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NEW INFORMATION ON THE FOREFIN OF *UTATSUSAURUS HATAII* (ICHTHYOSAURI A)

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ABSTRACT— *Utatsusaurus hataii,* an Early Triassic ichthyosaur from Japan, is represented by exceptionally well preserved materials but is poorly known because of incomplete preparation. Further preparation of the holotype and one of the paratype specimens has revealed nearly complete forefins that are pentadactyl, with no more than five phalanges in any of the digits. The first digit is not well developed, and the fifth distal carpal appears to be absent. The phalanges along the fin margin tend to be lunate; others are flattened cylinders. These findings indicate that the relationship of *Utatsusaurus* with other Early Triassic ichthyosaurs must be reconsidered.

INTRODUCTION

THE LIMBS of post-Triassic ichthyosaurs are highly modified as fins with closely packed elements, marked hyperphalangy, and often with hyperdactyly. Because they are so highly derived, it is difficult to make comparisons with the limbs of terrestrial amniotes. The fins of Triassic ichthyosaurs, in contrast, are less derived and therefore more suitable for comparative studies. The oldest ichthyosaur forefins are known from Spathian (Lower Triassic) deposits in Canada (Brinkman et al., 1992), China (Young and Dong, 1972; Chen, 1985), Japan (Shikama et al., 1978), Spitsbergen (Wiman, 1929, 1933) and possibly from Thailand (Mazin et al., 1991). With the exception of the Canadian materials, however, descriptions of these forefins have been either incomplete or inaccurate.

The forefin of *Utatsusaurus hataii* Shikama et al. (1978) from Japan is exceptionally well preserved, but the original description was inaccurate, largely because of incomplete preparation. The matrix of the holotype slab was painted white originally to make the bones stand out. This paint, however, covered bones in places, and some matrix was left unpainted and consequently appeared as a bone, which lead to misinterpretations (Motani, in press a). Some obvious errors in the first description have been corrected in the literature. For example, Mazin (1986) identified correctly the preaxial orientation of the forefin, which was transposed in the original study, and Carroll (1988) identified the proximal carpals from a figure in Shikama et al. (1978). The true morphology of the forefin remained unknown, however, because no preparation had been conducted since the original study.

Through the courtesy of the Tohoku University, Sendai, Japan, additional preparation of the holotype and paratype of *Utatsusaurus hataii* was undertaken. The purpose of the present paper is to redescribe the morphology of the forefin in the light of this work.

MATERIALS AND METHODS

The specimens prepared are the holotype (IGPS 95941, Institute of Geology and Paleontology, Tohoku University, Sendai) and one of the paratypes (IGPS 95942) of *Utatsusaurus hataii* Shikama, Kamei, and Murata, 1978. Each specimen consists of a main slab and counter slab, which are indicated by suffixes "a" and "b" respectively. They were collected from one quarry (site K of Shikama et al., 1978), and the similarities in their fins show that they belong to the same species, as argued by Shikama et al.

Preparation was conducted using mounted needles under a binocular microscope. An air-abrasive tool with dolomite powder also was used. Because some of the bones of the paratype overlap, conventional radiographs were taken prior to preparation. Measurements were taken with dial calipers and recorded to the nearest 0.1 mm. Angles were measured from photographs of the specimens by means of a protractor with a 0.5 degree scale and recorded to the nearest degree. The length and width of the humerus and ulna were measured as shown in Figures 1.4, 1.5. The relative osteological maturity of the specimens was judged on the basis of the criteria put forth by Johnson (1977) in a study of *Stenopterygius.*

To reconstruct an entire forefin, outlines of the three partial forefins (right from the holotype, right and left from the paratype) were scanned into a PC as bitmaps, which were traced using CorelTrace 5.0. The traced images were imported into CorelDraw 5.0. The trace of the two forefins of the paratype were combined in a composite image, which was then resized so that the distal width of the right ulna of the paratype equaled that of the right ulna of the holotype. Finally, the composite image of the paratype forefin was incorporated into the tracing of the holotype forefin in order to compensate for missing elements in the holotype.

