

UPPER INDIAN AND LOWER OLENEKIAN CONODONT ASSEMBLAGES FROM THE LOWEST PART OF THE BAC THUY FORMATION IN THE BAN RU AREA, NORTHEASTERN VIETNAM

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INTRODUCTION

Lower Triassic sediments within the An Chau basin occur widely in Lang Son Province, northeastern Vietnam (Fig. 1). The sediments are divided into the Lang Son and Bac Thuy formations (1). The Bac Thuy Formation conformably overlies the siliciclastic Lang Son Formation and is unconformably overlain by volcanic rocks of the Khon Lang Formation. The Bac Thuy Formation consists mainly of mudstone, marl, limestone, and limestone breccias, and it contains the middle Smithian to lower Spathian ammonoids *Flemingites rursiradiatus* Chao, *Owenites koeneni* Hyatt and Smith, *Tirolites* cf. *cassianus* (Quenstedt), and *Columbites* sp., and the conodonts *Novispathodus* ex gr. *waageni* (Sweet), *Discretella discreta* (Müller), *Neospathodus dieneri* Sweet, and *Icriospathodus collinsoni* (Solien) (2–5). According to (6), the Smithian–Spathian boundary occurs in the middle part of the Bac Thuy Formation, and the formation is characterized by a deepening-upward succession consisting of tidal-flat, wave-influenced carbonate platform, slope, and marginal basin-plain deposits. These fossil and stratigraphic data indicate the geological importance of the formation, but the geological age and lithology of the lower part of the formation in the Ban Ru area have not been well described. In this paper, we report a preliminary assessment of the lithology and conodont assemblages of the Ban Ru area.

1. RESEARCH METHODOLOGY

Four limestone beds in the lower part of the Bac Thuy Formation, Ban Ru area, Chi Lang District, were sampled (samples BR00-01 to -04) for microscopic observations of thin sections and conodont analysis (Figs. 2, 3). Samples BR00-01 to -03 were collected from limestone beds (21°44'16"N, 106°43'37"E). Sample BR00-04 was collected from micritic limestone bed (21°44'18"N, 106°43'06"E). Each 1–2 kg sample was crushed to fragments about 1–3 cm across and immersed in a 6%–8% solution of acetic acid for 2 or 3 days to remove carbonates. Subsequently, the residue was collected using 2 mm and 0.074 mm meshes. This procedure was repeated until all carbonate had been completely removed. Conodont elements were recovered from the residues.

2. RESEARCH RESULTS

2.1. Stratigraphy of the lower part of the Bac Thuy Formation in the Ban Ru area

Exposure.-One section, BR00, in the Chi Lang District (Figs. 1–3).

Thickness.-More than 130m. However, the upper layers were not examined closely (Fig. 2).

Lithology. The lower part of the formation is composed mainly of thick mudstone with intercalations of fine sandstone, limestone breccia, and bedded limestone. Lithologically, the lower part of the formation in the Ban Ru area closely resembles that in the Na Trang and Bac Thuy areas. However, the thickness is much greater in the Ban Ru area than in the other areas. The bedded limestone is dominated by wackestone and contains ooids and some megafossils and microfossils.

Fossil content. The bedded limestone in the basal part of the formation contains conodonts, such as *Neospathodus chaohuensis* Zhao and Orchard, *Ns. cf. concavus* Zhao and Orchard, *Ns. dieneri* Sweet, and *Ns. aff. dieneri* Sweet, as well as indeterminate ostracods and micro-bivalves. The bedded limestone in the upper layers contains conodonts, (*Discretella discreta* Müller, *Ns. dieneri*, *Neospathodus* sp. indet. A, and *Novispathodus* ex gr. *waageni* Sweet), juvenile ammonoid shells, bivalves, brachiopods, and foraminifera.

