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Authors: Takahashi, Yui, Nakajima, Yasuhisa, and Sato, Tamaki

Source: Paleontological Research, 18(4) : 258-262

Published By: The Palaeontological Society of Japan

URL: https://doi.org/10.2517/2014PR023

Paleontological Research, vol. 18, no. 4, pp. 258–262, October 1, 2014

doi:10.2517/2014PR023

An Early Triassic ichthyopterygian fossil from the Osawa Formation in Minamisanriku Town, Miyagi Prefecture, Japan

YUI TAKAHASHI[1], YASUHISA NAKAJIMA[2] AND TAMAKI SATO[3]

[1]*Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennoudai, Tsukuba City, Ibaraki 305-0001, Japan (e-mail: wqvqzzgp@geol.tsukuba.ac.jp)*
[2]*Steinmann Institute for Geology, Mineralogy and Paleontology, University of Bonn, Nussallee 8, 53115 Bonn, Germany*
[3]*Department of Astronomy and Earth Sciences, Tokyo Gakugei University, 4-1-1 Nukui-Kita-Machi, Koganei City, Tokyo 184-8501, Japan*

Received September 4, 2013; Revised manuscript accepted April 22, 2014

Abstract. The ichthyopterygian *Utatsusaurus hataii* Shikama *et al.* 1978 is the only valid reptilian taxon known from the Lower Triassic Osawa Formation in Minamisanriku Town, Miyagi Prefecture, which records the recovery of the marine ecosystem shortly after the end-Permian mass extinction. In this paper, we describe a fragmentary specimen of an indeterminate ichthyopterygian which is distinguished from *Utatsusaurus hataii* based on rib morphology. The discovery of a previously unknown ichthyopterygian implies that the taxonomic diversity of the reptilian fauna of this formation is higher than previously assumed.

Key words: Early Triassic, Ichthyopterygia, marine reptile, Osawa Formation, *Utatsusaurus*

Introduction

The Ichthyopterygia Owen, 1840 is a remarkable group of Mesozoic marine reptiles with distinctive fish-shaped bodies. There are conflicting views on the taxonomic nomenclature of ichthyopterygians (e.g. McGowan and Motani, 2003; Maisch, 2010). In this study, we employed the phylogeny and nomenclature of McGowan and Motani (2003) in which the term Ichthyosauria refers to a derived clade within the Ichthyopterygia; according to this system, *Utatsusaurus* is a basal ichthyopterygian and not an ichthyosaurian. The phylogenetic relationships and systematics within the group have been analyzed in recent synthetic studies (e.g. Motani, 1999; Sander, 2000; McGowan and Motani, 2003; Maisch, 2010), but a consensus is yet to be reached regarding the phylogenetic relationship with other reptiles (e.g. McGowan and Motani, 2003). More information on early ichthyopterygians is crucial to understand their origin.

The ichthyopterygian fossil record extends from the Early Triassic Olenekian to the Late Cretaceous Cenomanian (McGowan and Motani, 2003). Early Triassic taxa have been reported from Europe, North America, and Asia (Table 1). Note that some species are represented by fragmentary specimens, while the ichthyopterygian affinity of a few taxa has been debated (e.g. *Omphalosaurus* and "*Pessopteryx nisseri*"; Motani, 2000; Sander and Faber, 2003; McGowan and Motani, 2003; Dalla Vecchia, 2004; Maisch, 2010).

The Permian–Triassic mass extinction affected the marine ecosystem seriously (Raup, 1979; Sepkoski, 1984), and the Paleozoic fauna was largely replaced with the modern fauna (Sepkoski, 1984). The occurrence of marine reptiles added a new trophic level of top predators in the Mesozoic marine ecosystem, and their radiation started in the Olenekian (Chen and Benton, 2012; Fröbisch *et al.*, 2013). However, only a limited number of Early Triassic reptilian faunas actually document this process (e.g. Sulphur Mountain Formation in Canada, Vikinghøgda Formation in Norway, Nanlinghu Formation in China: see Table 1). The Osawa reptilian fauna is important in this regard as well.

In 2007, a partial skeleton of a reptile was discovered from the Lower Triassic Osawa Formation (upper Olenekian [Spathian]: Bando and Shimoyama, 1974; Bando and Ehiro, 1982), Inai Group, in Miyagi Prefecture, northeastern Japan (Figure 1). This formation has yielded a number of articulated skeletons of the primitive ichthyopterygian *Utatsusaurus hataii* Shikama *et al.*, 1978,

Table 1. List of recognized Early Triassic ichthyopterygian taxa and their occurrence data.