DESCRIPTION

General account. — Shikama et al. (1978) mistook the dorsal direction for the ventral in the holotype, which resulted in the misidentification of the right fin for the left. From their plate (Shikama et al., 1978, plate 1), it appears as if the body is exposed in dorsolateral aspect, with the mandible exposed ventrally. Their explanation for this seemingly strange preservation was that the neck had been twisted (Shikama et al., 1978). Examination of the main slab, however, reveals that this is an artifact of the white paint on the main slab. Almost all the ribs of the left side are preserved in the counter slab (IGPS 9594Ib), and corresponding impressions remain on the main slab. Thus, the body is exposed from ventrolateral aspect in the main slab, and there is no twist in the cervical region. Because the label on the back of the slab reads that the main slab was overlying the counter slab when the specimen was collected, the animal is preserved on the under surface of the main slab. Accordingly, the dead body of this individual came to rest with its dorsal side up.

Although IGPS 95941 and 95942 are dorsoventrally compressed, both retain some three dimensional shape. The bones

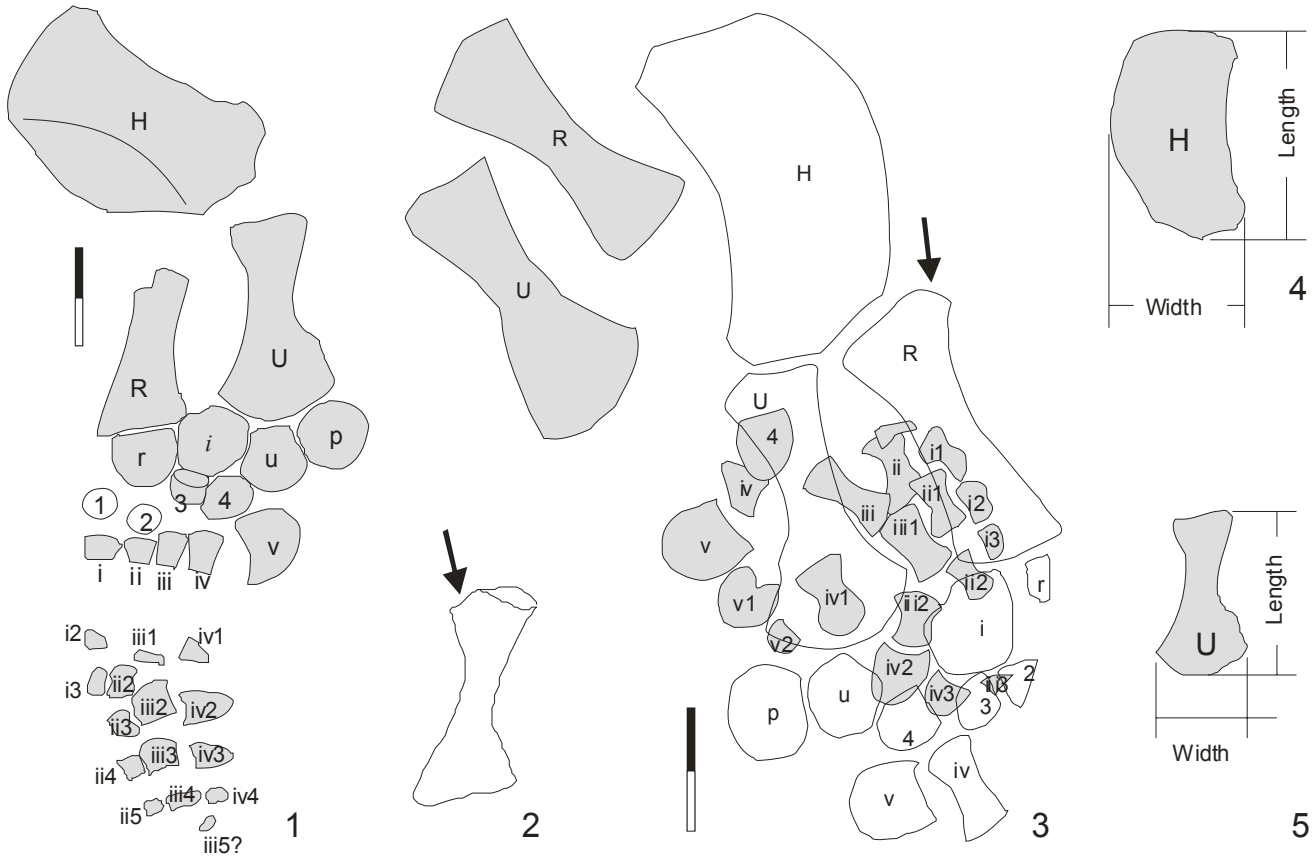

FIGURE *1—Utatsusaurus hataii,* outlines of forefin elements. /, right forefin of the holotype, ventral view (IGPS 95941); 2, left radius of the holotype, traced from a radiograph; 3, forefins preserved in one of the paratypes (IGPS 95942) based on radiographic images of the main and counter slabs (left forefin shown in outline only, right forefin shaded); *4,* 5, measurements taken for humerus and ulna. H, humerus; R, radius; U, ulna; /, intermedium; p, pisiform; r, radiale; u, ulnare; 1-4, distal carpals; i-iv, metacarpals; il-v2, phalanges. Arrows in *2* and *3* indicate the anteroproximal prominence of the radius mentioned in the text. Bar scales are two centimeters.

are well preserved, and small structures, such as surface striations and small processes, are clearly visible.

Both forefins are preserved in the holotype (IGPS 95941). The right forefin is exposed in ventral aspect on the main slab (IGPS 9594la). The slab is broken perpendicular to the long axis of the fin so that that proximal and distal parts occur in separate blocks (Figure 2.1). Shikama et al. (1978, plate 1) figured a small piece of rock that contained some proximal phalanges wedged between the two blocks; the subsequent loss of this piece (Mazin, 1986) raises the problem of the position of the distal slab relative to the proximal one. Because the specimen is preserved in slightly slaty shale, however, slaty cleavage