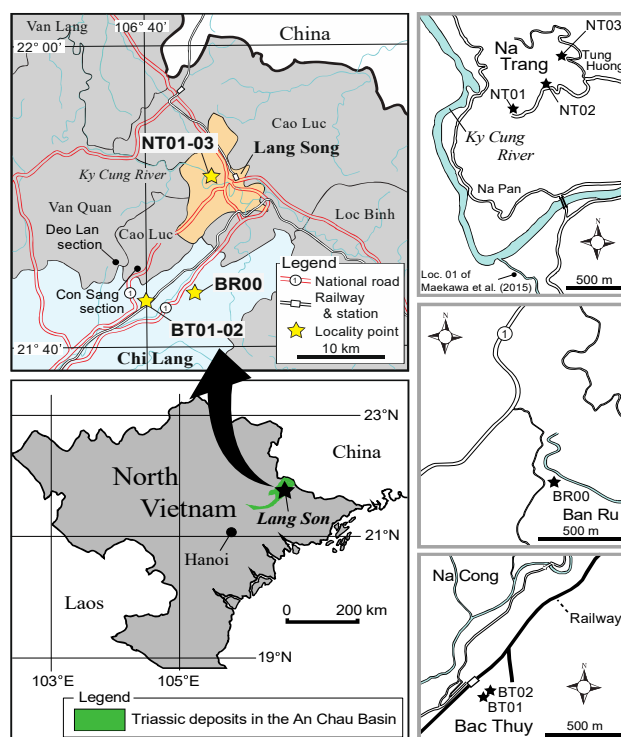


Figure 1. Maps showing the location of the study area and fossil sites within North Vietnam and within Lang Son Province

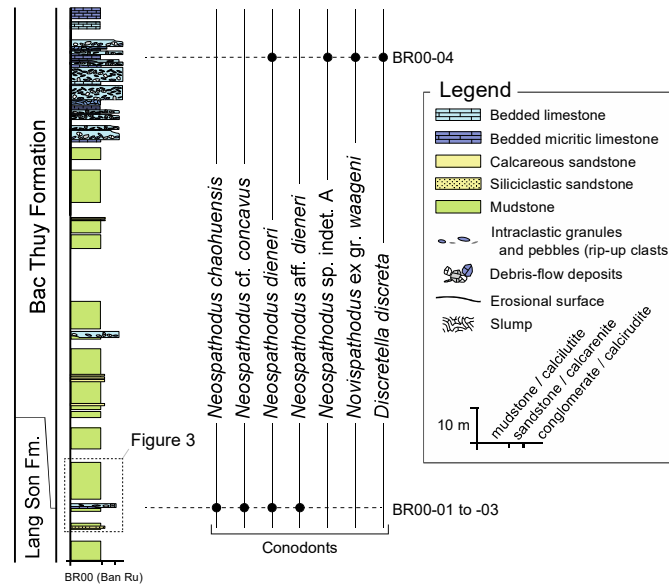


Figure 2. Columnar section in the Ban Ru area, Lang Son Province, showing the positions of sampled fossil horizons

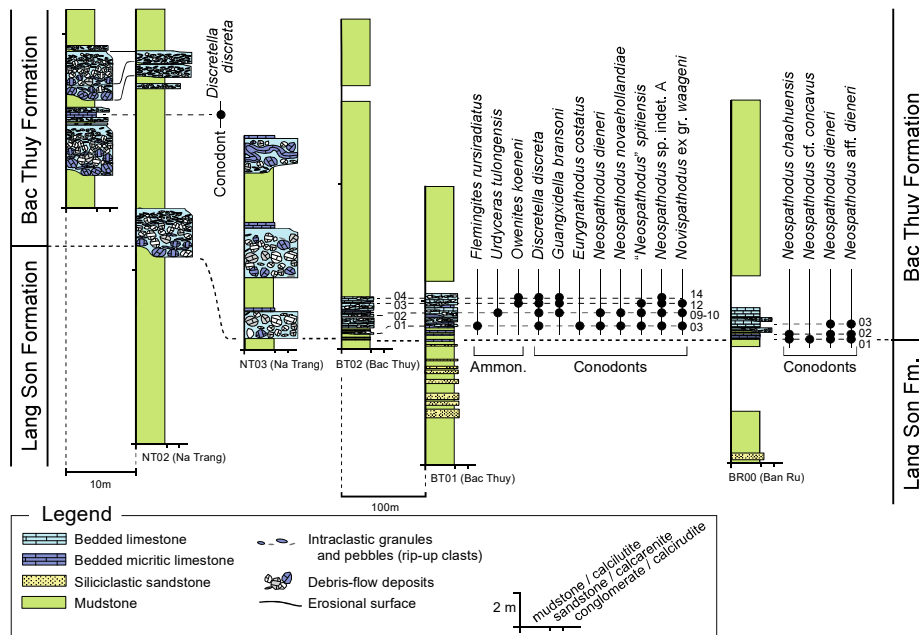


Figure 3. Columnar sections showing the boundary between the Lang Son and Bac Thuy formations in the Na Trang, Bac Thuy (stratotype section), and Ban Ru areas. The basal limestone beds in the Na Trang and Bac Thuy areas contain typical Smithian conodonts; those in the Ban Ru area yield a Dienerian conodont assemblage.
(by T. Maekawa)