Locality	Stratigraphy	Recognized taxa	Reference
British Columbia, Canada	Sulphur Mountain Formation	*Grippia* sp.	Brinkman *et al.*, 1992
		Utatsusaurus sp.	Nicholls and Brinkman, 1993
		Parvinatator wapitiensis	Nicholls and Brinkman, 1995
		Gulosaurus helmi	Cuthbertson *et al.*, 2013
Spitzbergen, Norway	Vikinghøgda Formation (Sticky Keep Formation)	*Grippia longirostris*	Wiman, 1929
		Besanosaurus sp.	McGowan and Motani, 2003: 135, 136
		Quasianosteosaurus vikinghoegdai	Maisch and Matzke, 2003
Anhui, China	Nanlinghu Formation	*Chaohusaurus geishanensis*	Young and Dong, 1972
Hubei, China	Jialingjiang Formation	*Chaohusaurus zhangjiawanensis*	Chen *et al.*, 2013
Southern Peninsula, Thailand	unrecorded horizon, probably Lower Triassic (McGowan and Motani, 2003: 63)	*Thaisaurus chonglacomanii*	Mazin *et al.*, 1991
Miyagi, Japan	Osawa Formation	*Utatsusaurus hataii*	Shikama *et al.*, 1978

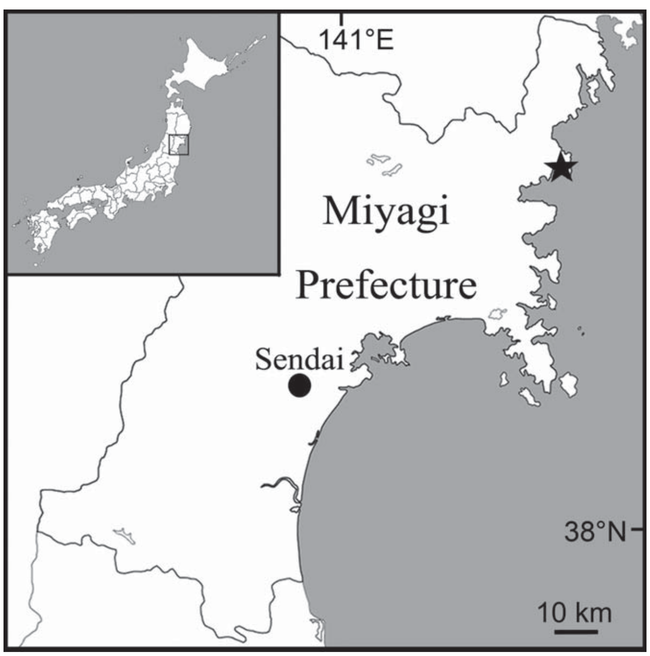

Figure 1. Locality map of UMUT MV 31051. The black star represents the locality in Minamisanriku Town, Miyagi Prefecture.

which is one of the oldest animals secondarily adapted to life in the open ocean (Nakajima *et al.*, 2014). Apart from *U. hataii*, only two other vertebrate taxa, i.e., a hybodontoid shark (Kato *et al.*, 1995) and "*Metanothosaurus nipponicus*" Yabe and Shikama, 1948, have been reported from the formation to science. The holotype and only specimen of the latter taxon is missing, and the existing information is not sufficient to determine its taxonomic status (e.g. sauropterygian in Mazin, 1986; ichthyosaur and not sauropterygian in Rieppel, 2000, p. 109); hence this taxon is regarded as *nomen dubium*.

The new specimen was discovered at the base of the dark gray shale exposed along the coast in Minamisanriku Town in the northeastern corner of Miyagi Prefecture. It was collected as a float but retained a fresh surface. The locality is within 1 km from the holotype locality of *Utatsusaurus hataii*, and the horizon of the new specimen is correlated to the middle part of the formation and is within the stratigraphic range of *Utatsusaurus* (Shikama *et al.*, 1978).

Institutional abbreviations.—IGPS, Institute of Geology and Paleontology, Tohoku University, Sendai, Japan; NSM, National Museum of Nature and Science, Tsukuba, Japan; UHR, The Hokkaido University Museum, Sapporo, Japan; UMUT, University Museum, University of Tokyo, Tokyo, Japan.

Systematic paleontology

Diapsida Osborn, 1903
Ichthyopterygia Owen, 1840
Ichthyopterygia indet.

