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ARTICLE

COMMENTS ON THE VALIDITY OF THE TAXONOMIC STATUS OF "*PUKYONGOSAURUS*" (DINOSAURIA: SAUROPODA)

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ABSTRACT

Associated materials of euhelopodid sauropod, *Pukyongosaurus millenniumi*, were reported in the year 2001 from Gyeongsang Basin, South Korea. However, some of the originally proposed autapomorphies for *Pukyongosaurus* are present in other sauropod taxa (i.e., somphospondylus vertebrae; ventral side of cervical centrum bent with a keel, or flat; opisthocoelous centrum of dorsal vertebrae with long and deep pleurocoels; dorsally opened chevron). Others (i.e., highly and anteriorly positioned cervical neural spine; parapophyses situated on the lateroventral edge of the centrum, posterior to the articular condyle) are too poorly preserved beyond observation. Therefore, the proposed diagnostic features for *Pukyongosaurus* and the combinations of these characters cannot be autapomorphies, and making the taxonomic name *nomen dubium*. Rather, a somphospondylus vertebrae of *Pukyongosaurus* indicates it is an indeterminate Titanosauriformes. Moreover, its "probable clavicle" material is re-identified as a chevron based on the morphological and anatomical profiles.

Key words : South Korea, Gyeongsang Supergroup, Hasandong Formation, Titanosauriformes, clavicle, chevron

INTRODUCTION

The Gyeongsang Supergroup (Hauterivian to Campanian?) of South Korea contains a variety of fossils (Lee et al., 2001), such as hard shelled invertebrates (e.g., Kobayashi and Suzuki, 1936; Yun et al., 2005), fishes (e.g., Yabumoto et al., 2006; Kim et al., 2014), and reptiles (e.g., Yun and Yang, 2001; Hwang et al., 2002; Yun et al., 2004; Lee et al., 2009). Dinosaur fossils (including birds) were also discovered from the supergroup (e.g., Lockley et al., 1992; Lim et al., 2001; Huh et al., 2003; Kim et al., 2005; Lee and Lee, 2007; Lee et al., 2011). Since the first discovery of a fragmentary humerus of a sauropod in 1973, a number of isolated dinosaur bone materials were reported (Kim, 1983; Lee et al., 1997). In 1998, the first associated materials of a dinosaur were excavated from the Hasandong Formation (Aptian), which forms the lower part of the Gyeongsang Supergroup, in Galsa-ri, Geumseong-myeon, Hadong County (Dong et al., 2001; Lee et al., 2012; Kang and Paik, 2013). All materials were discovered from the same horizon. Thus, Dong et al. (2001) assumed that they were from one individual, and assigned these to a new genus and species of Sauropoda, *Pukyongosaurus millenniumi*. The reported type specimen of *Pukyongosaurus* (PKNU-G.102–109) consists of four partial cervical vertebrae (PKNU-G.102–105), one partial dorsal vertebra (PKNU-G.106), one partial rib (PKNU-G.107), one complete chevron (PKNU-G.108), and one "probable clavicle" (PKNU-G.109) (Fig. 1) (According to the original description, there should be "seven cervical vertebrae" (Dong et al., 2001: 44–45) in the type specimen, but only four cervical vertebrae were included in the plates, with no further information about the three missing materials).

However, a number of authors have considered this taxon as a *nomen dubium* in previous reviews (Upchurch et al., 2004; Lee and Lee, 2006). Additionally, Mannion et al. (2013) regarded the taxon as an indeterminate titanosauriform sauropod, based on the presence of somphospondylus internal structure within the presacral vertebrae. But none of the authors made detailed comments about their reasoning. This article will focus on re-examining the taxonomic status of *Pukyongosaurus*. Here, the author will review each diagnostic feature of this taxon proposed by Dong et al (2001), and evaluate the previous identification of specimen PKNU-G.109, which was originally described as a "probable clavicle" of *Pukyongosaurus*.

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INSTITUTIONAL ABBREVIATIONS

AMNH, American Museum of Natural History, New York, U.S.A.; **DQ**, Dinosauria International (Dana Quarry collection), New York, U.S.A.; **GCP**, Grupo Cultural Paleontológico de Elche, Spain; **KUVP**, University of Kansas Natural History Museum, Kansas, U.S.A.; **MUCPv**, Museo de Geología y Paleontología de la Universidad Nacional del Comahue, Argentina; **PKNU**, Pukyong National University, South Korea; **SMA**, Sauriermuseum Aathal, Switzerland.

