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Reinterpretation of Early and Middle Ordovician conodonts from the Thong Pha Phum area, western Thailand, in the context of new material from western and northern Thailand

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Abstract. Early and Middle Ordovician conodonts are described and illustrated from the Thong Pha Phum and Kanchanaburi areas in western Thailand and the Li area in northern Thailand. The Thong Pha Phum fauna consists of 14 species representing ten genera and one unidentified species, and from the Kanchanaburi and Li sections two and five species, respectively, have been recovered. Two conodont zones, the *Triangulodus larapintinensis* and *Aurilobodus leptosomatus* zones, are established in the Thong Pha Phum section. The fauna from the *T. larapintinensis* Zone includes *Panderodus nogamii*, *Triangulodus larapintinensis*, and species of *Juanognathus*, and the *A. leptosomatus* Zone is characterized by *A. leptosomatus*, *Histiodella holodentata*, and *Plectodina onychodonta*. Two regression events are recorded in a lower part of the Thong Pha Phum section. The conodont biostratigraphy indicates that the regressions took place in latest Early Ordovician and earliest Middle Ordovician.

Key words: biostratigraphy, conodont, Kanchanaburi, Li, Ordovician, Thailand, Thong Pha Phum

Introduction

Paleontological knowledge of the Ordovician strata in Thailand started with the publication by Brown *et al.* (1951). Since they reported a cephalopod specimen from Ron Phibun in southern Thailand, various Ordovician fossils have been described from the southern areas of peninsular Thailand (Hamada *et al.*, 1975; Wongwanich *et al.*, 1990; Cocks *et al.*, 2005). Ordovician sedimentary rocks are also distributed in northern, northwestern, and western Thailand (Bunopas, 1992). Hahn and Siebenhüner (1982) reported occurrences of Ordovician trilobites, gastropods, bivalves, graptolites, and conodonts from northern and northwestern areas in Thailand, around Chiang Mai, Chiang Rai, Mae Hong Song, and Mae Sariang. In western Thailand, Kobayashi (1961, 1984) and Stait and Burrett (1984) described cephalopods from limestone beds in the Tak and Kanchanaburi areas, respectively. Ordovician limestones and siliciclastics distributed in the Thong Pha Phum and Kanchanaburi areas in western Thailand contain nautiloids, brachiopods, trilobites, and conodonts (Hagan and Kemper, 1976; Bunopas, 1981). However, these paleontological studies are only few compared with those in southern peninsular Thailand, because intensive metamorphism affected the Lower Paleozoic sedimentary rocks in northern, northwestern, and western Thailand (Bunopas, 1981) and these mountainous areas do not permit access. We worked in the field in northern, northwestern, and western Thailand between 2001 and 2005, and recovered several Ordovician conodont faunas. The occurrence of conodonts in the Thong Pha Phum area was already reported by Agematsu *et al.* (2006a). This study taxonomically describes these conodonts together with newly discovered Ordovician conodont faunas from the Kanchanaburi and Li areas in western and northern Thailand.

Geological setting

Lower Paleozoic sedimentary rocks distributed in northern, northwestern, and western Thailand were deposited on the Sibumasu Block, which is one of the major continental blocks in Southeast Asia (Bunopas,

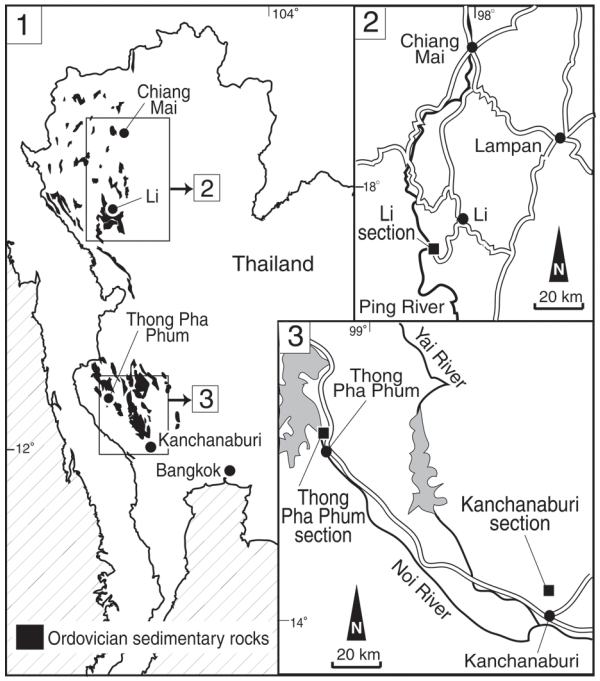

Figure 1. **1,** Index map showing the study areas and the distribution of Ordovician sedimentary rocks. **2,** Locality of the Li section. **3,** Locality of the Kanchanaburi and Thong Pha Phum sections.

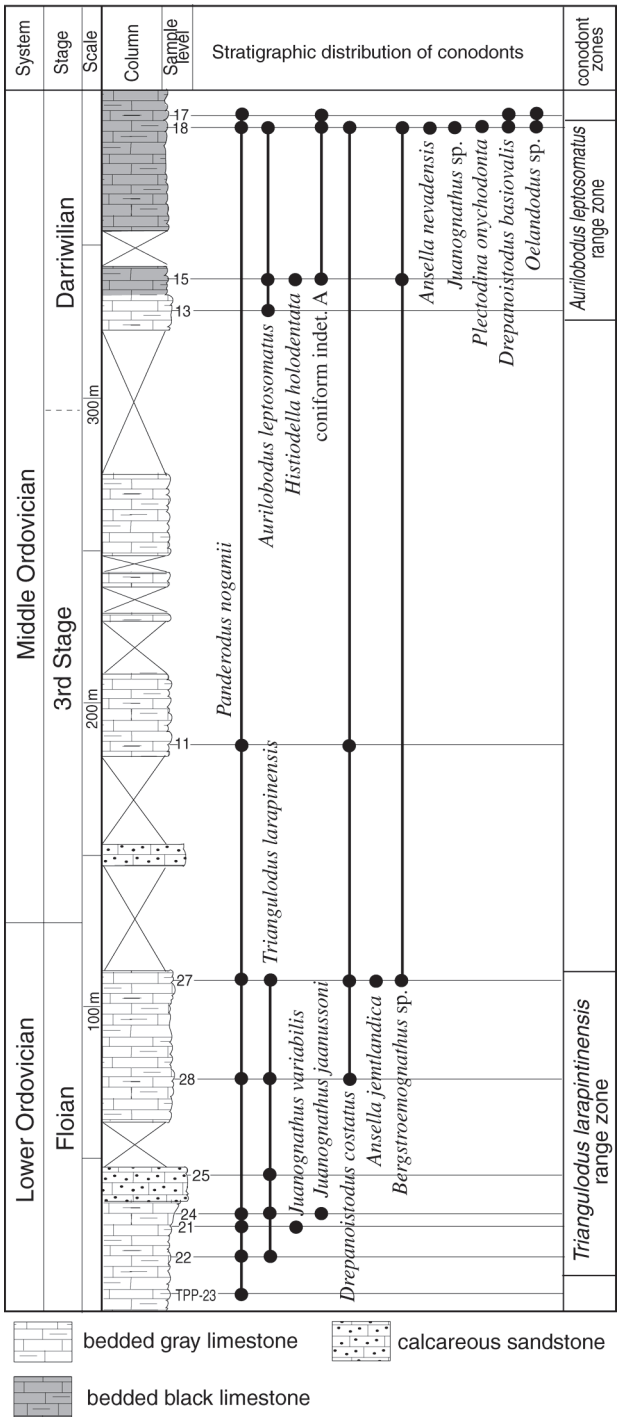

Figure 2. Column of the Thong Pha Phum section showing the stratigraphic distribution of conodonts.

