

Phosphatized rare star-like mouth disc of *Punctatus* and its functional morphology from the earliest Cambrian of the South Shaanxi China

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Abstract The Meishucun stage is the prelude in deciphering the Cambrian Explosion. In this prominent stage, rapid radioactive evolution and body-plan innovation have taken place and different associations of organism have been shaped. In this paper we report several 3D-preserved rare star-like fossils with finely preserved soft tissues which were recovered from the Kuanchuanpu Member of the Dengying Formation in South Shaanxi, China in 2003. By studying on functional morphology and analogy with mouthpart of *Punctatus*, there are evidences that this star-like organism approaches the coelenterates in systematic classification and the centre of star-like organism is its mouth. The appearance of coelenterates marks the real beginning of metazoan evolution. Therefore, it has the prominent position in the origin and evolutionary history of organisms. Perhaps the star-like organism represents the early types of coelenterate with original tentacles. These new materials provide new evidence for the origin, evolution and the functional evolution of the metazoan during the early stage of the Cambrian Explosion.

Keywords rare star-like mouth disc, *Punctatus*, coelenterat, functional morphology, Kuanchuanpu Member of the Dengying Formation, Ningqiang, Shaanxi

1 Introduction

From the end of Pre-Cambrian to the beginning of Cambrian is the most significant period that earth life evolution coursed,

the late Pre-Cambrian period multicellular organism has occurred obvious minute differences, Skeletonized arterial organism carapace has appeared their rudiment, but the biological evolution quality leap occurred in the Cambrian Explosion of the early time of early Cambrian period which was the most remarkable time in this living thing evolution history. Large radiate evolution of classified groups and rapid reformation of organism make the most outstanding phenomenon of Cambrian Explosion, which formed the most obvious difference with the Pre-Cambrian period biota (Feng et al., 2002). In the early Cambrian, the matter of grown phosphorus occurred, also because the phosphate mineral crystallized most early in diagenesis process, organism phosphatized quickly after the they died made lots of ultramicro-structure of the organism was preserved in this period, which offered good-given scientific window to open out the mysterious life panorama in the world of the early Cambrian.

Phosphorization stratum of northern edge Yangtze platform in early Cambrian Meishucunian stage is a biological preservation of fossils of early Cambrian. Some classes of the biologic groups were known, but the most are different from the species in the modern age. And they constituted the main body of the biota in Meishucunian ages. From the 1970s, the China-foreign scholar has been on deep studying and has got substantial result to the biota of this period. Qian (1977;1989; 1999), Qian et al. (1997), Yin et al. (1980), He (1987), Yang et al. (1983), Xing and Yue (1983), Yue (1986), Ding et al. (1992), Conway and Chen (1990; 1992), Yue and Bengtson (1997;1998), Steiner et al (2004) and Hua et al. (2004) had researched the micro skeleton fossils developed in northern edge Yangtze platform in early Cambrian epoch Meishucunian including *Punctatus* and embryo, which make people focus upon the researches on north edge Yangtze platform. In 2003, the authors found rich fossils samples in

Phosphorization stratum of early Cambrian Meishucunian stage, including *Punctatus emeiensis* He, 1980 (*pyrgites mirabilis* Yue, 1983 a different name), the whole *Punctatus*' mouthparts fossils sample and a species of phosphatized star-like fossils, in thesis we will emphasize these rare star-like fossils. Researches by analyzing the functional morphology and contrasting the characteristics indicate that these rare star-like fossils can be completely compared with the mouthparts of wimble-like beastie *Punctatus* which had been symbiotic with them, and the rare star-like fossils were possible to be oral disc of coelenterate, they will provide new material for announcing the origin and evolution of life, ontogenesis, system classification and other problems in the beginning of Cambrian Explosion.

