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Conodont faunas across the Mid-Carboniferous boundary in the Hina Limestone, Southwest Japan

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Abstract. **The Hina Limestone yields abundant conodont elements that range from early Visean to late Bashkirian in age. These conodont faunas permit detailed examination of the successive changes across the Mid-Carboniferous boundary. Six conodont zones can be recognized in ascending order: the *Gnathodus bilineatus, Declinognathodus inaequalis-Gnathodus bilineatus, Declinognathodus noduliferus, Neolochriea nagatoensis, Neolochriea koikei*, and *Neognathodus symmetricus* Zones. The Mid-Carboniferous boundary in the Hina Limestone can be identified by the base of the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone. A remarkable faunal transition occurs within the *Declinognathodus inaequalis-Gnathodus bilineatus* and *Declinognathodus noduliferus* Zones, in which Mississippian conodonts go extinct and several new typical Pennsylvanian taxa appear. Three *Declinognathodus* species, *Declinognathodus inaequalis, D. noduliferus*, and *D. japonicus*, successively appear in the order given. A new genus, *Neolochriea*, with *Neolochriea hisaharui*, sp. nov. as the type species and two other new species, *N. hisayoshii* and *N. koikei*, are described in addition to eight other species of conodonts. All *Neolochriea* species occur in the stratigraphic level between the extinction of Mississippian conodonts and the appearance of *Neognathodus symmetricus*.**

Key words: Biostratigraphy, conodont, *Declinognathodus*, Hina Limestone, Mid-Carboniferous boundary, *Neolochriea*

Introduction

In the late nineteenth century the Carboniferous System was subdivided into the Mississippian and Pennsylvanian Systems in the United States because of the presence of a sedimentary and faunal gap in the middle part of the Carboniferous in eastern North America. Subsequently, the Mississippian and Pennsylvanian were retained as Subsystems and their mutual boundary designated as the Mid-Carboniferous boundary.

In 1983, the Subcommission on Carboniferous Stratigraphy of the International Union of Geological Sciences approved a recommendation that the Mid-Carboniferous boundary should be placed at the level of the first appearance of the conodont *Declinognathodus noduliferus* in some continuously deposited sequence of rocks. This position coincides approximately with the *Eumorphoceras-Homoceras* ammonoid zonal transition (Lane and Manger, 1985). At the instigation of the Subcommission on Carboniferous Stratigraphy, the Mid-Carboniferous Boundary Working Group was organized to select a Mid-Carboniferous boundary stratotype in 1985. The working group has provided much new biostratigraphic information on faunal and floral changes of many marine and terrestrial fossil groups across the Mid-Carboniferous boundary (e.g., Ramsbottom *et al. eds.*, 1982; Lane *et al.*, 1985; Riley *et al.*, 1987; Rui *et al.*, 1987; Wang *et al.*, 1987b; Nemirovskaya, 1987; Nemirovskaya *et al.*, 1990; Varker *et al.*, 1990; Nigmadganov and Nemirovskaya, 1992). In a later decision the Arrow Canyon section in Nevada was selected as the stratotype of the Mid-Carboniferous boundary (Lane *et al.*, 1994; Lane, 1995; Brenckle *et al.*, 1997).

After the first report of Japanese Carboniferous conodonts by Igo and Koike (1964) from the Omi Limestone, many studies on Japanese Carboniferous conodonts have been carried out; these are summarized by Igo (1994). Koike (1967) established a Carboniferous conodont zonation based on faunas from the Atetsu Limestone. This conodont zonation has been used as the standard one in the Japanese Carboniferous. The *Gnathodus bilineatus-Declinognathodus noduliferus* Zone of the Atetsu Limestone is unique, because typical "Mississippian" taxa co-occur with "Pennsylvanian" species. Koike (1967) correlated this zone to the uppermost Chesterian of North America and the lower Namurian of Europe. However, *Gnathodus bilineatus* and *Declinognathodus noduliferus* have never been found together within the same stratigraphic level in Europe and North America. Therefore, the geological age assignment of the *Gnathodus bilineatus-Declinognathodus noduliferus* Zone of the Atetsu Limestone has been questioned by

European and North American conodont researchers (Webster, 1969 ; Lane and Straka, 1974 ; Higgins, 1975).

However, this conodont assemblage, recognized in the Atetsu Limestone, has been described not only from Japan (Haikawa, 1988) but also in Malaysia (Igo and Koike, 1968 ; Metcalfe, 1980) and China (Wang *et al*., 1987b). Haikawa (1988) suggested that *Lochriea commutata* and *Declinognathodus noduliferus* co-occurred in the Uzura Quarry in the

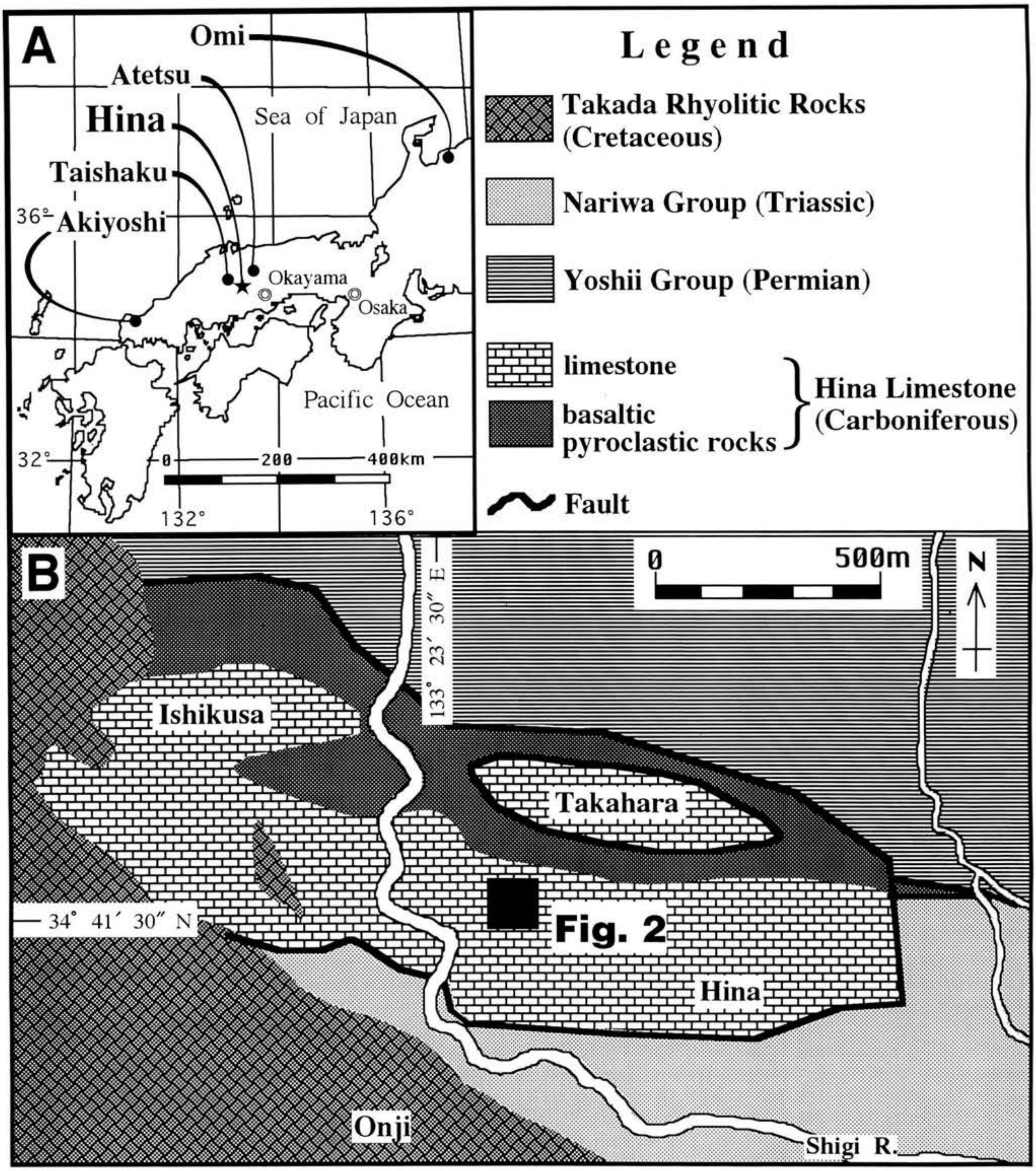


Figure 1. Location map of Hina in southwest Japan (A), and geological map of the Hina Limestone (B).

western part of the Akiyoshi Plateau although details of the stratigraphic relationship between them were not given. Up to the present, students of the Japanese Carboniferous have been uncertain about the details of the conodont faunal changes across the Mid-Carboniferous boundary.

In order to resolve this uncertainty, I have restudied the conodont faunal successions in the Akiyoshi, Omi, Atetsu, Taishaku, and Hina Limestones, all of which are exposed as isolated plateaus in the Inner Zone of southwest Japan (Figure 1-A). These consist mainly of pure, massive limestones that conformably overlie alkaline basalt flows or volcaniclastic rocks. This volcanic-limestone succession is interpreted to be a carbonate reef complex that formed on an oceanic seamount in Panthalassa during Late Paleozoic time (Kanmera and Nishi, 1983; Sano and Kanmera, 1988).

Recently, I discovered a new section of the Hina Limestone, in which the conodont faunas and the biostratigraphic succession across the Mid-Carboniferous boundary are excellently preserved. The present paper aims (1) to describe in detail the conodont succession and to propose a new conodont zonation across the Mid-Carboniferous boundary for the Hina Limestone, (2) to correlate these zones with those of other Japanese limestone untis, namely the Atetsu and Akiyoshi Limestones, with the important Mid-Carboniferous boundary section at Arrow Canyon, and also with the Stonehead Beck, Aksu-I, Zhelvakovaya Valley, and Luosu sections, and (3) to discuss the conodont faunas across the Mid-Carboniferous boundary in the Japanese Carboniferous.

Geologic setting

The Hina Limestone, located in the western part of Okayama prefecture, is a Carboniferous limestone mass in the Inner Zone of southwest Japan. The limestone and associated basaltic pyroclastic rocks are exposed over 2 km in an east-west direction and 0.8 km in a north-south direction. This limestone is overthrust the Permian Yoshii and Triassic Nariwa Groups and forms a klippe (Sada *et al.*, 1979).