Figure 2

Referred specimen.—UMUT MV 31051; six centra (one of them is very fragmentary), one neural arch, six

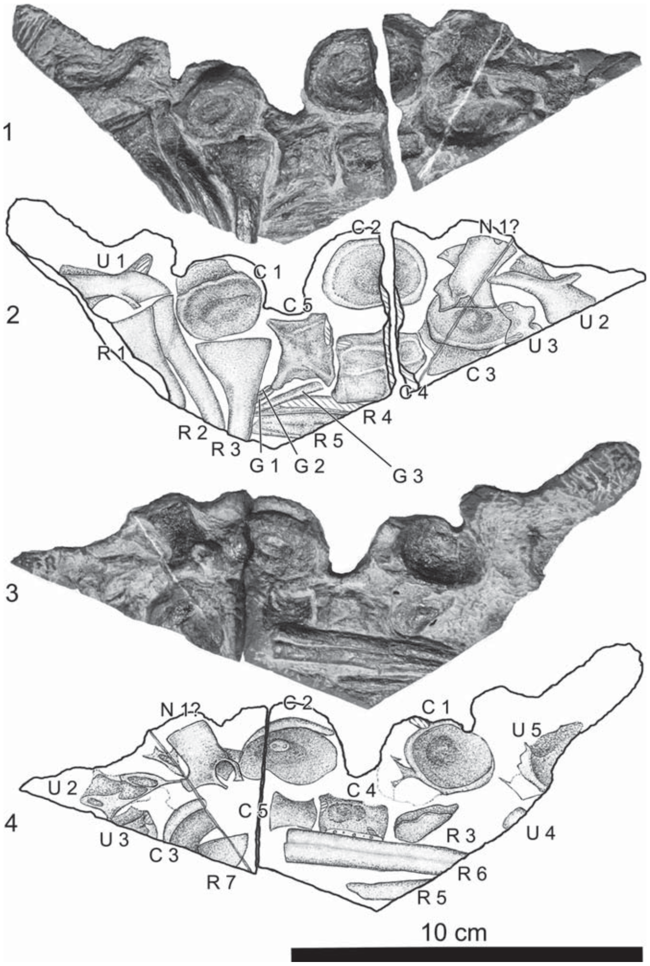

Figure 2. UMUT MV 31051 from the Osawa Formation (upper Olenekian). **1**, top side; **3**, reverse side; **2**, **4**, interpretations. R1–7 for ribs; C1–5 for centra; N for neural arch; G1–3 for gastralia; U for unidentified elements.

Figure 3. Comparison of proximal rib ends of UMUT MV 31051 and *U. hataii.* **1**, R3 of UMUT MV 31051; **2**, **3**, cervical ribs, IGPS 95941; **4–7**, anterior dorsal ribs; 4, IGPS 95941; 5 and 6, UHR 30691; 7, NSM PV 20028; **8**, **9**, dorsal ribs; 8, NSM PV 20028; 9, UHR 30691; **10**, **11**, posteromost dorsal to anteromost caudal ribs, NSM PV 20028; **12**, sacral rib, UHR 30691.

ribs, three gastralia and unidentified bone fragments in an about 18 cm wedge-shaped small slab (Figure 2).

Description.—The presence of the gastralia and ribs, as well as the lack of chevrons suggests that the specimen represents a part of the trunk, but it is impossible to determine the exact location and orientation within the vertebral column. The centra (centra 1–5; C1 to 5 in Figure 2) are all cylindrical and deeply amphicoelous, but flattened due to postmortem deformation. None of them is fused with the neural arch. The diapophysis is not observed on the neural arch in this specimen, and although not confirmed, it must be located on the lateral sides of the centrum but covered with sediment. Centra 1 to 3 are very short (13 mm long in average), with strong concavity of the articular surface. Centrum 4 dorsally bears a neural groove, and articulates with centrum 5. Exact height/length ratio of the centrum cannot be calculated due to preservation, but it is estimated to be 1.39–1.45 by using the major axis of the articular faces of centrum 1 and length of centrum 4. The probable neural spine is about 20 mm long and small relative to the centrum.

From the three associated ribs (ribs 1–3; R1 to 3 in Figure 2) only the proximal ends are preserved. Their proximal end is sturdy, and becomes rapidly broad and slightly flat; its proximal edge is straight, nearly perpendicular to the shaft and 23 mm wide (Figure 3). Ribs 4–6 are partial shafts and all are flat. Ribs 4–6 represent distal portions of dorsal ribs and ribs 4 and 5 bear a longitudinal groove. The specimen also contains three thin gastralia (G1 to 3 in Figure 2) and unidentified irregularly shaped elements (U1 to 5 in Figure 2); the overall morphologies of U1 and U2 vaguely resemble neural arches, but their morphology could not be exactly matched with the known morphological variation of ichthyopterygian neural arches.