2 Stratum of producing area

The sample was picked up from kuanchuanpu member of the Dengying Formation of Zhonggou section in Kuanchuanpu, Ningqiang, Shaanxi. This member, which is in conformable contact with beiwan member of underling stratum, and is in parallel uncomfortable contact with guojiaba formation of overlying stratum, is shallow sea carbonate rock sedimentation. The lithologic is deep gray-ash black middle layered limestone with bitumznite, calcarenite calcirudite with cellophane, siliceous rock phosphate rock and medium thick dolomite. Producing small shelly fossils: *Olivoooides*, *Circotheca*, *Anabarites*, *Carinachites*, *Protohertzina* and *Zhijinites*, etc., their assemblage appearance can be compared with traditional small shelly fossils of early Cambrian Meishucunian stage, so the times belonged to early Cambrian Meishucunian Period. In the region, they can have a contrast with other zones of Tianzhushan stage, Yanjiahe stage, Maidiping stage, Zhongyicun stage and Yangjiagou stage.

3 Materials and methods

We smashed the samples which were collected from the rich small shelly fossils phosphate rock to about 2–3 cm then took them into plastic container, then poured them into 8%–9% solution of industrial acetic acid to deal with acid, washed the samples and changed the acetic acid which had been mentioned every two or three days. The remaining material was sieved and washed with 120 eyes divert sample sieve, and then washed with soft irrigation of clean water. Let the samples we have got dried in thermostat or air-dried. At last, we used the double eyes stereomicroscopy to choose the fossil samples by manual. The samples what were used to show were plated film by Au/Pd alloy in vacuum, then scanned to be picture by scanning electron microscope.

4 Description of fossils

Class, order et family uncertain

Material: two uncompleted fossils and tens of fragments

4.1 Description

Many horn-like substances revolved around the centre stretching to form a star-like substance. Because the surface of the star-like fossils was filmed and they were hardly preserved completely, most of the fossils we got were uncompleted. By observing we found that each horn-like substance which formed the star-like substance looked the same, and the remaining horn-like substance had obvious trend of revolving around and stretching from the centre (Fig. 1(a)). Therefore, a complete horn-like substance was taken as a fundamental element, revolving around the centre and copying, repairing the hiatus parts, which will recover the appearance of radiation symmetrical horn-like substance (Fig. 1(b) and (c)).

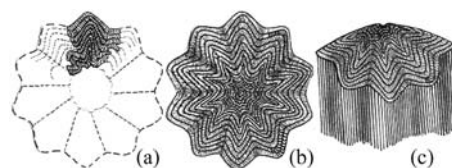


Fig. 1 Reconstruction of star-like fossil. (a) The feature of a star-like organism before its fragmentary sample is recovered (imaginary line is renovated orbit); (b) seen from the top, the renovated completed star-like organism was made up by about ten angles, the star-like substance is the organism's oral disk, with the mouthpart in its centre; (c) the side-look of the completed star-like substance shows that the center of the sample is protruding while the border is like a wave-like bamboo hat; the top connects with prism, their joint is an obvious slit.

4.2 Feature seen from the top

The diameter of star-like substance is about 3.6 mm, and it is about 1.7 mm high. There are four to eight star-like circles sticking together from extroversion inner.

The star-like fossil what is shown in plate 2-a1 is eight circles sticking together. The star-like fossil what is shown in plate 2-a1 is eight circles sticking together. Inner circle turn breaks angle being 30°. Outside circle turn breaks angle being 85°. The inner is the smallest, and the circle expands in proper order around the centre from inside to outside (Fig. 2(a1) and (b1)). Each single circle which is composed of star-like substance is about 100 μm, and its surface has extremely regulated detailed ornament of parallel veins. The thin line is about 10 μm wide, and the picture which was enlarged by scanning electron microscope (SEM) looked very like lines of corduroy surface (Fig. 2(a2)).

Another design of the star-like fossil's surface is the same as the fossil which had been mentioned, the star-like