Hase and Yokoyama (1975) subdivided the Hina Limestone into four foraminiferal zones, in ascending order, the *Endothyra, Eostaffella-Millerella, Pseudostaffella*, and *Profusulinella* Zones. They also reported some brachiopods from this

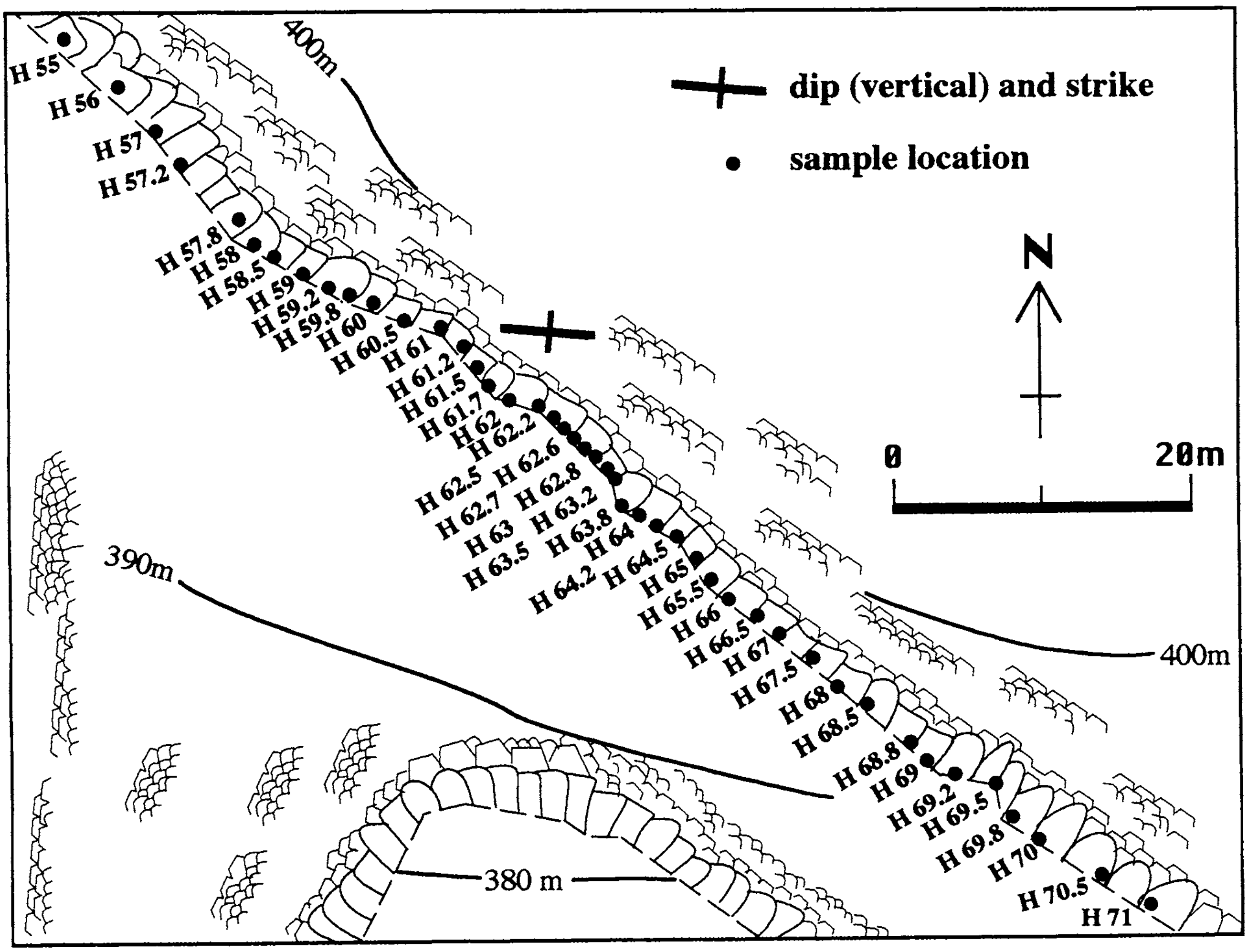


Figure 2. Sampling points in the examined section of the Hina Limestone.

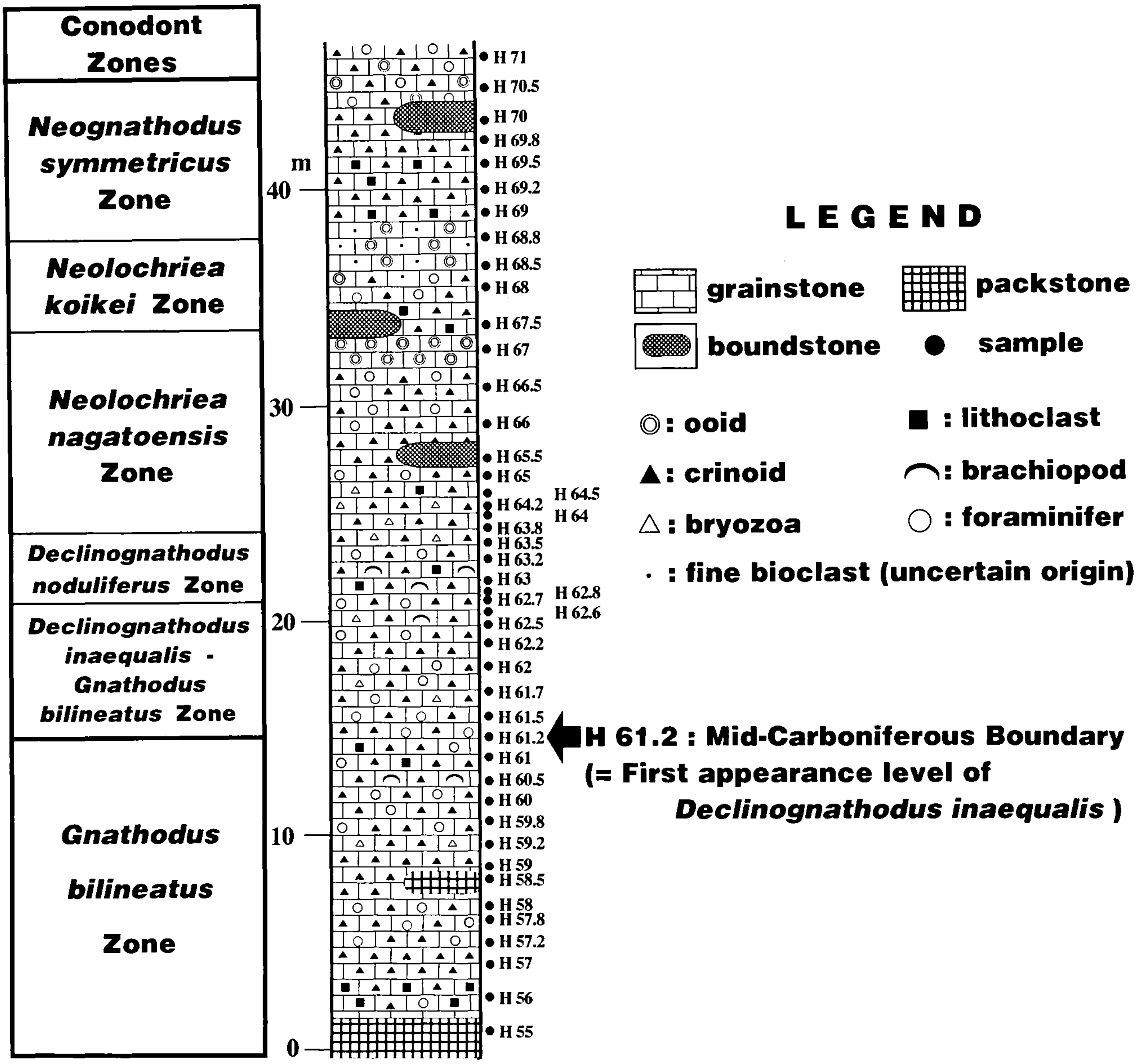


Figure 3. Geologic column of the measured section with indications of sampling levels and conodont zones established in this paper. The proposed Mid-Carboniferous boundary position (H 61.2) defined by the first appearance of *Declinognathodus inaequalis*.

limestone and assigned the *Endothyra* and *Eostaffella-Millerella* Zones to the early and late Visean of the European standard, respectively. Recently, Fujimoto and Sada (1994) studied the foraminiferal biostratigraphy of the Hina Limestone. However, the Mid-Carboniferous boundary in this limestone still remained ambiguous.

The measured limestone section in this study crops out in an abandoned limestone quarry of Kokan Kogyo Co., Ltd. in the eastern part of the Hina Limestone, Takahara area, and is about 50 m thick (Figures 1-B and 2). It corresponds to the middle part of the *Eostaffella-Millerella* Zone of Hase and Yokoyama (1975). The measured section represents a continuous succession composed mainly of massive, pure, shallow-marine limestones (Figure 3). Bioclastic (crinoidal-foraminiferal-bryozoan) grainstone predominates, with subordinate amounts of bioclastic packstone, oolitic grainstone, crinoidal-lithoclastic grainstone, and algal-coral boundstone. No distinctive physical breaks were observed in the section, and conodonts were obtained from most samples.

Conodont biostratigraphy

As shown in Figure 2, 45 samples were collected systematically for conodonts. I processed 2 to 5 kg of limestone

Table 1. Distribution of conodonts in the measured section of the Hina Limestone. Numerals show the number of conodont specimens per 1 kg limestone sample. Generic abbreviations: *D.-Declinognathodus, G.-Gnathodus, N.-Neolochriea.*

TAXA \ SAMPLE	H 55	H 56	H 57	H 57.2	H 57.8	H 58	H 58.5	H 59	H 59.2	H 59.8	H 60	H 60.5	H 61	H 61.2	H 61.5	H 61.7	H 62	H 62.2	H 62.5	H 62.6	H 62.7	H 62.8	H 63	H 63.2	H 63.5	H 63.8	H 64	H 64.2	H 64.5	H 65	H 65.5	H 66	H 66.5	H 67	H 67.5	H 68	H 68.5	H 68.8	H 69	H 69.2	H 69.5	H 69.8	H 70	H 70.5	H 71
Gnathodus bilineatus			2	11	8	5	6	3	9	2	17	6	1	2	1	2	1	5	1																										
Vogelgnathus campbelli				1							1	2			1																														
Vogelgnathus akiyoshiensis		1	1	1	1			1	3	1	1	2																																	
Cavusgnathus unicornis		1	1	5		1	6		1	2	2		2	1	1		1																												
Cavusgnathus sp. indet.				2	1		2		1	2				1		1																													
Hindeodus minutus							2	2	2	2	2	1	1	1		1	1	1			1				1		1	1	1						1		1	1							
Declinognathodus inaequalis														1			1	4	1	1	8	5	4	4								2													
Declinognathodus noduliferus																					1	3	6	8	11	3	1			1		3	1												
Declinognathodus japonicus																								2	8	6	2			1		4		1	1	3	1	2	1			7	2	2	2
Lochriea commutata		1	4	4	3	3	3		1		2							1	1		5	7	4																						
Lochriea nodosa														1																															
Neolochriea nagatoensis																										16	21	3					1												
Neolochliea hisayoshii sp. nov.																													4	1		1													
Neolochriea hisaharui sp. nov.																															20		3												
Neolochriea koikei sp. nov.																																			1		1	1	1			1			2
Neognathodus symmetricus																																						1	1				1	1	1
Conodont Zone	***Gnathodus bilineatus* Zone**													***D. inaequalis - G. bilineatus* Zone**							***D. noduliferus* Zone**					***Neolochriea nagatoensis* Zone**									***N. koikei* Zone**			***Neognathodus symmetricus* Zone**							

from each level in the measured section. A total of 16 conodont species were identified. Table 1 shows the distribution of conodonts in the measured section and the number of conodont elements extracted per 1 kg of limestone sample.

Based on the first appearance of biostratigraphically significant species, the following six conodont zones were established across the Mid-Carboniferous boundary for the Hina Limestone in ascending order: the *Gnathodus bilineatus, Declinognathodus inaequalis-Gnathodus bilineatus, Declinognathodus noduliferus, Neolochriea nagatoensis, Neolochriea koikei*, and *Neognathodus symmetricus* Zones.

