Environment, Resource and Ecology Journal (2022)
Clausius Scientific Press, Canada

DOI: 10.23977/erej.2022.060407
ISSN 2616-3756 Vol. 6 Num. 4

A Brief Description on a Recently Discovered Sarcopterygian Scale from Lower Devonian of Zhaotong

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Keywords: lower Devonian; dipnomorph; high resolution CT scan; scale morphology

Abstract: A sarcopterygian scale is discovered from Lower Devonian of Zhaotong, Yunnan province, China. It is characterized by its rhombic shape, cosmine and tubercles. The new scale shows traits different from other known sarcopterygian scales through comparison. Sarcopterygians belong to Osteichthyans, and have received wide attention due to their importance in prehistoric evolution pathways. Present evidence indicates that the scale belongs to an unknown dipnomorph, which provides new information on the early evolution of the dipnomorph lineage.

1. Introduction

Sarcopterygians and Actinopterygians both belong to Osteichthyans [1]. Different from actinopterygian fins which only contain fin rays, sarcopterygians have fleshy fins made up of bones. Sarcopterygians includes Actinistia, Onychodontiformes, dipnomorph, and tetrapods; since sarcopterygian is the ancestors of tetrapods, they have received wide attention during the evolution of sarcopterygians, their scales change in shape, pattern, and cosmine. As a result, scale is an important factor when discussing the classification of sarcopterygians. Primitive sarcopterygian scales have cosmine. During evolution, most sarcopterygians lost their cosmine and their shape changed to round, becoming thinner at the same time [2]. Through comparison between different sarcopterygian scale shapes, cosmine, and patterns, a gross classification for a certain species can be determined. In the past, we mainly use cutting sections to investigate the history of scales. However, this method damages scales, which affects further investigation on them. The alternative way is to use CT scanning and virtual segmentation [3]. In order to reach a preliminary hypothesis on its classification, the scale is scanned under high-resolution CT and reconstructed on computer to study its morphology and compare it with known sarcopterygian scales.

Material: a well-preserved sarcopterygian scale fossil excavated from Lower Devonian of Zhaotong, Yunan province, China.

Method: high-resolution CT scan and three-dimensional reconstruction

The traditional way to obtain three-dimensional structure of fish fossil is cutting sections. Fish fossils are cut into thin slices, thus enabling the observation on their inner structures. However, this method has several unignorable drawbacks. Its major defect is that it damages the fossils, making it inappropriate for rare specimens. Cutting sections is also time consuming and exhausting due to the lengthy polish process, in which each slice must be treated with smoothing tools from the roughest

to the smoothest, which slows down the whole research process. Computed tomography(CT) is a rising alternative to th e tr aditional me thod. First a pplied in me dicine, C T is in troduced t o paleontology t o r esearch on t he i nner s tructure of f ossils. This scale i s s canned unde r hi gh resolution C T. C T s canning ut ilizes X-ray t o pr oduce t omographic i mages of t he s cale, enabling observation of the surrounded part of the scale without physically cutting the scale into slices. It is also l ess t ime c onsuming t han t he c utting s ection m ethod. B y m easuring t he a bsorption a nd attenuation of X-ray, which is determined by the density of substance forming and surrounding the scale, the inner structure of scales can be revealed. High-resolution CT includes the industrial X-ray microtomography, which can provide tomography with resolution from 5μm to 100μm, and synchrotron X -ray m icrotomography, which c an obt ain m ore pr ecise resolution t han i ndustrial microtomography [3].

