

First occurrence of Early Triassic conodonts from the Lang Son Formation, northeastern Vietnam

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Abstract. The Early Triassic conodonts *Eurygnathodus costatus* Staesche, *E. hamadai* (Koike), *Neospathodus cristagalli* (Huckriede), and *Ns. pakistanensis* Sweet are newly reported from the upper part of the Lang Son Formation in Lang Son City, northeastern Vietnam. This association and particularly *E. costatus* and *E. hamadai* indicate the lower Smithian (lower lower Olenekian). Thus, the geological age of the upper part of the Lang Son Formation ranges from Induan to early Olenekian, and the stage boundary lies within the upper part of the formation.

Key words: An Chau sedimentary basin, conodont, Early Triassic, Induan-Olenekian boundary, Vietnam

Introduction

In the An Chau sedimentary basin of northeastern Vietnam, the Lower Triassic fossiliferous shallow marine deposits are divided into the Lang Son and Bac Thuy formations, in ascending order (Figures 1, 2). According to Vu Khuc *et al.* (1965), Vu Khuc (1991), Komatsu and Dang (2007), and Komatsu *et al.* (2008, 2010, 2014), the Lang Son Formation consists mainly of siliciclastics and commonly yields the Induan bivalves *Claraia aurita* (Hauer, 1865) and *C. concentrica* (Yabe, 1928), and the ammonoids *Lytosphericeras* and *Koninckites*. The overlying Bac Thuy Formation is characterized by carbonates and contains abundant Olenekian mollusks (Komatsu *et al.*, 2013, 2014; Shigeta and Nguyen, 2014), including middle Smithian to lower Spathian ammonoids, bivalves, and the conodonts *Novispathodus* ex gr. *waageni* (Sweet, 1970b), “*Neospathodus*” *spitiensis* Goel, 1977, *Icriospathodus collinsoni* (Solien, 1979), and “*Triassospathodus*” *symmetricus* (Orchard, 1995) in Lang Son City and Chi Lang district.

In the upper parts of the Lang Son Formation, the fossil record is quite sparse. Although an Induan bivalve assemblage dominated by *Claraia concentrica*, and also containing rare examples of the Olenekian bivalve *C. intermedia multistriata* Ichikawa in

Ichikawa and Yin, 1966 was reported from the upper part of the formation at the Deo Lan section, southern Van Quan District, Lang Son Province (Figures 1A, 3A; Komatsu and Dang, 2007), the geological age and fossils of this upper part of the formation remain largely unexplored (Figure 1), and microfossils have never been reported from the formation. In this paper, we report age-diagnostic conodonts in the upper part of the Lang Son Formation in Lang Son City.

Geologic setting

In the Con Sang section, Cao Lac District, the Lang Son Formation is about 200 m thick and is mainly composed of sandstone, mudstone, and intercalations of thin carbonate beds (Dang, 2006). In Lang Son City, the formation unconformably overlies the upper Permian Dong Dang Formation, and is conformably overlain by thick limestone of the Olenekian Bac Thuy Formation (Figure 2). According to Dang (2006), the Lang Son Formation is divided into three members (“1–3”) in Lang Son City (Figure 3B), the lower two of which are dominated by fossiliferous argillaceous mudstone, while member “3” (= upper part of the Lang Son Formation in Lang Son City) consists mainly of alternations of sandstone and mudstone. Komatsu and Dang (2007) reported an Induan