2.2. Systematic paleontology

The specimens described in this paper are stored in the Vietnam National Museum of Nature (VNMN). Specimen numbers CS-1008 to CS-1033. All elements are dark gray in color and are illustrated in Figures 4 and 5.

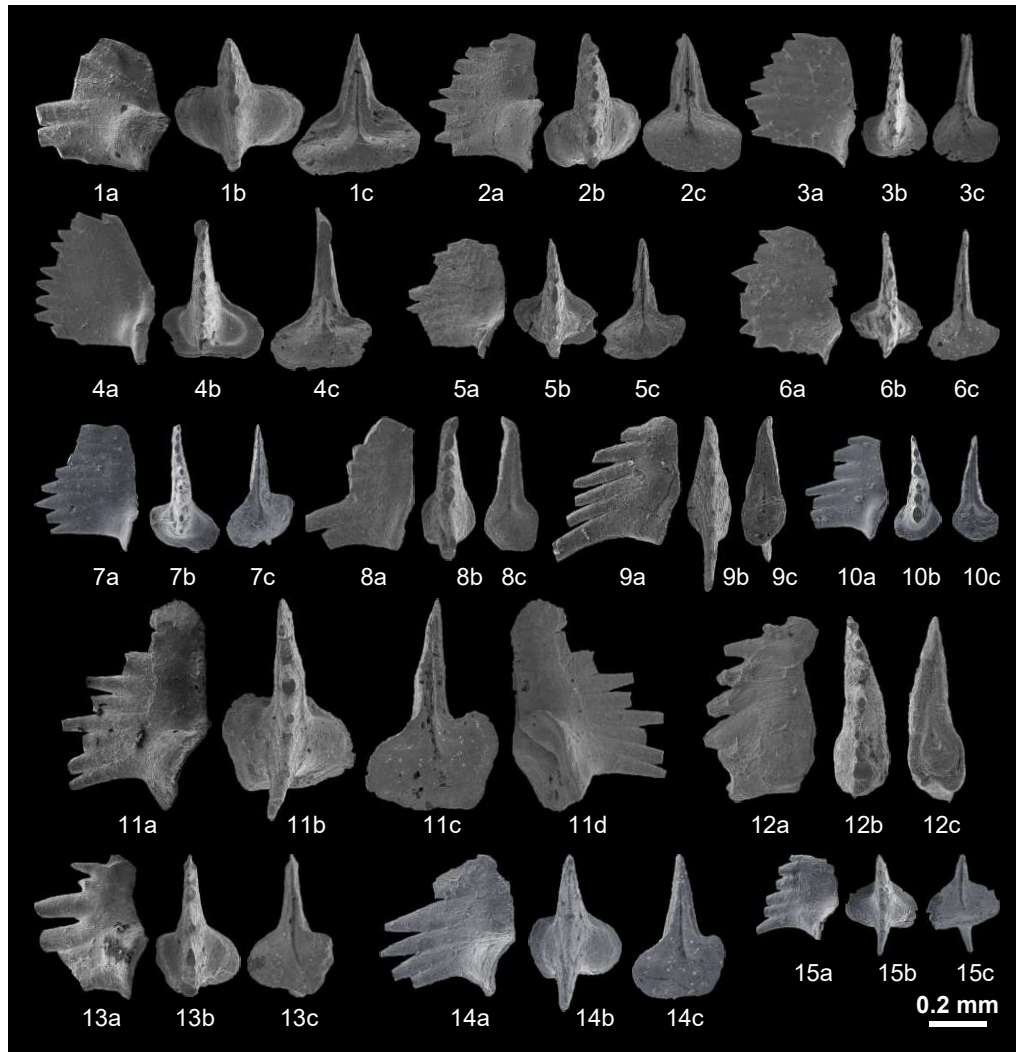


Figure 4. SEM images of Lower Triassic conodonts from the lowermost part of the Bac Thuy Formation, Ban Ru area. **1–7**, *Neospathodus chaohuensis* Zhao and Orchard, 2007, P₁ element. 1–6, CS-1008 to -1013, from BR00-01; 7, CS-1014, from BR00-02.

