represent the concentric growth bands, similar to those of e.g. sharks (Newbrey et al., 2013); thus, possibly, additionally indicating the maturity of these specimens. The peripheral region of articular surfaces is slightly raised over the remaining outer surface and bears rugose ornamentation laterally and ventrally. The ventral surface of each centrum lacks a ventral keel and bears small paired foramina. The lateral surface has a poorly pronounced lateral keel, located close to the presumed articulation with the cervical rib. The rib articulations are located ventrolaterally and are anteroposteriorly elongated and dorsoventrally compressed; they occupy no less than a half of the centrum length. Proximally, the ribs bear anterior and posterior grooves terminating in pits. The pits are origins of a thin horizontal canal, separating the rib articulation with the centrum onto two parts. This canal could be observed in the broken rib of ZIN PH 85/211 (Fig. S4d). The neural arch is nearly completely preserved in ZIN PH 86/211 with only the dorsal portion of the neural spine broken (Fig. S4a). The prezygapophyses are not medially united to each other and their combined width is narrower that the centrum width. The prezygapophyseal facets are somewhat trough-like and face dorsomedially (Fig. S4a1). The postzygapophyseal facets face ventrolaterally (Fig. S4a4). The neural canal is mediolaterally narrow and, where preserved, is circular in cross-section (Fig. S4a, c, e).

Considering a unique combination of their proportions, platycoelous type, complete fusion of neural arch and ribs, bipartite rib articulation, lack of ventral keel and particularly the presence of lateral keels, these vertebrae could be referred to *Microcleidus* Watson, 1909 *sensu* Benson et al. (2012) (see also Vincent et al., 2019).

The specimen **ZIN PH 94/211** is similar in its proportions to the vertebrae described above, differing in the lack of the lateral keel and that the ribs are not fused to the centrum (this could be interpreted as immature condition *sensu* Brown, 1981). The rib facets in this specimen are oval in outline, anteroposteriorly longer than dorsoventrally high. A narrow longitudinal groove separates the facet onto two parts. This centrum is also likely to belong to a medium-sized microcleidid plesiosaurian (centrum length is 45 mm), but is probably from the posterior part of the cervical series or belongs to an immature individual, therefore, its generic referral is problematic.

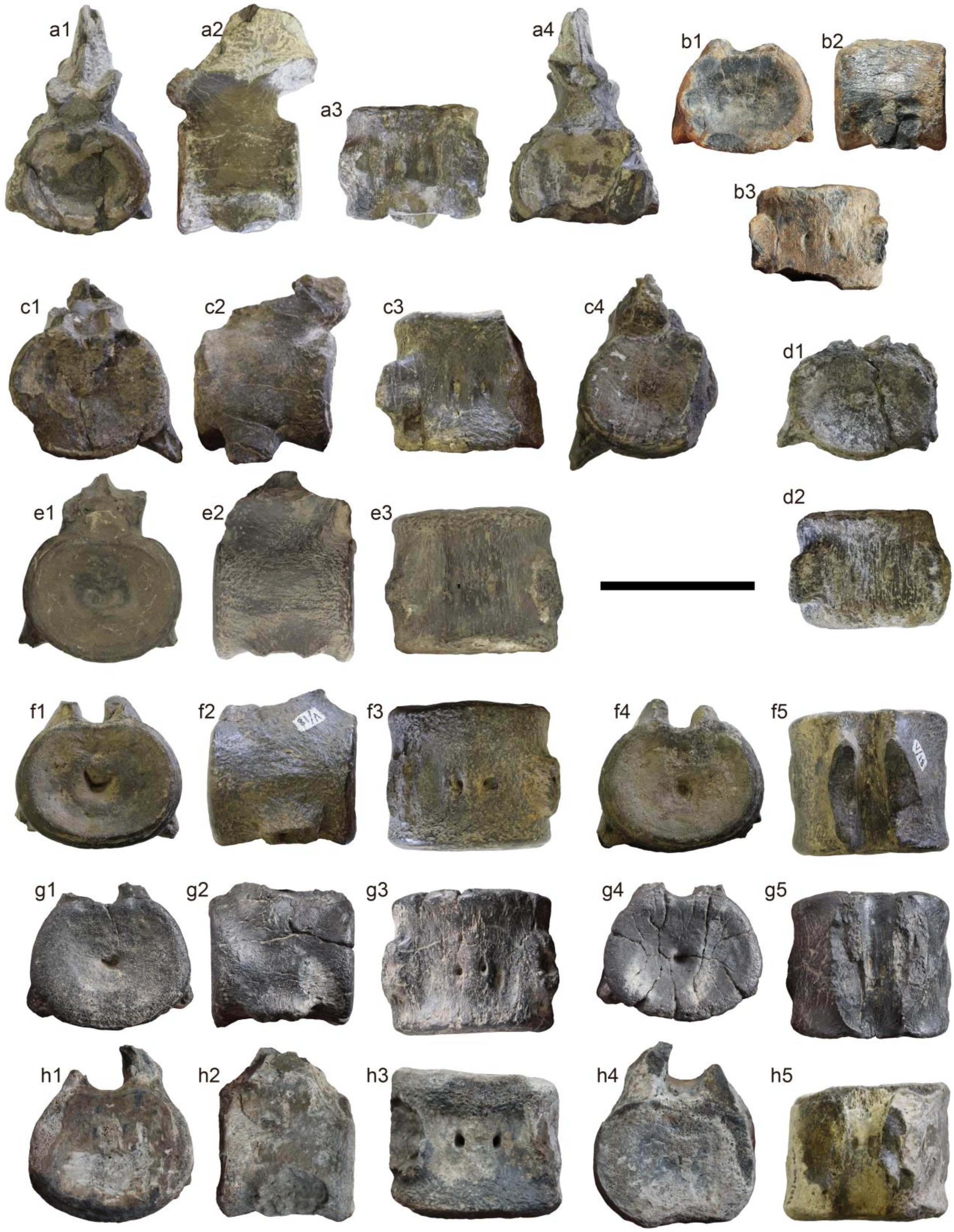

Figure S4. Cervical vertebrae of *Microcleidus* spp. from the Toarcian of Eastern Siberia. (a) ZIN PH 86/211, (b) ZIN PH 48/211, (c) ZIN PH 93/211, (d) ZIN PH 85/211, (e) SPbU VZ R Sp22c, (f) SPbU VZ R Sp36, (g) ZIN PH 110/211. (h) Microcleididae indet. ZIN PH 94/211. Numbers indicate the following views: 1, anterior view; 2, lateral view; 3, ventral view; 4, posterior view; 5, dorsal view. Scale bar represents 5 cm.