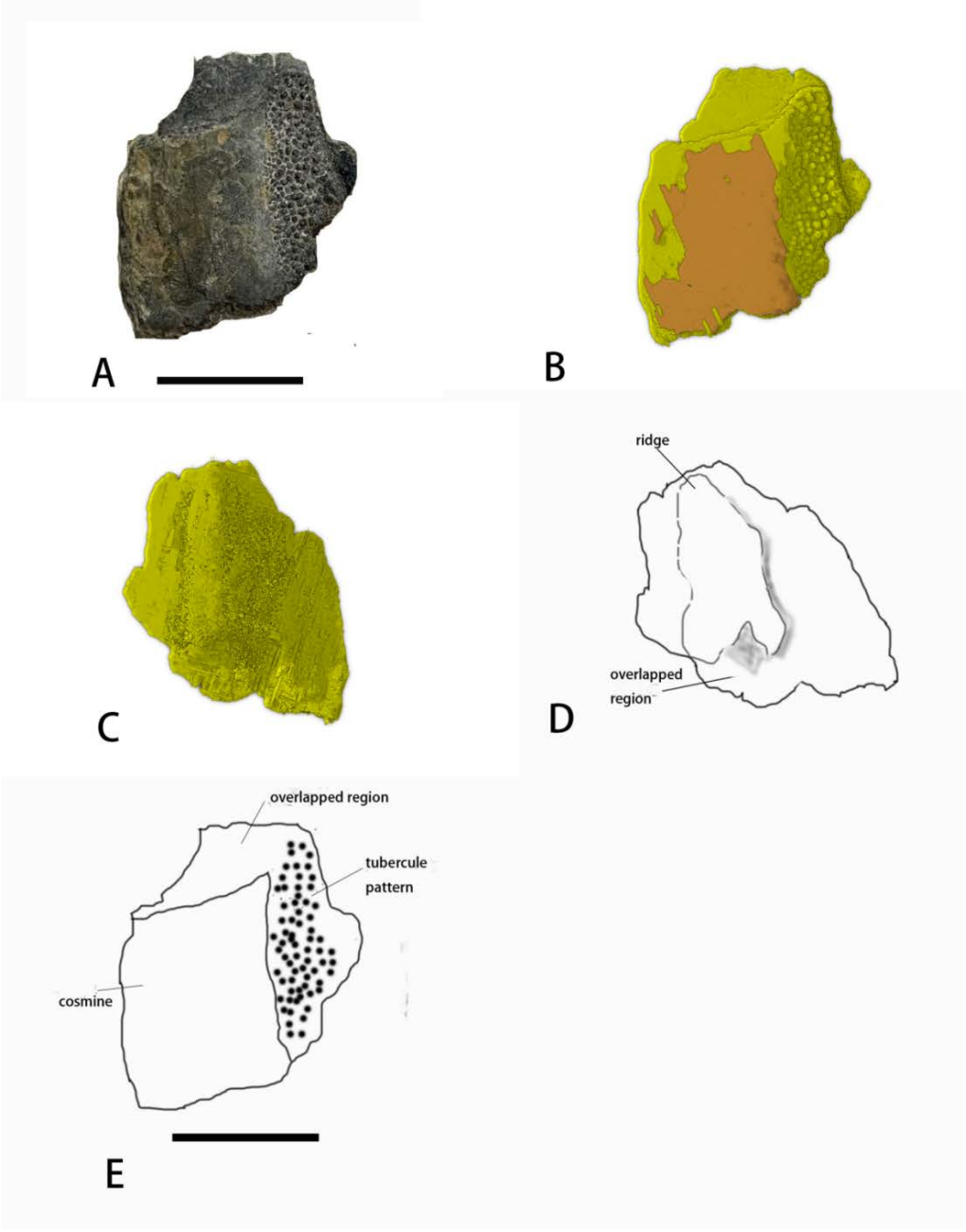

Figure 1: The new discovered scale from lower Devonian

A: Picture of the outer surface of the scale; B: Picture of the outer surface of the reconstructed scale, the orange-coloured region represents for its cosmine; C: Picture of the inner surface of the reconstructed scale; D: Line diagram of the inner surface of the scale; E: Line diagram of the outer surface of the scale. All measuring scale represents 1 centimetre. A, B, and C share the same measuring scale, while D and E share the other measuring scale.

Three-dimensional reconstruction is the reconstruction of the scale on computer based on its tomographic images taken by CT scanning. CT scanning result will be showed in gray value. Higher gray value is shown by whiter colour, which represents for region formed by material with higher density. The scale fossil is relatively whiter than the surrounding, suggesting its higher density formation than its surrounding rocks. By distinguishing the gray value outline of the scale on program the Mimics Research and separating from its surrounding rocks, a scratch reconstruction is created. The cosmine, which is shown with the whitest colour under CT scanning, is also independently recognized and separated from the scale to reveal its own structure. The scratch is further polished with the program Vayu to highlight details by adjusting light, contrast ratio and colour for clearer observation.