8–10, *Neospathodus dieneri* Sweet, 1970a, P₁ element. 8–9, CS-1016, 1017, from BR00-01; 10, CS-1018, from BR00-02. **11, 13–15**, *Neospathodus* aff. *dieneri* Sweet, 1970a, P₁ element. 11, 13, CS-1019, 1020, from BR00-01; 14, CS-1021, from BR00-02; 15, CS-1022, from BR00-03. **12**, *Neospathodus* cf. *concavus* Zhao and Orchard, 2007, P₁ element, CS-1015, from BR00-01. For 1–21: a, d, lateral views; b, upper view; c, lower view

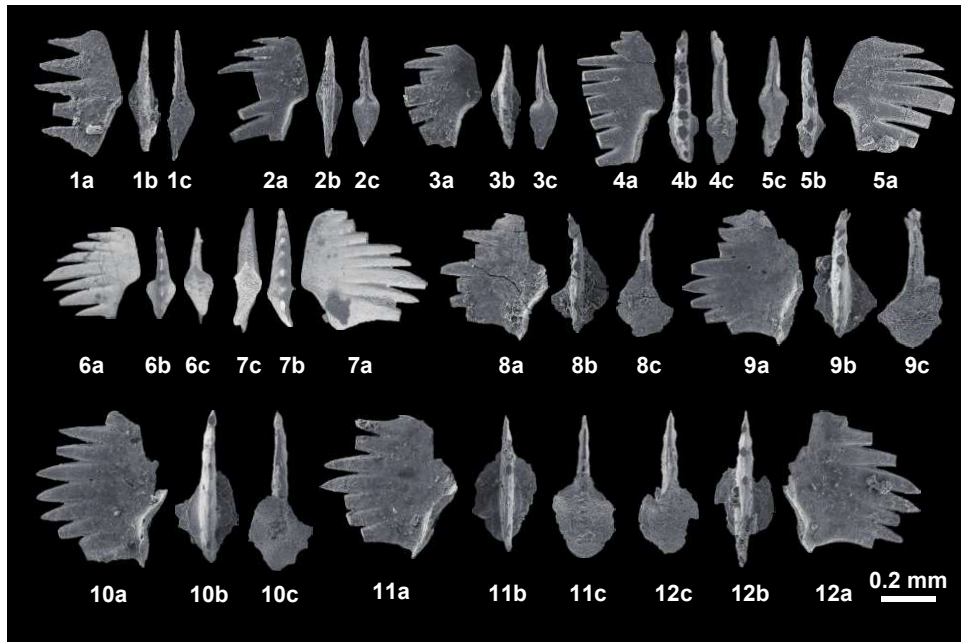


Figure 5. SEM images of Lower Triassic conodonts from the lower part of the Bac Thuy Formation. **1**, *Discretella discreta* Müller, 1956, P₁ element, CS-1023, from BR00-04. **2–7**, *Neospathodus* sp. indet. A, P₁ element. 2–5, CS-1024 to -1027, from BR00-04; 6, MPC25367, from BT01-10; MPC25382, from BT01-12. **8–12**, *Novispathodus* ex gr. *waageni* Sweet, 1970b, P₁ element, CS-1028 to -1032, from BR00-04. For 1–12: a, lateral view; b, upper view; c, lower view

Order Ozarkodinida Dzik, 1976⁷

Superfamily Gonodolelloidea (Lindström, 1970)⁸

Family Gondolelloidae Lindström, 1970⁸

Subfamily Mullerinae Orchard, 2005⁹

Genus *Discretella* Orchard, 2005⁹

Type species: Ctenognathus discreta Müller, 1956¹⁰.

Discretella discreta (Müller, 1956)¹⁰

Fig. 5.1

Ctenognathus discreta Müller, 1956¹⁰, p. 821, pl. 95, fig. 28.

Neospathodus conservativus (Müller, 1956)¹⁰. Koike, 1982¹¹, p. 36, pl. 6, figs. 12–14.

Neospathodus discretus (Müller, 1956)¹⁰. Tian *et al.*, 1983¹², p. 376, pl. 95, fig. 1.