The *Gnathodus bilineatus* Zone is the lowest conodont zone in the measured section and is at least 15 m thick (sample no. H 55-H 61.2). Typical Mississippian conodonts, including *Gnathodus bilineatus*, *Lochriea commutata, Vogelgnathus campbelli* (Figure 11-7), *V. akiyoshiensis* (Figure 11-6), and *Cavusgnathus unicornis* (Figure 11-4a, b) occur characteristically from this zone. Except for *V. akiyoshiensis*, which disappears at the upper part of this zone (H 60.5 level), all the species survive into the overlying zone. *L. commutata* is common in the lower part of this zone.

The *Declinognathodus inaequalis-Gnathodus bilineatus* Zone is 6 m thick (H 61.2-H 62.7). Its base is defined by the first appearance of *Declinognathodus inaequalis* and the top is defined by the first appearance of *D. noduliferus*. The conodont assemblage of this zone is characterized by the co-occurrence of typical "Mississippian" species with the "Pennsylvanian" species *D. inaequalis*. Except for *Lochriea commutata*, most of the "Mississippian" conodonts become extinct in this zone. *L. nodosa* was obtained only from the H 61.2 level, at the base of this zone.

The *Declinognathodus noduliferus* Zone is about 4 m thick (H 62.7-H 63.8). Its base is defined by the first appearance of *Declinognathodus noduliferus* and the upper limit is defined by the first appearance of *Neolochriea nagatoensis. Lochriea commutata* is still found in this zone (H 62.7, H 62.8, and H 63). *D. inaequalis* occurs together with the nominate species through this zone. On the other hand, *D. japonicus* first appears in the upper part of this zone (H 63.2).

The *Neolochriea nagatoensis* Zone is 9 m thick (H 63.8-H 67.5). It is defined as the stratigraphic interval between the first appearances of *Neolochriea nagatoensis* and *N. koikei* sp. nov.; the latter is the defining species of the overlying zone. The conodont fauna of this zone is characterized by the occurrence of *Neolochriea* gen. nov. *N. nagatoensis*, which occurs abundantly from the H 63.8 and H 64 levels, is also found from H 64.2 and H 66.5. *N. hisayoshii* sp. nov. first appears from H 64.5 and is found up to H 66. *N. hisaharui* sp. nov. occurs abundantly in H 65.5 and is found up to H 66.5. These three *Neolochriea* species have short stratigraphic ranges in comparison with other conodonts in the Hina Limestone.

In addition to the index species, *Declinognathodus inaequalis, D. noduliferus, D. japonicus, N. hisayoshii* sp. nov., and *N. hisaharui* sp. nov. occur from the *Neolochriea nagatoensis* Zone. *D. inaequalis* is very rare and occurs only from H 66. *D. noduliferus* occurs up to the H 66.5 level in this zone. In contrast to other *Declinognathodus* species, *D. japonicus* occurs commonly throughout this zone.

The *Neolochriea koikei* Zone is 5 m thick (H 67.5-H 68.8). Its base is marked by the first appearance of *Neolochriea koikei* sp. nov. In addition to the index species, *Hindeodus minutus* and *Declinognathodus japonicus* occur from this zone. *D. inaequalis* and *D. noduliferus* were not recovered from this zone.

The *Neognathodus symmetricus* Zone is the uppermost conodont zone in the measured section and is at least 8 m in thickness (H 68.8 and higher). The lower limit is defined

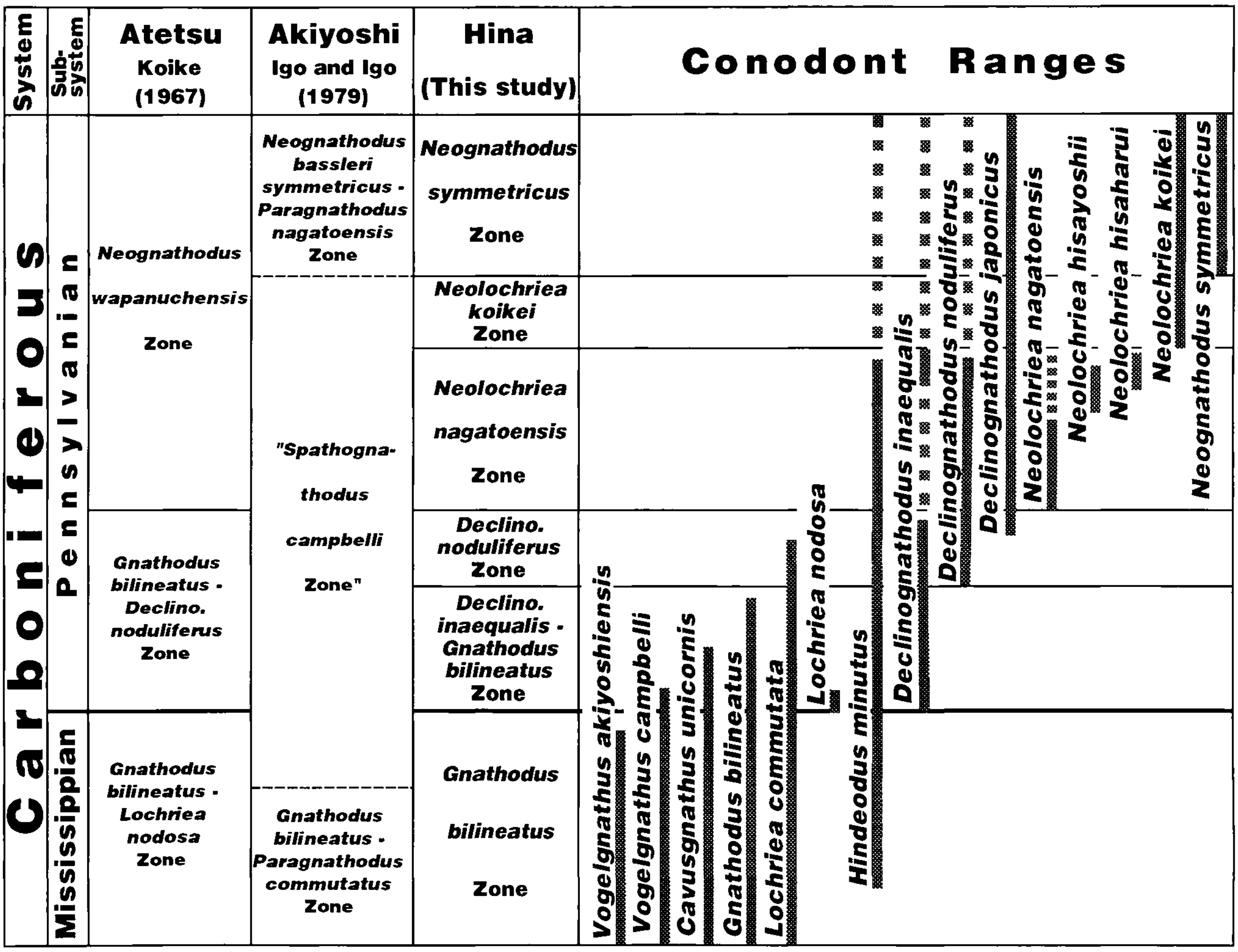


Figure 4. Range chart of conodont species in the measured section of the Hina Limestone. Generic abbreviation : *Declino.-Declinognathodus*.

by the first appearance of *Neognathodus symmetricus*, a well-known index species for the lower Bashkirian. *Declinognathodus japonicus* and *Neolochriea koikei* sp. nov. occur in this zone and are also found from stratigraphically higher levels in the measured section.

Correlation with Japanese Limestone

1. Atetsu Limestone

Koike (1967) established seven Carboniferous conodont zones in the Nagoe and Kodani Formations of the Atetsu Limestone. Recently, some of the zones were revised by Igo (1994). According to him, three conodont zones across the Mid-Carboniferous boundary are recognized in ascending order (Figure 4).

(1) *Gnathodus bilineatus-Lochriea nodosa* Zone

This zone is characterized by *Gnathodus bilineatus, Lochriea commutata, L. nodosa*, and *Vogelgnathus campbelli*, typical Mississippian conodont species. Except for the presence of *L. nodosa*, this fauna is almost the same as the conodont fauna of the *Gnathodus bilineatus* Zone in the Hina Limestone. *L. nodosa* is very rare in the Hina Limestone and was not obtained from the *G. bilineatus* Zone.

(2) *Gnathodus bilineatus-Declinognathodus noduliferus* Zone

Declinognathodus noduliferus first appears from the base of this zone in association with Mississippian conodonts. The specimen assigned to *Gnathodus nodulifera* by Koike (1967, pl. 3, fig. 10) has four distinctive outer nodes and can be included in *D. inaequalis*. Therefore, this zone in the Atetsu Limestone can be correlated with the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone in the Hina Limestone.

(3) *Neognathodus wapanuckensis* Zone

This zone is defined by the total range of *Neognathodus wapanuckensis*. *Declinognathodus noduliferus, Paragnathodus ? nagatoensis* and other taxa are also abundant in the *Neognathodus wapanuckensis* Zone (Igo, 1994, p. 101). However, *N. wapanuckensis* was not reported from the lower part of this zone in the Atetsu Limestone (e.g., Koike, 1967, localities 37a, 38, 40, 123, 124). At these localities, *D. noduliferus* and *P. ? nagatoensis* occur abundantly and

Mississippian conodonts become extinct below this zone. *P.* ? *nagatoensis* can be assigned to *Neolochriea* spp. including *N. nagatoensis* in the Hina Limestone. Therefore, the *N. wapanuckensis* Zone in the Atetsu Limestone can be correlated with the *Neolochriea nagatoensis* to *N. symmetricus* Zones in the Hina Limestone.

2. Akiyoshi Limestone

Igo and Igo (1979) established the following three conodont zones across the Mid-Carboniferous boundary in the lower part of the Akiyoshi Limestone (Figure 4). Besides this, Haikawa (1988) established five Lower Carboniferous conodont zones below the Mid-Carboniferous boundary.

(1) *Gnathodus bilineatus-Paragnathodus commutatus* Zone

This zone includes the *Gnathodus bilineatus-Cavusgnathus charactus* Zone and *Lochriea nodosa* Zone by Haikawa (1988). It is characterized by typical Mississippian conodonts and can be correlated with the *G. bilineatus* Zone in the Hina Limestone.

(2) "*Spathognathodus campbelli* Zone"

This zone was established in the Shishidedai area in the northeastern part of the Akiyoshi Limestone Plateau (Igo and Igo, 1979). *Vogelgnathus campbelli* [=*Spathognathodus campbelli* in Igo and Igo, 1979] is particularly abundant and ranges up to the uppermost part of this zone, whereas *V. akiyoshiensis* disappears in the lower part of this zone. In the Akiyoshi Limestone this zone cannot be determined exactly because the occurrence of conodonts is rare.

(3) *Neognathodus bassleri symmetricus-Paragnathodus nagatoensis* Zone

This zone was established in the Uzura quarry in the western part of the Akiyoshi Limestone Plateau (Igo and Igo, 1979). *Neognathodus bassleri symmetricus* [=*Neognathodus symmetricus*], *Paragnathodus nagatoensis*, *Idiognathoides opimus*, and *Hindeodus minutus* are found in this zone. Based on the occurrence of *Lochriea commutata* and *Declinognathodus noduliferus* Haikawa (1988) supposed an earliest Pennsylvanian age for the quarry. However, the exact stratigraphic levels of *L. commutata*, *D. noduliferus*, and *N. symmetricus* have not been made clear in the Uzura quarry. Using the occurrence of *N. symmetricus*, this zone can be correlated with the *Neognathodus symmetricus* Zone in the Hina Limestone. Further investigation, however, will be necessary to settle the detailed correlation of conodont zones between the Akiyoshi Limestone and the Hina Limestone.