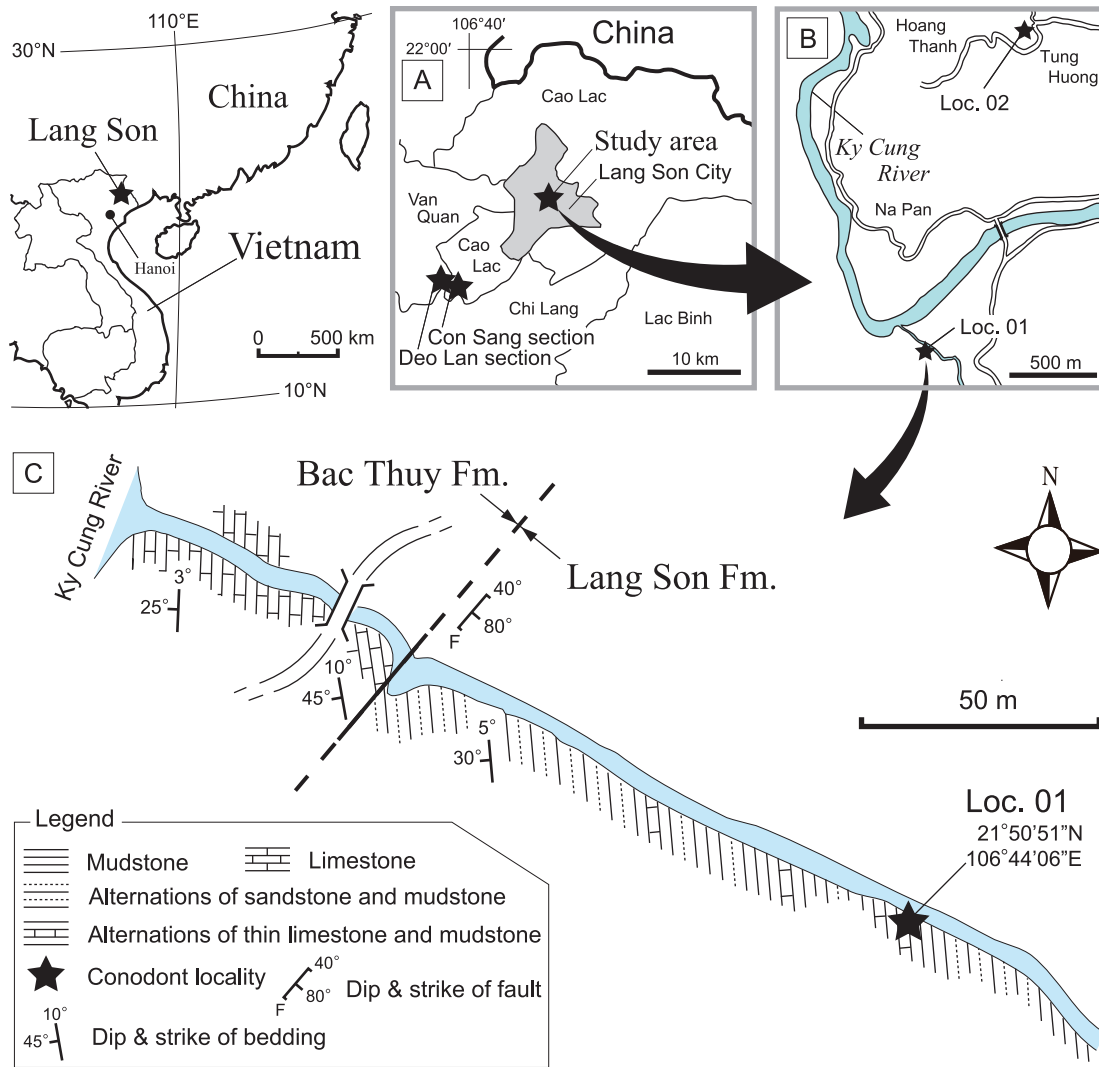


Figure 1. A, B, Index maps of studied area showing the Lower Triassic fossil localities; C, Route map of studied area. The upper part of the Lang Son Formation is in fault contact with the lower part of the Bac Thuy Formation consisting mainly of Olenekian carbonates. Conodont fossils were found at the Loc. 01. The Induan bivalve assemblages composed of *Claraia aurita* and *C. concentrica* reported by Komatsu and Dang (2007) and Komatsu *et al.* (2008) were found at Loc. 02. For orientation of the maps in A and B, see the small-scale map of Vietnam at upper left.

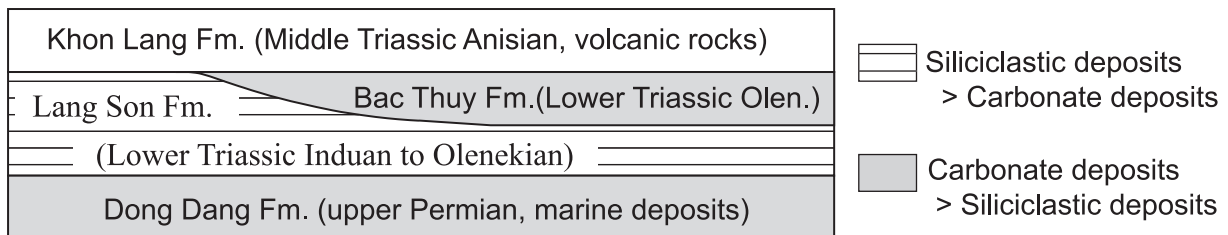


Figure 2. Stratigraphy of the Lower Triassic Lang Son and Bac Thuy formations in the An Chau Basin, northeastern part of Vietnam.