1992; Metcalfe, 2006). Bunopas (1981) classified these rocks and subdivided them into the Upper Cambrian to Middle Ordovician Chao Nen Quartzite Formation and the Middle Ordovician Tha Manao Limestone Formation. The Chao Nen Quartzite Formation is subdivided into a lower, a middle, and an upper member. The lower member mainly comprises fine- to medium-grained sandstone and quartzite, and the middle member consists of sandstone beds with shale and limestone layers yielding Late Cambrian trilobites. The upper member is composed of sandstone and limestone, which contains shell fragments, including Ordovician nautiloids, gastropods, pelecypods, and brachiopods. The Tha Manao Limestone Formation conformably overlies the Chao Nen Quartzite Formation and is classified into a lower and an upper member. The lower member is characterized by calcareous mudstone, sandstone, and limestone, containing Ordovician nautiloids. The upper member is thinly bedded limestone with sandstone layers. Bunopas (1981) tentatively compared these formations with the Cambrian Tarutao Formation and the Ordovician Thung Song Formation, which were established in southern peninsular Thailand (Bunopas, 1981).

Bunopas (1992) integrated Lower Paleozoic sedimentary rocks distributed in northern, northwestern, western, and southern Thailand into the Tarutao and Thung Song groups (formations). Nomenclature of the Cambrian and Ordovician sequences in southern peninsular Thailand has recently been reviewed and revised (Cocks *et al.*, 2005). However, it is difficult to precisely compare Lower Paleozoic strata in the northern, northwestern

Table 1. List of conodonts recovered from the Thong Pha Phum, Kanchanaburi, and Li sections. Numbers on the right side of each species name represent the number of element contained in each 1 kg sample.

	Thong Pha Phum secton													Kanchanaburi section						Li section				
sample number	23	22	21	24	25	28	27	11	13	15	18	17	total	1	5	7	11	12	total	28	29	30	31	total
thickness above the base (m)	5	18	26	32	45	75	110	188	328	340	378	390	400	23	41	50	69	75	77	0.3	3.2	6.8	8.2	8.3
species																								
Ansella jemtlandica							2						2											
Ansella nevadensis											3		3											
Aurilobodus leptosomatus									1	1	1		3											
Bergstroemognathus sp.							1			4	1		6											
Drepanoistodus basiovalis											1	1	2											
Drepanoistodus costatus						2	1	1			1		5	1					1	1		2	2	5
Histiodella holodentata										1			1											
Juanognathus jaanussoni				1									1										1	1
Juanognathus variabilis			1										1											
Juanognathus sp.											1		1											
Oelandodus sp.											3	4	7											
Panderodus nogamii	1	1	1	2		8	4	10			7	5	39							1	1			2
Phragmodus sp.																						1	1	2
Plectodina onychodonta											2		2											
Scolopodus striatus														1	1	3	2	2	9					
Triangulodus larapintinensis		3		2	1	5	5						16									1	1	2
coniform indet. A										1	1	2	4											
total	1	4	2	5	1	15	13	11	1	7	21	12	93	2	1	3	2	2	10	2	1	4	5	12

and western areas with those in the southern area of Thailand, because these strata contain a large variety of rocks (Bunopas, 1981) and lithostratigraphic studies are insufficient in northern, northwestern, and western Thailand. In this study, we follow Bunopas (1992) and use the name Thung Song Formation for the Ordovician limestone sequences in the study area.

Conodont biostratigraphy

Conodonts were recovered from sections in the Thong Pha Phum, Kanchanaburi, and Li areas (Figure 1). The Thong Pha Phum section, about 400 m thick, is located along a small road, which is about 5 km northeast of Thong Pha Phum City (Agematsu *et al.*, 2006a). Agematsu *et al.* (2006a) reported occurrences of 43 species of conodonts belonging to 26 genera and established four conodont zones. This study reconsiders these conodont specimens and systematically describes 14 species representing 10 genera and 1 unidentified species (Table 1). Based on reexaminations of the conodont biostratigraphy, the *Triangulodus larapintinensis* range Zone and the *Aurilobodus leptosomatus* Range Zone are established (Figure 2).

Triangulodus larapintinensis Range Zone

The lower zone in the Thong Pha Phum section ranges from 20 m to 110 m above the base of the section. This zone coincides with the stratigraphic range of *Triangulodus larapintinensis* (Crespin, 1943). *Panderodus nogamii* (Lee, 1975) occurs throughout the zone and *Juanognathus variabilis* Serpagli, 1974 and *Juanognathus jaanussoni* Serpagli, 1974 are contained in the lower part of the zone. The upper part of this zone is characterized by occurrences of *Drepanoistodus costatus* (Abaimova, 1971), *Ansella jemtlandica* (Löfgren, 1978), and *Bergstroemognathus* sp.

The nominate species, *T. larapintinensis*, has been reported from Australia and Thailand (Cooper, 1981; Watson, 1988; Stait and Druce, 1993; Zhen *et al.*, 2003a; Agematsu *et al.*, 2006b). This species has a relatively long stratigraphic range, which covers an interval corresponding to the *Reutterodus andinus* Zone to the *Histiodella holodentata* Zone in the North American Midcontinent standard (Figure 3). Two species of *Juanognathus* Serpagli, which were first described by Serpagli (1974), are representative species of late Early Ordovician and early Middle Ordovician strata in North America, South China, Argentina, and Australia (e.g., Ethington and Clark, 1981; Repetski, 1982; Wang and Luo, 1984; Albanesi, 1998a; Zhen *et al.*, 2003a). These species occur mainly from the strata, which are compared with the *R. andinus* Zone in the Midcontinent standard and *Oepikodus evae* Zone in the North Atlantic standard. Stratigraphic ranges of these species extend into the older and younger strata in South China (Wang *et al.*, 1996). Therefore, the *T. larapintinensis* Zone in the Thong Pha Phum section is roughly correlated with