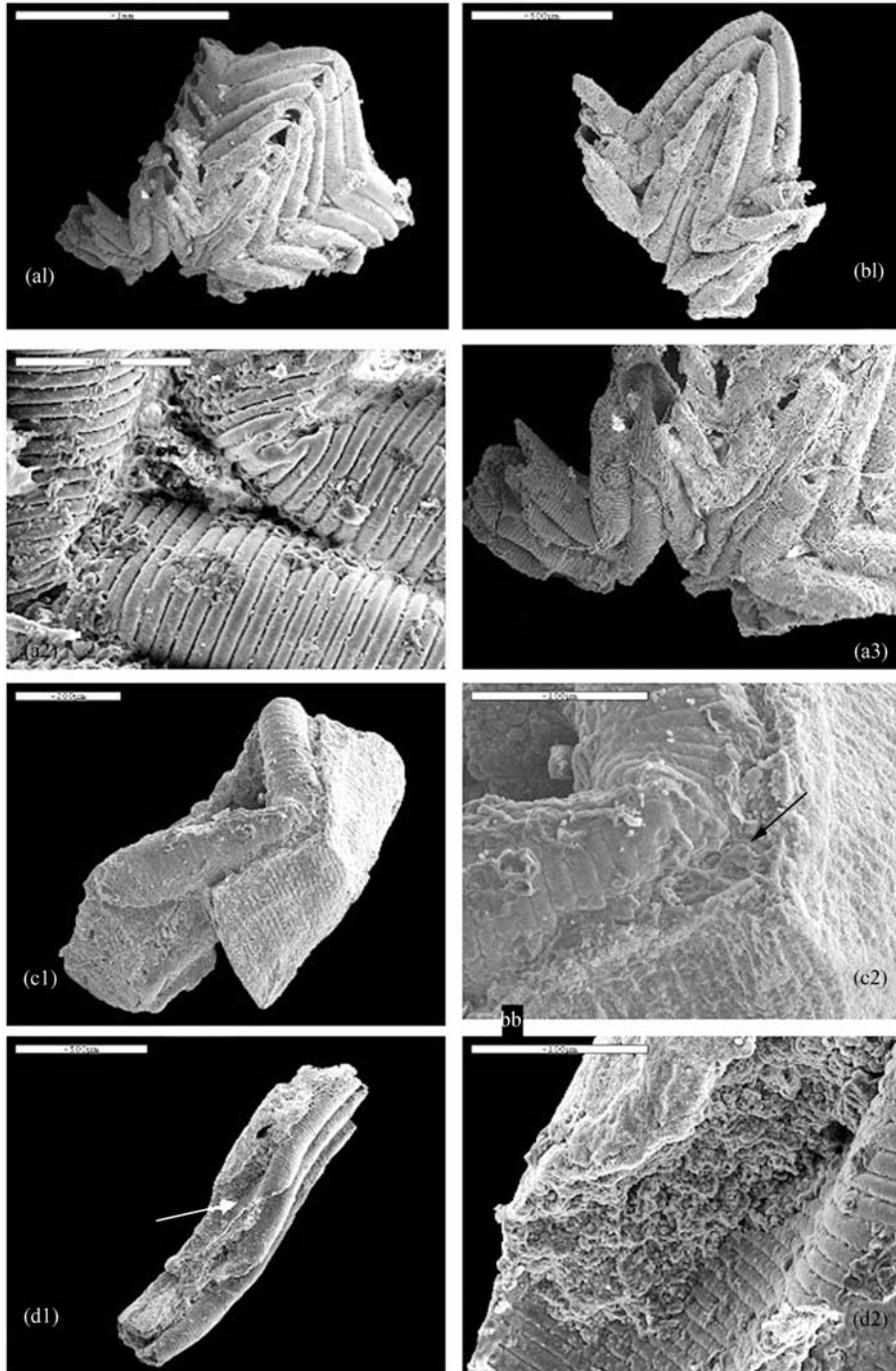


Fig. 2 Feature of rare star-like fossils. Note: (a1) Seen from the top of the horn-like substance which formed the star-like substance, it has a trend that it is an inside track surrounding the centre and circumrotatorily spreading out, their surface is film of ornament of parallel tiny vein, $\times 60$; (b1) the other uncompleted star-like substance, its feature is the same as a, $\times 65$; (a2) the amplificatory part of (a1) shows that the surface of the star-like substance besprinkle parallel design, this is very like the feature of the surface of the corduroy veins. That parallel design film is bending but not cracking shows that it has the feature of parenchyma, $\times 500$; (a3) the amplificatory part of (a2), it shows the trend that it is surrounding the centre and circumrotatorily spreading out, $\times 110$; (c1) the star-like substance connects with prism, this shows rudimental star-like substance's last circuit, its surface has the same parallel design as the last, $\times 150$; (c2) the amplificatory part of (c1) shows dense ornament of parallel vein of the star-like substance's surface, the star-like substance lies at the end of the cross section of prism, the width of their joint is about 20 μm (arrow show), the surface of prism is the same as its, $\times 500$; (d1) the broken side show pucker mode of star-like substance, $\times 75$; (d2) the place of (d1) in which arrow shows is the part that is magnified, in fact, it shows that the star-like substance is made up of a completed film and wavilness bent break, $\times 500$; Kuanchuanpu Member of the Dengying Formation, Ningqiang, Shaanxi.

substances are formed by four circles sticking together from exterior to inner, the difference is that its shape is closer.

4.3 Feature of side-looking

The center of the star-like substance bulges, and it generally lower to the outside circle. The collection between the center of star-like and prominent of horn-like substance is a bulge line. The both ends which take the bulge line as a symmetrical line are plunging down, which to be a hollow line between the horn and horn. Therefore, seen from the side, the center of the sample is protruding while the border is like a wave-like bamboo hat (Fig. 1(c)).

4.4 Tiny texture

Seen from the surface, the star-like substance seems to be made up of some rope-like substances with ornament of parallel veins. In fact, seen under the SEM, it is a complete film of ornament of parallel veins, around the central mouthparts, wave-like curved exchanges are formed by certain circles sticking together (Fig. 2(d1) and (d2)). It is granular texture which has soft film of parallel tiny design (Fig. 3(a3), (a4), (b2), (b4), (b5), (b6), (c3) and (c4)), which is different from grain texture of secondary phosphate hyperplasia tier. Coelenterate