A Deo Lan section, Van Quan District, Lang Son Province

Formation and Members	Lithology	Characteristic fossils	Stage
Lang Son Fm.	"4" Argillaceous mudstone	<i>Claraia intermedia multistriata</i> [bivalves]	Olenekian
		<i>C. aurita</i> <i>C. concentrica</i> [bivalves]	
	"3" Argillaceous mudstone, marl and marly mudstone	<i>C. aurita</i> <i>C. concentrica</i> [bivalves]	Induan
	"2" Argillaceous mudstone and cherty mudstone	<i>C. aurita</i> <i>C. concentrica</i> <i>C. stachei</i> [bivalves]	
	"1" Argillaceous mudstone and cherty mudstone	<i>C. aurita</i> <i>C. concentrica</i> [bivalves]	

Dang (2006), Komatsu and Dang (2007)

B Lang Son City, Lang Son Province

Formation and Members	Lithology	Characteristic fossils	Stage
Lang Son Fm. (=Upper part of Lang Son Fm. in this study)	"3" Alternations of fine-grained sandstone and mudstone, and thin limestone and marl beddings	<i>Eurygnathodus costatus</i> <i>E. hamadai</i> [conodonts]	Olenekian
		<i>C. aurita</i> <i>C. concentrica</i> <i>C. stachei</i> [bivalves]	
	"2" Argillaceous mudstone, marl and marly mudstone	<i>C. aurita</i> <i>C. concentrica</i> [bivalves]	Induan
	"1" Argillaceous mudstone and cherty mudstone	<i>C. aurita</i> <i>C. concentrica</i> [bivalves]	

Dang (2006), Komatsu *et al.* (2008) and this study**Figure 3.** Stratigraphic divisions of the Lang Son Formation in the Deo Lan section (A) and Lang Son City (B).

bivalve assemblage consisting of *Claraia. aurita* and *C. concentrica* from Member "3" in Lang Son City (Loc. 02, Figure 1B).

In our study area, along a branch of the Ky Cung River situated in the central part of Lang Son City, the upper part of the Lang Son Formation (= Member "3" in Dang, 2006) crops out (Loc. 01, Figure 1B), and consists of alternations of fine-grained sandstone and mudstone occasionally intercalating with thin limestone and marl beds. At Locality 01, several thin bioclastic and micritic limestone beds (1–5 cm thick), and marl beds (1–20 cm thick), are embedded in the alternations of very fine to fine grained sandstone and mudstone. The carbonates contain rare conodonts, small bivalves, fish teeth, and radiolarians.

Methods

Thirty limestone beds and lenses were sampled for conodont analysis along the branch of the Ky Cung River, Lang Son City (Figure 1). Each 2 kg sample was crushed to fragments about 1–3 cm in diameter and immersed in a 5–6% solution of acetic acid to remove

carbonates. As a result, a few conodont fragments were found in two of the limestone samples, but unfortunately, age-diagnostic conodont species were found in only one of them (Loc. 01, Figure 1).

Systematic paleontology

(by T. Maekawa)

Described specimens in this paper are stored in the Faculty of Science, Kumamoto University (KMSP). The measurements and nomenclature are shown in Figure 4. All elements are well preserved and of a dark-gray color.

Order Ozarkodinida Dzik, 1976
 Superfamily Gondolelloidea (Lindström, 1970)
 Family Gondolelloidae Lindström, 1970
 Subfamily Neogondolellinae Hirsch, 1994
 Genus *Neospathodus* Mosher, 1968

Type species.—*Spathognathodus cristagalli* Huckriede, 1958.