planes can be used to estimate the relative orientations of the two slabs. I placed the distal slab so that its proximal margin, formed by a slaty cleavage, is parallel to the distal slaty cleavage of the other slab (Figure 2.1). These two cleavage surfaces, which are similarly colored by sulfur, are in partial contact, but this contact is too deep to be seen in Figure 2.1. This placement differs from that of Shikama et al. (1978, plate 1), and suggests that the proximal portion of the distal slab was omitted in the original illustration. As shown below, the new configuration is consistent with the morphology of the paratype fins.

The left forefin is exposed in dorsal aspect on the counter slab (IGPS 95941b). Because the fin is overlain distally by the vertebral column and ribs, only the propodial and epipodial elements are well exposed. The proximal parts of both forefins are preserved in IGPS 95942, the right one being exposed from dorsal aspect, the left one from ventral aspect. The two fins overlap partially (Figures 1.3, 2.2). Because the left forefin is shifted proximally relative to the right, it is possible to distinguish between the elements of the two forefins.

Humerus (Figures 1, 3).—Ventral and dorsal aspects of the humeri are exposed in the right and left forefins of the holotype, respectively. The right humerus is 45.7 mm long and 28.4 mm wide anteroposteriorly, and the left humerus is 45.2 mm long and 27.1 mm wide. Other measurements are presented in Table 1.

The humerus is unusual for amniotes in having a thin anterior expansion, often referred to as the anterior flange, which projects from the shaft (Figures 1, 2). The surface striations on the anterior flange are radial in direction. The two ends of the shaft are nearly parallel to each other and, thus, depart from the basic amniote pattern of a tetrahedral configuration. The proximal end of the shaft is straight in both dorsal and ventral views, indicating incomplete ossification and the presence of a cartilaginous head. This end is slightly convex dorsally and slightly concave ventrally, as in many terrestrial diapsids, but unlike later ichthyosaurs. The deltopectoral crest is not fully developed, probably because of immaturity, but can be seen as a small prominence at the anteroproximal end of the ventral surface of the shaft. Distal to the deltopectoral crest is a well-marked tuberosity, just proximal to the middle of the shaft, which is more pronounced than the immature deltopectoral crest. A weak tuberosity is present on the dorsal aspect at about the same level. The surface texture is rough proximally, again indicating osteological immaturity.