is the lowest one of Metazoans, the body has two inside and outside germinal layers, and had sample differentiation tissue, but had not formed organ. Tissue was cells which were assembled with many similar with shape and the same function. Each tissue accomplished a certain function, such as muscular tissue is assembled with many muscular cells with flexible functions. The modern biological researches expressed that Coelenterate only has epithelial muscular cells, that epithelium and muscle have not separated is a primitive phenomenon. Epithelial muscular cells had separated sample tissues, formed the surface of the inner and extracorporeal body, and separated sense cells, digestive cells with non-nerve conduction function (Compiled together by Wuhan University, Nanjing University, Beijing Normal University, 1978). The ornament of parallel vein film should be the surface of the organism.

4.5 Shape structure

It is very meaningful that at the basic of choice, a lot of fossils which contain star-like substances and prism substances were joined (a fossil was broken during selection). It remained star-like substance's edge, its surface was the same as the last specimens parallel design on utensils star-like substance (Fig. 2(c1)). At the end of the lateral section, these have a joint line of 20 μm , such a characteristic is a special feature of the star-like organism. Compared with this, two flower-like mouthparts of *Punctatus* as shown in the picture 4, mouthparts and prism's surface are included by a completed film, but without any joint (Fig. 4); prism's surface has the same parallel tidy design, and the extension of design is the same

as the design of star-like substance. Every outstanding angle corresponds to every edge of prism (Fig. 1(c); Fig. 2(c1) and (c2)). In other words, star-like organism has several angles, and the prism has several angles, forming the pattern of body's construction of "ridge corresponding with angle".

5 Bizarre star-like organism compare with flower-like mouthparts of *punctatus*

Punctatus, as a kind of distinct metazoan of ancient sea, is mainly born in near the Sinian-Cambrian of Kuanchuanpu, Ningqiang, Shanxi and Maidiping, Emei, Sichuan. At present, it is Coelenterata. *Punctatus*'s body, from foot to top, one is a closed cone, the other is an open-mouth with prism between them. Such an organism is characterized by surface with completed film of parallel design (Fig. 4).

Observation of researches: about a body's construction and characteristics, bizarre star-like organism is analogy with *Punctatus*, having the following bases.

(1) Detailed parallel veins of their surface are identical, the width of a vein is 10 μm . Magnified SEM photo is alike to the design of corduroy's surface. Their width and distance are nearly identical (Fig. 2(a2); Fig. 4(b) and (d)).