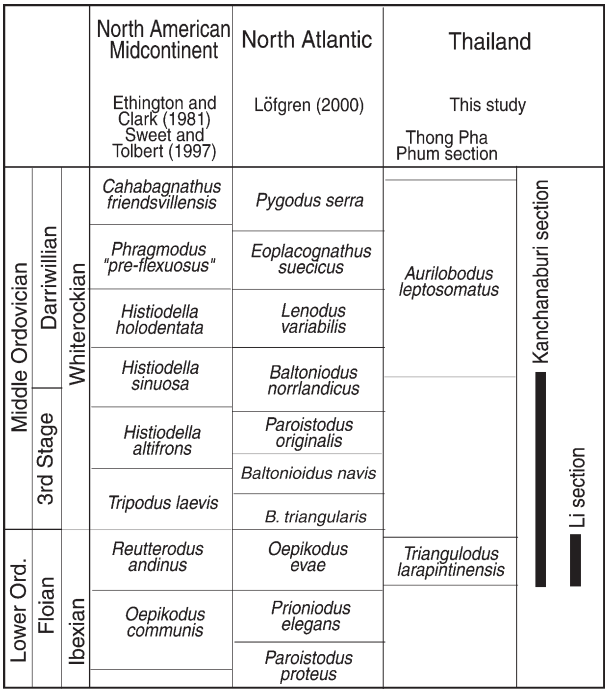

Figure 3. Age of the Kanchanaburi and Li sections and correlation of the conodont zones in the Thong Pha Phum section with the standard zonations in the North American Midcontinent and North Atlantic schemes.

the *R. andinus* Zone in the Midcontinent standard and *O. evae* Zone in the North Atlantic standard (Figure 3).

Aurilobodus leptosomatus Range Zone

The upper range zone includes the interval of 330 m to 390 m above the base of the Thong Pha Phum section (Figure 2). The base and top of this zone are defined by the first and last occurrences of *Aurilobodus leptosomatus* An in An *et al.*, 1983, respectively. This zone contains *Histiodella holodentata* Ethington and Clark, 1981 in the lower part and *Panderodus nogamii*, *Plectodina onychodonta* An and Xu in An *et al.*, 1983, *Drepanoistodus basiovalis* (Sergeeva, 1963), *Ansella nevadensis* (Ethington and Schumacher, 1969), *Oelandodus* sp., and *Juanognathus* sp. in the upper part.

A. leptosomatus is a characteristic species in North China and Australia and has been reported from Lower and Middle Ordovician strata, corresponding to the *R. andinus* to *Phragmodus* "*pre-flexuosus*" zones in the Midcontinent standard (An *et al.*, 1983; Watson, 1988; Stait and Druce, 1993; Kuhn and Barnes, 2005). *H. holodentata* is an index species of the *H. holodentata* Zone in North America (Ethington and Clark, 1981). This species is known from Middle Ordovician rocks in North and South China, and these rocks are contemporaneous with the *Histiodella sinuosa* to *Phragmodus* "*pre-flexuosus*" zones in the Midcontinent standard and the *Eoplacognathus suecicus* to *Baltoniodus norrlandicus* zones in the North Atlantic standard (Wang *et al.*, 1996). Watson (1988) also described this species from the Middle Ordovician sequence in Australia. *P. onychodonta* has been reported from the Middle Ordovician rocks in North China and Australia (An *et al.*, 1983; Wang *et al.*, 1996; Nicoll and Metcalfe, 2001). These strata are equivalent with the *P.* "*pre-flexuosus*" Zone to the *Cahabagnathus friendsvillensis* Zone in the Midcontinent standard. Stratigraphic ranges of these species indicate that the *A. leptosomatus* Zone in the Thong Pha Phum section is comparable to the *H. sinuosa* Zone to the *C. friendsvillensis* Zone in the Midcontinent standard (Figure 3).

Conodonts from the Kanchanaburi section

The Kanchanaburi section is located along the northern foot of Mt. Tham, about 12 km north of Kanchanaburi City. This section consists of bedded gray limestone, about 40 m in thickness, and contains poorly preserved conodonts, *Drepanoistodus costatus* and *Scolopodus striatus* Pander, 1856 (Table 1). The Kanchanaburi section only shares *D. costatus* with the Thong Pha Phum and Li sections. *S. striatus* is a generally known species in the North Atlantic area and ranges from the *Paroistodus proteus* Zone to the *Baltoniodus norrlandicus* Zone in the North Atlantic standard zonation (Tolmacheva, 2006). *D. costatus* is also a long-ranging species, and has been known from strata corresponding to the *Oepikodus evae* to *Lenodus variabilis* zones in the North Atlantic standard (Zhen *et al.*, 2003b). Therefore, the Kanchanaburi section is roughly correlated with the *Oepikodus evae* to *Baltoniodus norrlandicus* zones in the North Atlantic standard (Figure 3).

Conodonts from the Li section

The Li section lies about 25 km west of Li City along the Ping River (Figure 1). This section, about 10 m thick, is made up of bedded gray limestone. Conodonts recovered from the section are poorly preserved, but are identified with five species belonging to five genera, *Drepanoistodus costatus*, *Juanognathus jaanussoni*, *Panderodus nogamii*, *Triangulodus larapintinensis*, and *Phragmodus* sp. (Table 1). These are common species of faunas from the *T. larapintinensis* Zone in the Thong Pha Phum section, except for *Phragmodus* sp. A faunal correlation between the Li and Thong Pha Phum section is difficult, because the Li fauna has few conodonts. However, the Li section may be an equivalent to the *T. larapintinensis* Zone in the Thong Pha Phum section (Figure 3).

Depositional environment and sea-level change of the Thong Pha Phum section

Depositional environment of the Thong Pha Phum section is here inferred from field observations and thin section analyses. Reconstructed paleoenvironments and sea-level changes are shown in Figure 4. The lithology of the Thong Pha Phum section was described in detail by Agematsu *et al.* (2006a). The lower strata of the section, about 300 m thick, consist of calcareous sandstones and limestones cemented by sparite. These rocks contain abundant fossils, for example, trilobites, brachiopods, and shell fragments, and silt- to coarse-grained quartz. Some limestone beds of the lower part exhibit cross laminations (Figure 4). The upper 100 m of the section is made up of limestones with a micrite matrix (Figure 4). Macrofossils, such as trilobites, nautiloids, and shell fragments, and silt-grained quartz occur from these limestones. Agematsu *et al.* (2006a) interpreted the depositional environments of the section as follows: limestone and calcareous sandstone of the lower part of the section deposited in a high-energy, middle or outer shelf and shoal condition; micritic limestone of the upper part of the section accumulated in a deeper-water, middle or outer shelf environment (Figure 4). The sea-level changes in the Thong Pha Phum section are shown in Figure 4. The section is divided into two parts: the lower 300 m of strata are interpreted as a relatively low sea-level interval and the upper 100 m is a high sea-level interval. Two major regression events, which are represented by sedimentation of two calcareous sandstone beds, are recognized in the lowstand interval (Figure 4). On the basis of the conodont biostratigraphy, these regressions took place during the latest Early Ordovician and earliest Middle Ordovician time.