There are three articular facets on the distal end. The most anterior facet, which is for the radius, faces anterodistally. The

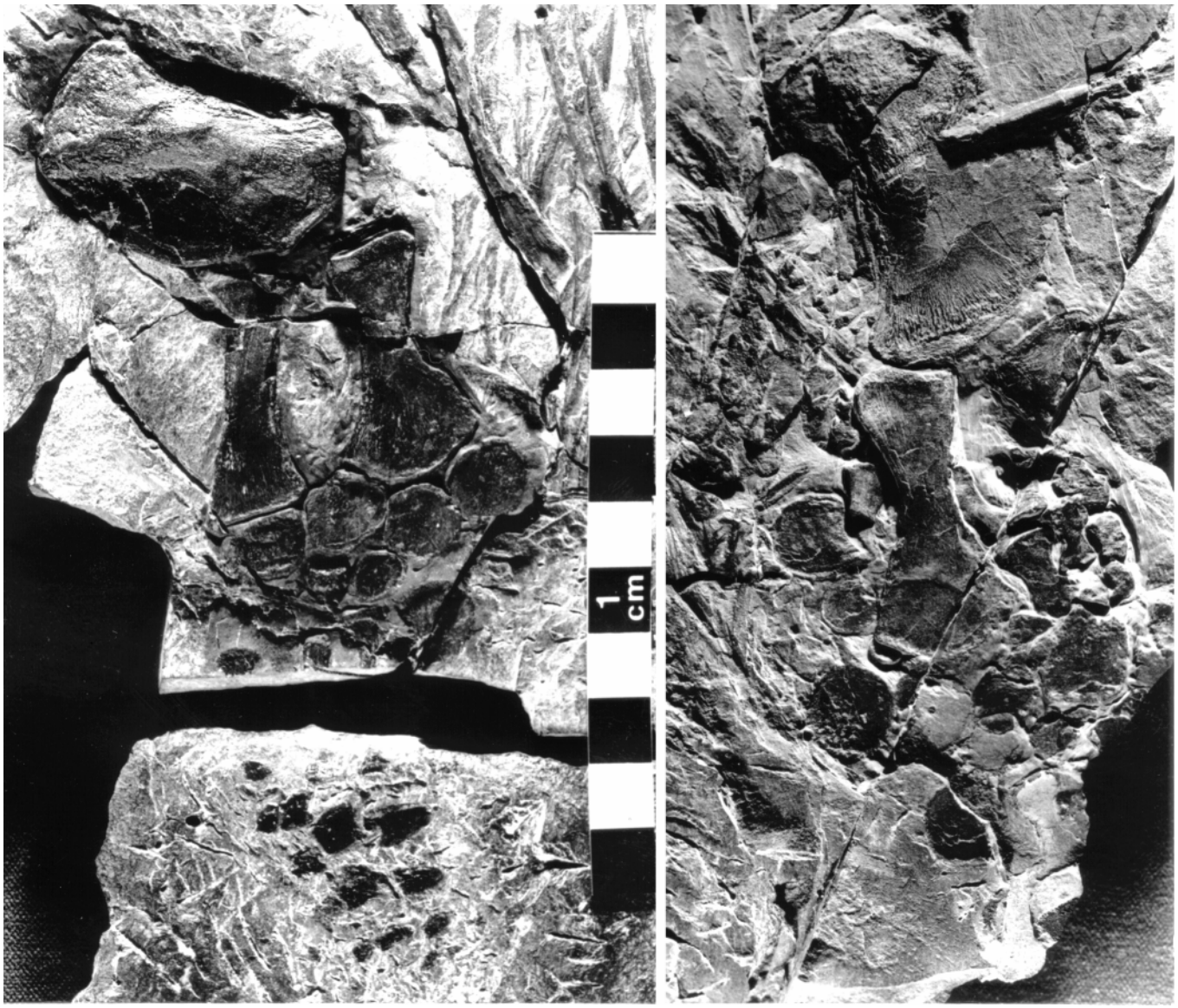

FIGURE 2—*Utatsusaurus hataii,* photographs of forefins. 7, right forefin of the holotype (IGPS 95941); 2, forefins of one of the paratypes (IGPS 95942) on the counter slab. See Figure 1 for the identifications of each element. Scale in centimeters.

middle facet, for the ulna, is directed posterodistally. The most posterior facet is rather small and triangular and is directed posteriorly. This facet may have articulated with a cartilaginous olecranon process of the ulna, which is not preserved.