A number of small cervical centra and one pectoral centrum belong to osteologically immature and likely juvenile plesiosaurians (Fig. S5). This is suggested based on their small size (the width of the largest specimen, ZIN PH 14/211, is 47 mm, length = 31 mm) and that the neural arches and ribs are not fused to the centrum (criterion of immaturity *sensu* Brown, 1981). The centra are mediolaterally wider than anteroposteriorly long and dorsoventrally high. Contrary to the proportions observed in the above described specimens, the length and height of these centra are either equal, or height slightly exceeds the length. The articular surfaces are nearly flat and bear a distinct notochordal pit, U-shaped in some specimens (e.g. Fig. S5a1, b1). The concentric grooves on articular surfaces and peripheral region are absent, supporting the immaturity of these specimens, in case if our suggestion regarding the nature of these structures is correct. The peripheral region of articular surfaces is either smooth or finely rugose ventrally and laterally. The ventral surface lacks a ventral keel and bears proportionally large paired foramina. The paired foramina are also present dorsally, in the middle of the neural canal floor, which is somewhat hourglass-shaped. The neural arch facets are lenticular in dorsal view. In lateral view, the neural arch facets form V-shaped notches; in ZIN PH 14/211, they extend ventrally up to the level of rib facets. In ZIN PH 16/211 and 113/211 the neural arch facets are fused with the dorsal rib facet (Fig. S5e2, f2), indicating that these centra are from posteriormost part of the neck or from the anterior pectoral region. The rib facets are bipartite with dorsal part triangular in outline and ventral part oval to semicircular in outline. The two parts are separated by a thin longitudinal groove. In ZIN PH 16/211 and 113/211, the middle of this groove is pierced by a foramen (Fig. S5e2).

The pectoral centrum **ZIN PH 111/211** (Fig. S5g) has oval, gently concave articular surfaces and convex ventral surface with widely spaced subcentral foramina and no ventral keel (Fig. S5g4). The neural arch facets are subcircular in outline and partially separated from the rib facet by a thin longitudinal groove. The contribution to a rib facet of the centrum is semi-oval in outline (Fig. S5g2).

Based on their general proportions, platycoelous type and absence of ventral keel these cervical and pectoral centra (Fig. S5) are somewhat conventionally referred to as Microcleididae indet., however, their affinity to other plesiosauroids (e.g. *Plesiopterys wildi* O'Keefe, 2004, recovered as a sister taxon to derived plesiosauroids by some researchers [Benson et al., 2012], despite being considered a junior subjective synonym of the microcleidid *Seeleyosaurus guilelmiimperatoris* (Dames, 1895) by Großmann [2007]) cannot be excluded, but requires additional data on the vertebral morphology and phylogenetic relations of the Early Jurassic plesiosaurians.

Figure S5. Cervical and pectoral vertebral centra of juvenile plesiosaurians Microcleididae indet. from the Toarcian of Eastern Siberia. (a) ZIN PH 87/211, (b) ZIN PH 14/211, (c) ZIN PH 31/211, (d) SPbU VZ R Sp35, (e) ZIN PH 16/211, (f) ZIN PH 113/211, (g) ZIN PH 111/211. Numbers indicate the following views: 1, anterior view; 2, lateral view; 3, dorsal view; 4, ventral view. Scale bar represents 3 cm.

Ten cervical vertebrae are characterized by markedly concave articular surfaces (amphicoelous type), presence of the ventral keel and proportional shortening (Fig. S6). Based on these features, the specimens could be referred to Rhomaleosauridae and/or Pliosauridae (e.g. Benson et al., 2012) or to basal plesiosaurians with somewhat uncertain phylogenetic position, such as *Anningasaura* or *Lindwurmia* (Vincent & Benson, 2012; Vincent & Storrs, 2019).

The specimen **ZIN PH 67/211** (Fig. S6a) is an isolated centrum that is slightly shorter anteroposteriorly than high dorsoventrally and slightly broader mediolaterally than dorsoventrally. Ventrally, it has a well-pronounced, sharp ventral keel. The ventral foramina are small and located close to the median keel (Fig. S6a3). The area adjacent to anterior and posterior articular surfaces is rugose ventrally. Dorsally, the floor of the neural canal is hourglass-shaped; the neural arch facets are somewhat lenticular. In lateral view, the neural arch facets form V-shaped notches and contact the diapophysis of the rib facet (Fig. S6a2; this feature, when occurred along the entire length of the neck, is suggested to be a synapomorphy of *Hauffiosaurus* O'Keefe, 2001 and included in the diagnosis of the genus [Benson et al., 2011]). The rib facet is bipartite with its dorsal part triangular in outline and twice smaller than the ventral part, which is elongated oval in outline, nearly as long as the centrum length (Fig. S6a2). The two parts are deeply concave and are separated by a thin longitudinal ridge.

The cervical vertebrae **ZIN PH 6/211** (Fig. S6e), **ZIN PH 109/211** (Fig. S6f) and **SPbU VZ R Sp31** (Fig. S6g) are similar in their proportions and morphology to the above described ZIN PH 67/211. These three specimens differ in their larger size and in having neural arches and ribs completely fused to the centrum. The ventral keel in these specimens is less sharp than in ZIN PH 67/211, but also narrow and plate-like and has closely located and relatively small ventral foramina (Fig. S6e3, f3, g3). The prezygapophyses preserved in SPbU VZ R Sp31 were nearly as wide as the centrum mediolateral width. Following the orientation of bone texture, and considering the presence of a vertical eminence between the rib and the neural arch, it could be suggested that these two elements are articulated.