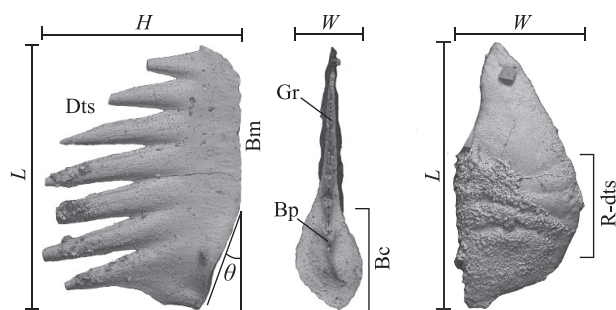


Figure 4. The measurements and nomenclature of *Neospathodus* and *Eurygnathodus*. *L*, length of element; *H*, height of element; *W*, width of element; θ , degrees of upturn of basal margin; Dts, denticles; R-Dts, ridge-like denticles; Bm, basal margin; Bc, basal cavity; Bp, basal pit; Gr, groove.

Neospathodus cristagalli (Huckriede, 1958)

Figure 5.4–5.6

Spathognathodus cristagalli Huckriede, 1958, p. 161, pl. 10, figs. 14, 15.

Neospathodus cristagalli (Huckriede). Sweet, 1970a, p. 9, pl. 1, figs. 18, 21; Sweet, 1970b, p. 246, pl. 1, figs. 14, 15; Mosher, 1973, p. 170–171, pl. 20, fig. 4; Matsuda, 1982, p. 92, pl. 3, figs. 1–12; Tian *et al.*, 1983, p. 375, pl. 80, figs. 2a, 2b; Orchard and Krystyn, 2007, pl. 1, fig. 5; Maekawa and Igo, 2014, p. 223–224, figs. 161.10–161.12.

Neospathodus cf. *cristagalli* (Huckriede). Igo, 2009, p. 186, figs. 151.4–151.5.

multielement apparatus, *Neospathodus* cf. *cristagalli* (Sweet). Orchard, 2005, p. 88, text-fig. 14.

Material examined.—Three specimens, KMSP5202–5204, from Loc. 01.

Description.—Laterally compressed blade-like element, 0.2–0.27 mm, average 0.22 mm in length; 0.15–0.21 mm, average 0.18 mm in height; length to height ratio 1.3–1.4, average 1.33 in three specimens, with arched upper edge. Basal margin straight anteriorly and turned upward 15–25 degrees in the posterior one-third. Discrete and sharply pointed denticles, 7–8 in number, erect or reclined anteriorly in anterior half and reclined posteriorly in posterior half, highest point situated in posterior one-third of element. Large, triangular-shaped denticle is situated at the posterior end, beneath which elliptical basal cavity surrounds a deep pit; a groove runs from the pit to the anterior end.

Remarks.—The described specimens from the Lang Son Formation are well preserved and have the characteristic triangular-shaped posterior denticle, which is a diagnostic character of *Neospathodus cristagalli*. Furthermore, the Vietnamese specimens are very similar to the hypotypes of the species from Kashmir, India (Sweet,

1970a, pl. 1, figs. 18, 21).

Occurrence.—This species also occur in Dienerian (upper Induan) to Smithian (lower Olenekian) in Kashmir, India (Sweet, 1970a; Matsuda, 1982), Salt Range, (former) West Pakistan (Zone 5, Sweet, 1970b), British Columbia (Mosher, 1973), Tibet (Tian *et al.*, 1983), the Zhitkov Formation, South Primorye, Russia (*Neospathodus dieneri*-*Ns. pakistanensis* Zone with *Clypeoceras timorense* beds, Shigeta and Igo, 2009), Spiti, India (Krystyn *et al.*, 2007; Orchard and Krystyn, 2007), and many other localities in the world. According to Orchard (2007a), this species ranges from the early Dienerian (early late Induan) to late Smithian (late early Olenekian).

Neospathodus pakistanensis Sweet, 1970b

Figure 5.3

Neospathodus pakistanensis Sweet, 1970b, p. 254, pl. 1, figs. 16, 17; McTavish, 1973, p. 295, pl. 1, figs. 1, 2; Buryi, 1979, p. 57, pl. 9, fig. 2, pl. 18, fig. 5; Wang and Cao, 1981, p. 367, pl. 2, fig. 27; Matsuda, 1983, p. 87, pl. 1, figs. 1–5; Tian *et al.*, 1983, p. 379, pl. 81, fig. 3; Hatleberg and Clark, 1984, pl. 1, fig. 5; Beyers and Orchard, 1991, pl. 5, fig. 2; Cao and Wang, 1993, pl. 56, fig. 14; Wang and Zhong, 1994, p. 401, pl. 1, figs. 16, 24; Buryi, 1997, pl. 2, fig. 9; Orchard, 2007b, figs. 19, 20, 23–26; Orchard and Krystyn, 2007, figs. 19–20; Orchard, 2008, p. 407, figs. 8.10, 8.11; Igo, 2009, p. 190, figs. 151.18–151.26, 152.1–152.7, 152.10–152.13, 152.20–152.21, 153.1–153.7, 154.1–154.6; Maekawa and Igo, 2014, p. 228, 230, figs. 165.4–165.24.