Summary

Ordovician conodonts, which are reported by Agematsu *et al.* (2006a) from the Thong Pha Phum area in western Thailand, are reexamined and taxonomically described as 14 species belonging to 10 genera and one unidentified species. Two conodont biostratigraphic zones, the lower *Triangulodus larapintinensis* Range Zone and the upper *Aurilobodus leptosomatus* Range Zone, are established in the Thong Pha Phum section. The *T. larapintinensis* Zone is correlated with the *Reutterodus andinus* Zone in the North American Midcontinent standard zonation and the *Oepikodus evae* Zone in the North Atlantic standard zonation. The *A. leptosomatus* Zone is inferred to be an equivalent to the *Histiodella sinuosa* to *Cahabagnathus friendsvillensis* zones in the Midcontinent standard. Conodonts recov-

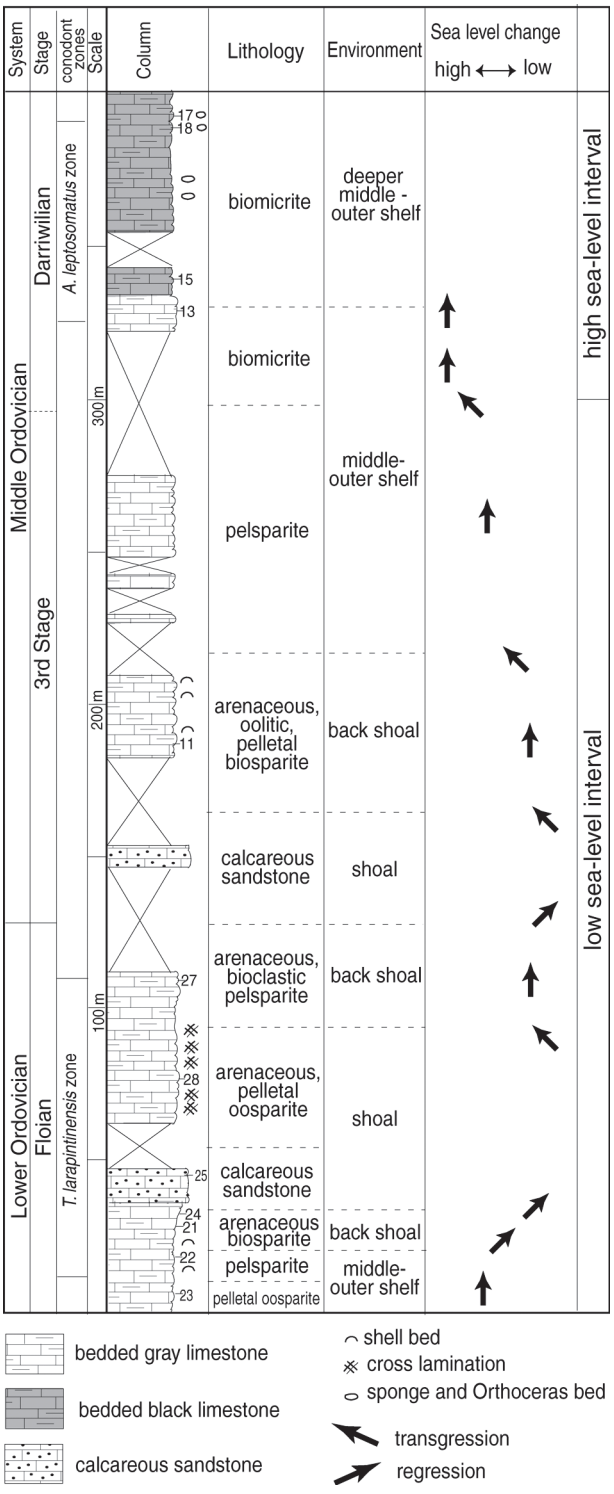

Figure 4. Lithologic column of the Thong Pha Phum section, reconstructed depositional environments, and sea-level change.

ered from the Kanchanaburi area in western Thailand and the Li area in northern Thailand are identified with two and five species, respectively. The Li section is biostratigraphically comparable with the *T. larapintinensis* Zone in the Thong Pha Phum section.

The Thong Pha Phum section is divided into the uppermost Lower Ordovician to Middle Ordovician low sea-level interval and the Middle Ordovician high sea-level interval. Two major regression events, which took place in latest Early Ordovician and earliest Middle Ordovician, are recorded in the lowstand interval.

Systematic paleontology

All specimens described in this paper are deposited in the Institute of Geoscience, University of Tsukuba, with the prefix IGUT. Conodont taxa herein are only classified to genus and species. Genera and species are listed in alphabetical order. Element terminology basically follows that of Barnes *et al.* (1979).

Genus ***Aurilobodus*** Xiang and Zhang in An *et al.*, 1983

Type species.—Tricladiodus? aurilobodus Lee, 1975.

Aurilobodus leptosomatus An in An *et al.*, 1983

Figures 7.3, 7.4

Aurilobodus leptosomatus An in An *et al.*, 1983, p. 72, 73, pl. 21, figs. 14–17, pl. 22, fig. 1; Kuhn and Barnes, 2005, p. 319, fig. 2.1, 2.2; Agematsu *et al.*, 2006a, fig. 7.12, 7.16.

Aurilobodus? leptosomatus An. Stait and Druce, 1993, p. 302, fig. 17. a–c.

Juanognathus leptosomatus (An). Watson, 1988, p. 116, pl. 1, figs. 1–3, 6; Lehnert, 1995, p. 92, 93, pl. 12, fig. 9, pl. 13, fig. 4.

Material.—Three specimens; one asymmetrical and two symmetrical elements (IGUT-ag2028, 2029, 3547).

Remarks.—Watson (1988) recognized asymmetrical *t* and *t′* and symmetrical *s* and *s′* elements as an apparatus of this species. Specimens recovered from the study section coincide with his *t* and *s* elements.

Occurrence.—This species has been known from the Floian to the lower Darriwilian strata in North China and Australia (An *et al.*, 1983; Watson, 1988; Stait and Druce, 1993). Specimens of this species are also contained in the *A. leptosomatus* Zone of the Thong Pha Phum section.

Genus ***Bergstroemognathus*** Serpagli, 1974

Type species.—Oistodus extensus Graves and Ellison, 1941

Bergstroemognathus sp.

Figures 5.3, 5.4, 7.1

Material.—Eight specimens; three *c*, one *d*, and two *g* elements (IGUT-ag2026, 3489 to 3493).

Description.—Palmate alate *c* element is anteroposteriorly compressed. Fused, high denticles are located on lateral processes. Anterior face is gently convex. Small basal cavity opens below the cusp and is expanded posteriorly. *d* element is bipennate with a large cusp and denticulated anterior and posterior processes. The processes are laterally compressed and discrete denticles are inclined inwardly. Basal cavity is lozenge-shaped in aboral view. *g* element is strongly compressed anteroposteriorly and has thinly denticulated anterior process.