The above described cervical centra ZIN PH 67/211, ZIN PH 6/211, ZIN PH 109/211 and SPbU VZ R Sp31 are very similar in their morphology to the cervical vertebrae of the pliosaurid *Hauffiosaurus* (White, 1940; Vincent, 2011; Benson et al., 2011). The neural arch pedicles contacting the diapophysis of the rib facet along the entire length of the neck, was suggested to be a synapomorphy of *Hauffiosaurus* and included in the diagnosis of the genus (Benson et al., 2011). Later Benson et al. (2012) reported that the condition with this contact occurs in some cervical vertebrae of a basal pliosaurid *Thalassiodracon hawkinsii* (Owen, 1838) and a similar

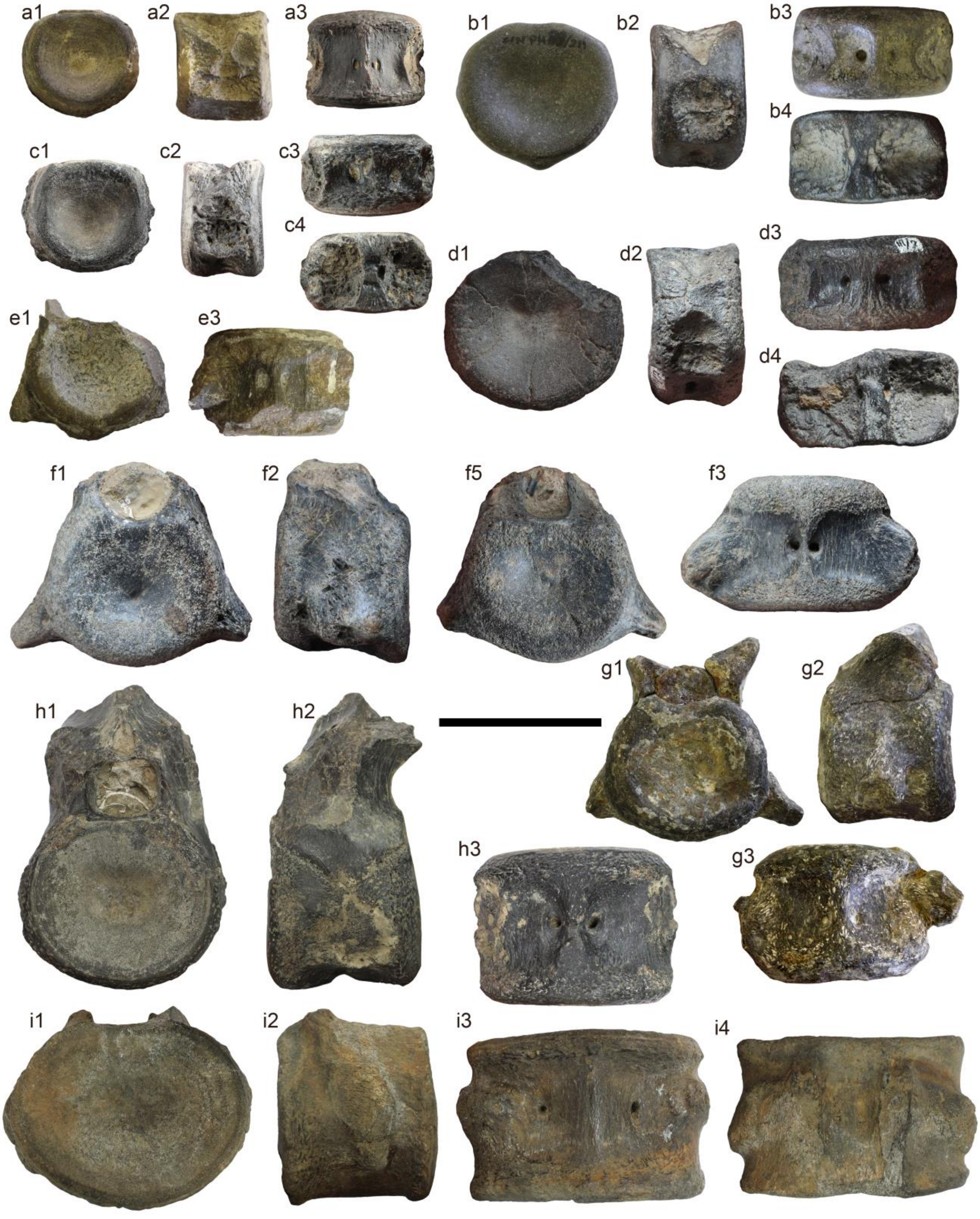

Figure S6. Cervical vertebrae of pliosaurids and rhomaleosaurids from the Pliensbachian–Toarcian of Eastern Siberia. (a) ZIN PH 67/211, (b) ZIN PH 83/211, (c) ZIN PH 68/211, (d) ZIN PH 15/211, (e) ZIN PH 6/211, (f) ZIN PH 109/211, (g) SPbU VZ R Sp31, (h), SPbU VZ R Sp22b; (i) SPbU VZ R Sp22a. ZIN PH 6/211 is late Pliensbachian and the remaining specimens are all Toarcian in age. Numbers indicate the following views: 1, anterior view; 2, lateral view; 3, ventral view; 4, dorsal view; 5, posterior view. Scale bar represents 5 cm.

condition was later reported for a Triassic plesiosaurian *Rhaeticosaurus mertensi* Wintrich et al., 2017, which was also recovered within Pliosauridae (Wintrich et al., 2017). Given that the studied vertebrae are isolated it is impossible to unambiguously define their relative position in the neck; we also cannot be sure that they all belong to one taxon, thus it is impossible to say if this contact of the neural arch pedicle and rib occurred along the entire length of the neck. Therefore, we refer these specimens to as Pliosauridae indet., although their affinity to *Hauffiosaurus* is possible.