The right humerus of the paratype is exposed in dorsal aspect (Figure 2.2). It is slightly larger than the humeri of the holotype and the ossification of the head is more advanced (compare Figure 3.1 and 3.2) as shown by the slightly convex proximal end of the shaft.

Radius (Figures 1, 3).—The right radius of the holotype is exposed but broken proximally, and the left radius is exposed only proximally. Complete exposure of the left radius was not possible because it would have required the destruction of overlying bones; the depiction of this radius in Figure 1.2 is based on a radiograph. An unusual triangular prominence is present proximally on the anterior aspect of the articular facet for the humerus, as seen in both holotype and paratype (Figure 1.2 and 1.3, arrows). The function of this prominence is unknown, but it may have been related to that of the anterior flange of the humerus.

Ulna (Figures 1, 3).—The ulna has a flattened shaft that is broadly expanded distally but only moderately so proximally. It is slightly shorter than the humerus and almost as long as the radius (Table 1). The distal end has three articular facets for the

TABLE 1 — *Utatsusaurus hataii,* measurements of the right forefin elements of the holotype (IGPS 95941) in mm.

	Length	Width
Humerus	45.7	28.4
Ulna	37.8	21.7
Radius	^39	16.5
	Max. Diameter	Min. Diameter
Radiale	13.5	9.5
Intermedium	14.3	10.9
Ulnare	12.1	11.6
Pisiform	13.0	11.4
Distal Carpal 3	6.5	^4
Distal Carpal 4	9.7	7.4
Metacarpal 5	12.8	11.1

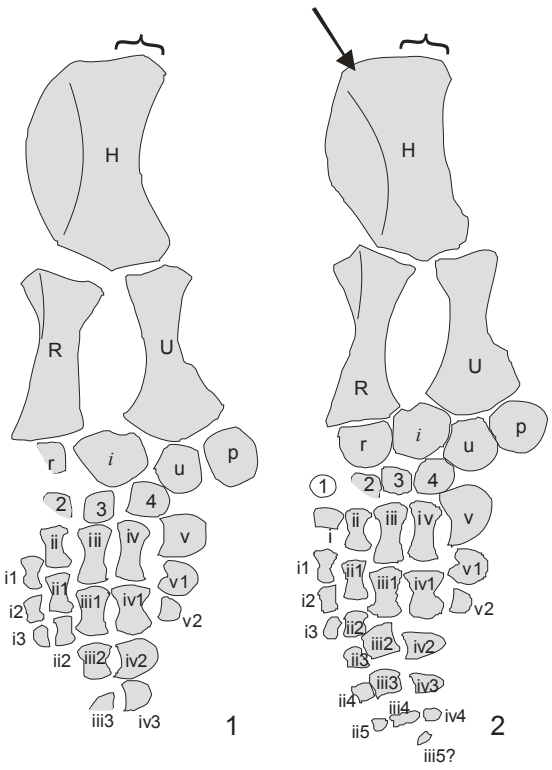

FIGURE J— *Utatsusaurus hataii,* reconstruction of forefin. 7, composite image of the forefms of the paratype reconstructed as the right forefin, ventral view; 2, composite image of Figures 1.1 and 3.1. Brackets indicate the position of the humeral head, which is developed in the paratype but not in the holotype. Arrow indicates the position of the deltopectoral crest. Midshaft tuberosity mentioned in the text is located in the position of H. Abbreviations as in Figure 1.

intermedium, ulnare, and pisiform. A small prominence on the posterior margin of the distal expansion results in an asymmetric outline that differs from Mazin's (1986) description of a symmetrical shape. The shape of the proximal end varies among individuals (compare Figure 1.1 and 1.3). The proximal end forms the articular facet for the humerus. In the holotype, this is much longer than that of the corresponding articular facet of the humerus, which suggests that a cartilaginous olecranon was present.