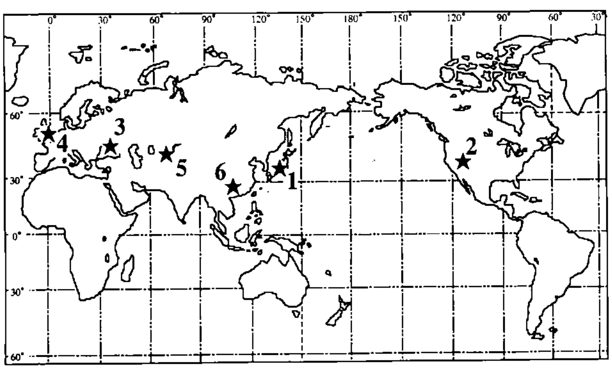


Figure 5. Map showing important localities of the Mid-Carboniferous boundary sections: 1. Hina Limestone (Japan), 2. Arrow Canyon section (U.S.A.), 3. Donets Basin (Ukraine), 4. Stonehead Beck section (England), 5. Aksu-I section (Uzbekistan), 6. Luosu section (China).

International correlation

1. Arrow Canyon section (U.S.A.)

This section is located in the Arrow Canyon Range about 80 km northeast of Las Vegas, Nevada. Recently, this section was selected as boundary stratotype of the Mid-Carboniferous boundary because of the complete exposure of marine deposits across the boundary (Lane, 1995; Brenckle *et al.*, 1997). According to Baesemann and Lane (1985), four conodont zones across the Mid-Carboniferous boundary are recognized in the ascending order (Figure 6).

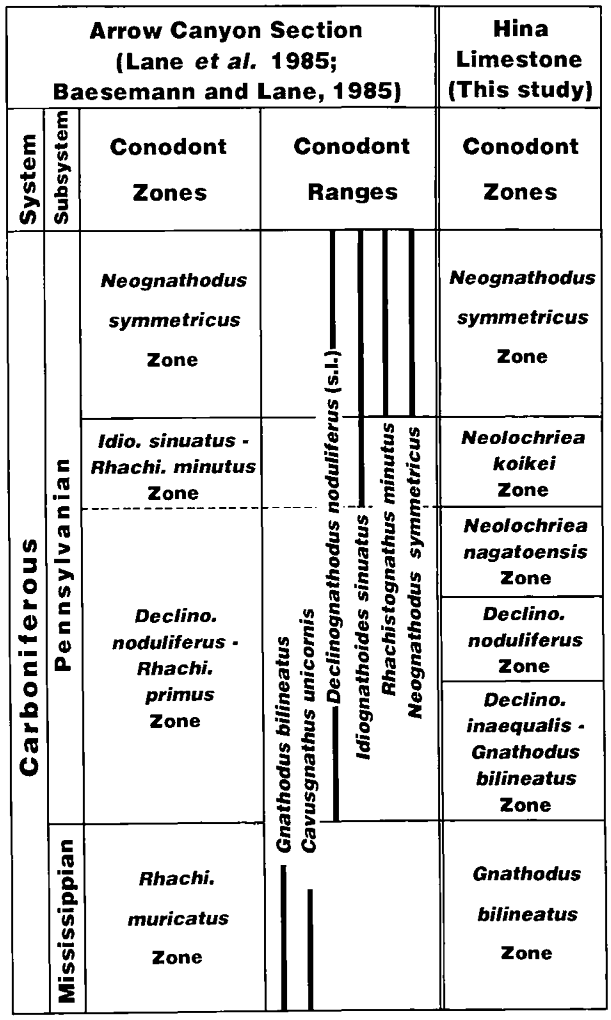


Figure 6. Range chart of conodont species in the Arrow Canyon section and comparison with the Hina Limestone. Generic abbreviations: *Declino.*-*Declinognathodus*, *Idio.*-*Idiognathoides*, *Rhachi.*-*Rhachistognathus*.

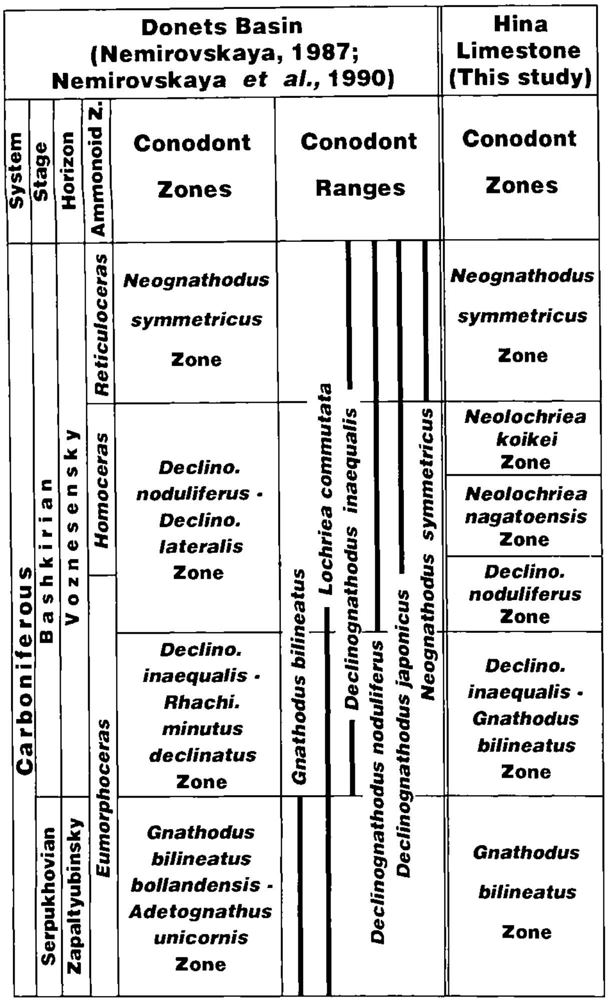


Figure 7. Range chart of conodont species in the Donets Basin and comparison with the Hina Limestone. Generic abbreviations: *Declino.-Declinognathodus, Rhachi.-Rhachistognathus*.

(1) *Rhachistognathus muricatus* Zone

This zone is the latest Mississippian conodont zone in the Arrow Canyon section. In addition to the index species, *Gnathodus bilineatus* and *Cavusgnathus unicornis* are found. Therefore, this zone is correlated with the *Gnathodus bilineatus* Zone in the Hina Limestone.

(2) *Declinognathodus noduliferus-Rhachistognathus primus* Zone

The Mid-Carboniferous boundary is placed at the base of this zone (61B level) where *Declinognathodus noduliferus* (s.l.) first appears (Brenckle *et al*., 1997). The specimens of *D. noduliferus* (s.l.) obtained from Sample 61B and Sample 62 are illustrated in Brenckle *et al.* (1997, pl. 1, figures 2-4). However, these are quite similar to *D. inaequalis*. Using the first appearance of *D. inaequalis*, the lower part of this zone can be correlated with the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone in the Hina Limestone.

(3) *Idiognathoides sinuatus-Rhachistognathus minutus* Zone

The base of this zone is defined by the first appearance of *Idiognathoides sinuatus*. As *I. sinuatus* and *Rhachistognathus minutus* have not been found in the Hina Limestone, this zone could not be recognized in it. The equivalent stratigraphic interval of the *Declinognathodus noduliferus, Neolochriea nagatoensis*, and *Neolochriea koikei* Zones in the Hina Limestone may correspond to the *D. noduliferus-Rhachistognathus primus* plus *Idiognathoides sinuatus-R. minutus* Zones in the Arrow Canyon section.

(4) *Neognathodus symmetricus* Zone

The lower limit of this zone is defined by the first appearance of *Neognathodus symmetricus*. Therefore, the base of this zone is referable to the base of the same zone in the Hina Limestone.

2. Donets Basin (Ukraine)

Nemirovskaya *et al.* (1990) proposed the Zhelvakovaya Valley section along the Kal'mius River in the Donets Basin for the Mid-Carboniferous boundary stratotype. This section is also the stratotype of the Zapaltyubinsky Horizon (uppermost Serpukhovian Stage) and of the Voznesensky Horizon (lowermost Bashkirian Stage). The conodont zones across the Mid-Carboniferous boundary in this section are as follows (Figure 7). The conodont fauna observed in the Zhelvakovaya Valley section is quite similar to that observed in the Hina Limestone.

(1) *Gnathodus bilineatus bollandensis-Adetognathus unicornis* Zone

This zone is characterized by typical Mississippian conodont species. Except for *Lochriea commutata*, the "Mississippian" conodonts are restricted to this zone. Therefore, this zone can be correlated with the *Gnathodus bilineatus* Zone in the Hina Limestone.

(2) *Declinognathodus inaequalis-Rhachistognathus minutus declinatus* Zone

The Mid-Carboniferous boundary is placed at the base of this zone where *Declinognathodus inaequalis* first appears in the Donets Basin. Using the first appearance of *D. inaequalis*, this zone can be correlated with the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone in the Hina Limestone.

(3) *Declinognathodus noduliferus-Declinognathodus lateralis* Zone

The base of this zone is defined by the first appearance of *Declinognathodus noduliferus*. *Lochriea commutata* ranges up to this zone. The first appearance datum of *D. japonicus* is found in this zone. Therefore, this zone can be correlated with the *Declinognathodus noduliferus* Zone in the Hina Limestone.

(4) *Neognathodus symmetricus* Zone

In the Donets Basin, *Neognathodus symmetricus* first appears with *Reticuloceras* from the base of this zone (Nemirovskaya, 1987). Because of the occurrence of *N. symmetricus*, this zone can be correlated with the same zone in the Hina Limestone.

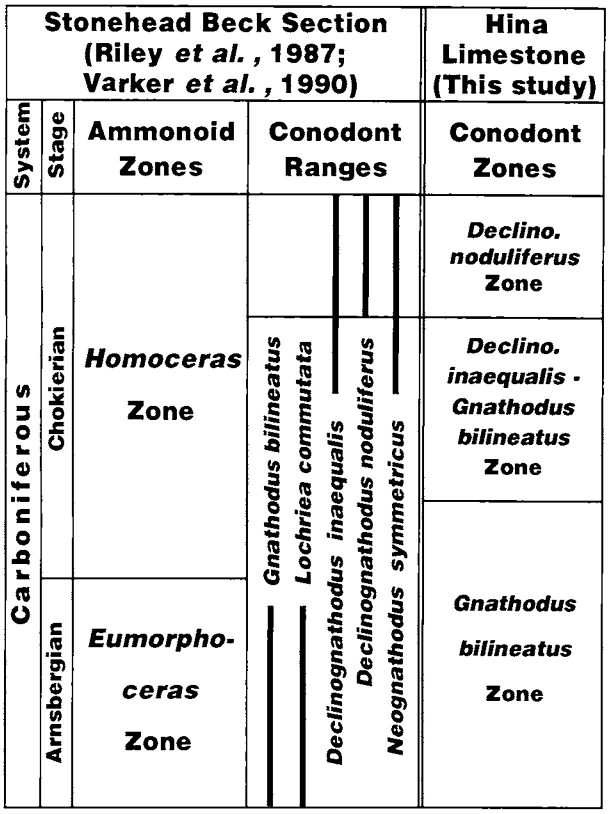


Figure 8. Range chart of conodont species in the Stonehead Beck section and comparison with the Hina Limestone. Generic abbreviation : *Declino.*-*Declinognathodus*.