Material examined.—One specimen, KMSP5205, from Loc. 01.

Remarks.—The described specimen lacks the anterior part of the element but the blade-like element has a down-turned posterior basal margin like that typical of *Neospathodus pakistanensis*. Denticulation and element size of the Vietnamese specimen are very similar to one specimen from the Zhitkov Formation, South Primorye (Igo, 2009, fig. 152.6), and specimens from the Mud section, Spiti, India (Orchard, 2007b, figs. 19, 20, 23–26).

Occurrence.—*Neospathodus pakistanensis* was originally described from West Pakistan (Sweet, 1970b), and is also known to occur in South Primorye, Russia (Buryi, 1979; Igo, 2009), South China (Wang and Cao, 1981; Wang and Zhong, 1994; Zhao *et al.*, 2007), Kashmir, India (Matsuda, 1983), British Columbia, Canada (Beyers and Orchard, 1991), Spiti, India (Orchard, 2007b; Orchard and Krystyn, 2007), the Canadian Arctic (Orchard, 2008), and other localities in the world. The range of *Ns. pakistanensis* is from upper Dienerian to Smithian (Zhao *et al.*, 2007; Orchard, 2007a, b; Orchard and Krystyn, 2007; Igo, 2009).

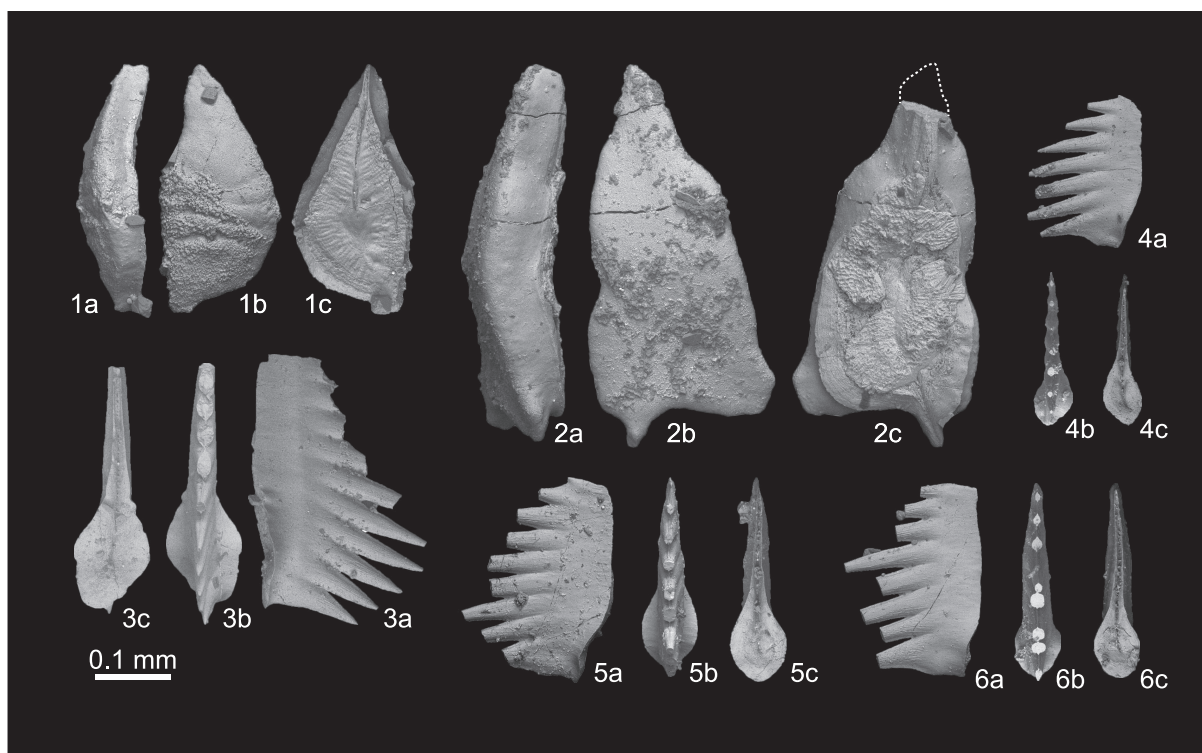


Figure 5. SEM images of Lower Triassic conodonts from Loc. 01 in the upper part of the Lang Son Formation. **1**, *Eurygnathodus costatus* Staesche, 1964, P_a element, KMSP5200; **2**, *E. hamadai* (Koike, 1982), P_a element, KMSP5201; **3**, *Neospathodus pakistanensis* Sweet, 1970b, P₁ element, KMSP5205; **4–6**, *N. cristagalli* (Huckriede, 1958), P₁ element, KMSP5202–5204. For 1–6: a, lateral view; b, upper view; c, lower view.

Family Uncertain

Genus *Eurygnathodus* Staesche, 1964

Type species.—*Eurygnathodus costatus* Staesche, 1964.

Remarks.—Two species of this genus, *Eurygnathodus costatus* and *E. hamadai*, are reported from lower Olenekian marine deposits. The former species is the type, described from South Tirol (Staesche, 1964). Both are characterized by flattened segminiplanate P₁ elements that show considerable morphological variations in ornamentation and platform shape (Koike, 1988).

Eurygnathodus costatus Staesche, 1964

Figure 5.1