(2) Their mouth disc is constructed with film which has soft tissues (Fig. 2(a1) and (b1); Fig. 4(a) and (c)).

(3) Their construction of oral disk is identical: mouthpart is center, show radiation and symmetric (Figs. 2 and 4).

(4) Their oral disk lies in one end of prism, and different prisms of *Punctatus* are cylinder, transitional of connection (Fig. 4(a) and (c)); and the star-like substance is prism, there is apparent slit of connection between oral disk and prism (Fig. 2(c1) and (c2)).

6 Analyzes of functional morphology and the relative of organism

Coelenterate has fixed a radiated and symmetric system. It has bodily forms: living by sessile hydra type and plankton medusa type; hydra type shows a section of thick bamboo, one bottom is closed, and the other is open, and only the open part is its mouth, which is not only feeding but also excreting; the tower of mouthparts is connected with digestive cavity.

The mouthparts of star-like organism and *Punctatus*, the whole shape, surface ornament of parallel vein even the width of tiny veins and analysis of function are very similar in morphology. Their similarity declares that the star-like organism is very similar to Coelenterate in sort.

Every outstanding angle of organism shows a primitive touching of Coelenterate in prologue of Cambrian Explosion. The star-like organism's primitive touching is swung by film of mouthparts' surface, leading to water flowing and bringing food. Primitive touching is very weak and the touching field is very small, which shows the organism's primitive characteristics, and represents the primitive type of touching before Cambrian Explosion.