3. Stonehead Beck section (England)

The Stonehead Beck section is located in the Craven Basin at the northwestern end of the Pendle Monocline, about 35 km west-northwest of Leeds, England. This section covers the *Eumorphoceras* Zone (Arnsbergian Stage) and the *Homoceras* Zone (Chokierian Stage) (Varker *et al.*, 1990). Riley *et al.* (1987) and Varker *et al.* (1990) reported the distribution of ammonoids, conodonts, and miospores in the Stonehead Beck section, however, conodont recovery has been poor in the strata across the Arnsbergian/Chokierian boundary (Figure 8).

(1) *Eumorphoceras* Zone

Mississippian conodonts are restricted in the *Eumorphoceras* Zone in the Stonehead Beck section. Therefore, this zone almost corresponds to the *Gnathodus bilineatus* Zone in the Hina Limestone.

(2) *Homoceras* Zone

Neognathodus symmetricus appears together with *Declinognathodus inaequalis* from 9.4 m above the base of this zone. After their appearance, *D. noduliferus* first appears from 9.8 m above the base of this zone (Figure 8). *D. japonicus* has not been found in the Stonehead Beck section.

Neognathodus symmetricus occurs with *Declinognathodus japonicus* from the *Reticuloceras* Zone in the Donets Basin (Figure 7) (Nemirovskaya, 1987). On the other hand, in England *D. japonicus* first appears at the base of the Alportian Stage (upper *Homoceras* Zone) and is abundant at the Marsdenian Stage (*Reticuloceras* Zone) in the Namurian of the Central Province (Higgins, 1975). Therefore, *N. symmetricus* might appear earlier in the Stonehead Beck section than in the Donets Basin.

Because of the first appearance of *Declinognathodus noduliferus* and the absence of *D. japonicus*, the lower part of the *Declinognathodus noduliferus* Zone in the Hina Limestone can be correlated with the *Homoceras* Zone in the Stonehead Beck section. The equivalent stratigraphic level of the *D. inaequalis*-*Gnathodus bilineatus* Zone in the Hina Limestone may correspond to the stratigraphic level up to the first occurrence of *D. noduliferus* in the Stonehead Beck section.

4. Aksu-I section (Uzbekistan)

The Aksu-I section is located at the south point of the Surkhantau Ridge, which belongs to the southwestern part of the Gissar Ridge, South Tienshan, Uzbekistan. The Aksu-I section represents deep-water deposits across the Mid-Carboniferous boundary and five conodont zones are recog-

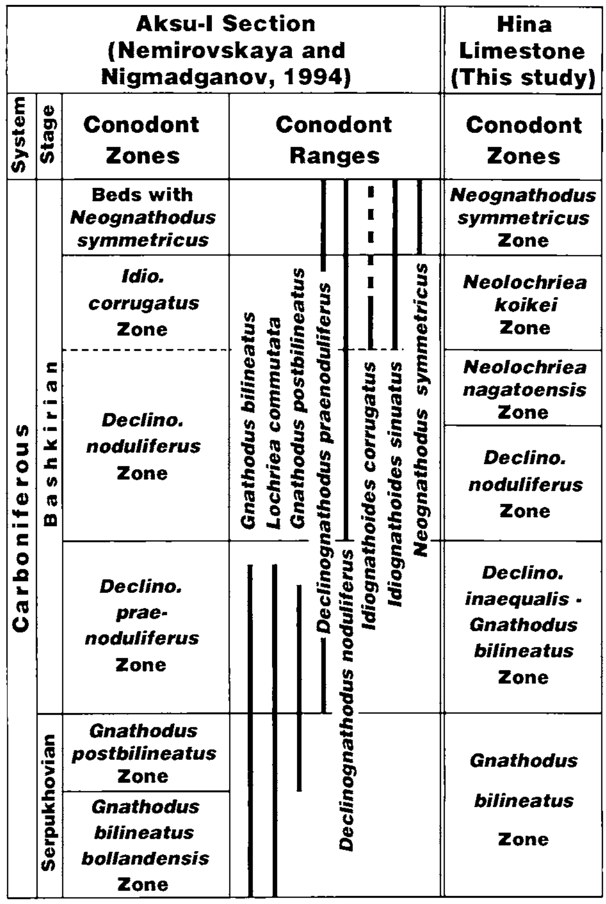


Figure 9. Range chart of conodont species in the Aksu-I section and comparison with the Hina Limestone. Generic abbreviations : *Declino.*-*Declinognathodus*, *Idio.*-*Idiognathoides*.

nized (Figure 9) (Nemirovskaya and Nigmadganov, 1994).

(1) *Gnathodus bilineatus bollandensis* Zone

(2) *Gnathodus postbilineatus* Zone

These two zones are characterized by Mississippian conodont species. Therefore, these zones can be correlated with the *Gnathodus bilineatus* Zone in the Hina Limestone.

(3) *Declinognathodus praenoduliferus* Zone

Nemirovskaya and Nigmadganov (1994) defined the Mid-Carboniferous boundary as lying at the base of this zone. They considered that *Declinognathodus praenoduliferus* phylogenetically arose from *Gnathodus bilineatus* and is the first representative of *D. noduliferus* (s.l.). They considered also that this species is the index of the Mid-Carboniferous boundary (oral communication with Nemirovskaya, 1996). A few Mississippian conodonts including *Gnathodus bilineatus* and *Lochriea commutata* range up to the uppermost level of this Zone. Therefore, this zone can be correlated with the *Declinognathodus inaequalis*-*Gnathodus bilineatus* Zone in the Hina Limestone.

(4) *Declinognathodus noduliferus* Zone

The base of this zone is defined by the first appearance of *Declinognathodus noduliferus*. Therefore, the base of this zone is referable to the base of the same zone in the Hina Limestone.

(5) *Idiognathoides corrugatus* Zone

Idiognathoides corrugatus and *I. sinuatus* occur before the appearance of *Neognathodus symmetricus* in the Aksu-I section. This zone could not be recognized in the Hina Limestone. However, *I. sinuatus* appears earlier than *Neognathodus symmetricus* as shown in the Arrow Canyon section (Baesemann and Lane, 1985). Accordingly, the equivalent stratigraphic interval of the *Declinognathodus noduliferus, Neolochriea nagatoensis*, and *N. koikei* Zones in the Hina Limestone may correspond to *D. noduliferus* plus *Idiognathoides corrugatus* Zone in the Aksu-I section.

5. Luosu section (China)

The Luosu section, which ranges from early Carboniferous (Tatangian Stage) to early Permian (Chihsian Stage), is exposed along the Wangmo-Luodian highway, located about 7 km southwest of Luosu, southern Guizhou Province, south China. Many conodont elements have been reported in this section (e.g., Rui *et al.*, 1987 ; Wang *et al.*, 1987b ; Wang and Higgins, 1989). According to Wang *et al.*, (1987b), the conodont zones across the Mid-Carboniferous boundary in the Luosu section are as follows (Figure 10).

(1) *Gnathodus bilineatus bollandensis* Zone

This zone in the Luosu section is correlated to the *Gnathodus bilineatus* Zone in the Hina Limestone.

(2) *Declinognathodus noduliferus* Zone

Wang *et al.* (1987b) defined the base of this zone as the Mid-Carboniferous boundary. In the Luosu section, Mississippian and Pennsylvanian conodonts co-occur obviously in this zone. On the other hand, they co-occur in the same or lower horizons (*Declinognathodus inaequalis*-*Gnathodus bilineatus* Zone) in the Hina Limestone. Following the proposal of the Madrid Congress in 1983 (Lane and Manger, 1985), the Mid-Carboniferous boundary in the Luosu section

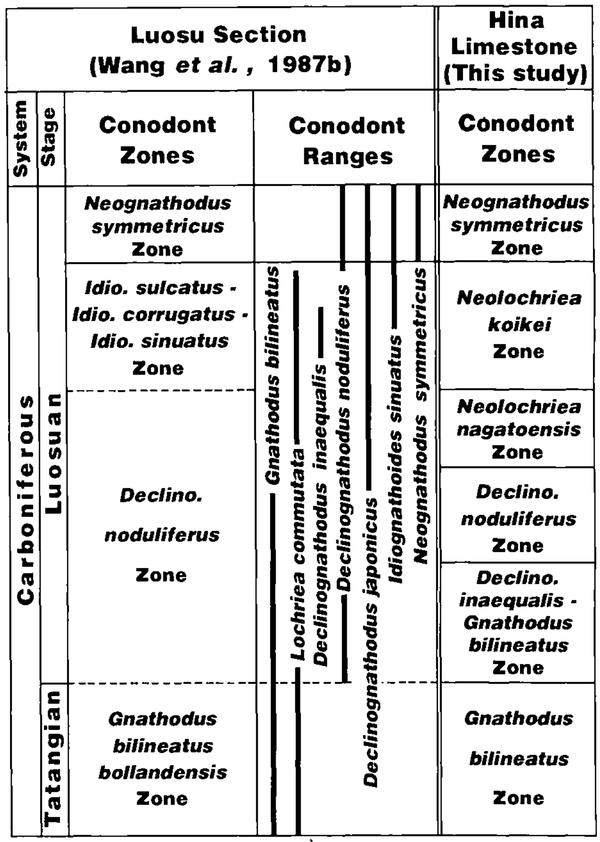


Figure 10. Range chart of conodont species in the Luosu section and comparison with the Hina Limestone. Generic abbreviations : *Declino.*-*Declinognathodus, Idio.*-*Idiognathoides*.

can be correlated to the base of the *D. inaequalis*-*G. bilineatus* Zone in the Hina Limestone. However, there is another possibility, namely, that the Mid-Carboniferous boundary exists below the base of the *D. noduliferus* Zone in the Luosu section. This is because *D. inaequalis* was found very rarely in the Luosu section. This species was obtained only from the *Idiognathoides sulcatus*-*I. corrugatus*-*I. sinuatus* Zone.

(3) *Idiognathoides sulcatus*-*I. corrugatus*-*I. sinuatus* Zone

Based on the occurrence of *Idiognathoides sinuatus*, the equivalent stratigraphic level of this zone may be below the *Neognathodus symmetricus* Zone in the Hina Limestone.

(4) *Neognathodus symmetricus* Zones

This zone in the Luosu section is correlated to the same zone in the Hina Limestone.

Discussion

1. Notes on Mid-Carboniferous boundary

Table 2 shows the international correlation of conodont zones in the Hina Limestone across the Mid-Carboniferous boundary. As shown above, the *Declinognathodus* species are the most important elements in defining the Mid-Carboniferous boundary in each section.

Table 2. Correlation of conodont zones established in the Hina Limestone with those in five important sections of the Mid-Carboniferous boundary. Generic abbreviations: *Declino.*-*Declinognathodus*, *I.*-*Idiognathoides*, *Rhachi.*-*Rhachistognathus*.

