Histological observation of some primitive euconodonts of Late Cambrian from Liaoning*

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Abstract The histology of some euconodonts of Late Cambrian from Benxi and Fuxian County, Liaoning Province is studied by the oil-immersion technique. The histological characteristics of six primitive species of euconodonts - *Proconodontus muelleri*, *Proconodontus tenuiserratus*, *Granatodontus ani*, *Rotundoconus tricarinatus*, *Teridontus nakamurai* and *Cordylodus proavus* are described in detail. Tubular dentine and atubular (parallel- and wavy-lamellar) dentine are found in the basal bodies of the primitive euconodonts *Proconodontus tenuiserratus* and *Proconodontus muelleri*, respectively. The tubular dentine and spherulitic dentine are also recognized from the basal bodies of *Granatodontus ani* and *Rotundoconus tricarinatus*. Since the histological characteristics of the studied six species of euconodonts belonging to *Proconodontus* lineage and *Teridontus* lineage Sensu Miller (Univ Kansas Paleontol Contr, 1980, 99: 1—39) seems to be almost the same, euconodonts are proposed as possibly monophyletic herein.

Keywords: histology, primitive euconodonts, Late Cambrian, Liaoning.

The histological study of conodonts can be traced back to the 1930s[1]. Müller[2], the initiator of the systematic study on Cambrian conodonts, began the histological study of conodont by microscopic observation in 1962. However, conodont histology had not attached attention until the conodont animal was found in the 1980s. Since then the western scholars have pubulished many important findings in the past twenty years. It was Wang[3] who first studied the conodont histology in China, and Lai[4] and Zhang[5] also discussed the histology of conodonts. So far, the study on the histology of protoconodont and highly derived euconodont after Cambrian has made great progress, while the study on the histology of paraconodont and primitive euconodont of Cambrian[6—9]1) is far behind for the limited available fossil materials. In this study, we observed histological characteristics of six well preserved euconodont specimens collected from Benxi and Fuxian County of Liaoning Province, and found that these euconodonts are possibly monophyletic herein.

1 Materials and method

The materials were collected from Changshan and Fengshan Formations in Benxi and Fuxian County of Liaoning Province. Abundant conodont specimens were obtained after processing of etching samples with acetic acid, filtration and selection under a microscope. The selected specimens were photographed with a SEM for histological study. The conodont elements studied included *Proconodontus muelleri*, *Proconodontus tenuiserratus*, *Granatodontus ani*, *Rotundoconus tricarinatus*, *Teridontus nakamurai* and *Cordylodus proavus*.

The oil-immersion method developed by Donoghue[10] was used for the histological study. The principle of this technique is that the liquid has a similar refractive index with conodont. The material immersing in a liquid of similar refractive index appears transparent and the internal structure can be viewed in transmitted light. The main composition of conodont is the apatite whose refractive index is about 1.63—1.66. Therefore we chose the clove oil whose refractive index is similar to the apatite. Furthermore, the clove oil has high viscosity and surface tension, so that it can avoid the specimens flowing away during the study. The detailed operations have been given in Ref. [10]. It is often preferable to spread the

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oil evenly so that the meniscus just overlies the highest point of the specimen to prevent oiling the lenses. The specimen can then be studied using differential interference contrast optics. After the study, specimens can be recovered undamaged by cleaning with a picking brush in a small bath of solvent such as ethanol or acetone, and it can be further studied by a scanning electron microscope.

2 Component tissues of euconodont elements

Characteristically, euconodont elements are composed of two basic units: the crown and the underlying basal body. The crown is composed of either entire lamellar crown tissue or a combination of lamellar crown and white matter. Lamellar tissue is the basic structure of the euconodonts crown, and white matter is a derived characteristic of crown. White matter can also be classified into true white matter and pseudo white matter[11]. Basal tissue of euconodonts is the most variable of all conodont hard tissues. At present, the cartilage-like lamellar structure and bone-like spherulitic structure[12] have been recognized in the basal body of *Neurodontiformes*, the spherular structure[11,13–16] and thinner lamellar structure[16,17] discovered in the basal body of *Cordylodus* and *Pseudooneotodus* and lamellar and tubule structures[13,15,18] are also recognized in the basal body of *Chirognathus* and *Neocoleodus*.

3 Description of the histology of euconodonts from Benxi and Fuxian County of Liaoning

Description:

Crown tissue is thin, no white-matter develops, and no swallow-tail extinction is observed.

For the basal body, crystalline near the junction of the crown and basal body (CBJ) is fine. Towards the centre of the element, basal tissue changes its appearance gradually, taking on parallel lamellar tissues at first, wavy lamellar tissues then and spherulitic crystalline last further from the crown-base junction (Fig. 1(b)).