Remarks.—According to Zhen *et al.* (2001), the apparatus of *Bergstroemognathus* consists of *a*, *b*, *c*, *d*, *e*, *f*, and *g* elements. Although *c*, *d*, and *g* elements are included in the study section, their poor preservation prevents an identification of species.

Occurrence.—These elements occur in the uppermost part of the *Triangulodus larapintinensis* Zone and the *Aurilobodus leptosomatus* Zone of the Thong Pha Phum section.

Genus ***Drepanoistodus*** Lindström, 1971

Type species.—Oistodus forceps Lindström, 1955

Drepanoistodus costatus (Abaimova, 1971)

Figures 6.1–3

➡ **Figure 5.** SEM photos of conodonts. Scale bars indicate 100 μm. **1–2**, *Scolopodus striatus* Pander, 1856. 1, lateral and aboral views of the acontiodiform element from sample 07, Kanchanaburi section, IGUT-ag3566, ×80; 2, lateral and aboral views of scandodiform element from sample 05, Kanchanaburi section, IGUT-ag3564, ×80. **3–4**, *Bergstroemognathus* sp. 3, posterior and aboral views of c element from sample 15, Thong Pha Phum section, IGUT-ag2026, ×50; 4, lateral view of g element from sample 18, Thong Pha Phum section, IGUT-ag3489, ×80. **5–7**, *Oelandodus* sp. 5, lateral view of a element from sample 17, Thong Pha Phum section, IGUT-ag3495, ×150; 6, lateral and aboral views of *f* element from sample 17, Thong Pha Phum section, IGUT-ag3497, ×100; 7, lateral view of *b* element from sample 17, Thong Pha Phum section, IGUT-ag3494, ×150. **8**, Coniform indet. A, lateral and aboral views, sample 17, Thong Pha Phum section, IGUT-ag3549, ×70. **9–11, 14**, *Panderodus nogamii* (Lee, 1975). 9, lateral and aboral views of *a* element from sample 11, Thong Pha Phum section, IGUT-ag3511, ×150; 10, lateral and aboral views of *c* element from sample 11, Thong Pha Phum section, IGUT-ag3506, ×100; 11, lateral and aboral views of *b* element from sample 17, Thong Pha Phum section, IGUT-ag3502, ×150; 14, lateral and aboral views of *g* element from sample 18, Thong Pha Phum section, IGUT-ag3520, ×150. **12–13**, *Juanognathus jaanussoni* Serpagli, 1974. 11, lateral and aboral views of *b* element from sample 31, Li section, IGUT-ag3562, ×150; 12, lateral and aboral views of *a* element from sample 24, Thong Pha Phum section, IGUT-ag3546, ×150.

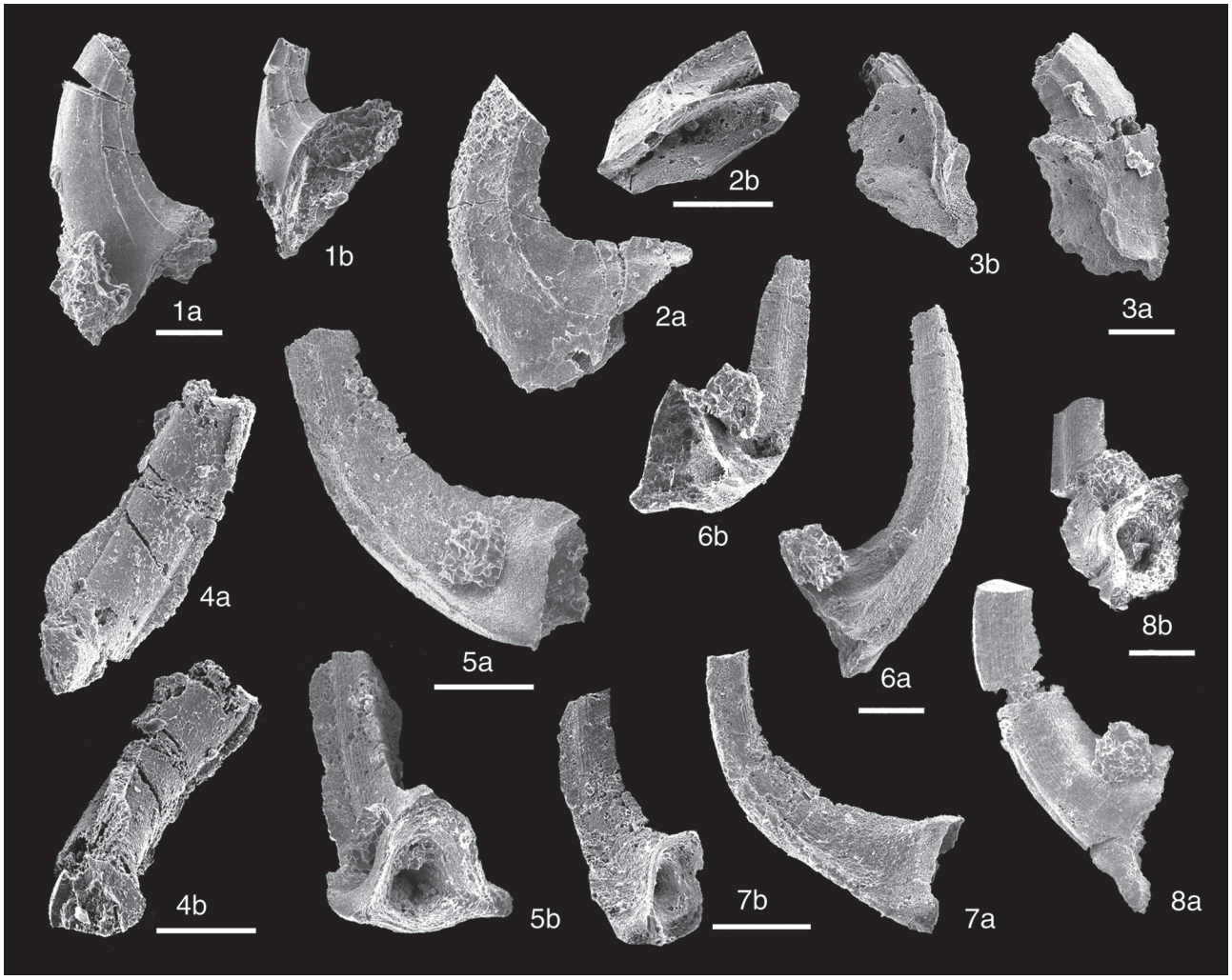

Figure 6. SEM photos of conodonts. Scale bars indicate 100 μm. **1–3**, *Drepanoistodus costatus* (Abaimova, 1971). 1, lateral and aboral views of *c* element from sample 27, Thong Pha Phum section, IGUT-ag3543, ×100; 2, lateral and aboral views of *d* element from sample 18, Thong Pha Phum section, IGUT-ag3541, ×150; 3, lateral and aboral views of *e* element from sample 30, Li section, IGUT-ag3559, ×100. **4–8**, *Triangulodus larapintinensis* (Crespin, 1943). 4, lateral and aboral views of *d* element from sample 31, Li section, IGUT-ag3552, ×150; 5, lateral and aboral views of *c* element from sample 28, Thong Pha Phum section, IGUT-ag3475, ×150; 6, lateral and aboral views of *b* element from sample 28, Thong Pha Phum section, IGUT-ag3476, ×100; 7, lateral and aboral views of *a* element from sample 28, Thong Pha Phum section, IGUT-ag3473, ×150; 8, lateral and aboral views of *f* element from sample 24, Thong Pha Phum section, IGUT-ag3483, ×100.