A complete scale was discovered in Zhaotong, Yunnan from Pragian (Early Devonian). The scale is surrounded by matrix, the inner surface of which cannot be observed directly (Figure 1A). The scale is about 1.75 cm in width and 2cm in length. Cosmine covered part of the scale is light brown, while the uncovered part is black. The overall shape of the scale is rhombic; the cosmine covering the majority of the outer surface also has a rhombic shape. The right side of the scale is covered with dense tubercle, whose shape, size, and pattern are all irregular. (Figure 1) A similar large-scale covering of tubercle is also found in *Onychodus*. The upper part of the scale is the smooth overlapped region with no pattern. The outer surface is complete under direct observation, but it is discovered that part of the cosmine is lost under a CT scan. The inner surface of the scale is rough with ridges and pits. The scale has obvious anteroventral process but does not feature an anterodorsal process. (Figure 1B, C)

2. Discussion

2.1. Comparison with stem dipnomorph Arquatichthys porosus

The scale of stem dipnomorph *Arquatichthys porosus* is rhombic and covered with cosmine, similar to that of the discovered scale. Both scales have an anteroventral process and no anterodorsal process. Different from the smooth anteral of this scale, the scale of *Arquatichthys porosus* has a sharp anteral. Arquatichthys porosus also has a larger cosmine-covered area compared to this scale. (Figure 2) The most remarkable difference between the two scales is in their pattern: dense tubercles can be found on this scale, while no such pattern is observed on *Arquatichthys porosus*. Instead, several ridges can be found on the border of overlapping and non-overlapping areas [6].

Figure 2: Line diagram of Arquatichthys porosus

It has an anteroventral process and a pointy head. A few ridges are shown on the edge of the cosmine-covered region of this scale.

2.2. Comparison with Porolepiformes

Porolepiformes belong to stem dipnomorph. During their evolution, the scale of porolepiformes changes from a rhombic *porolepis* scale covered with cosmine to a round *Holoptychius* scale without cosmine cover [5]. In this process, one intermediate species named *Heimenia* reveals the similarity with this scale. *Heimenia* scale is ellipse-shaped, while its cosmine still possesses the rhombic characteristic of its ancestors. Tubercle structure similar to this scale can also be found on *Heimenia*; however, different from covering the majority of cosmine uncovered area, the tubercle on *Heimenia* only covers the intersection between cosmine covered and uncovered area with one to three rows of lined tubercle,(figure 3) [7].

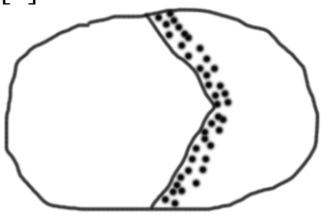

Figure 3: Line diagram of Heimenia scale

The white region on the left side represents cosmine-covered are; on its right hand side lies two rolls of tubercles.

2.3. Comparison with early sarcopterygian Onychodus

Onychodont *Onychodus* reveals a similar tubercle structure as the examined scale (figure 4) which is uncommon in sarcopterygian scales [4]. However, *Onychodus* shares no other relating characteristics with this new scale, since *Onychodus* scale is round and lacks cosmine. As a result, there is no close relationship between *Onychodus* and this new scale.

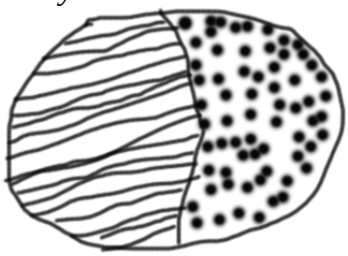

Figure 4: Line diagram of Onychodus scale

Tubercle pattern can be observed.

3. Conclusion

By comparison with other known sarcopterygians, the new scale we describe here may represent a new stem dipnomorph due to its remarkable differences from other sarcopterygian scales. Understanding its phylogenetic position needs further investigation and more materials.

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