Neospathodus aff. *crisagalli* (Huckriede, 1958)¹³. Bui, 1989¹⁴, p. 404, pl. 30, fig. 1.

multielement apparatuses, *Discretella* sp. A, Orchard, 2005⁹, p. 83, text-fig. 8.

Discretella discreta (Müller, 1956)¹⁰. Orchard, 2008¹⁵, p. 402, figs. 8.18–8.19; Beranek *et al.*, 2010¹⁶, figs. 6.18, 6.19; Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 196, 202, figs. 142–145, 146.1–146.30.

Material examined.—One specimen, CS-1023, from BR00-04.

Description.—Laterally compressed segminate element 0.46mm in length; 0.32mm in height; length-to-height ratio 1.4. Entirely discrete denticles, five in number, erect and sharply pointed. Basal margin biangular in form. In lower view, basal cavity laterally flanged anteriorly and sharply diminished to posterior end, groove runs from thin basal pit to anterior end of element.

Remarks.—This specimen has discrete denticles on the upper edge of the segminate element, which is the typical form of *Discretella discreta*. The biangular basal margin is similar to *Discretella* sp. indet. B from the *Flemingites rursiradius* beds in the stratotype section of the Bac Thuy Formation (5), but that species has a more elongate element with more than nine denticles.

Occurrence.—This species occurs in middle Smithian strata of Nevada (*Meekoceras* beds, 10), Southwest Japan (17, 18), Gunong Keriang, West Malaysia (11), Tibet (12), Jabal Safra, Oman (9), British Columbia, Canada (16), the Canadian Arctic (*Euflemingites romunderi* Zone, 15), and northeastern Vietnam (*Novispathodus* ex gr. *waageni* Zone with *Flemingites rursiradius* to *Owenites koeneni* beds, 5).

Subfamily Neogondolellinae Hirsh, 1994¹⁹

Genus *Neospathodus* Mosher, 1968²⁰

Type species.—*Spathognathodus cristagalli* Huckriede, 1958¹³.

Neospathodus chaohuensis (Zhao and Orchard, 2007)²¹

Figs. 4.1-4.7

Neospathodus chaohuensis Zhao and Orchard, in Zhao *et al.*, 2007²¹, p. 35, pl. 1, figs. 6A, B.

Material examined.—Six specimens, CS-1008 to -1013, from BR00-01; one specimen, CS-1014, from BR00-02.

Description.—Segminate element 0.41–0.52mm in length; 0.34–0.42mm in height; length-to-height ratio 0.9–1.3 in seven specimens. Upper edge bears 7–11 triangular-shaped, compressed and fused denticles, arranged in radial fashion, height gradually increases posteriorly, cusp situated above basal cavity, posterior end abrupt. Lower edge straight or slightly upturned anteriorly, posterior one-third upturned at 2–5 degrees. Basal cup indented at the posterior margin, expanded onto each side of basal cavity. Elliptical basal cavity extended laterally with a deep pit that continues to groove that runs to anterior end.

Remarks.-These Vietnamese specimens show a strongly expanded basal cavity and small denticulation, which is very similar to the holotype of *Neospathodus chaohuensis* described by (21).

Occurrence.-The species ranges from the upper Dienerian to lower Smithian in Thailand (22), the West Pingdingshan section, South China (21), and the Kamura Limestone, Southwest Japan (unpublished data).

Neospathodus cf. *concavus* Zhao and Orchard, 2007²¹

Fig. 4.12

Neospathodus concavus Zhao and Orchard, in Zhao *et al.*, 2007²¹, p. 35, pl. 1, figs. 1A, B, C; Orchard and Krystyn, 2007²³, pl. 1, fig. 4; Igo in Shigeta *et al.*, 2009²⁴, p. 184, 186, fig. 154.13.

Material examined.-One specimen, CS-1015, from BR00-01.

Remarks.-The Vietnamese specimen is a robust segminate element with node-like denticles, bowed basal margin, and rounded basal cavity. The posterior denticles are broken, but the specimen is probably the cusp of the element. These features are similar to *Neospathodus concavus*, although this is difficult to judge from this specimen.

Occurrence.-*Neospathodus concavus* occurs in the upper Dienerian of Thailand (22), the Kamura Limestone of Southwest Japan (unpublished data), lowermost Smithian strata in South China (21, 26), at Spiti in India (25, 26), and in the Tahoe Limestone of Southwest Japan (unpublished data).