COMMENTS ON DIAGNOSTIC FEATURES

According to Dong et al. (2001), *Pukyongosaurus* is diagnosed by the following characters: (1) somphospondylus vertebrae; (2) highly and anteriorly positioned cervical neural spine; (3) parapophyses situated on the lateroventral edge of the centrum, posterior to the articular condyle; (4) ventral side of cervical centrum bent with a keel, or flat; (5) opisthocoelous centrum of dorsal vertebrae with long and deep pleurocoels; (6) dorsally opened chevron. However, the diagnostic features of this taxon are inadequate because of the following reasons.

1. Somphospondylus vertebrae

According to Dong et al. (2001), somphospondylus vertebrae of *Pukyongosaurus* are all presacral elements. This is a synapomorphy of Titanosauriformes, and this can be seen throughout the clade. Although not common, it occurs within certain non-titanosauriform eusauropods as well (e.g, *Mamenchisaurus*) (Upchurch et al., 2004).

2. Highly and anteriorly positioned cervical neural spine

Dong et al. (2001) described the cervical vertebra of *Pukyongosaurus* based on PKNU-G.102. Although the anterior and posterior portion are not preserved and the remaining medial region is laterally compressed and shattered, a partial neural spine can be observed in this specimen. Dong et al. (2001) stated that the partial neural spine in PKNU-G.102 is relatively tall and shows an inclining dorsoanterior surface which makes it steeper than that of *Mamenchisaurus*, *Omeisaurus*, and *Euhelopus*. However, the morphology of the neural spine can differ depending on the position of the cervical vertebra. In many cases, cervical vertebrae situated at the posterior part of the neck show a tendency to have relatively higher neural spines with a steeper dorsoanterior surface (e.g., *Puertasaurus*, *Sauroposeidon*, *Mamenchisaurus*). On the other hand, the location of PKNU-G.102 in the neck is unclear. With only a handful of materials, the overall shape of the cervical neural spines of *Pukyongosaurus* is uncertain and therefore cannot be compared with other sauropods.

3. Parapophyses situated on the lateroventral edge of the centrum, posterior to the articular condyle

Dong et al. (2001) mentioned that the position of the parapophyses in *Pukyongosaurus* is quite similar to those of *Euhelopus* and *Camarasaurus*. But all known sauropods tend to have parapophyses projected lateroventrally from the centrum, and closely situated to the condyle. Moreover, the presented cervical materials in Dong et al. (2001) have incomplete anterior portions, which makes it uncertain whether the position or morphology of the parapophyses is comparable to other sauropods.