Drepanodus costatus Abaimova, 1971, p. 490, pl. 10, fig. 6, text-fig. 3.
Drepanodus pitjanti Cooper, 1981, p. 162, pl. 26, figs. 3–5, 7, 8; Watson, 1988, p. 111, pl. 3, figs. 14, 16, 17, pl. 5, fig. 15; Albanesi, 1998b, p. 136, pl. 4, figs. 1–7, text-fig. 16.
Drepanoistodus costatus (Abaimova). Stait and Druce, 1993, p. 303, figs. 12.l–m, 17.j–n; Zhen *et al.*, 2003a, p. 191, 194, fig. 15.a–r.
Scolopodus cornutiformis Lee, 1976, p. 172, pl. 2, fig. 18.
Scolopodus ordosensis Wang and Luo, 1984, p. 284, pl. 4, figs. 22, 23.

Material.—Ten specimens; five *c*, three *d*, and two *e* elements (IGUT-ag3541 to 3545, 3557 to 3561, 3572).

Remarks.—We follow an apparatus reconstruction of Zhen *et al.* (2003b). Specimens recovered from the study sections are identified with *c*, *d*, and *g* elements.

Occurrence.—This species has been reported from Floian to Darriwilian rocks in Australia, Argentina, Siberia, and China (e.g., Abaimova, 1971; Cooper, 1981; Wang and Luo, 1984; Stait and Druce, 1993; Albanesi, 1998b). The Thong Pha Phum, Kanchanaburi, and Li sections in this study contain this species.

Genus ***Histiodella*** Harris, 1962

Type species.—*Histiodella alfrons* Harris, 1962.

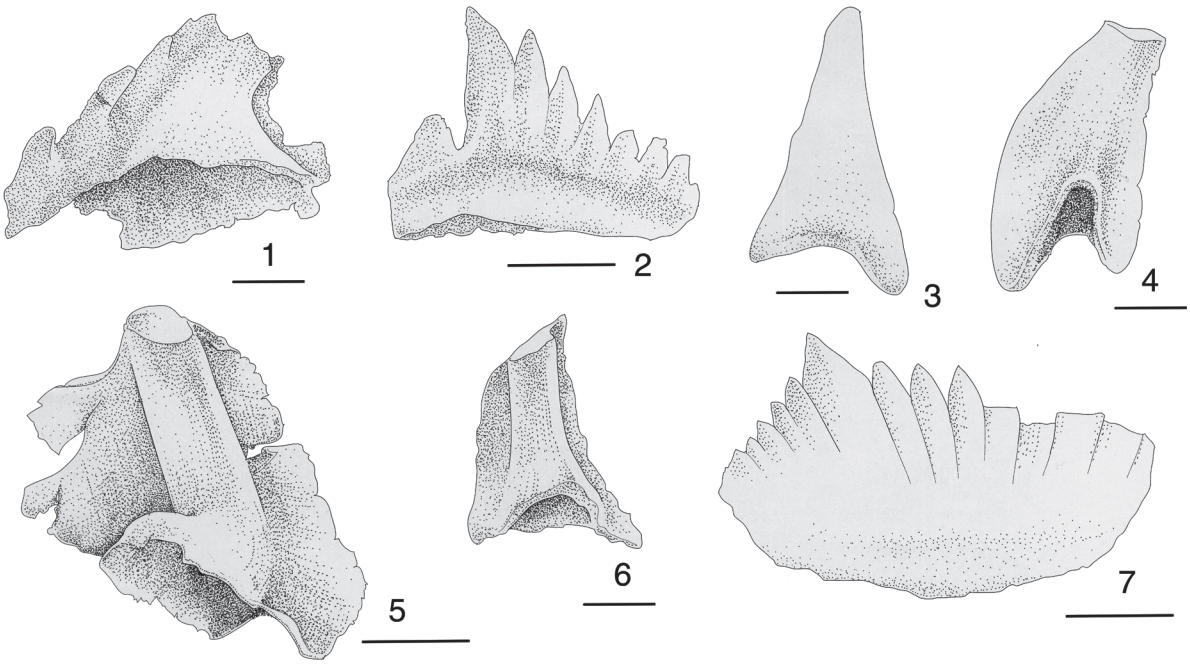

Figure 7. Line illustrations of conodonts. Scale bars indicate 100 μm. **1**, *Bergstroemognathus* sp., lateral and aboral views of *d* element from sample 15, Thong Pha Phum section, IGUT-ag3492, ×100. **2**, *Plectodina onychodonta* An and Xu in An *et al.*, 1983, lateral and aboral views of *g* element from sample 18, Thong Pha Phum section, IGUT-ag2019, ×150. **3–4**, *Aurilobodus leptosomatus* An in An *et al.*, 1983. 3, posterior view of *s* element from sample 13, Thong Pha Phum section, IGUT-ag2028, ×100; 4, posterior and aboral views of *t* element from sample 15, Thong Pha Phum section, IGUT-ag2029, ×100. **5**, *Juanognathus* sp., posterior and aboral views, sample 18, Thong Pha Phum section, IGUT-ag2022, ×150. **6**, *Juanognathus variabilis* Serpagli, 1974, posterior and aboral views of *b* element from sample 21, Thong Pha Phum section, IGUT-ag2002, ×100. **7**, *Histiodella holodentata* Ethington and Clark, 1981, lateral view of bladelike element from sample 15, Thong Pha Phum section, IGUT-ag2025, ×150.

Histiodella holodentata Ethington and Clark, 1981

Figure 7.7

Histiodella holodentata Ethington and Clark, 1981, p. 47, 48, pl. 4, figs. 1, 3, 4, 16; Nowlan and Thurlow, 1983, pl. 1, figs. 1, 3, 5; Watson, 1988, p. 115, 116, pl. 4, figs. 15, 20; Lehnert, 1995, p. 90, 91, pl. 9, figs. 7, 10, pl. 11, fig. 7; Wang *et al.*, 1996, pl. 1, figs. 12, 13; Keller and Lehnert, 1998, fig. 10.3; Rasmussen, 2001, p. 82, pl. 7, figs. 18, 19; Du *et al.*, 2005, p. 365, pl. 1, figs. 22–26, 28. Agematsu *et al.*, 2006a, fig. 7.18.