	U. S. A.	Western Europe	Eastern Europe	U. S. A. Arrow Canyon Section Lane *et al.* (1985) Baesemann & Lane (1985)	ENGLAND Stonehead Beck Section Riley *et al.* (1987) Varker *et al.* (1990)	UKRAINE Donets Basin Nemirovskaya (1987) Nemirovskaya *et al.* (1990)	UZBEKISTAN Aksu-I Section Nemirovskaya & Nigmadganov (1994)	CHINA Luosu Section Wang *et al.* (1987b)	JAPAN Hina Limestone (This Study)
				Conodont Zones	Ammonoid Zones	Conodont Zones	Conodont Zones	Conodont Zones	Conodont Zones
Carboniferous	Pennsylvanian / Morrowan	Kinderscoutian	Bashkirian	***Neognathodus symmetricus* Zone**		***Neognathodus symmetricus* Zone**	**Beds with *Neognathodus symmetricus***	***Neognathodus symmetricus* Zone**	***Neognathodus symmetricus* Zone**
Carboniferous	Pennsylvanian / Morrowan	Alportian	Bashkirian	***I. sinuatus - Rhachi. minutus* Zone**	***Homoceras* Zone**	***Declino. noduliferus - Declino. lateralis* Zone**	***I. corrugatus* Zone**	***I. sulcatus - I. corrugatus - I. sinuatus* Zone**	***Neolochriea koikei* Zone**
Carboniferous	Pennsylvanian / Morrowan	Alportian / Chokierian	Bashkirian	***Declino. noduliferus - Rhachi. primus* Zone**			***Declino. noduliferus* Zone**	***Declino. noduliferus* Zone**	***Neolochriea nagatoensis* Zone** ***Declino. noduliferus* Zone**
Carboniferous	Pennsylvanian / Morrowan	Chokierian	Bashkirian			***Declino. inaequalis - Rhachi. minutus declinatus* Zone**	***Declino. praenoduliferus* Zone**		***Declino. inaequalis - Gnathodus bilineatus* Zone**
Carboniferous	Mississippian / Chesterian	Chokierian / Arnsbergian	Serpukhovian	***Rhachi. muricatus* Zone**	***Eumorphoceras* Zone**	***Gnathodus bilineatus bollandensis - Adetognathus unicornis* Zone**	***Gnathodus postbilineatus* Zone** ***Gnathodus bilineatus bollandensis* Zone**	***Gnathodus bilineatus bollandensis* Zone**	***Gnathodus bilineatus* Zone**

Higgins (1975) subdivided *Declinognathodus noduliferus* into three subspecies, *Idiognathoides noduliferus inaequalis*, *I. n. noduliferus* (s.s.), and *I. n. japonicus*. He showed that these subspecies form a transition series characterized by the reduction of the nodes of the outer lateral platform. It has been considered that *I. n. inaequalis* and *I. n. noduliferus* appear together from the same stratigraphic level.

In the Hina Limestone, *Declinognathodus inaequalis*, *D. noduliferus* and *D. japonicus* appear successively from the H 61.2, H 62.7, and H 63.2 levels, respectively (Table 1 and Figure 4). It is evident that these species appear successively not only in the Hina Limestone but also in the Zhelvakovaya Valley section of the Donets Basin (Figure 7). Therefore, I treat these three subspecies as independent species because of their different form and different stratigraphic appearance.

At the 13th International Congress on Carboniferous-Permian, Mizuno and Ueno (1995) proposed placing the Mid-Carboniferous boundary at the base of *Declinognathodus noduliferus* Zone (H 62.7 level) in the Hina Limestone because the Mid-Carboniferous boundary should be defined as the first appearance datum of *Declinognathodus noduliferus* (s.s.). However, the Mid-Carboniferous Boundary Working Group concluded that the occurrence of any "*Declinognathodus noduliferus*" (s.l.) could become the index of the Mid-Carboniferous boundary. "*D. noduliferus*" (s.l.) here includes not only *D. inaequalis* but also *D. praenoduliferus* from the Aksu-I section in Uzbekistan (oral communication, Nemirovskaya, 1996).

I suppose that such ambiguities in the definition of "*Declinognathodus noduliferus*" gave rise to inconsistency in determining the Mid-Carboniferous boundary. Following the Mid-Carboniferous Boundary Working Group conclusion, in this paper I place provisionally the Mid-Carboniferous boundary in the Hina Limestone at the base of the *Declinognathodus inaequalis*-*Gnathodus bilineatus* Zone (H 61.2 level). However, more detailed examination in other Mid-Carboniferous sections is necessary to resolve this inconsistency.

2. Notes on *Declinognathodus* species

Many conodont workers argue that the ancestor of *Declinognathodus* species including *D. inaequalis* and *D. praenoduliferus* is not *Gnathodus girtyi simplex* but *G. bilineatus* (e.g., Grayson *et al.*, 1990; Nemirovskaya and Nigmadganov, 1994). In contrast, North American workers have considered *G. girtyi simplex* as the ancestor (e.g., Dunn, 1970, 1971; Lane and Straka, 1974; Lane *et al.*, 1985; Brenckle *et al.*, 1997). Except for the Arrow Canyon section, *G. g. simplex* has not been recorded across the Mid-Carboniferous boundary. On the other hand, *G. bilineatus* is recorded in all sections including the Arrow Canyon and Japanese sections. As *G. g. simplex* is not recorded either in the Hina Limestone or in the Atetsu Limestone, I presume that the ancestor of *Declinognathodus* species is *G. bilineatus*.

3. Co-occurrence of Mississippian and Pennsylvanian conodonts

Precise observations on the stratigraphic occurrence of conodont faunas across the Mid-Carboniferous boundary in the Hina Limestone reveal that "Mississippian" conodonts co-occur with *Declinognathodus* species (see Table 1 and Figure 4). Koike (1967) had already reported this unique conodont composition in his *Gnathodus bilineatus-Declinognathodus noduliferus* Zone in the Atetsu Limestone. However, Lane and Straka (1974) did not approve of the co-occurrence of Mississippian conodonts and *Declinognathodus* species in the Atetsu Limestone and they assigned *D. noduliferus* (="*Gnathodus nodulifera*" by Koike, 1967) to *G. girtyi simplex*.

The holotype of *Gnathodus girtyi simplex* Dunn (1965, pl. 140, fig. 3a) has only one large node in the posterior half of the platform, while the specimen of "*G. nodulifera*" shown by Koike (1967, pl. 3, fig. 10) has four distinctive nodes. Therefore, Koike's "*G. nodulifera*" should be taxonomically included in *Declinognathodus inaequalis*.

Co-occurrence of Mississippian conodonts and *Declinognathodus* species across the Mid-Carboniferous boundary is not peculiar in Japan but widespread in several regions; e.g., in the Aksu-I and Luosu sections (see Figures 9 and 10).

4. Notes on *Neolochriea* gen. nov.

Above the Mid-Carboniferous boundary in the Hina Limestone, a new conodont genus *Neolochriea* appears (described later). *Neolochriea nagatoensis* first appears at the H 63.8 level, that is, slightly higher than the last occurrence datum of *Lochriea commutata* (H 63). Above H 63.8, three new species of *Neolochriea* appear. Except for *N. koikei* sp. nov. the stratigraphic ranges of *Neolochriea* species are very short. The occurrence of *N. nagatoensis, N. hisayoshii* sp. nov., and *N. hisaharui* sp. nov. are restricted to the *Neolochriea nagatoensis* Zone in the Hina Limestone. On the other hand, *N. koikei* first appears at the H 67.5 level and ranges upto the H 71 level in the Hina Limestone.

Neolochriea koikei sp. nov. closely resembles some of the *Idiognathoides* species, such as *I. pacificus* and *I. convexus*, but the former differs from the latter by the absence of the sulcus. The *Idiognathoides* species are dominant in the Late Carboniferous. They survived at the stratigraphically higher level in the measured section. *Lochriea, Neolochriea*, and *Idiognathoides* species occur successively also from other seamount limestones in the Akiyoshi Terrane of southwest Japan. Considering the resemblance of form and the successive faunal appearance of these species in the Hina Limestone, I suppose that the *Neolochriea* species may be a transitional form which is derived from *Lochriea* and evolves into *Idiognathoides*. More detailed examination in other seamount limestones are necessary to confirm this hypothesis.

Conclusions

1. The following six conodont zones are established in the uppermost Mississippian and lowermost Pennsylvanian strata in the Hina Limestone in ascending order.
   (1) *Gnathodus bilineatus* Zone
   (2) *Declinognathodus inaequalis-Gnathodus bilineatus* Zone
   (3) *Declinognathodus noduliferus* Zone
   (4) *Neolochriea nagatoensis* Zone
   (5) *Neolochriea koikei* Zone
   (6) *Neognathodus symmetricus* Zone
2. According to the conventional boundary definition, the base of the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone (the first appearance level of *Declinognathodus inaequalis*) is provisionally defined as the Mid-Carboniferous boundary level in the Hina Limestone. However, the definition of the Mid-Carboniferous boundary should be revised by detailed faunal analyses in the future.
3. Successive faunal changes characterized by the extinction of most Mississippian conodonts and introduction of several new elements typical of the Pennsylvanian occur in the conodont fauna across the Mid-Carboniferous boundary in the Hina Limestone.
4. Co-occurrence of Mississippian conodonts with Pennsylvanian conodonts is recognized in the *Declinognathodus inaequalis-Gnathodus bilineatus* Zone to the *Declinognathodus noduliferus* Zone in the Hina Limestone.
5. A new genus *Neolochriea*, which appears above the Mid-Carboniferous boundary, may be a transitional form from *Lochriea* which evolved into *Idiognathoides*.

Systematic paleontology

All of the conodont specimens figured in the present paper are registered and stored in the collections of the Department of Earth Sciences, Faculty of Science, Chiba University (DESC).

Genus **Declinognathodus** Dunn, 1966

Type species.—*Cavusgnathus nodulifera* Ellison and Graves, 1941

Declinognathodus inaequalis (Higgins, 1975)

Figures 12-1—5

Idiognathoides noduliferus inaequalis Higgins, 1975, p. 53, pl. 12, figs. 1-7, 12, pl. 14, figs. 11-13, pl. 15, figs. 10, 14; Metcalfe, 1980, p. 306, pl. 38, figs. 10-12, 15.

Gnathodus nodulifera (Ellison and Graves). Koike, 1967, p. 297, 298, pl. 3, fig. 10 (only).

Idiognathoides noduliferus (Ellison and Graves). Igo and Koike, 1968, p. 28, 29, pl. 3, figs. 8, 9 (only).

Declinognathodus noduliferus (Ellison and Graves). Grayson *et al.*, 1985, p. 163, pl. 1, figs. 1, 5, 10 (only); Nigmadganov and

Nemirovskaya, 1992, pl. 3, figs. 5, 8 (only); Brenckle *et al.*, 1997, pl. 1, figs. 2-4.

Declinognathodus noduliferus inaequalis (Higgins). Higgins, 1985, pl. 6.2, figs. 11, 12, 14, pl. 6.3, figs. 1, 4; Li *et al.*, 1987, pl. 1, figs. 3, 4; Nemirovskaya, 1987, pl. 1, figs. 6, 10, 13, 14; Wang *et al.*, 1987a, p. 126, 127, pl. 3, figs. 1, 2, pl. 6, fig. 10; Wang *et al.*, 1987b, pl. 2, fig. 1; Wang and Higgins, 1989, p. 276, pl. 13, figs. 5, 12; Nemirovskaya *et al.*, 1990, pl. 4, figs. 3-18, 20-22, 24, 28.