The vertebrae **SPbU VZ R Sp22b** (Fig. S6h) and **SPbU VZ R Sp22a** (Fig. S6i) are larger than the above described vertebrae. The mediolateral width of SPbU VZ R Sp22a is 65 mm and it is unambiguously from the posterior part of the cervical series having widely spaced ventral foramina (Fig. S6i3), reduced diapophyses and enlarged parapophyses connected to the neural arch by the vertical ridge (Fig. S6i2). The ventral surface of SPbU VZ R Sp22a bears a ventral keel. The mediolateral width of SPbU VZ R Sp22b is 54 mm. It has an incompletely developed ventral keel disrupted in the middle (Fig. S6h3) and relatively closely spaced ventral foramina. The neural arch and ribs in SPbU VZ R Sp22b are partially fused with the centrum preserving a suture line. The neural canal is squared in cross-section (Fig. S6h1). The neural arch pedicle is V-shaped and nearly reaches the rib that is tapered dorsally (Fig. S6h2). The rib base is nearly as long as the centrum length and dorsoventrally flattened. Considering the proportional elongation of these two centra (anteroposterior length is only slightly less than the dorsoventral height), we are inclined to refer them to basal pliosaurids rather than to rhomaleosaurids.

The specimens **ZIN PH 83/211** (Fig. S6b), **ZIN PH 68/211**(Fig. S6c) and **ZIN PH 15/211**(Fig. S6d) are vertebral centra that are anteroposteriorly shortened relative to their nearly equal mediolateral width and dorsoventral height. The articular surfaces of these centra are strongly concave. The neural canal floor is hourglass-shaped and bears two distinct foramina in its middle (Fig. S6b4, c4). The neural arch facets are deeply concave and form a V-shaped notch in lateral view, but not reaching the rib facet (Fig. S6b2). The rib facets are relatively large and semicircular in outline. They are separated onto two nearly equal parts by the longitudinal ridge. In ventral view, there is a pair of well-pronounced circular foramina, each situated in a squared depression, constricted medially by a ventral keel and laterally by a raised border of the rib facet. This condition is typical of rhomaleosaurids (e.g. Smith & Vincent, 2010; Smith & Benson, 2014; Smith & Araujo, 2017). The ventral keel is less sharp than in the above described pliosaurid vertebrae. Given the described traits, the rhomaleosaurid attribution of these three specimens is most plausible.

Five dorsal vertebrae (**ZIN PH 92/211, 91/211, 90/211, 50/211** and **SPbU VZ R Sp30**) are characteristically shortened anteroposteriorly and have distinctly concave articular surfaces with raised rims (Fig. S7). The rims are rugose laterally and ventrally. The lateral surfaces are concave. The articular surfaces are circular in outline. The anterior dorsal vertebra ZIN PH 92/211 (Fig. S7a) is in articulation with the neural arch with the preservation of suture. The rib facet is located on the transverse process of the neural arch (Fig. S7a1, a2). The rib facet is dorsoventrally high, teardrop-shaped, tapering ventrally. The neural canal is somewhat triangular in cross-section similarly to that of *Hauffiosaurus* (White, 1940, according to Benson et al., 2011). The zygapophyses are separated medially and their articular faces are oriented nearly horizontally. In the caudal direction, the neural arch suture in lateral view changes from U-shaped (Fig. S7b2) to shallowly concave or nearly horizontal (fig. S7c2, d2, e2). The ventral surfaces of these vertebrae bear numerous small irregularly arranged foramina. In the dorsal centra, a single foramen appears on each lateral side, in its middle (Fig. S7c2, e2). Dorsally all these vertebrae have an hourglass-shaped neural canal floor strongly constricted in its mid-length (Fig. S7b3, c3, d3, e3). Ventrally one centrum (ZIN PH 90/211) bears a smooth median ridge (Fig. S7c4), similar to those reported for dorsal vertebrae of *Rhomaleosaurus thorntoni* Andrews, 1922 (Smith & Benson, 2014).

Considering that the anteroposteriorly shortened and amphicoelous pectoral and dorsal vertebrae are reported for both basal pliosaurids (White, 1940 *sensu* Benson et al., 2011; Sachs & Kear, 2018) and derived rhomaleosaurids (e.g. Smith & Benson, 2014), the above described vertebrae could be referred to both these groups. Further study of the axial skeleton of plesiosaurians is required for clarification of the affinity of the described vertebrae.

The specimen **SPbU VZ R Sp40** is a fragmental dorsal centrum, largest in the available materials (Fig. S8f); it is 85 mm in maximum diameter and 51 mm long. It has deeply concave articular surfaces and rugose peripheral areas. Therefore, it likely belonged to a relatively large plesiosaurian, probably a representative of the family Rhomaleosauridae, considering that its members were the largest plesiosaurians of the Early Jurassic (e.g. Benson et al., 2012).

ZIN PH 107/211 (Fig. S7f) is a relatively large caudal centrum 75 mm in maximum diameter. It has concave articular surfaces with rounded outline and a somewhat rectangular general outline due to protruding chevron facets. It is markedly shortened anteroposteriorly and is mediolaterally wider than dorsoventrally tall. The neural canal floor is very narrow mediolaterally and the neural arch facets are extensive and squared in outline (Fig. S7f3). The rib facet is confluent with the neural arch facets. Ventrally there are two triangular protrusions bearing chevron facets, between then the ventral surface is nearly flat and bears two widely spaced symmetrical foramina (Fig. S7f4). As in the case of the above described dorsal vertebrae the listed conditions occur in rhomaleosaurids and pliosaurids, thus the univocal taxonomic referral of ZIN PH 107/211 is problematic.