Eurygnathodus costatus Staesche, 1964, p. 269, pl. 28, figs. 1–6; Budurov and Pantic, 1973, p. 51, pl. 1, figs. 1–15. Igo, 2009, p. 183, figs. 152.23–152.24; Orchard, 2010, figs. 5.9, 5.10; Maekawa and Igo, 2014, p. 220, 222, figs. 161.4–161.6.
Platyvillosus costatus (Staesche). Goel, 1977, p. 1098, pl. 2, figs. 15–21; Wang and Cao, 1981, p. 371, pl. 2, figs. 1–4, 28, 29, 30, 33;

Koike, 1982, p. 44, pl. 5, figs. 1–9; Matsuda, 1984, p. 128, pl. 6, figs. 6–10; Duan, 1987, pl. 3, fig. 4; Koike, 1988, pl. 1, figs. 1–57, pl. 2, figs. 1–37; Bui, 1989, p. 411, pl. 31, figs. 7–9; Beyers and Orchard, 1991, pl. 5, fig. 10; Cao and Wang, 1993, pl. 56, fig. 16; Wang and Zhong, 1994, p. 404, pl. 1, figs. 15, 23.

Material examined.—One specimen, KMSP5200, from Loc. 01.

Description.—One dextral segminiplanate element; subrounded platform with slightly sharpened ends and an inner constriction near the anterior end. Length 0.33; width 0.16; giving length to width ratio 1.9. Upper surface of the platform bears four narrow, continuous thin ridgelike denticles. Broadly moundlike form in lateral view. Dishlike lower surface exhibits a subrounded basal cavity with an outline similar to that of the element. Groove runs from basal pit to anterior end.

Remarks.—Koike (1988) described morphological variation of *Eurygnathodus costatus* based on abundant specimens from the Taho Limestone, Southwest Japan. Koike (1988) divided *E. costatus* into 4 morphotypes (α , β , γ , δ) each with 3–4 variations of oral ornamentation.

Morphotype δ , characterized by reduced ornamentation, is subdivided into 4 forms (L, M, N and O) based on the distributions of residual ridges. Faint ridges of Form L are distributed over the entire platform, whereas in the other three forms, ridges are present only in the lateral margins, in the axial region, or irregularly arranged on the platform (Koike, 1988).

The described specimen from the Lang Son Formation corresponds to Form N of Morphotype δ in which the denticles are confined to the center of the platform. This form is comparable to specimens from Japan (Koike, 1988, pl. 2, fig. 25) and Spiti (Goel, 1977, pl. 2, fig. 18).