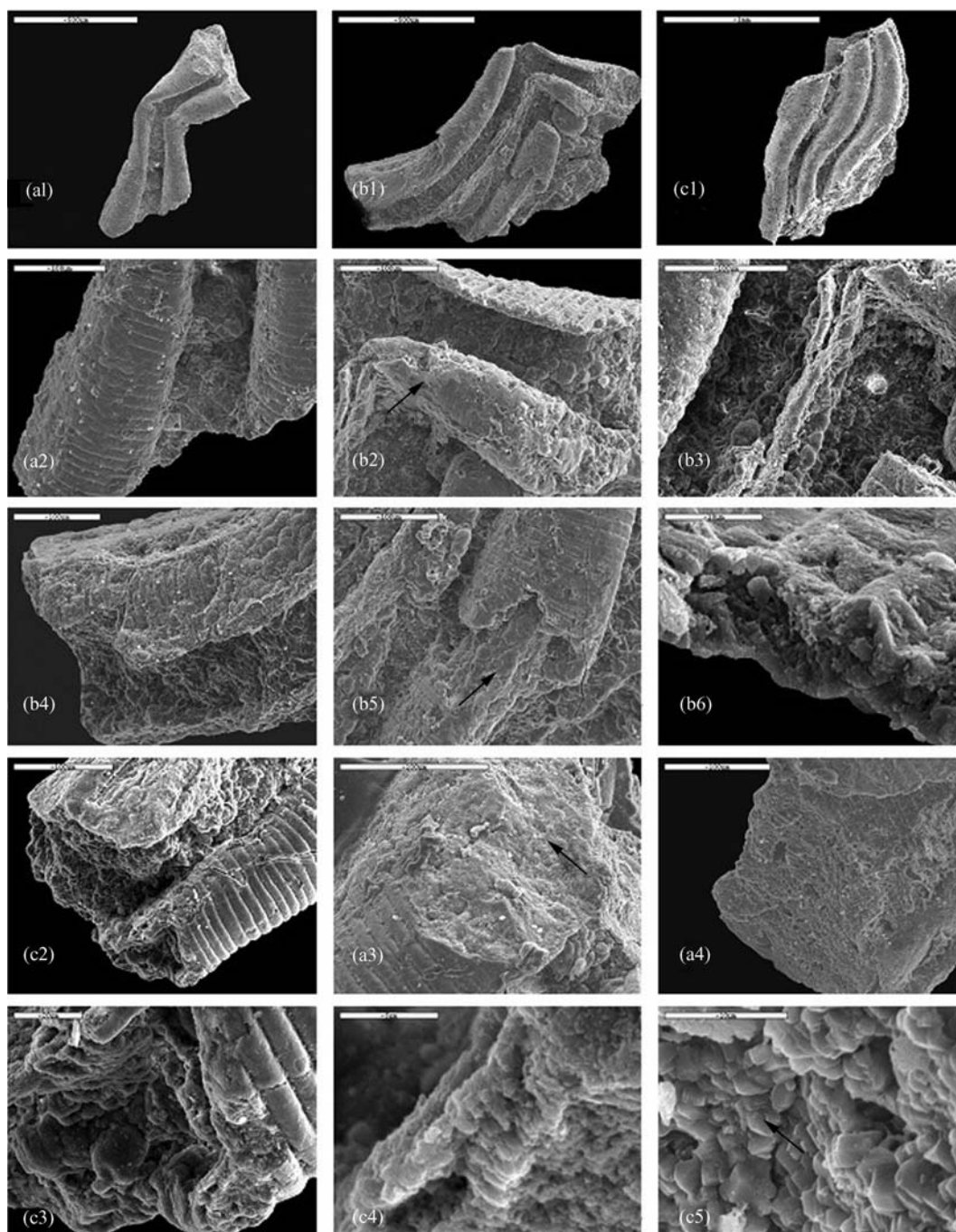


Fig. 3 Feature of rare star-like fossils. Note: (a1) The surface of the horn-like substance which forms the star-like substance is a parallel design of parenchyma, $\times 100$; (b1) the feature of the other uncompleted star-like substance's back, $\times 110$; (c1) the fragment of the star-like substance shows their contorted state, $\times 65$; (a2) the amplificatory part of (a1), it shows that the surface of star-like substance besprinkle parallel design, which is very like the veins' feature of the surface of corduroy. That parallel design film is bending but not cracking shows that it has the feature of parenchyma, $\times 370$; (b2) the amplificatory part of (b1), it shows the state of star-like substance's fold and granular parenchyma after parallel design fell off on the surface (arrowhead indicated), $\times 400$; (b3) the amplificatory part of (b1), it shows that the feature of the round place of the star-like substance's rear and hypo-accrue fill in their sunken place, $\times 500$; (b4) the amplificatory part of (b1) it, shows granular parenchyma after parallel design fell off on the surface of star-like substance $\times 350$; (b5) the amplificatory part of (b1), it shows parallel design on the surface of the star-like substance and granular texture after parallel design fell off (arrowhead indicated), $\times 400$; (b6) the amplificatory part of (b1), its soft film of parallel design shows the granular texture, $\times 4000$; (c2) the amplificatory part of (c1), with soft film of parallel design and their section, $\times 400$; (a3) the amplificatory part of (a1), parallel thin design film and the granular texture (arrowhead indicated), $\times 600$; (a4) the amplificatory part of (a1), parallel thin design film and the granular texture, $\times 430$; (c3) granular texture of the section in (c1), $\times 1400$; (c4) the amplificatory part of (c1), it shows granular texture of this section, $\times 8000$; (c5) the amplificatory part of (c1), it shows granule-shape hypo-accrue phosphatized overgrowth tier of the star-like substance (arrowhead indicated), $\times 5000$; Kuanchuanpu Member of the Dengying Formation, Ningqiang, Shaanxi.