Histiodella sinuosa (Graves and Ellison). Barnes and Poplawski, 1973, p. 776, pl. 1, figs. 17, 18.

Histiodella sp. 1 Harris, Bergström, Ethington, and Ross, 1979, pl. 1, fig. 9.

Histiodella infrequensa An in An *et al.*, 1983, pl. 25, fig. 2.

Histiodella serrata Harris. Wang and Luo, 1984. p. 262, 263, pl. 10, fig. 1, pl. 11, figs. 6, 7.

Histiodella tableheadensis Stouge, 1984, p. 87, 88, pl. 18, figs. 8, 12–14, text-fig. 17.

Material.—One bladelike element (IGUT-ag2025).

Remarks.—Element coincides with the description by Ethington and Clark (1981). They recognized bladelike elements, symmetrical elements, and oistodiform elements in an apparatus of *Histiodella*.

Occurrence.—Since the erection of *H. holodentata* and the delineation of the *H. holodentata* Zone in Middle Ordovician deposits of Utah, North America (Ethington and Clark, 1981), the taxon has been recognized in many parts of the world (see synonymy). In this study, the single specimen has been recovered from the *Aurilobodus leptosomatus* Zone of the Thong Pha Phum section.

Genus ***Juanognathus*** Serpagli, 1974

Type species.—*Juanognathus variabilis* Serpagli, 1974.

Juanognathus jaanussoni Serpagli, 1974

Figures 5.12, 5.13

Juanognathus jaanussoni Serpagli. Albanesi, 1998b, p. 125, pl. 5, figs. 1–9, text-fig. 13 (including synonymy); Johnston and Barnes, 2000, p. 21, pl. 13, fig. 11; Pyle and Barnes, 2002, p. 75, 76, pl. 24, figs. 5–8.

Material.—Two specimens; one *a* element and one *b* element (IGUT-ag3546, 3562).

Remarks.—Collection of this study contains subsym-

metrical and asymmetrical coniform elements. These forms accord with a description of *a* and *b* elements of Albanesi (1998b).

Occurrence.—Albanesi (1998b) described this species from the uppermost part of the Third Stage to lower Darriwilian sequences in Argentina. *J. jaanussoni* also has been reported from the *Retterodus andinus* to *Tripodus laevis* zones in North America (Ethington and Clark, 1981; Repetski, 1982). This species occurs in the *Triangulodus larapintinensis* Zone of the Thong Pha Phum section and the lowermost part of the Li section.

Juanognathus variabilis Serpagli, 1974

Figure 7.6

Juanognathus variabilis Serpagli. Zhen *et al.*, 2003a, p. 53, 54, pl. 4, figs. 1–14 (including synonymy); Agematsu *et al.*, 2006a, fig. 7.4 (only).

Material.—One specimen; one *b* element (IGUT-ag 2002).

Remarks.—According to Zhen *et al.* (2003a), *a*, *b*, *c*, *d*, and *e* elements constitute an apparatus of this species. The specimen reported herein is subsymmetrical juanognathiform and coincides with the description of the *b* element of Zhen *et al.* (2003a).

Occurrence.—This is a representative species of the Floian and has been reported from Argentina (Serpagli, 1974; Albanesi, 1998a), Australia (Zhen *et al.*, 2003a), North America (Ethington and Clark, 1981; Stouge and Bagnoli, 1988; Pohler, 1994), and Malaysia (Igo and Koike, 1967). The stratigraphic range of this species extends up into the lower Darriwilian in South China (Chen *et al.*, 1995; Wang *et al.*, 1996). The *Triangulodus larapintinensis* Zone of the Thong Pha Phum section includes this species.

Juanognathus sp.

Figure 7.5

Juanognathus sp. B. Agematsu *et al.*, 2006a, fig. 7.19.

Material.—One specimen (IGUT-ag2022).

Remarks.—Specimen is asymmetrical, conical in form and has remarkable, bladelike lateral costae. Cusp is proclined and twists inward. Anterior and posterior sides are flattened and rounded, respectively. Short base is posteriorly expanded. Bladelike costae of the element are similar to those of *Juanognathus variabilis*, but *Juanognathus* sp. differs from *J. variabilis* by the sharp blades and shallow and laterally narrow base.

Occurrence.—The upper part of the *Aurilobodus leptosomatus* Zone of the Thong Pha Phum section.

Genus ***Oelandodus*** van Wamel, 1974

Type species.—*Oistodus elongatus* Lindström, 1955

Oelandodus sp.

Figures 5.5–5.7

Material.—Seven specimens; four *a*, one *b*, and two *f* elements (IGUT-ag3494 to 3500).

Description.—All specimens are laterally compressed. *a* elements are subsymmetrical and geniculate. Anterior and posterior margins of cusps and bases are sharply keeled. The cusp inclines slightly inwardly and bears a mid carina on the outer side. *b* element is asymmetrical with keeled anterior and posterior margins. Sharply edged anterolateral costa ranges from tip of cusp to basal margin. The geniculate *f* elements are asymmetrical with inwardly inclined cusp. Outer face of the cusp is broadly convex and has a mid carina. Base is characterized by carina parallel to the basal margin.

Remarks.—Van Wamel (1974) reconstructed the apparatus of this genus, which is composed of *a*, *b*, *c*, *e*, and *f* elements. *a*, *b*, and *f* elements are found in collections of this study.

Occurrence.—Specimens of this species occur from the upper part of the *Aurilobodus leptosomatus* Zone of the Thong Pha Phum section in this study.

Genus ***Panderodus*** Ethington, 1959

Type species.—*Paltodus unicostatus* Branson and Mehl, 1933.

Panderodus nogamii (Lee, 1975)

Figures 5.9–5.11, 5.14

Panderodus sp. Serpagli, 1974, p. 59, pl. 24, figs. 12, 13, pl. 30, figs. 12, 13.

Panderodus nogamii (Lee). Cantrill and Burrett, 2003, p. 410–415, pl. 1, figs. 1–16; Zhang *et al.*, 2003, p. 16, pl. 5, figs. 1–5; Kuhn and Barnes, 2005, p. 324, 326, figs. 3.19–3.21; Agematsu *et al.*, 2006b, p. 225, 226, figs. 3.3, 3.4.

Parapanderodus nogamii (Lee). Watson, 1988, p. 124, 125, pl. 3, figs. 1, 6.

Parapanderodus paracornuformis (Ethington and Clark). Albanesi, 1998b, p. 116, 117, pl. 12, figs. 8–10, 12, 13 (only), text-fig. 9.

Protopanderodus nogamii (Lee). Zhen *et al.*, 2003b, p. 207, 209, figs. 23.a–23.q; Zhen and Percival, 2004, p. 104, 105, figs. 18.a–18.k.