Occurrence.—This species was reported from the upper Dienerian (upper upper Induan) to lower Smithian (lower lower Olenekian) in South Tirol (Staesche, 1964), Spiti, India (Goel, 1977; Krystyn *et al.*, 2007; Orchard and Krystyn, 2007; Orchard, 2010), South China (Wang and Cao, 1981; Wang and Zhong, 1994; Zhao *et al.*, 2007), Kashmir, India (Matsuda, 1984), the Taho limestone, Southwest Japan (Koike, 1988), the Bac Thuy Formation, northeastern Vietnam (Bui, 1989; Maekawa and Igo, 2014), and the Zhitkov Formation, South Primorye, Russia (Igo, 2009). Recently, Goudemand (2014) reported a new subspecies of *Novispathodus waageni* from the lowermost part of the Olenekian in Spiti and South China and pointed out the first occurrence (FO) of the subspecies below the FO of *Eurygnathodus costatus*. Thus, the species indicates an early Smithian age. Probably, the first occurrence datum of *Novispathodus waageni* will be changed in several upper “Dienerian” localities.

Eurygnathodus hamadai (Koike, 1982)

Figure 5.2

Platyvillosus costatus (Staesche). Wang and Cao, 1981, p. 371, pl. 2, figs. 31–32.

Platyvillosus hamadai Koike, 1982, p. 45, pl. 5, figs. 10–36; Koike, 1988, pl. 2, figs. 38–45.

Material examined.—One specimen, KMSP5201, from Loc. 01.

Description.—One dextral segminiplanate element; platform shows isosceles triangle-like outline with sharply pointed anterior and inner posterior end, and nodelike outer posterior end which extends from the center of the platform. Length 0.5 mm; width 0.24 mm; giving a length to width ratio of 2.1. In lateral view, broadly arched. Without upper surface ornamentation. Slightly concave lower surface has a subrounded basal cavity, and a low groove extending to both the anterior and posterior ends.

Remarks.—*Eurygnathodus hamadai* is distinguished

from *E. costatus* by its lack of ornamentation. In addition, the described specimen has a nodelike ledge on the outer side of the platform. This morphology is the same as that shown by specimens from Malaysia (Koike, 1982, pl. 5, fig. 36) and Japan (Koike, 1988, pl. 2, fig. 45).

Occurrence.—*Eurygnathodus hamadai* has been identified from Smithian carbonates in China (Wang and Cao, 1981), Malaysia (Koike, 1982), Taho, Southwest Japan (Koike, 1988), and Spiti, India (Orchard, 2007a; Orchard and Krystyn, 2007). In these localities, it cooccurs with *Novispathodus waageni*, *E. costatus*, and/or early Smithian ammonoids, demonstrating that *E. hamadai* is a useful index fossil for the early Smithian.

Geologic age of the upper part of the Lang Son Formation

In this study, we recovered a fauna of conodont specimens comprising Morphotype δ (Form N) of *Eurygnathodus costatus*, *E. hamadai*, *Neospathodus cristagalli*, and *Ns. pakistanensis* from the upper part (Member 3) of the Lang Son Formation.

In general, the basal Olenekian was defined by the first appearance datum (FAD) of *Novispathodus waageni* (Orchard, 2010). Goudemand (2014) reported the occurrence of *Nv. waageni* new subspecies A and an earliest Olenekian ammonoid *Flemingites bhargavai* Brühwiler *et al.*, 2010 from bed 10, Mud section, Spiti, India and pointed out the FO of *E. costatus* and *E. hamadai* above the FO of *Nv. waageni* (beds 12, 13). Thus, the ranges of *E. costatus* and *E. hamadai* would start in the lower Smithian (lower lower Olenekian). The Morphotype δ of *E. costatus* which has a transitional morphology between *E. costatus* and *E. hamadai* (Koike, 1988), has an FAD that is stratigraphically higher than other morphotypes of the species (Figure 6). Generally, Morphotype δ cooccurs with Olenekian conodonts such as *Nv. waageni* and *E. hamadai* (Koike, 1988).

Neospathodus cristagalli and *Ns. pakistanensis* are common in the Lower Triassic Tethyan and Panthalas-sean sections, and range in age from Dienerian to Smithian (Orchard, 2007a; Orchard and Krystyn, 2007; Orchard, 2010). Therefore, the total conodont assemblage from the upper part of the Lang Son Formation indicates the Smithian (early Olenekian). Much the same conodont assemblage was reported around the IOB of the Mud section, Spiti, India (Orchard and Krystyn, 2007; Orchard, 2010; Goudemand, 2014), and West Pingdingshan section, Anhui Province, South China (Zhao *et al.*, 2007); these sections are candidates for the GSSP (Global boundary Stratotype Section and Point) of the IOB.