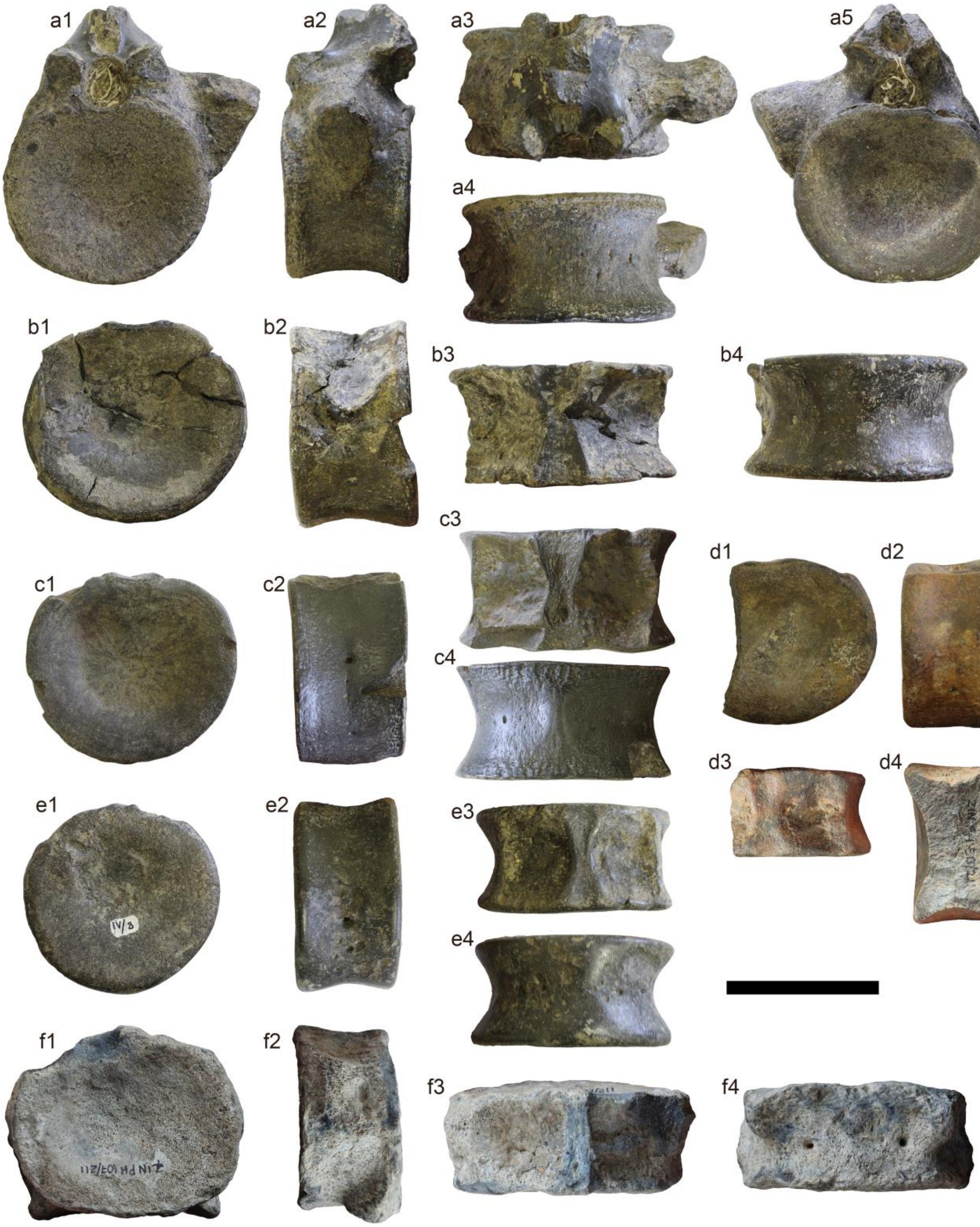

Figure S7. Dorsal and caudal vertebrae of pliosaurids and/or rhomaleosaurids from the Toarcian of Eastern Siberia. (a–d) Dorsal vertebrae: (a) ZIN PH 92/211, (b) ZIN PH 91/211, (c) ZIN PH 90/211, (d) ZIN PH 50/211, (e) SPbU VZ R Sp30, (f) caudal centrum ZIN PH 107/211. Numbers indicate the following views: 1, anterior view; 2, lateral view; 3, dorsal view; 4, ventral view (except for d); 5, posterior view; d4, cross-section. Scale bar represents 5 cm.

The specimens **ZIN PH 17/211** (Fig. S8a), **SPbU VZ R Sp33** (Fig. S8b), **ZIN PH 82/211** (Fig. S8c), **SPbU VZ R Sp34** (Fig. S8d) and **ZIN PH 66/211**(Fig. S8e) are dorsal vertebrae characterized by the articular surfaces ovoid (or somewhat heart-shaped) in outline, nearly as dorsoventrally high as mediolaterally wide, but being the widest in the dorsal half and constricting in width ventrally (Fig. S8). The anteroposterior length is less than the mediolateral width, but it is not as shortened as in the above described morphotype of dorsal vertebrae (L/W ratio ranges from 0.8 to 0.61; cf 0.55 in the above described morphotype). The articular surfaces of these vertebrae are concave. The lateral surfaces bear one or two foramina in the middle (Fig. S8b2, c2, d2, e2). The neural arches are fused to the centrum with no trace of a suture in all but ZIN PH 82/211, which is an isolated centrum not articulated with the neural arch (Fig. S8c). The neural canal cross-sectional outline ranges from subquadrate in ZIN PH 17/211 to oval in SPbU VZ R Sp33 and somewhat triangular in SPbU VZ R Sp34. The transverse processes are quadrangular in cross-section with the ridges forming their edges ventrally and dorsally. Especially well-pronounced is the ridge on the anterodorsal leading edge, connecting the transverse process with the prezygapophysis. The prezygapophyses are poorly preserved in all these specimens. The better preserved left prezygapophysis of ZIN PH 17/211 has the articular facet facing dorsally and only slightly inclined medially. The postzygapophyses of ZIN PH 17/211 are facing ventrolaterally forming the angle of 108-110° relative to each other. Their articular surfaces are anteroposteriorly shorter than mediolaterally wide. In ZIN PH 66/211, which is likely a posterior dorsal vertebra (judging from the low position of transverse processes and a relatively small diameter of the neural canal), the angle between the articular zygapophyseal surfaces is well the same, but their proportions are different, being as anteroposteriorly long as mediolaterally wide (Fig. S8e).