Declinognathodus noduliferus noduliferus (Ellison and Graves). Higgins, 1985, pl. 6.3, fig. 7 (only).

Declinognathodus inaequalis (Higgins). Riley *et al.*, 1987, pl. 3, figs. 28-40; Kulagina *et al.*, 1992, pl. 30, figs. 5, 6, 11.

Declinognathodus noduliferus (Ellison and Graves). Grayson *et al.*, 1990, p. 363, 364, pl. 1, fig. 22 (only).

Description.—Blade is as long as platform or slightly longer than it. It is straight or slightly curved inward, and continues onto platform as a carina. Carina bends slightly on the anterior part of the unit and straightens on the posterior end. Parapet is well developed along the inner lateral platform and fuses with the carina to form transverse ridges on posterior part of unit. Median trough is rather deep. Nodes are developed along the anterior part of outer lateral platform and form a straight line. Four or more nodes are present.

Remarks.—*Declinognathodus inaequalis* was originally described by Higgins (1975) from the *Homoceras subglobosum* Zone of the central Pennines region in England. It is characterized by having four or more nodes on the outer lateral platform. The Hina specimens are quite congruent with the original ones.

Gnathodus nodulifera described by Koike (1967) from the Atetsu Limestone seems to be divisible into three species of *Declinognathodus* by the difference in the number of outer nodes. The specimen illustrated in plate 3, figure 10 of Koike (1967) has four nodes and can be included in *D. inaequalis*.

Two specimens of *Idiognathoides noduliferus* illustrated by Igo and Koike (1968) from the Panching Limestone, west Malaysia, also have four nodes. Metcalfe (1980) restudied the conodont faunas of the Panching Limestone and established the *Idiognathoides noduliferus inaequalis*-*Gnathodus commutatus* Subzone in the lower part of this limestone. He reported that the Mississippian conodonts and *D. inaequalis* occur together in samples of this subzone. In the Hina Limestone, *D. inaequalis* also occurs with Mississippian conodonts from the *Declinognathodus inaequalis*-*Gnathodus bilineatus* Zone to the *D. noduliferus* Zone. The first appearance of *D. inaequalis* defines the Mid-Carboniferous boundary in the Hina Limestone.

Materials.—DESC-95347 from H 62.7, DESC-95348 from H 62.8, DESC-95349 from H 62.7, DESC-95352 from H 66, DESC-96006 from H 61.2.

Declinognathodus japonicus (Igo and Koike, 1964)

Figures 12-9—12

Streptognathodus japonicus Igo and Koike, 1964, p. 188, 189, pl. 28, figs. 5-23.

Declinognathodus nevadensis Dunn, 1966, p. 1300, pl. 158, figs. 4, 8.

Idiognathoides aff. *noduliferus* (Ellison and Graves). Lane, 1967, p. 938, pl. 123, figs. 9-11, 13, 16, 17.

?*Gnathodus nodulifera* (Ellison and Graves). Koike, 1967, p. 297, 298, pl. 3, fig. 9 (only).

Gnathodus japonicus (Igo and Koike). Higgins and Bouckaert, 1968, p. 35, 36, pl. 4, figs. 1, 2, 4.

Idiognathoides noduliferus (Ellison and Graves). Igo and Koike, 1968, p. 28, 29, pl. 3, figs. 10, ?12 (only); Thompson, 1970, p. 1046, pl. 139, figs. 2, 3, 5, 6, 20 (only).

Streptognathodus noduliferus (Ellison and Graves). Webster, 1969, p. 48, 49, pl. 4, fig. 7 (only).

Idiognathoides noduliferus japonicus (Igo and Koike). Higgins, 1975, p. 54, pl. 14, figs. 7-10; Metcalfe, 1980, p. 306, pl. 38, figs. 14, 17.

Declinognathodus noduliferus (Ellison and Graves). Grayson *et al.*, 1985, p. 163, pl. 1, figs. 13, 18, 25 (only); Lane *et al.*, 1985, figs. 7-D, E, F, G; Nigmadganov and Nemirovskaya, 1992, pl. 3, figs. 3, 9, 11, 13, 14, 17 (only).

Declinognathodus noduliferus japonicus (Igo and Koike). Higgins, 1985, pl. 6.3, figs. 2, 9; Nemirovskaya, 1987, pl. 1, figs. 12, 15, 19; Wang and Higgins, 1989, p. 276, pl. 1, figs. 6-9.

Declinognathodus praenoduliferus Nigmadganov and Nemirovskaya, 1992, pl. 2, figs. 10, 11, pl. 3, fig. 2 (only).

Declinognathodus japonicus (Igo and Koike). Kulagina *et al.*, 1992, pl. 30, figs. 12-15, 17.

Description.—Blade is almost as long as platform. It is slightly curved inward, and continues onto platform as a carina. Carina is slightly bent on the anterior part of unit and curves slightly inward on the posterior end. A parapet is developed along inner lateral platform. Median trough is shallow and extends between the carina and parapet to near the posterior end of platform. Only a single node is developed at anterior part of outer lateral platform.

Remarks.—This species is characterized by having a single node on the outer lateral platform. The presence of a thick carina ornamented with node-like ridges, a distinctive single node, and a small ridge on the outer side of the carina were illustrated on the holotype of *Declinognathodus japonicus*. All specimens listed in synonymy have a single distinctive node on the outer side of the carina. The holotype of *D. nevadensis* of Dunn (1966), *Idiognathoides* aff. *noduliferus* of Lane (1967), and *Streptognathodus noduliferus* of Webster (1969) also have a single distinctive node on the outer side of the carina. Therefore, they can be assigned to *D. japonicus*.

The specimen of *Gnathodus nodulifera* illustrated by Koike (1967, pl. 3, fig. 9) has a single node but it is very small. This small specimen may be an immature form and therefore is questionably included as a synonym. Three specimens illustrated as *Declinognathodus praenoduliferus* by Nigmadganov and Nemirovskaya (1992, pl. 2, figs. 10, 11, and pl. 3, fig. 2) have a distinctive single node on the outer side of the carina. They closely resemble the Hina specimens. For this reason they are placed in *D. japonicus*.

Materials.—DESC-95374 from H 63.5, DESC-95376 from H 63.5, DESC-96008 from H 63.2, DESC-96009 from H 63.2.

Declinognathodus noduliferus (Ellison and Graves, 1941)

Figures 12-6—8

Cavusgnathus nodulifera Ellison and Graves, 1941, p. 4, pl. 3, figs. 4, 6.
Gnathodus nodulifera (Ellison and Graves). Koike, 1967, p. 297, 298, pl. 3, figs. 11, 12 (only).
Gnathodus noduliferus (Ellison and Graves). Higgins and Bouckaert, 1968, p. 33, 34, pl. 2, figs. 6, 12.
Idiognathoides noduliferus (Ellison and Graves). Igo and Koike, 1968, p. 28, 29, pl. 3, figs. 7, 11 (only); Thompson, 1970, p. 1046, pl. 139, figs. 8, 16 (only); Lane and Straka, 1974, p. 85-87, figs. 35. 1-15; figs. 41. 15-17.
Streptognathodus noduliferus (Ellison and Graves). Webster, 1969, p. 48, 49, pl. 4, fig. 8 (only).
Declinognathodus noduliferus (Ellison and Graves). Dunn, 1970, p. 330, pl. 62, figs. 1, 2; Grayson *et al*., 1985, p. 163, pl. 1, figs. 9, 15 (only); Riley *et al*., 1987, pl. 3, figs. 41-47; Nigmadganov and Nemirovskaya, 1992, pl. 3, figs. 4, 6, 7, 10, 12, 15, 16 (only); Kulagina *et al*., 1992, pl. 30, figs. 2-4, 7-10.
Idiognathoides noduliferus noduliferus (Ellison and Graves). Higgins, 1975, p. 54, pl. 14, figs. 15, 16; Metcalfe, 1980, p. 306, pl. 38, figs. 16, 18.
Declinognathodus noduliferus noduliferus (Ellison and Graves). Higgins, 1985, pl. 6.2, fig. 13 (only); Li *et al*., 1987, pl. 1, fig. 1; Nemirovskaya, 1987, pl. 1, figs. 7, 9, 11, 20, 21; Wang *et al*., 1987a, p. 127, pl. 3, figs. 3-5, pl. 7, fig. 1; Wang *et al*., 1987b, pl. 1, figs. 4, 5, 8; Wang and Higgins, 1989, p. 276, 277, pl. 2, figs. 5-9.
"Declinognathodus" noduliferus (Ellison and Graves). Grayson *et al*., 1990, p. 363, 364, pl. 1, fig. 21 (only).

Description.—Blade is almost as long as platform. It is slightly curved inward, and continues onto platform as a carina. Carina is slightly bent at anterior part of unit and curves slightly inward on the posterior end. A parapet is developed along the inner lateral platform. Median trough is rather deep in anterior part of platform and rather shallow in posterior part. Two or three nodes are well developed at anterior part of outer lateral platform.

Remarks.—*Declinognathodus noduliferus* was first described by Ellison and Graves (1941). According to them, three nodes commonly extend in a row posteriorly from the junction of the blade and outer side of the platform. The specimens identified as *D. noduliferus* in this study are characterized by having two or three nodes on the outer lateral platform. All of the specimens mentioned in synonymy have also two or three nodes on the outer side of the carina.

The specimens described by Koike (1967) as *Gnathodus nodulifera* have from one to four nodes. Among them, only two specimens illustrated with two nodes (pl. 3, fig. 11) and three nodes (pl. 3, fig. 12) are assigned to *Declinognathodus noduliferus*.

Materials.—DESC-95362 from H 62.8, DESC-95365 from H 62.8, DESC-96007 from H 62.7.

Genus ***Gnathodus*** Pander, 1856

Type Species.—*Polygnathus bilineatus* Roundy, 1926

Gnathodus bilineatus (Roundy, 1926)

Figures 11-1—3.