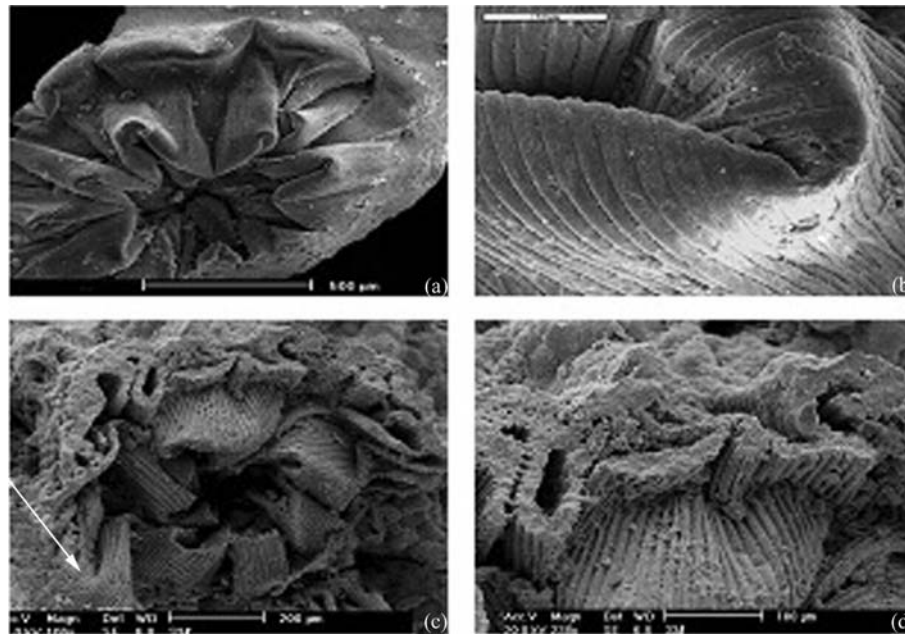


Fig. 4 Features of phosphatized mouthparts of *Punctatus* and its surface ornament of parallel vein. Note: (a) The whole watches like the texture of *Punctatus emeiensis*' flower-like double-deck close mouthparts and a section of column which connects with it, $\times 60$; (b) the amplificatory part of (a), the amplificatory petal-shape original touching shows the modality and its surface ornament of parallel veins, $\times 700$; (c) through overlooking the sub-rotundity flower-like mouthparts, most of the film between edge of mouthparts and column's surface had broken off, but a little reserved (arrowhead indicated); six petal-shape original touchings gather to the centre, the centre of the mouthpart splays a little, $\times 106$; (d) the amplificatory part of (c), it shows the mutually overlap feature of film's fracture at the edge of mouthpart, $\times 238$; Kuanchuanpu Member of the Dengying Formation, Ningqiang, Shaanxi.

7 Discussion: developing of primitive touching of coelenterate and initial reason

In the sea of Pre-Cambrian, carnivorous animals had not appeared in a large quantity. There were a lot of film of bacteria and alga covering the surface of the sea's bottom. Passive filter-food organisms filter the tiny grains to satisfy the nutrition they need, so the passive filter-food organisms lived in an ecological environment which is rich in natural resources and relative safe. With many classes of organism appeared suddenly, it broke the fragile balance of ecology which took the film of bacteria and alga as the main food, that origin was at the bottom of the sea. The change of ecological environment and the differentiation of the animals' feeding pattern may be the motivity of the evolution of organism. The unprecedented selecting pressure provides a force and shows the stages for the diversity eruption of animals' figure texture. Complex environment maybe provided extremely good chances for the origin of genes, the genes' acquirement of new abilities, plastic explosion of the regulation mechanism of genetic development. Therefore, it led to the organism release of lots of accumulated saltation, and fast produced forms' diversity, which is difficult to believe (Wang, 2003).

For protecting itself, some surface of organism has exoskeleton. Coelenterates, by living under pressure, mainly produce all kinds of touchings in order to enhance their

moving, feeling and feeding, it shows cruelty and intense of competitor from another in Cambrian Explosion. Because of choice, animals do their best to enhance their feeding through all kinds of roads, so the living competition of Cambrian ocean comes into being. It is a competition of touching about coelenterates, which only try their best to enhance their touching function, and get victory in intense competition. The present biologic research discovers that with the help of touching, coelenterate can catch food which is bigger than itself. In Meishuchun period, *punctatus* develop flexible "primitive touching" organism's feeding from passive to relative driving, so they have a chance to catch more and bigger food and get more nutrition, but also make progress with moving, sensitivity and feeding of primitive touching. More and more food is got and the ability of touching is enhanced by and by. To a large extent, making body's construction of coelenterate and touching function to be complicated in order to radiated evolution of coelenterate at a large extent.

In Meishuchun period, discovering and researching of *punctatus*' flexible primitive touching is very meaningful. It gives important researching data to explore the radiated evolution of metazoan. It is a special coelenterate.