Neospathodus dieneri Sweet, 1970a²⁷

Figs. 4.8–4.10

Neospathodus dieneri Sweet, 1970a²⁷, p. 9, pl. 1, fig. 17; Sweet, 1970b²⁸, p. 249, pl. 1, figs. 1, 4; McTavish, 1973²⁹, p. 293, pl. 2, figs. 3, 6; Birkenmajer and Trammer, 1975³⁰, pl. 1, fig. 4; Buryi, 1979³¹, p. 52, pl. 7, fig. 7; Wang and Cao, 1981³², pl. 2, figs. 24, 25; Matsuda, 1982³³, p. 90, pl. 2, figs. 1–11; Koike, 1982¹¹, p. 37, pl. 6, figs. 15–21, 25; Beyers and Orchard, 1991³⁴, pl. 5, fig. 4; Wang and Zhong, 1994³⁵, p. 400, pl. 1, fig. 18; Zhao and Orchard, in Zhao *et al.*, 2007²¹, p. 35, pl. 1, figs. 12A, B, 9A, B, C, 11A, B, C; Orchard and Krystyn, 2007²³, figs. 3, 6, 7; Igo, in Shigeta *et al.*, 2009²⁴, p. 186, 188, figs. 151.6–151.16, 152.8, 152.9; Beranek *et al.*, 2010¹⁶, figs. 6.20, 6.21; Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 224, 228, figs. 161.13–45, 162, 163, 164.1–164.6.

Material examined.-Two specimens, CS-1016, -1017, from BR00-01; one specimen, CS-1018, from BR00-02.

Description.-Segminate element 0.36–0.50mm in length; 0.28–0.45mm in height; length-to-height ratio 1.1–1.3 in three specimens. Upper edge consists of 6–7 discrete denticles that become gradually larger and longer posteriorly. Lower edge straight anteriorly and slightly upturned in posterior one-third. Cusp situated at or in front of

posterior end. In lower view, rounded or elliptical basal cavity has thin pit, groove runs from pit to anterior end.

Remarks.-The specimens described herein are typical of *Neospathodus dieneri*.

Occurrence.-The species has been reported from the Dienerian to the Smithian worldwide, including Kashmir in India (27), West Pakistan (28), western Australia (29), South Primorye in Russia (24, 31), Malaysia (11), Canada (16, 34), South China (21, 35), and northeastern Vietnam (5).

Neospathodus aff. *dieneri* Sweet, 1970a²⁷

Figs. 4.11, 4.13–4.15

Material examined.-Two specimens, CS-1019, -1020, from BR00-01; one specimen, CS-1021, from BR00-02; one specimen, CS-1022, from BR00-03.

Description.-Segminate element 0.29–0.74mm in length; 0.29–0.52mm in height; length-to-height ratio 1.0–1.4 in four specimens. Upper edge gradually rises posteriorly, and bearing 6–9 discrete pole-like denticles with sharp pit, reclined to posterior. Posterior denticle curved to caudal or rostral side. Lower edge straight or bowed in anterior half, upturned by 10–25 degrees in posterior half. Basal cup indented at posterior margin and expanded on each lateral side. In lower view, asymmetrical basal cavity expanded in posterior half of element, posterior margin straight and has deep pit. Deep furrow runs from basal pit to anterior end.

Remarks.-The described specimens have a widely flanged basal cavity, which distinguishes this species from *Neospathodus dieneri*. Additionally, the reclined discrete pole-like denticles and asymmetrical basal cavity are useful in separating the species from *Ns. chaohuensis*.

Occurrence.-This species is known from the Dienerian of the Bac Thuy Formation, Northeastern Vietnam.

Neospathodus sp. indet. A

Figs. 5.2–5.7

Neospathodus spitiensis Goel, 1977³⁶. Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 232, 237, figs. 168.19–168.24, 168.28–168.36, 169.4–169.9, 169.30–169.32, 170.1–170.3.

Neospathodus sp. indet. A. Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 237, figs. 170.7–170.33.

Novispathodus ex gr. *waageni* (Sweet, 1970b). Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 244, 252, figs. 179.4–179.6, 179.13–179.15, 181.25–181.27.

Material examined.-Four specimens, CS-1024 to -1027, from BR00-04.