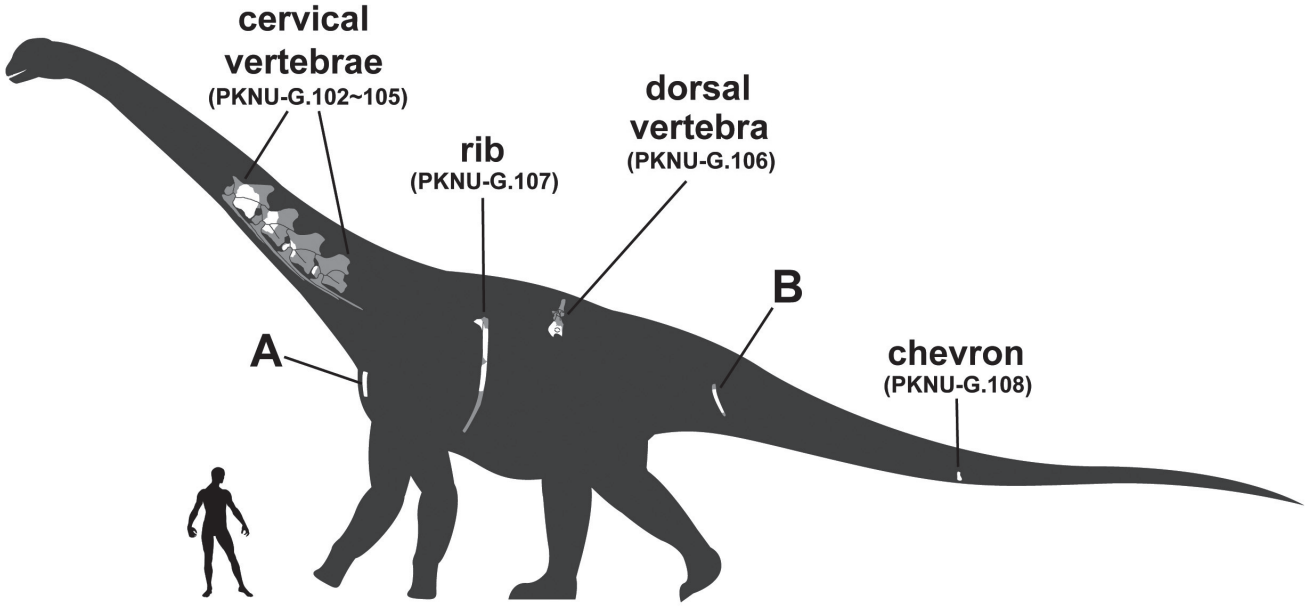

FIGURE 1. Full body silhouette of "*Pukyongosaurus millenniumi*" with preserved elements of PKNU-G.102–109 highlighted in white. **A–B,** Position of specimen PKNU-G.109 as **A,** a clavicle according to Dong et al. (2001) and **B,** as a proximal chevron according to this study. Height of human silhouette = 1700 mm.

4. Ventral side of cervical centrum bent with a keel, or flat

Among the four cervical vertebrae presented in the plates of Dong et al. (2001), only one specimen (PKNU-G.102) has a nearly complete ventral surface with an arched surface in lateral view. According to Upchurch et al. (2004), the ventrally arched surface can be generally observed in many sauropod taxa (e.g., *Apatosaurus*, *Barosaurus*, *Bonitasaura*, *Camarasaurus*, *Haplocanthosaurus*, *Qiaowanlong*).

5. Opisthocoelous centrum of dorsal vertebrae with long and deep pleurocoels

Dorsal vertebrae that are opisthocoelous can be observed in all macronarians (Upchurch, 1998; Wilson and Sereno, 1998). The pleurocoels in *Pukyongosaurus* are deep, and seem to be continuous with chambers within the body of the centrum. This is a feature that can be seen in *Omeisaurus* and neosauropods (Upchurch et al., 2004).

6. Dorsally opened chevron

Macronarian sauropods are known by having proximally open chevrons (Calvo and Bonaparte, 1991; Upchurch, 1995), but in some unusual examples, like the Chinese titanosauriforms *Dongbeititan* (Wang et al., 2007), *Daxiatitan* (You et al., 2008), *Xianshanosaurus* (Lü et al., 2009), the North American camarasaurid *Camarasaurus lewisi* (McIntosh et al., 1996), and the European brachiosaurid *Lusotitan* (Mannion et al., 2013), the proximal rami are linked by a bridge of bone. With only one complete chevron material of *Pukyongosaurus* reported from Dong et al. (2001), the author thinks that it is too soon to conclude whether this taxon had proximally opened or closed chevrons.

For these reasons, any features presented by Dong et al. (2001) cannot be autapomorphies for *Pukyongosaurus*, nor the combination of these characteristics can be stated as diagnostic for this taxon. The type specimen of *Pukyongosaurus* has an opisthocoelous dorsal vertebrae that can be seen in all Macronaria, and show one synapomorphy of Titanosauriformes, a somphospondylus vertebrae. Therefore it is reasonable to conclude that the specimen should be reclassified as an indeterminate Titanosauriformes, and since *Pukyongosaurus* has no diagnostic features, the taxon should be stated as a *nomen dubium*.

EVALUATION OF THE PROBABLE CLAVICLE MATERIAL

Dong et al. (2001) identified a bone as a "probable clavicle" (Fig. 2) from one of the type specimen of "*Pukyongosaurus*" (PKNU-G.109): "It is almost certainly a clavicle; it is trident-shaped, being rodlike at one end and two-headed at the other. Unfortunately, the distal end is broken. It is possibly a right clavicle and distinctive from previously known clavicle".

In a number of studies including Dong et al. (2001), rodlike elements associated with the pectoral girdles were interpreted as putative clavicle materials of sauropods, and many authors

FIGURE 2. Specimen PKNU-G.109. Scale bar = 50 mm.