The vertebral centra of derived microcleidids are commonly proportionally elongated with their length nearly equal to height (NGZ pers. obs., also see Dames, 1895; Bardet et al., 1999, both *sensu* Benson et al., 2012). In contrast, basal Plesiosauroidea, including basal microcleidids, as well as basal rhomaleosaurids and Late Triassic pistosaurians have the dorsal vertebrae with the proportions similar to the above described morphotype (e.g. Ketchum & Smith, 2010; Benson et al., 2012; Dalla Vecchia, 2017; Wintrich et al., 2017; NGZ pers. obs. on cited literature), indicating that this condition is likely a plesiomorphic state in plesiosaurians. Therefore, we refer the above described vertebrae to as Plesiosauria indet.

Figure S8. Dorsal vertebrae of plesiosaurians, Plesiosauria indet. from the Toarcian of Eastern Siberia. (a) ZIN PH 17/211, (b) SPbU VZ R Sp33, (c) ZIN PH 82/211, (d) SPbU VZ R Sp34, (e) ZIN PH 66/211, (f) SPbU VZ R Sp40. Numbers indicate the following views: 1, anterior view; 2, lateral view (ventral for e); 3, dorsal view (cross-sectional for e); 4, ventral view; 5, posterior view. Scale bar represents 5 cm.

Of certain interest are the specimens **SPbU VZ R Sp11** and **Sp38** representing the articulated plesiosaurian remains from the uppermost Toarcian to lowermost Aalenian of the Markha River (Fig. S9). SPbU VZ R Sp11 is a part of the dorsal vertebral column consisting of six articulated vertebrae. The morphology of these vertebrae is highly similar to that of the specimens described above and depicted on the Fig. S8. SPbU VZ R Sp38 comprises associated sacral vertebrae and a partial pelvis. The sacral vertebrae have circular articular surfaces (Fig. S9b1) and bear extensive dorsoventrally elongated rib facets divided between the centrum and the neural arch (Fig. S9b2). The acetabular surface of the pelvis is irregularly pitted and relatively dorsoventrally thick. The proximal pubis is convex and tapered laterally and posteriorly. Its ischial facet of the pubis is well demarcated from the acetabular contribution, forming the angle close to 90°. The acetabular head of the ischium is massive, it has tree clearly demarcated facets. The ischial neck, which connected the acetabular head and the ischial blade (not preserved), is relatively slender and has concave anterior and posterior edges (the ischial neck:acetabular process ratio is 0.5). The ilium is slender and curved element articulated to the ischium. The proximal end of the ilium is expanded transversely, forming the ischial facet and iliac portion of the acetabulum, squared in articular outline (Fig. S9b2). Although both these specimens lack diagnostic features and could be assigned only as Plesiosauria indet., they are significant indicators of the perspective for the further search of articulated skeletal remains in the Lower Jurassic of the Vilyuy River basin.

Several plesiosaurian vertebrae from the pectoral, dorsal, sacral and caudal regions (Fig. S10) are difficult to attribute more precise than Plesiosauria indet. In this regard, we reduce their description and mention only some peculiar features. The specimens **ZIN PH 5/211**, **84/211**, **108/211** and **65/211** have their articular faces nearly flat and slightly convex in the central part. The mediolateral width is greater than the dorsoventral height and anteroposterior length; length and height are nearly equal, the condition similar to microcleidid plesiosaurians. ZIN PH 84/211, and 65/211 have flattened ventral surfaces, giving them a somewhat rectangular outline (Fig. S10c3, d3). In ZIN PH 108/211 the ventral surface bears a median depression, which may be a pathologic condition (Fig. S10b3). The specimens **ZIN PH 53/211[partim]** and **SPbU VZ R Sp32** are anterior-most (or posterior-most) dorsal vertebral centra, which is evident from the presence of rudimentary parapophyses posteroventral to the neural arch facet (Fig. S10f2, g2). The caudal vertebra **ZIN PH 46/211** is proportionally high dorsoventrally and has rectangular articular face (Fig. S10e1); its rib facets are located in the dorsal half and fused to the neural arch (Fig. S10e2).

A number of elements of the appendicular skeleton, especially propodial elements, is present in the collection of T.A. Kirina. The better preserved and most remarkable specimens are depicted on Figs. S11–S13.

The specimen **ZIN PH 37/211** is a nearly complete right ischium missing a part of its anterior portion (Fig. S11i). Judging by the preserved part it was nearly as wide as long (as preserved c 22 cm long and 19 cm wide). The acetabular head of the ischium is massive; it has a poorly ossified surface with indistinctly demarcated facets (Fig. S11i4). The ischial neck connecting the acetabular head and the ischial blade, is relatively slender and has concave anterior and posterior edges (the ischial neck:acetabular process ratio is 0.58). The posterior end of the ischial blade is rounded in dorsal view. The medial surface of the ischium forms a slightly S-shaped curved facet (Fig. S11i2).

Figure S9. Articulated remains of Plesiosauria indet. from the Toarcian–?lowermost Aalenian of Eastern Siberia (a) Partial dorsal series SPbU VZ R Sp11 in right lateral (a1), dorsal (a2), ventral (a3), anterior (a4) and posterior (a5) views. (b) Concretion with associated sacral vertebrae and partial pelvis SPbU VZ R Sp38; (b1) sacral vertebra in anterior articular view, ilium in lateral view; (b2) sacral vertebra in left lateral view, ilium, ischium and pubis in ventral view. Scale bar represents 5 cm.

Figure S10. Pectoral and/or sacral, dorsal and caudal vertebrae of plesiosaurians, Plesiosauria indet. from the Toarcian of Eastern Siberia. (a) Pectoral vertebra ZIN PH 5/211; (b) pectoral vertebra ZIN PH 84/211, (c) anterior dorsal vertebra ZIN PH 108/211, (d) sacral vertebra ZIN PH 65/211, (e) caudal vertebra ZIN PH 46/211, (f) anterior-most dorsal vertebra ZIN PH 53/211[partim], (g) anterior-most (or posterior-most) dorsal vertebra SPbU VZ R Sp32. Numbers indicate the following views: 1, anterior view; 2, lateral view; 3, ventral view; 4, dorsal view; 5, posterior view. Scale bar represents 5 cm.