In the Deo Lan section, ~15 km southwest of Lang Son City (Figures 1A, 3A), the Lang Son Formation is dom-

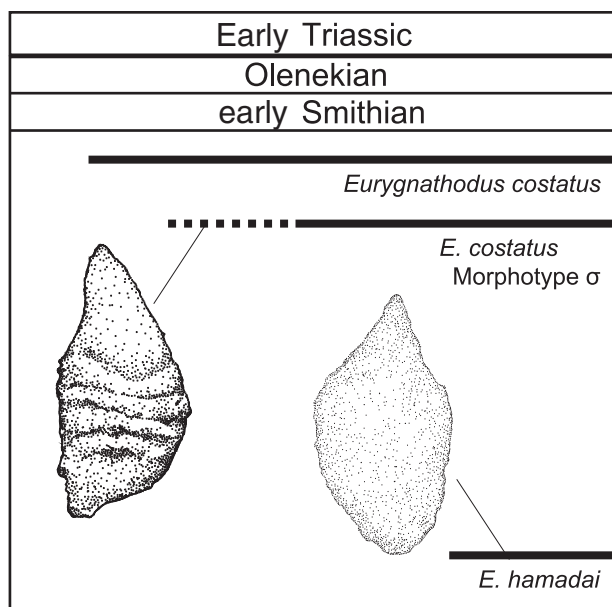


Figure 6. Evolutionary process of *Eurygnathodus* in the early Olenekian. The ornamentation of *E. costatus* gradually diminishes from *E. costatus*, through *E. costatus* Morphotype δ (sketched from Figure 5.1, KMSP5200 in this paper), to *E. hamadai* (sketched from Japanese specimen in Koike, 1988, pl. 2, fig. 41).

inated by offshore and hemipelagic argillaceous mudstone, and occasionally intercalations of thin-bedded cherty mudstone, calcareous mudstone, and thin limestone beds (Dang, 2006). Dang (2006) divided the formation into four members (“1–4”) in this area, although these are lithologically quite different from members in the Lang Son City. Members “1–3” and the lower part of Member “4” yield abundant Induan ammonoids and bivalves (Dang, 2006; Komatsu and Dang, 2007). The upper part of Member “4” consists of offshore argillaceous mudstone that contains rare specimens of the Olenekian bivalve *Claraia intermedia multistriata* (Komatsu and Dang, 2007). Thus, in the Deo Lan section, the boundary between Induan and Olenekian seems to be intercalated in the offshore mudstone of Member “4” of the Lang Son Formation. However, we were unable to find conodonts in calcareous mudstone and limestone of members “3” and “4” in this section.

In northwestern Lang Son City, ~1.5 km northeast of the study area, the typical Induan bivalves *Claraia aurita* and *C. concentrica* were found in the wave- and storm-dominated shelf sandstones in the lower part of the upper Lang Son Formation (Figures 1B, 3B; Komatsu and Dang, 2007). Therefore, the upper Lang Son Formation (= Member “3” in Lang Son City, in Dang, 2006) is probably composed of both Induan to Olenekian shallow

marine deposits, with the IOB occurring within it.

Conclusions and remarks

A Lower Triassic Olenekian conodont assemblage consisting of *Eurygnathodus costatus* Morphotype δ , *E. hamadai*, *Neospathodus cristagalli* and *Ns. pakistanensis* is reported from the upper part of the Lang Son Formation, Lang Son City, northeastern Vietnam. Although undefined at present, the probable boundary between the Induan and Olenekian stages is probably intercalated within the upper part (= Member “3”) of the formation.

Candidate sections for the GSSP of the Induan–Olenekian boundary include the Mud section, Spiti, India, and that at Chaohu, Anhui Province, China (Krystyn *et al.*, 2007; Orchard and Krystyn, 2007; Orchard, 2007a; Zhao *et al.*, 2007). It has been proposed that the basal Olenekian be defined by the first appearance of *Novispathodus waageni* (Orchard, 2007a; Orchard and Krystyn, 2007; Zhao *et al.*, 2007; Goudemand, 2014). Unfortunately, we have not yet recovered *Nv. waageni* in the Lang Son Formation. However, abundant *Nv. waageni* has been reported from the Olenekian *Flemingites* and *Owenites* ammonoid zones in the overlying basal Bac Thuy Formation (Komatsu *et al.*, 2011; Maekawa *et al.*, 2012; Maekawa and Igo, 2014) and so its occurrence in other sections of the Lang Son Formation may be anticipated.

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