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References

- Bengtson S, Yue Z (1997). fossilized metazoan embryos from the earliest Cambrian. *Science*, 277: 1645–1648
- Conway M S, Chen Meng'e (1990). Tommotiids from the Lower Cambrian of South China. *Journal Paleontology*, 64(2): 169–184
- Conway M S, Chen Meng'e (1992). Carinacitids, hexaconulariids, and Punctatus: problematic metazoans from the Early Cambrian of South China. *Journal of Paleontology*, 66(3): 384–406
- Ding L F, Zhang L Y, Li Y (1992). The Study of the Late Sinian-Early Cambrian Biotas from the Northern Margin of Yangtze Platform. Beijing: Scientific and Technical Documents Publishing House, 1–135
- Feng W M, Chen Z, Sun W G (2002). The Study of the microstructure differentiation on organisms skeleton in Late Precambrian-Early Cambrian. *Science in China (Series D)*, 32(10): 850–855
- He T G (1987). Early Cambrian conulariids from the Yangtze Platform and their early evolution. *Journal of Chengdu College of Geology*, 14(2): 7–18 (in Chinese)
- Hua H, Chen Z, Zhang L Y (2004). Phosphatized metazoan embryos fossils of blastulation and gastrulation from the earliest Cambrian in southern part of Shaanxi, China. *Chinese Science Bulletin*, 49(2): 177–180
- Qian Y (1977). Hyolitha and some problematica from the Lower Cambrian Meishucun Stage in central and Southwest China. *Acta Palaeontologica Sinica*, 16: 255–275 (in Chinese)
- Qian Y (1989). Early Cambrian small shelly fossils of China with special reference to the Precambrian-Cambrian boundary. In: Nanjing Institute of Geology and Palaeontology, Academia Sinica ed.. *Stratigraphy and Palaeontology of Systematic Boundaries in China, Precambrian-Cambrian Boundary (2)*. Nanjing: Nanjing University Publishing House
- Qian Y (1999). *Taxonomy and Biostratigraphy of Small Shelly Fossils in China*. Beijing: Science Press, 1–247
- Qian Y, Vaniten H, Cox R S, Zhu M Y, Zhuo E J (1997). A brief account of Emeiconularia trigemme, a new genus and species of protoconulariid. *Acta Micropalaeontologica Sinica*, 14(4): 475–488
- Steiner M, Li G X, Qian Y, Zhu M Y (2004). Lower Cambrian Small Shelly Fossils of northern Sichuan and southern Shaanxi (China), and their biostratigraphic importance. *Geobios*, 37: 259–275
- Wuhan University, Nanjing University, Beijing Normal University (1978). *General Zoology*. Science Press, 60–93
- Wang Xiuqiang (2003). Hox genes and the early radiateon of arthropods. Nanjing Institute of Geology and Palaeontology. Doctmoth dissertation of Chinese Academy of Sciences, 1–106
- Xing Y S, Yue Z (1983). The Sinian-Cambrian boundary in southern part of Shaanxi. In: Xing Yusheng et al., eds. *Special issue on the Sinian-Cambrian boundary of China*. *Bulletin of the Institute of Geology, Chinese Academy of Geological Science*, 10: 111–125 (in Chinese)
- Yang X H, He Y X, Deng S H (1983). On the Sinian-Cambrian boundary and the small shelly fossil assemblages in Nanjiang area, Sichuan. *Bulletin of the Chengdu Institute of Geology and Mineral Resources, Chinese Academy of Geological Sciences*, 4: 91–110 (in Chinese)
- Yin J C, Ding L F, He T G, Li Shilin, Shen Lijuan (1980). *The Palaeontology and Sedimentary Environment of the Sinina System in Emei-Ganluo Area*. Chengdu: Sichuan People Publishing House (in Chinese)
- Yue Z (1986). Microstructure and systematic position of *Olivoooides* (Porifera). *Bulletin of the Institute of Geology, Chinese Academy of Geological Sciences*, 14: 147–152
- Yue Z, Bengtson S (1998). Phosphatized metazoan embryo fossils in Cambrian Explosion, *Chinese Science Bulletin*, 43: 1858–1882