Figure S11. Elements of the appendicular skeleton of plesiosaurians from the Toarcian of Eastern Siberia. Distal parts of the propodial bones ZIN PH 11/211(a) and ZIN PH 97/211 (b), in dorsal or ventral (a1, b1), anterior (a2), posterior (b2) and distal (a3, b3) views. Isolated phalanxes ZIN PH 7/211 (c), SPbU VZ R Sp27 (d) and ZIN PH 44/211 (e). Radius or tibia ZIN PH 13/211 (f) and SPbU VZ R Sp29 (h) in dorsal or ventral (f1, h1), anterior (f2, h2) proximal (f3, h3) and posterior (h4) views. (g) Ulna or fibula ZIN PH 36/211 in proximal (g1), dorsal or ventral (g2) and anterior (g3) views. (i) Right ischium, ZIN PH 37/211, in ventral (i1), medial (i2), dorsal (i3) and acetabular (i4) views. (j) ?chevron, SPbU VZ R Sp39. The lines in g2, i1 and i3 show the hypothetically reconstructed outlines of the elements. Scale bar represents 5 cm for (a)–(i) and 2 cm for (j).

Two specimens **ZIN PH 13/211** (Fig. S11f) and **SPbU VZ R Sp28** (Fig. S11h) could be identified as the radius or tibia. These are stout elements with an approximately rectangular outline in dorsal and ventral views (Fig. S11f1, h1). The anterior leading edge is weakly concave and the posterior edge is strongly concave forming the margin of the epipodial foramen. One of the surfaces (dorsal or ventral) is transversely convex, whereas the other surface is flattened, however it is hardly possible to identify which of them is dorsal and which is ventral. The proximal end is more expanded anteroposteriorly than the distal end. The articular surfaces are incompletely ossified and convex; their facets are poorly demarcated.

ZIN PH 36/211 is a fragmental ulna or fibula. It is much shorter proximodistally than the above described radius/tibia and is isometric in shape being as wide anteroposteriorly as long proximodistally. The anterior edge of this element is concave forming a posterior margin of the epipodial foramen (Fig. S11g2).

ZIN PH 7/211 (Fig. S11c), **SPbU VZ R Sp27** (Fig. S11d) and **ZIN PH 44/211** (Fig. S11e) are phalanges with an hourglass shape typical of plesiosaurians.

ZIN PH 11/211(Fig. S11a) and **ZIN PH 97/211** (Fig. S11b) are distal parts of the propodial bones that could be equally identified as humeri or femora. These elements are widest distally mostly due to a posterodistal expansion. Their anterior leading edges are tapered and posterior edges are more rounded. The distal end is convex with poorly demarcated distal facets. The anterior facet is the largest; it faces nearly distally being only slightly inclined anteriorly. The posterior facet is markedly deflected posterodistally. In distal view, the articular surface is lenticular in outline (dorsoventral thickness: anteroposterior width ratio = 0.3 in ZIN PH 11/211 and 0.37 in ZIN PH 97/211).

ZIN PH 96/211 (Fig. S12c) and **ZIN PH 51/211** (Fig. S12d) are distal parts of the propodial bones similar to those described above, but more robust and more proportionally thickened distally compared to ZIN PH 11/211 (dorsoventral thickness: anteroposterior width ratio = 0.4 in ZIN PH 96/211 and 0.36 in ZIN PH 51/211).

ZIN PH 12/211 (Fig. S12a) is a proximal part of the humerus of a moderately large plesiosaurian. The capitulum is circular in outline (80 mm in diameter); its articular surface is flattened and is connected with the dorsal tuberosity (Fig. S12a3). The tuberosity is anteroposteriorly wider than the capitulum and is markedly offset postaxially, being continued by a posteriorly convex ridge (Fig. S12a1).