Discussion: Basal tissue of euconodont is the most variable of all conodont hard tissues. Lamellar structure, wave-lamellar structure and spherulitic structure are recognized in the basal body of *Proconodontus muelleri*.

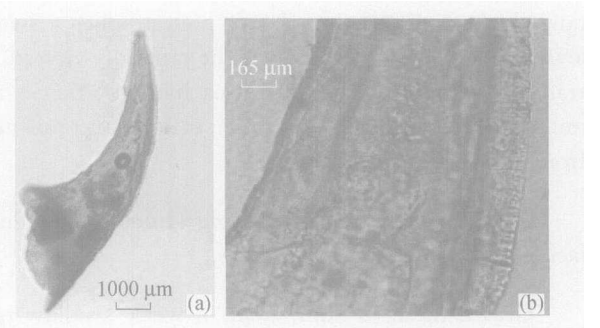

Fig. 1. The histology of *Proconodontus muelleri* Miller, 1969. (a) Lateral view; (b) magnification of part of (a), showing the compact lamellar, wave-lamellar and spherulitic tissues (from outside to inside).

Description:

Crown is weak, posterior edge is serration-like (Fig. 2(a)). The crystalline by which crown is composed of is fine, its long axis is perpendicular to the junction of crown and basal body. White matter does not develop, but weak swallow-tail extinction pattern can be recognized.

The characteristic of the basal body is obvious. Regular tubular dentine can be observed clearly (Fig. 2 (b)).

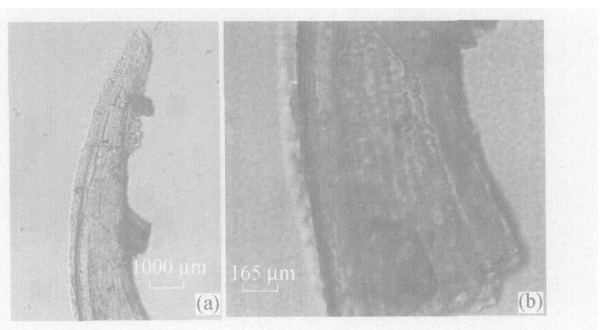

Fig. 2. The histology of *Proconodontus tenuiserratus* Miller, 1980. (a) Lateral view; (b) magnification of part of (a), showing the regularly arranged tubular dentine.

Discussion: Dentine has different forms. Donoghue[11] once indicated that "tubular, lamellar and circle-lamellar structures are features of a common tissue-dentine", and "well-organized lamellar and tubular structures represent slower, ordered growth". Sansom et al.[14] have discovered tubular dentine in the basal body of *Chirognathus* from upper Ordovician. We discovered tubular dentine in the basal body of *Proconodontus tenuiserratus*, which is the most primitive euconodont of Cambrian, and this further confirms that the euconodont animal is closely related to vertebrates. Crystallites are sometimes ar-

ranged into radiating bundles, which produce a swallow-tail extinction effect when the crown is viewed in transmitted light. Swallow-tail extinction effect is an important characteristic, which differs euconodonts from paraconodonts.

Description: With warts and stings on the surface (Fig. 3(a)).

Crown tissue is thin, with a weak swallow-tail extinction effect, and without the white matter.

Crystallites near the junction of crown and basal body are arranged into lines, which parallel to the CBJ, and become spherulitic structure far from the crown-base junction. Regular tubular dentine can be observed in the basal body (Fig. 3(b)).

Discussion: Tubular dentine is first discovered in the basal body of *Granatodontus ani*. Tubular dentine arrangement is similar to that of *Proconodontus tenuiserratus*. It indicates that different species of conodonts appear to have had the ability to mineralize the same tissue types in their basal bodies.

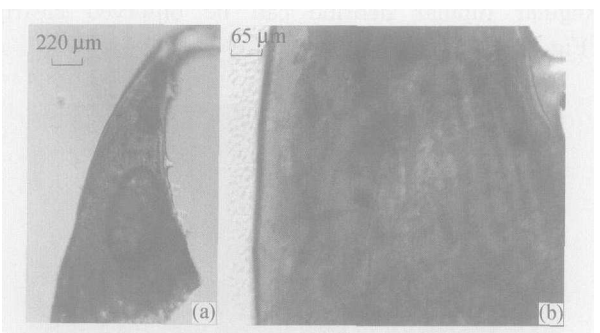

Fig. 3. The histology of *Granatodontus ani* (Wang, 1985). (a) Lateral view, basal cavity deep and large, with sculpture of warts structure on the surface; (b) magnification of part of (a), showing the longitudinally arranged tubular dentine.