Description.-Segminate element 0.38–0.50mm in length; 0.28–0.44mm in height; length-to-height ratio 0.9–1.2 in four specimens, with arched upper edge. Knife-shaped, moderately fused denticles, 6–9 in number, slightly reclined to posterior end, highest cusp situated in center of element, denticle at posterior end larger and triangular in shape. Biangular lower edge upturned by 5–10 degrees in anterior half and by 20–35 degrees in posterior half. Triangular basal cavity flanged in anterior one-third and elongated posteriorly. Groove runs from basal pit to anterior end.

Remarks.-The most important features of the species are the arched upper edge with knife-like denticles, the biangular lower edge, and the posteriorly elongated triangular shape basal cavity. Both the lateral and basal cavities are close to “*Neospathodus*” *spitiensis*, but the length-to-height ratio is smaller in this material than in that species.

Occurrence.-The species occurs in the lower Smithian of the Bac Thuy Formation in the Chi Lang District and Lang Son City, northeastern Vietnam (*Novispathodus* ex gr. *waageni* Zone with *Flemingites rursiradiatus*, *Urdoceras tulongensis*, and *Owenites koeneni* beds, 5).

Subfamily Novispathodinae Orchard, 2005⁹

Genus *Novispathodus* Orchard, 2005⁹

Type species: *Novispathodus abruptus* (Orchard, 1995)³⁷.

Novispathodus ex gr. *waageni* (Sweet, 1970b)²⁸

Figs. 5.8–5.12

Neospathodus waageni Sweet, 1970b²⁸, p. 260, pl. 1, figs. 11, 12; McTavish, 1973²⁹, p. 300, pl. 2, figs. 11, 22. 25–28; Mosher, 1973³⁸, p. 172, pl. 20, fig. 5; Goel, 1977³⁶, p. 1094, pl. 2, figs. 1–4; Solien, 1979³⁹, p. 304, pl. 3, fig. 9; Buryi, 1979³¹, p. 56, pl. 7, figs. 8, 9; Wang and Cao, 1981³², pl. 2, fig. 26; Koike, 1982¹¹, p. 39, pl. 6, figs. 24–27; Matsuda, 1983⁴⁰, p. 88, pl. 1, figs. 6–10, pl. 2, figs. 1–7; Duan, 1987⁴¹, pl. 2, figs. 7; Cao and Wang, 1993⁴², p. 261, pl. 56, figs. 5, 11; Wang and Zhong, 1994³⁵, p. 402, pl. 1, figs. 12, 13; Nakrem *et al.*, 2008⁴³, figs. 5.7, 5.8, 5.11, 5.14; Orchard, 2008¹⁵, p. 40, figs. 8.1, 8.2, 8.8, 8.9; Beranek *et al.*, 2010¹⁶, figs. 6.22, 6.23.

Neospathodus waageni waageni Sweet. Zhao and Orchard, in Zhao *et al.*, 2007²¹, p. 36, pl. 1, figs. 10A, B.

Neospathodus waageni eowaageni Zhao and Orchard, in Zhao *et al.*, 2007²¹, p. 36, pl. 1, figs. 5A, B.

Neospathodus ex gr. *waageni* (Sweet, 1970b)²⁸. Orchard and Krystyn, 2007²³, figs. 8–18; Igo, in Shigeta *et al.*, 2009²⁴, p. 194, figs. 152.14–152.19, 156.7–156.19; Maekawa and Igo, in Shigeta *et al.*, 2014⁵, p. 244, 252, figs. 174.31–174.57, 175–178, 179.1–179.3, 179.7–179.12, 179.16–179.39, 180, 181.1–181.24, 181.28–181.31.

Novispathodus waageni (Sweet, 1970b)²⁸. Goudemand and Orchard, in Goudemand *et al.*, 2012⁴⁴, p. 1031, figs. 3D, E, H, N, S, T.

Material examined. -Five specimens, CS-1028 to -1032, from BR00-04.

Description.-Segminate element 0.47–0.58mm in length; 0.40–0.50mm in height; length-to-height ratio 1–1.2 in five specimens, with arched upper edge. Laterally compressed denticles with sharp tip, arranged in radial fashion, fused lower half and discrete upper half. Basal margin straight anteriorly, posterior half upturned by 15–30 degrees. Rounded or elliptical basal cavity expands in posterior half with thin pit that continues to anterior groove.