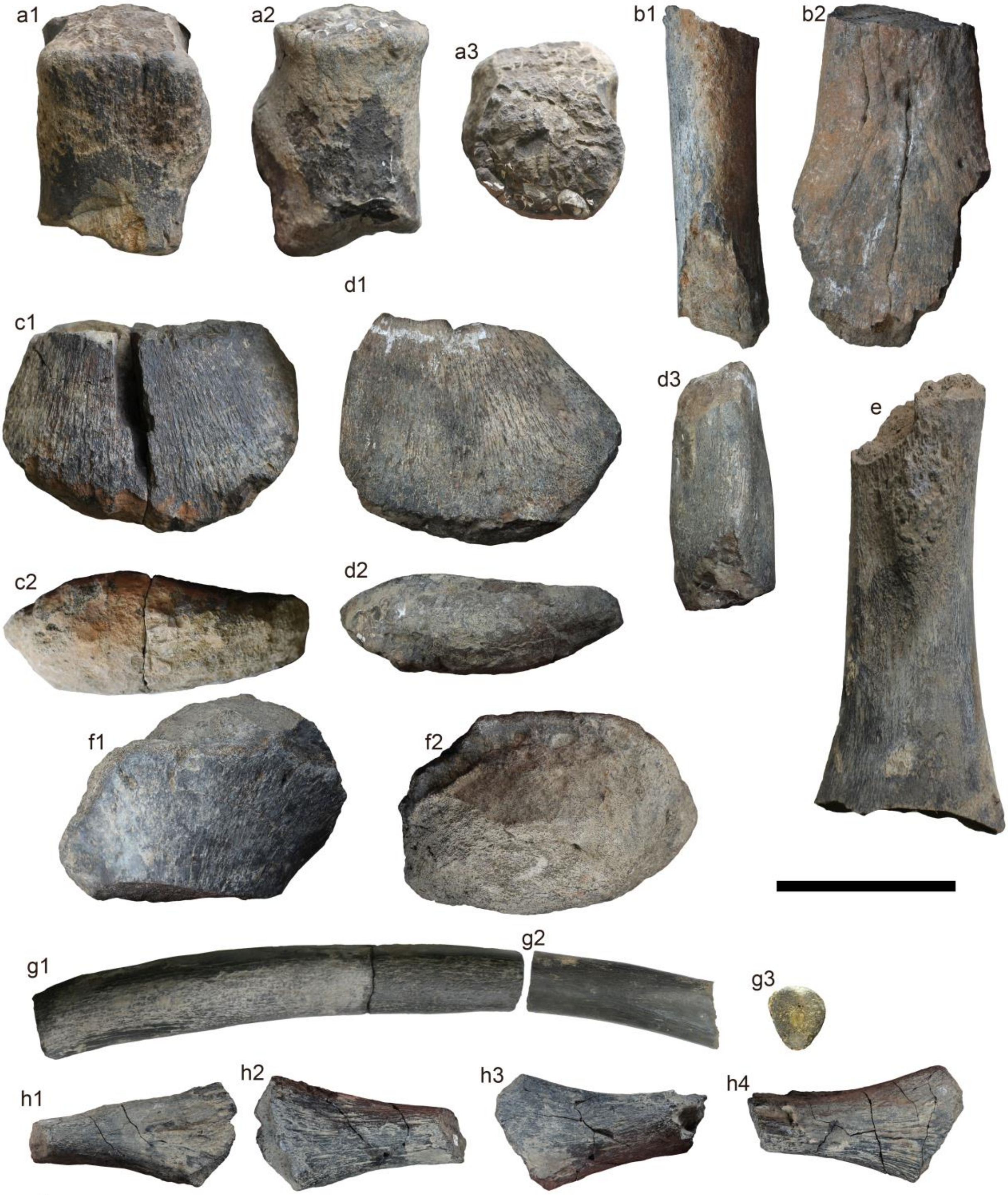

Figure S12. Elements of the appendicular skeleton and ribs of moderate and large plesiosaurians from the Toarcian of Eastern Siberia. (a) Proximal part of the humerus ZIN PH 12/211 in dorsal (a1), ventral (a2) and proximal (a3) views. (b) Distal portion of the propodial ZIN PH 101/211 in posterior (b1) and ventral or dorsal (b2) views. Distal portions of propodials ZIN PH 96/21 (c) and ZIN PH 51/211 (d) in ventral or dorsal (c1, d1) and distal (c2, d2) views. (e) Diaphyseal portion of the propodial ZIN PH 103/211 in dorsal or ventral view. (f) Acetabular portion of the pathologic ischium ZIN PH 95/211 in ventral (f1) and acetabular (f2) views. (g) Dorsal rib ZIN PH 32/211 (g1) and SPbU VZ R Sp8 (g2, g3). (h) Sacral? rib ZIN PH 26/211 in different views (h1–h3). Scale bar represents 10 cm.

ZIN PH 101/211 (Fig. S12b) and **ZIN PH 103/211** (Fig. S12e) are diaphyseal portions of propodials of moderately large plesiosaurians. ZIN PH 101/211 has a robust diaphysis dorsoventrally compressed and oval in cross-section and ZIN PH 103/211 has an elongated and slender diaphyseal part with circular cross-section.
Considering the general uniformity of propodial morphology in basal plesiosaurians (compared to a wider range of morphologies in derived taxa) all the above described propodial fragments, despite some differences, are referred to as Plesiosauria indet.

ZIN PH 95/211 is interpreted as an acetabular portion of the ischium of a large plesiosaurian (its maximum dimension is 155 mm (cf 90 mm in ZIN PH 37/211 and 80 mm in SPbU VZ R Sp38). This specimen is interesting by the presence of an enlarged hemispherical bulge with an irregularly rugose texture occupying much of the articular surface. This structure likely represents a pathologic condition (Fig. S12f).

ZIN PH 32/211 and **SPbU VZ R Sp8** are two parts of a large and robust dorsal rib (Fig. S12g) that is 40 mm in maximum diameter. This is the only specimen from the Linde River, tributary of the Lena River and is late Toarcian in age. It is likely that this rib belonged to a rhomaleosaurid as other plesiosaurian groups, including pliosaurids, were smaller in the Toarcian (e.g. Benson et al., 2012).

ZIN PH 26/211 is interpreted as a sacral rib in hawing expanded and strongly compressed proximal and distal ends with their long axes twisted relative to each other at approximately 90° (Fig. S12h). One of the ends bears an elongated depression in its middle (Fig. S12h1), similar to that present on proximal ends of sacral ribs in *Rhomaleosaurus* (Smith & Benson, 2014). The preserved proximodistal length of this rib is 125 mm long, thus it also belonged to a large plesiosaurian, likely a rhomaleosaurid (see rationale above).

Several propodial elements in the studied material are relatively small with poorly ossified distal and proximal ends, including poorly demarcated distal facts, and most importantly, poorly demarcated capitulum and dorsal trochanter proximally (Fig. S13). These specimens are identified as belonging to juvenile and/or infant animals (for juvenile criteria see Brown, 1981). From these, the smallest propodial, **ZIN PH 21/211**, is 104 mm in proximodistal length (Fig. S13a), the largest, **ZIN PH 119/211**, is 182 mm long (Fig. S13e). During the preparation of ZIN PH 119/211 it was possible to observe the bone structure in the diaphysis cross-section. The observed cortical bone was exclusively radially vascularized, similarly to the condition reported for fetal polycotylids (O'Keefe et al., 2019). This further supports the identification of the early ontogenetic stage of the specimen.

Figure S13. Propodial bones of juvenile and/or infant plesiosaurians from the Toarcian of Eastern Siberia. (a) ZIN PH 21/211 in ventral or dorsal (a1) anterior (a2) and distal (a3) views. (b) Proximal part ZIN PH 25/211 in ventral (b1), anterior or posterior (b2), dorsal (b3) and proximal (b4) views. (c) ZIN PH 104/211 in dorsal or ventral view. (d) ZIN PH 100/211 in dorsal or ventral (d1) and distal (d2) views. (e) ZIN PH 119/211 in dorsal or ventral (e1) and proximal (e2) views. (f) ZIN PH 56/211 in dorsal or ventral (f1) and anterior (f2) views. Scale bar represents 5 cm.

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