Description:

Crown is thin; growth line is parallel to the junction of crown and basal body (Fig.4 (b)—(c)). The swallow-tail extinction pattern can be seen obviously.

Basal body is weak, and crystalline near the junction of crown and basal body is out of order. Spherulitic or microspherulitic dentine can be observed obviously in the middle of basal body.

Discussion: Müller et Nagami[13,18], Sansom et al.[14] and Donoghue[11] discovered coarser spherulitic structure in the basal body of *Cordylodus angulatus*; furthermore, Donoghue[11] recognized spherulitic structure in the basal body of *Pseudooneotodus*, and Sansom[15] discovered microspherulitic structure in the basal body of *Pseudooneotodus*. These are all different forms of dentine[11]. We discovered spherulitic dentine in the genus of *Rotundoconus* for the first time.

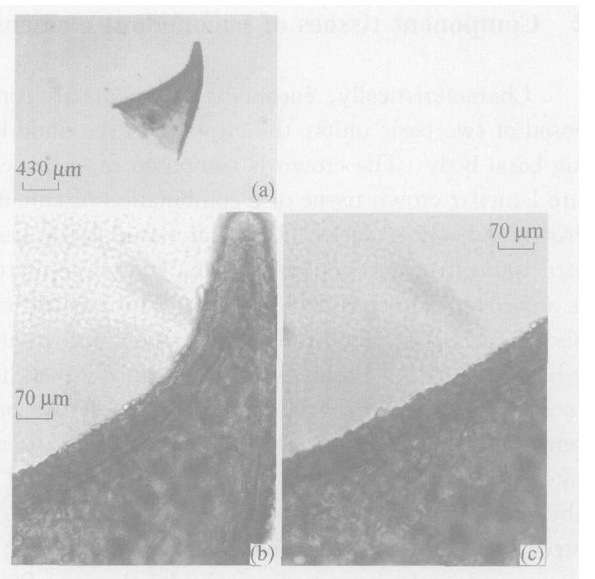

Fig. 4. The histology of *Rotundoconus tricarinatus* (Nogami, 1967). (a) Lateral view, basal cavity extending nearly to the tip; (b) and (c) magnification of part of (a), showing that crown is thin and composed of paralled growth lamellar; spherulitic dentine can be observed in the basal body.

Description:

Crown is thick, the growth lines of crystalline can be seen, which are parallel to each other. The angle between the growth increments of the lamellar crown and the underlying junction with the basal body is usually steeper, about 15 degree.

White matter: The tip of the cusp of *Teridontus nakamurai* appears opaque in transmitted light. Incremental lines are perpendicular to the cusp (Fig. 5 (a)—(d)). The swallow-tail extinction pattern is obvious.

Basal body: The presence of iron-oxide staining in the material has obscured the details of the base. But spherulitic structure can be observed in the basal body.

Discussion: White matter is present in the genus of *Teridontus*. The arrangement of white matter can be observed clearly in the transmit light. They are

typically "pseudo white matter"[11]. This is a remarkable characteristic, which distinguishs the *Teridontus* from primitive euconodont. Its presence or absence is of taxonomic importance.

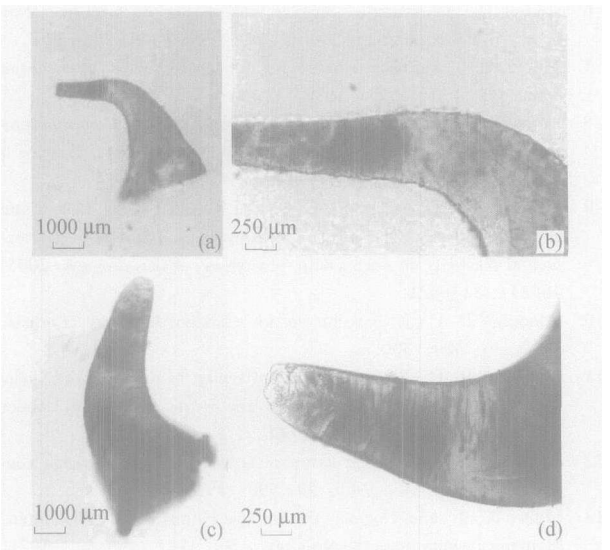

Fig. 5. The histology of *Teridontus nakamurai* (Nogami, 1967). (a) and (c) Lateral view; (b) and (d) magnification of part of (a) and (c) respectively, showing that white matter is perpendicular to cusp, swallow-tail extinction pattern is obvious; (b) spherulitic structures can be observed in the basal body.