Discussion

Morphological comparison between U. hataii *and the new specimen.*—The short centra of UMUT MV 31051 are deeply amphicoelous and not fused with the neural arches, and the diapophysis is located on the centrum. These characters suggest its affinity with ichthyopterygians. The flat and narrow shaft with a groove (ribs 4 and 5) and the straight distal portion of the ribs are similar to those of *U. hataii*. However, the proximal portion of the ribs (ribs 1–3) show the difference between *U. hataii* and UMUT MV 31051 as follows. Figure 3 shows variations of the proximal rib ends of *U. hataii* (2–12) and

UMUT MV31051 (1). *U. hataii* specimens have both single- and double- headed ribs. The single-headed ribs with relatively wide, straight-edged proximal ends and morphologically comparable to those of UMUT MV 31501 are located in anterior dorsal (6 in Figure 3) and posteromost dorsal to anteromost caudal regions (11 in Figure 3). These dorsal ribs are distinctively narrower than those of UMUT MV 31051, both in absolute and relative thickness when compared with the size of associated centra (Figure 2 and 3). Based on this difference, we consider UMUT MV 31051 cannot be assigned to *U. hataii*. Because of the fragmentary nature of the specimen, its taxonomic identity at lower ranks cannot be determined with certainty. However, morphological comparison of the ribs permits us to distinguish UMUT MV 31051 from *U. hataii*.

Significance of the UMUT MV 31051.—Utatsusaurus hataii is so far the only known reptilian taxon of the Osawa Formation, but the discovery of the new specimen suggests its potential to yield the evidence of more diverse reptilian fauna. Zakharov *et al.* (2008) reconstructed the paleoposition of the South Kitakami Massif at the fringe of Palaeo-Tethys near the western edge of Panthalassa during the Early Triassic. Nakajima and Schoch (2011) and Brayard *et al.* (2009) suggests the close paleogeographic relationships between the South Kitakami Massif and North or South China in the Early Triassic based on the similarity of temnospondyls and ammonoids, respectively. In addition to the small *Chaohusaurus geishanensis* which had been the only valid ichthyopterygian species from the Chinese Lower Triassic, another small species (*C. zhangjiawanensis*) was recently described (Chen *et al.*, 2013), implying a higher taxonomic diversity of the ichthyopterygian fauna in China as well. These recent discoveries from East Asia call for further investigation of local faunas to understand the rise of the new ecosystem at the eastern margin of Pangea. The Lower Triassic in Minamisanriku Town gives a glimpse of the diversification of marine reptiles in the Early Triassic in less than five million years after the Permian–Triassic mass extinction.

Conclusion

Morphological comparisons of ribs suggest that UMUT MV 31051 represents an ichthyopterygian and one that is clearly distinguished from *U. hataii*. *U. hataii* has been practically the only valid reptilian taxon known from the Osawa Formation, and the occurrence of UMUT MV 31051 implies that the taxonomic diversity of the reptilian fauna of this formation is higher than previously assumed. The Osawa fauna gives a rare snapshot of the Early Triassic reptiles at the eastern end of Paleo-Tethys, and the discovery of this previously unknown taxon indicates the diversification of marine reptiles shortly after the Permian–Triassic mass extinction in this area.

Acknowledgments

We thank Shoya Oikawa, Choei and Yukie Abe, Tsukasa Takahashi and other staff of the Board of Education, Minamisanriku Town, and Miho Ogishima of Tokyo Gakugei University for assisting our local fieldwork. Jun Nemoto of IGPS, Makoto Manabe, Chisako Sakata of NSM and Ryoko Matsumoto of Kanagawa Prefectural Museum of Natural History, Yoshitsugu Kobayashi and Hiroki Echizenya of UHR, Hiroshige Matsuoka of Kyoto University and Takenori Sasaki and Yasuhiro Ito of UMUT and other museum staff generously provided necessary information and/or access to the specimens under their care. The constructive comments from the editors and two anonymous reviewers improved the manuscript significantly. This research was financially supported for Y. N by JSPS Postdoctoral Fellowships for Research Abroad (project no. 25.498) and for Y. T. and T. S. by Tokyo Gakugei University.

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