Carpals (Figures 1, 3).—There are four proximal carpals, identified as the radiale, intermedium, ulnare, and pisiform by Carroll (1988, figure 12-30). Although five distal carpals were figured by Shikama et al. (1978), recent preparation of the holotype revealed that the anterior two are absent. Given the immaturity of the humerus, these two distal carpals may not have been ossified. Alternatively, because this region was deeply excavated previously and because the two element were restored subsequently by Shikama et al., they may have been present originally. The second distal carpal is partially preserved in the right forefin of the paratype, which is osteologically more mature than the holotype. The rest of the elements figured as distal carpals by Shikama et al. (1978) are identified here as the third and fourth distal carpals and the fifth metacarpal.

The proximal carpals are disks of similar size. The radiale is nearly semicircular, with its chord directed proximally. The intermedium is the largest of the carpals and is almost hexagonal. The ulnare is nearly pentagonal, and the pisiform is discoidal. The third distal carpal is an oval disk that has been displaced slightly, lying oblique to the bedding plane. The fourth distal carpal is similar to the third in being oval but is larger. The second distal carpal resembles the third in size and shape.

Metacarpals (Figures 1, 3).—There are five metacarpals, of which the fifth is exceptional in being lunate, with the chord directed anteriorly. The rest of the metacarpals are incomplete in the holotype, but some are complete in the paratype. They are similar to those of terrestrial amniotes in having expanded extremities and narrow shafts, but differ in being flattened. Although Shikama et al. (1978) figured five elongated elements in the metacarpal row, only four are present.

Phalanges.—The phalanges vary in shape from being flattened cylinders, as in the metacarpals, to being lunate disks. The cylindrical phalanges, which occur proximally in the second to fourth digits, become shorter distally. The lunate phalanges only occur close to the leading and trailing edges of the forefin, and their convex edges are directed towards the closest free margin of the fin (Figure 3.2). The proximal phalanges of the first digit are intermediate between being lunate and cylindrical. Shikama et al. (1978, figure 11) figured all the phalanges as being rectangular.

DISCUSSION

The right forefin of the holotype is nearly complete, except for the middle portion, which is known in the paratype. It is, therefore, possible to reconstruct the entire forefin of *Utatsusaurus hataii* by filling the missing part of the holotype fin with paratype elements (Figure 3.2). The preserved phalangeal formula is 3-5-5-4-2. Although some distal elements may possibly be missing, the small size of the most distal elements suggests this is unlikely. Mazin (1986) proposed a reconstruction with up to eight phalanges per digit, but there is no evidence to support this. In contrast to *Mixosaurus cornalianus,* a geologically younger pentadactyl ichthyosaur from the Middle Triassic (Repossi, 1902), the first digit is not well developed in *U. hataii.*

The paratype represents an osteologically older individual than the holotype: the humerus is larger and the ossification of the head is more advanced. Similarly, the second and third phalanges of the fourth digit, the second phalanx of the third digit, and the second phalanx of the second digit, are more elongated in the paratype than in the holotype. Therefore, the reconstruction (Figure 3.2) contains elements from two different growth stages.

The forefin of *Utatsusaurus hataii* shows much resemblance to the forefins described by Brinkman et al. (1992) from the Lower Triassic of British Columbia as *Grippia.* Because Brinkman et al. (1992) relied upon inaccurate descriptions of *Utatsusaurus* (Shikama et al., 1978; Mazin, 1986) the identity of Canadian material should be reconsidered. However, these Canadian forefins are tectonically deformed (Motani, 1994), and their images have to be undeformed before comparisons can be made with other forefins. Moreover, *Grippia* is a poorly known genus (Motani, in press b), and a reasonable description of its forefin is long overdue. Such studies are beyond the scope of the present paper, however, and further taxonomic discussion must be postponed pending their completion.

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