Description:

Crown: The lamellar crown tissue of *Cordylodus proavus* is crystalline, with the elongated crystallites arranged perpendicular to the growth increments, which in turn diverge from the distinct crown-basal body junction at a shallow angle with 15 degree (Fig. 6(d)). Crystallites are sometimes arranged into radiating bundles, which produce a swallow-tail extinction effect when the crown is viewed in transmitted light.

White matter: *Cordylodus proavus* appear to possess well-developed white matter in the tip of their cusp and denticles, arranging perpendicular to the growth increments.

Basal body: None tissue structure is recognized in the basal body of *Cordylodus proavus*.

Discussion: Sansom et al.[14] discovered globular calcified cartilage in the basal body of the *Cordylodus angulatus*, which has been interpreted as dentine by Donoghue[11]. Globular structure is not discovered in the more primitive species of *Cordylodus* genus. Furthermore, white matter of *C. proavus* is different from that of *Teridontus nakamurai*. The differences include the arrangement, color under transmitted light and its development degree of white matter. White matter of the former is transverse arrangement, black to opaque and well-developed; however, the latter's white matter is radiating arrangement, deep brown and weakly-developed. These indicate that besides the presence or absence, the degree of white matter development is also an important aspect of genus characteristic.

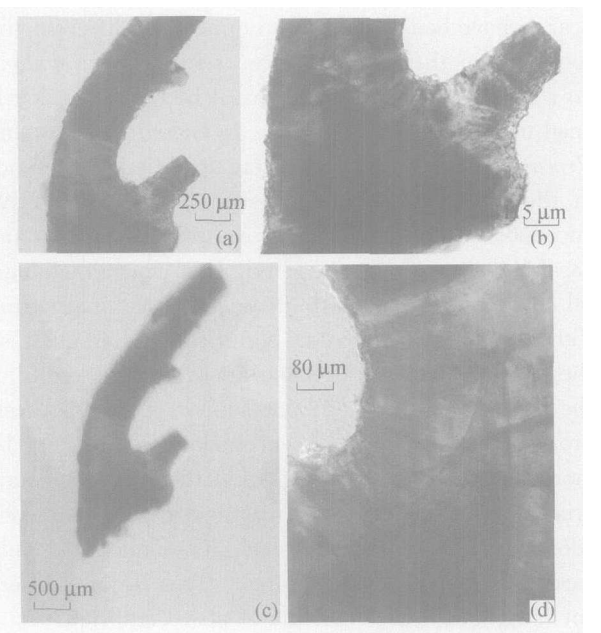

Fig. 6. The histology of *Cordylodus proavus* Müller, 1959. (a) Lateral view, opaque white matter is perpendicular to cusp; (b) magnification of part of (c), showing opaque white matter; (c) lateral view, showing opaque white matter is perpendicular to the cusp and denticle; (d) magnification of part of (a), showing the swallow-tail extinction pattern.

4 Conclusions

Based on the morphological characteristics, Miller[19] proposed two euconodont lineages, i.e. the *Proconodont* lineage and the *Teridontus* lineage, which have been accepted by some conodont workers. In this work we selected the conodonts of *Proconodontus muelleri*, *Proconodontus tenuiserratus*, *Cordylodus proavus* and *Teridontus nakamurai* belonging to the above two lineages and studied their histology. It was discovered that no white matter develops on the most primitive euconodont *proconodontus*, and that its crown is thinner, but the tissue type of its basal body is various. Furthermore, the lamellar, wave-lamellar, spherulitic structures and well-preserved tubular dentine are recognized. However,

in *Cordylodus proavus* and *Teridontus nakamurai*, the crown is thicker, swallow-tail extinction pattern is obvious, white matter is developed, although their tissue types of basal body are simplex. In *Granatodontus ani* and *Rotundoconus tricarinatus*, the structures on the surface of the elements are diverse, the crown is thin, white matter and steady swallow-tail extinction pattern are not found, but tubular and spherulitic dentine develops obviously in the basal body. According to these findings we think that different species of a single euconodont genus appear to have had the ability to mineralize different tissue types in their basal bodies, such as *proconodontus*; the same tissue type of basal body can be developed in different genus, such as *Granatodontus* and *Proconodontus*. Although there is a little difference in the histological characteristics between primitive euconodonts, the tissue types composed of crown and basal body are almost the same. In a word, histological characteristics of both *Proconodontus* lineage and *Teridontus* lineage have no significant differences, so they may belong to the same lineage. Our results of the histological study do not support the hypothesis proposed by Miller, the euconodonts appear to be monophyletic. We also think that the study on Cambrian conodonts including protoconodonts, paraconodonts and primitive euconodonts cannot be only based on the morphological data. This is quite different from that of euconodonts of post-Cambrian.

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