Remarks.-The described specimens have the typical form of *Novispathodus ex gr. waageni*. The denticulation and strongly expanded basal cavity are very similar to those of some specimens (e.g., 5, figs. 179.16–179.18, 180.43–180.45, 181.7–181.9) from the *Urdyceras tulongensis* Zone and the lower part of the *Owenites koeneni* Zone of the Bac Thuy Formation in the Lang Son and Chi Lang areas.

Occurrence.-The species marks the Induan–Olenekian boundary and has a range of the entire Smithian and the lowermost Spathian. It is also reported from West Pakistan (28), Kashmir in India (40), Spiti in India (23, 36), western Australia (29), Utah in the USA (39), South Primorye in Russia (24, 31), Malaysia (11), Canada (15, 16, 34, 38), South China (21, 35), and Northeastern Vietnam (5).

3. DISCUSSION: Geological age of the conodont assemblage in the Ban Ru section

In the Ban Ru area, the bedded limestones (BR00-01 to BR00-03) in the basal part of the Bac Thuy Formation contain conodonts, such as *Neospathodus chaohuensis*, *Ns. cf. concavus*, *Ns. dieneri*, and *Ns. aff. dieneri*. The range of *Ns. chaohuensis* is limited to the upper Dienerian and the species does not co-occur with *Novispathodus ex gr. waageni*, indicating an Olenekian age in the West Pingdingshan section, South China (*Ns. dieneri* Morphotype 2 and 3 zones with the *Gyronites–Prionolobus* zone, 21), northern Thailand, and the Kamura limestone, Southwest Japan (22). Thus, the geological age of the conodont assemblage is probably upper Dienerian.

Loc. BR00-04 in the lower part of the Bac Thuy Formation contains typical Smithian conodonts: *Discretella discreta*, *Ns. dieneri*, *Neospathodus sp. indet. A*, and *Novispathodus ex gr. waageni*. These conodonts have been reported from the *Flemingites rursiradiatus* beds to the *Leyceras* horizon of the *Owenites koeneni* beds of the lower part of the Bac Thuy Formation in the Bac Thuy (stratotype section) and Ky Cung River areas (Fig. 3; 45). The conodont assemblage from Loc. BR00-04 indicates a probable middle Smithian age. The middle Smithian conodonts were obtained from carbonates about 120 m above the basal part of the formation. Thus, the Induan–Olenekian boundary is probably within the lower part of the formation, which consists mainly of mudstone and sandstone (beds BR00-01 to BR00-04).

A Dienerian conodont assemblage has never been reported from the Bac Thuy and Lang Son formations, but the Induan bivalves *Claraia aurita* (Hauer) and *C. concentrica* (Yabe) were found in the Lang Son Formation in the Lang Son City, Con San, and Deo Lan sections (2, 46). (18) reported a lower Smithian conodont assemblage containing *Eurygnathodus costatus* Staesche and *E. hamadai* (Koike) from Loc. 01 of the formation in Lang Son City, about 10 km north of the study area. (2) described the Olenekian bivalve *C. intermedia multistriata* (Ichikawa) from the upper part of the Lang Son Formation in the Deo Lan section, 5 km northwest of the Ban Ru area. Therefore, the carbonate facies of the Bac Thuy Formation changed laterally into the siliciclastic facies of the Lang Son Formation during the latest Induan to earliest Olenekian. The timing of accumulation of thick carbonates was probably earlier in the Ban Ru area than in other sections.

4. CONCLUSION

The lower part of the Bac Thuy Formation in the Ban Ru area consists mainly of bedded limestone, limestone breccia, mudstone, and sandstone. The lithology is quite similar to that in the Bac Thuy and Na Trang areas, but the basal limestone beds (BR00-01 to -03) contain the upper Induan conodonts *Neospathodus chaohuensis*, *Ns.* cf. *concaus*, *Ns. dieneri*, and *Ns.* aff. *dieneri*. About 120 m above that interval, bedded limestone contains the middle Smithian conodonts *Discretella discreta*, *Neospathodus dieneri*, *Neospathodus* sp. indet. A, and *Novispathodus ex gr. waageni*. Therefore, in the Ban Ru area the Induan–Olenekian boundary occurs within the lower part of the Bac Thuy Formation.

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