Protopanderodus primitus (Druce). Cooper, 1981, p. 174, 175, pl. 27, figs. 3, 4; Agematsu *et al.*, 2006a, figs. 7.1–7.3.

Protopanderodus? *primitus* Cooper. Stait and Druce, 1993, p. 307, 308, text-figs. 13.a–c, 18.d, e, g–k.

Scolopodus cf. *bassleri* (Furnish), Igo and Koike, 1967, p. 23, pl. 3, figs. 7, 8, text-fig. 6.b.

Scolopodus nogamii Lee, 1975, p. 179, pl. 2, fig. 13, text-fig. 3.l.

Material.—Forty-one specimens; ten *a*, twelve *b*, eight *c*, and eleven *g* elements (IGUT-ag3501 to 3539, 3555, 3556).

Remarks.—*a*, *b*, *c*, and *g* elements are found in the study section. The *a*, *b*, and *c* elements construct a symmetry transition series. Specimens with a laterally compressed, short base are identified with the *g* element.

Occurrence.—*P. nogamii* is a relatively long-ranging species, reported from Middle and Upper Ordovician strata in Australia, China, Argentina, and Southeast Asia (Cantrill and Burrett, 2003). This species is present in the Thong Pha Phum and Li sections.

Genus ***Plectodina*** Stauffer, 1935
Type species.—*Prioniodus aculeatus* Stauffer, 1930

Plectodina onychodonta An and Xu in An *et al.*, 1983

Figure 7.2

Plectodina onychodonta An and Xu in An *et al.*, 1983, p. 121, pl. 23, figs, 1–16, pl. 24, figs. 1–15, pl. 25, figs. 4, 7, text-figs. 13.19–24; Nicoll and Metcalfe, 2001, figs. 6.5–6.7.

Material.—Two specimens: two *g* elements (IGUT-ag 2019, 3540).

Remarks.—Ethington and Clark (1981) reconstructed apparatuses of this genus and described *a*, *b*, *c*, *e*, *f*, and *g* elements. Specimens from the study section correspond to the *g* element and coincide with the description of a prioniodiniform element of An *et al.* (1983).

Occurrence.—This species is known from the upper Darriwilian rocks in North China (An *et al.*, 1983; Wang *et al.*, 1996) and the Middle Ordovician Stokes Siltstone in Australia (Nicoll and Metcalfe, 2001). In this study, *P. onychodonta* occurs in the uppermost part of the *Aurilobodus leptosomatus* Zone in the Thong Pha Phum section.

Genus ***Scolopodus*** Pander, 1856
Type species.—*Scolopodus sublaevis* Pander, 1856

Scolopodus striatus Pander, 1856

Figures 5.1, 5.2

Scolopodus quadratus Pander. Zhen *et al.*, 2003a p. 58, 59, pl. 5, figs. 15–21.
Scolopodus rex Lindström. Wang *et al.*, 1996, pl. 2, figs. 18, 19; Albanesi, 1998b, p. 133, pl. 12, figs. 14–17.
Scolopodus striatus Pander. Tolmacheva, 2006, p. 255–259, figs. 5.a, 5.b, 5.d–f, 6–8 (including synonymy).

Material.—Nine specimens: six "acontiodiform" and three "scandodifrom" elements (IGUT-ag3563 to 3571).

Remarks.—Our specimens are symmetrical acontiodiform and asymmetrical scandodiform elements, and coincide with the description by Tolmacheva (2006).

Occurrence.—This is a widely known species in the North Atlantic area and stratigraphically ranges from the *Paroistodus proteus* Zone to the *Baltoniodus norrlandicus* Zone. This species has also been reported from China, Australia, and Argentina (Wang *et al.*, 1996; Albanesi, 1998b; Zhen *et al.*, 2003a). The Kanchanaburi section yields this species.

Genus ***Triangulodus*** van Wamel, 1974
Type species.—*Paltodus volchovensis* Sergeeva, 1963

Triangulodus larapintinensis (Crespin, 1943)

Figures 6.4–6.8

Oistodus larapintinensis Crespin, 1943, p. 231, pl. 31, figs. i-6, 9, 12, 13.
Scandodus brevibasis (Sergeeva). Agematsu *et al.*, 2006a, fig. 7.20.
Triangulodus comptus (Branson and Mehl). Agematsu *et al.*, 2006a, figs. 7.8, 7.9.
Triangulodus larapintinensis (Crespin). Stait and Druce, 1993, p. 315, 317, figs. 14.a–c, 21.d–f, h–j; Zhen *et al.*, 2003a, p. 212–216, figs. 28.a–v; Agematsu *et al.*, 2006b, p. 228, figs. 3.21–3.23.
Trigonodus larapintinensis (Crespin). Cooper, 1981, p. 180, pl. 27, figs. 5, 6, 11, 12, 16, 17; Watson, 1988, p. 129, pl. 2, figs. 12–14, 18–20, 22, 23.

Materials.—Eighteen specimens; four *a*, nine *b*, and three *c* elements, one *d* element, and one *f* element (IGUT-ag2034, 2035, 3473 to 3486, 3551, 3552).

Description.—Specimens are slender coniform. The asymmetrical *a* element is characterized by erect cusp with keeled anterolateral and posterior margins. The *b* element is asymmetrical tricostate with an erect cusp. Anterior, posterior and inner sides bear sharply edged costae running throughout the unit. Anterior surface is round to flat. Basal margin is triangular in aboral view. Symmetrical *c* element has proclined to erect cusp with one posterior and two keeled lateral costae. *d* element resembles *a* element, but is twisted and asymmetrical. Laterally compressed *f* element has erect cusp and anterior and posterior edges.

Remarks.—We follow the description of Zhen *et al.* (2003b). Collections of this study yield *a*, *b*, *c*, *d*, and *f* elements. Agematsu *et al.* (2006a) assigned the specimens regarded as *b* elements in this study to *Acodus comptus* (Branson and Mehl, 1933). According to Ethington and Clark (1981) and Zhen *et al.* (2003a), the apparatus of *A. comptus* contains multicostate elements, which develop three or more bladelike costae. However, all specimens in this study bear less than three costae, which are keeled but inconspicuous.

Occurrence.—This species has been reported from the Lower and Middle Ordovician rocks in Australia and Thailand (Cooper, 1981; Watson, 1988; Zhen *et al.*, 2003a; Agematu *et al.*, 2006b). Specimens of this species are found in the *T. larapintinensis* Zone in the Thong Pha Phum section and the upper part of the Li section.

Genus Unknown

Coniform element indet. A

Figure 5.8

Materials.—Four specimens (IGUT-ag2023, 3548 to 3550).

Remarks.—Specimens are strongly anteroposteriorly compressed. Elements are characterized by faint carinae on lateral sides of cusp, by a short base, and a small basal cavity expanded inward.

Occurrence.—In the *Aurilobodus leptosomatus* Zone of the Thong Pha Phum section.

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