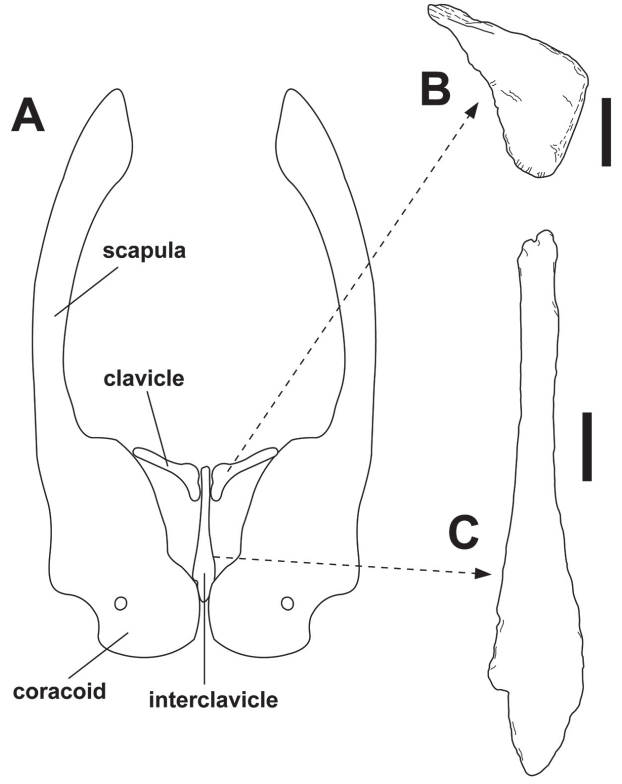

FIGURE 3. Clavicle and interclavicle in sauropod dinosaurs. **A,** Reconstructed chest region of a sauropod dinosaur (based on Tschopp and Mateus (2013). **B,** left clavicle (internal view) and **C,** interclavicle (external view) from *Spinophorosaurus nigerensis* (GCP-CV 4229) (based on Remes et al., 2009). All scale bars = 100 mm.

have anticipated it to have connected the scapulae and coracoids dorsally (e.g., Dong and Tang, 1984; He et al., 1988; Zhang, 1988; Sereno et al., 1999; Harris, 2007; Remes et al., 2009). However, a recent study by Tschopp and Mateus (2013) leads to the conclusion that many of the materials, that were previously known to be clavicles, were actually interclavicle. True clavicles from sauropods are L-shaped with a concave surface internally, and a convex surface on the other. Usually found in pairs, the elements have a D-shaped or crescent-like in the midlength cross-section (Tschopp and Mateus, 2013) (Fig. 3B). However, PKNU-G.109 does not fit in to this general morphology, and does not show any related anatomical features. Therefore, the "probable clavicle" identification for this sauropod material is erroneous. So far, true clavicle materials from sauropods are reported from a non-somphospondylian macronarian sauropod (SMA 0009) (Schwarz et al., 2007), the holotype of *Spinophorosaurus nigerensis* (GCP-CV 4229) (Remes et al., 2009), three associated elements (one pair: DQ-SB and one single isolated material: DQ-TY) from diplopocid sauropods (Galiano and Albersdörf, 2010), from *Camarasaurus* sp. (KUVP 129716) (Bader et al., 2009), and two pairs from the Howe Quarry sauropods (?Diplodocidae) (SMA K 24-3, 6; AMNH 30789) (Tschopp and Mateus, 2013).

Moreover, PKNU-G.109 is not morphologically similar to other sauropod interclavicles, either. According to Tschopp and Mateus (2013), the interclavicle in sauropods is relatively stout, elongated, and bowed in shape with a spatulate end posteriorly, and a bifurcate end anteriorly (Fig. 3C). Although PKNU-G.109 shows a bifurcate shape at the anterior end, it has a more elongated and widely divided end, which is quite different from other known interclavicle materials in sauropods. In addition, the shaft beneath the bifurcate end is more compressed laterally and blade-like, which is different from the cranially flat surfaced interclavicle. Therefore, PKNU-G.109 is not an interclavicle material.

Although only the median part of the specimen is preserved, the elongated Y-shaped profile clearly shows that this material is a partial chevron/haemal arch. The overall morphology of the Y-shaped chevron can be verified in many other dinosaurian clades; two rami forming the proximal end, each ramus constituting the haemal canal, and a distal portion terminating as a laterally compressed blade.

The preserved medial part of the specimen is 314 mm in dorsoventral length, and the preserved haemal canal is about 75 mm. Because the proximal end is not fully preserved, it is unclear whether the proximal end of this material is closed by a bar of bone or not. Judging from the morphological profiles, it is certain that PKNU-G.109 is much more proximally placed than PKNU-G.108, near the base of the tail.

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