Polygnathus bilineatus Roundy, 1926, p. 13, pl. 3, figs. 10a-c.
Gnathodus bilineatus (Roundy). Hass, 1953, p. 78, pl. 14, figs. 25-28; Higgins, 1961, pl. 10, fig. 5; Koike, 1967, p. 296, pl. 1, figs. 9-11; Wirth, 1967, p. 205, pl. 19, figs. 6-9; Igo and Koike, 1968, p. 29, pl. 3, figs. 6; Rhodes *et al*., 1969: p. 94, 95, pl. 18, figs. 14a-17d; Igo, 1973, p. 193, pl. 29, figs. 1-5 (only); Igo and Kobayashi, 1974, p. 419, 420, pl. 56, figs. 1-3; Watanabe, 1975, p. 163, pl. 14, figs. 1-5; Metcalfe, 1980, p. 302, pl. 38, figs. 5, 8, 9; Metcalfe, 1981, pl. 3, figs. 2a-4d; von Bitter and Plint-Geberl, 1982, pl. 6, figs. 8-11; Haikawa, 1988, pl. 6, fig. 11, pl. 7, figs. 3, 4; Grayson *et al*., 1990, p. 361, 362, pl. 1, fig. 1.
Gnathodus bilineatus bilineatus (Roundy). Bischoff, 1957, p. 21, 22, pl. 3, figs. 11, 15-20, pl. 4, fig. 1; Higgins and Bouckaert, 1968, p. 29, pl. 3, fig. 9; Higgins, 1975, p. 28, 29, pl. 11, figs. 1-4, 6, 7; Higgins, 1985, pl. 6.1, figs. 1, 2; Li *et al*., 1987, pl. 1, fig. 12; Riley *et al*., 1987, pl. 2, figs. 2, 4; Wang *et al*., 1987a, p. 128, pl. 1, fig. 6; Wang *et al*., 1987b, pl. 3, fig. 12; Wang and Higgins, 1989, p. 277, 278, pl. 6, figs. 7-11; Varker *et al*., 1990, pl. 1, fig. 1; Kulagina *et al*., 1992, pl. 28, figs. 4-7; Nigmadganov and Nemirovskaya, 1992, pl. 1, fig. 3.
Gnathodus modocensis Rexroad, 1957, p. 30, 31, pl. 1, figs. 15-17; Rexroad, 1958, p. 17, 18, pl. 1, figs. 1, 2.
Gnathodus smithi Clarke, 1960, p. 26, 27, pl. 4, figs. 13, 14, pl. 5, figs. 9, 10.
Gnathodus bilineatus bollandensis Higgins and Bouckaert, 1968, p. 29, 30, pl. 2, figs. 10, 13, pl. 3, figs. 4-8, 10; Higgins, 1975, p. 29, pl. 11, figs. 5, 8-13; Higgins, 1985, pl. 6.1, figs. 4, 5; Li *et al*., 1987, pl. 1, fig. 11; Riley *et al*., 1987, pl. 2, figs. 5-8, 12; Wang *et al*., 1987a, p. 128, pl. 1, figs. 7-10; Wang *et al*., 1987b, pl. 2, figs. 9, 12; Wang and Higgins, 1989, p. 278, pl. 12, figs. 8-11; Varker *et al*., 1990, pl. 1, figs. 2-12; Kulagina *et al*., 1992, pl. 28, figs. 8, 9, 12; Nigmadganov and Nemirovskaya, 1992, pl. 1, figs. 1, 2, 4; Nemirovskaya and Nigmadganov, 1993, pl. 2, fig. 1.
Gnathodus postbilineatus Nigmadganov and Nemirovskaya, 1992, pl. 1, figs. 7-9, pl. 2, figs. 1, 2, 4 (only).

Remarks.—Many workers have subdivided this species into two subspecies: *G. bilineatus bilineatus* (s.s.) and *G. b. bollandensis*. Higgins (1975) stated that distinctive characters of *G. b. bollandensis* are a narrow, rectangular to semiovate outer platform and the lack of a posterior lateral row of nodes adjacent to the carina, which is a common feature of *G. b. bilineatus*.

The Hina specimens are the nearest to *Gnathodus bilineatus bollandensis* (see Higgins, 1975, pl. 11, figs. 5, 8-13). However, some of their features seem to be in the range of variation of *G. b. bilineatus*. Although additional taxonomic study is necessary, I treated *G. b. bilineatus* (s.s.) and *G. b. bollandensis* by Higgins (1975) as a single species, *G. bilineatus*.

This species closely resembles *Gnathodus postbilineatus*, but it is distinguished from the latter by having a parapet without fusing in the carina. Six of the specimens of *G. postbilineatus* described by Nigmadganov and Nemirovskaya (1992) may be identical with *G. bilineatus*.

Materials.—DESC-95250 from H 57.2, DESC-96001 from H

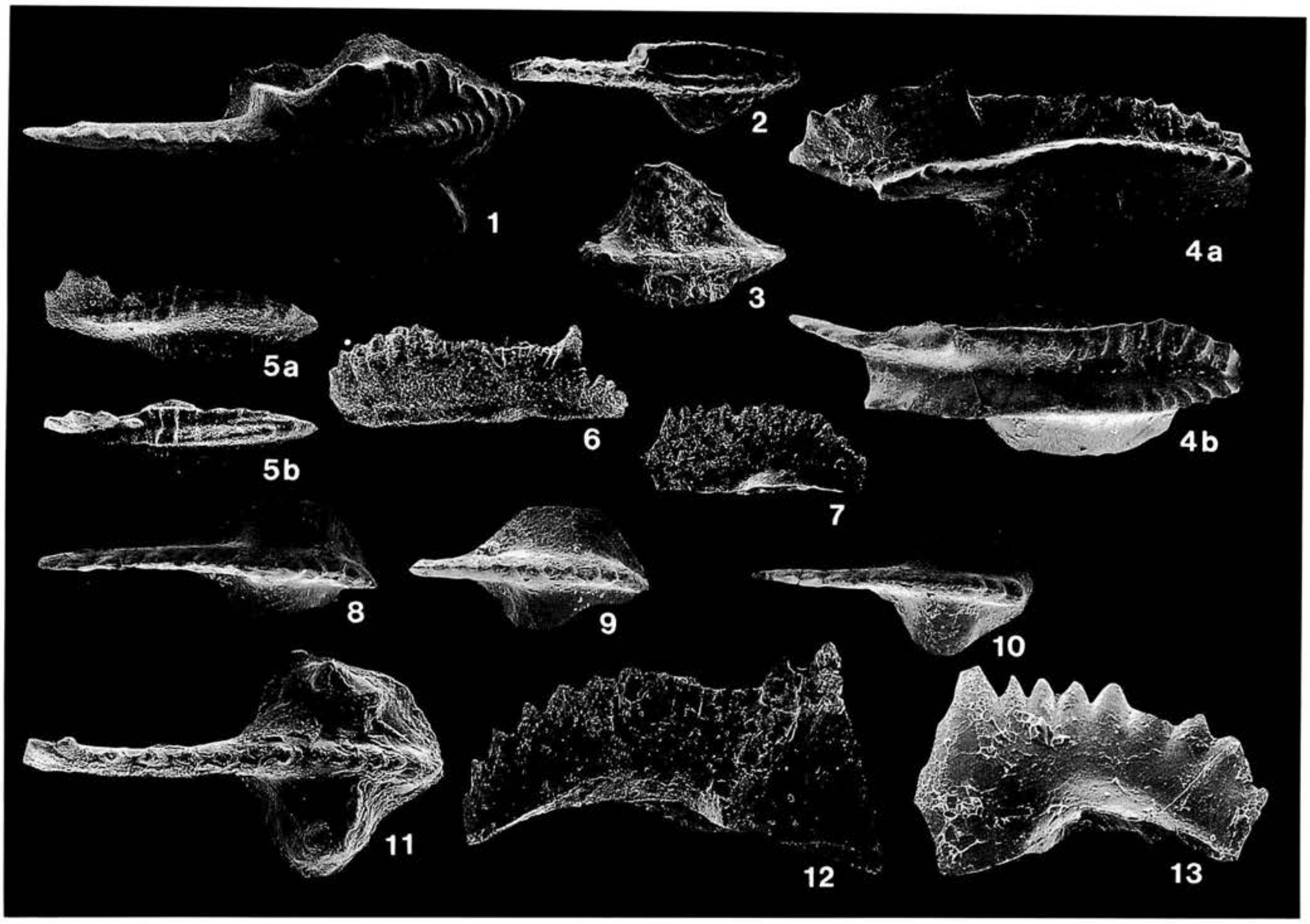


Figure 11. 1-3. *Gnathodus bilineatus* (Roundy). 1: DESC-95250 from Loc. H 57.2, upper view, ×40, 2: DESC-96001 from Loc. H 61.7, upper view, ×60, 3: DESC-96002 from Loc. H 62.5, upper view, ×60. **4a, 4b.** *Cavusgnathus unicornis* Youngquist and Miller, DESC-95258 from Loc. H 61. 4a: oblique upper view, ×60, 4b: upper view, ×60. **5a, 5b.** *Cavusgnathus* sp. indet., DESC-95261, from Loc. H 58.5. 5a: oblique upper view, ×60, 5b: upper view, ×60. **6.** *Vogelgnathus akiyoshiensis* (Igo), DESC-96003, from Loc. H 60, lateral view, ×60. **7.** *Vogelgnathus campbelli* (Rexroad), DESC-96004, from Loc. H 61.5, lateral view, ×60. **8-10.** *Lochriea commutata* (Branson and Mehl), 8: DESC-95289 from Loc. H 62.7, upper view, ×60, 9: DESC-95291 from Loc. H 62.8, upper view, ×60, 10: DESC-95293 from Loc. H 63, upper view, ×60. **11.** *Lochriea nodosa* (Bishoff), DESC-95281 from Loc. H 61.2, upper view, ×60. **12, 13.** *Hindeodus minutus* (Ellison). 12: DESC-96005 from Loc. H 59.2, lateral view, ×60, 13: DESC-95274 from Loc. H 64, lateral view, ×60.

61.7, DESC-96002 from H 62.5.

Genus ***Lochriea*** Scott, 1942

Type species.—*Spathognathodus commutatus* Branson and Mehl, 1941

Lochriea commutata (Branson and Mehl, 1941)

Figures 11-8—10

Spathognathodus commutatus Branson and Mehl, 1941, p. 98, pl. 19, figs. 1-4; Clarke, 1960, p. 19, pl. 3, figs. 4, 5.

Gnathodus inornatus Hass, 1953, p. 80, pl. 14, figs. 9-11; Stanley, 1958, p. 465, pl. 68, figs. 5, 6.

Gnathodus commutatus commutatus (Branson and Mehl). Bischoff, 1957, p. 22, pl. 4, figs. 2-6, 15; Koike, 1967, p. 269, 267, pl. 1, figs. 12-16; Wirth, 1967, p. 206, pl. 19, figs. 10, 11.

Gnathodus commutatus var. *commutatus* (Branson and Mehl). Higgins, 1961, p. 212, 213, pl. 10, fig. 6.

Gnathodus commutatus (Branson and Mehl). Stibane, 1967, p. 334, pl. 36, figs. 25-28; Higgins and Bouckaert, 1968, p. 30, pl. 2, fig. 5; Webster, 1969, p. 31, pl. 5, fig. 13; Rhodes *et al.*, 1969, p. 95, 96, pl. 19, figs. 9a-12d; Igo, 1973, p. 193, pl. 29, figs. 8-13; Igo and Kobayashi, 1974, p. 420, 421, pl. 56, figs. 6, 7; Watanabe, 1975, p. 164, pl. 14, figs. 8-11; Metcalfe, 1980, p. 309, pl. 38, figs. 3, 4; Metcalfe, 1981, p. 21, 23, pl. 7, figs. 6, 7.

Paragnathodus commutatus (Branson and Mehl). Higgins, 1975, p. 70, 71, pl. 7, figs. 7-9, 11, 13, 16, 20, 21; Belka, 1982, pl. 1, fig. 11; Grayson *et al.*, 1985, p. 169, pl. 1, fig. 24, pl. 2, fig. 19; Riley *et al.*, 1987, pl. 2, figs. 1, 3; Wang *et al.*, 1987a, p. 130, 131, pl. 2, fig. 12; Wang *et al.*, 1987b, pl. 2, fig. 2, pl. 3, fig. 10; Kulgina *et al.*, 1992, pl. 29, figs. 1, 2; Haikawa, 1988, pl. 6,

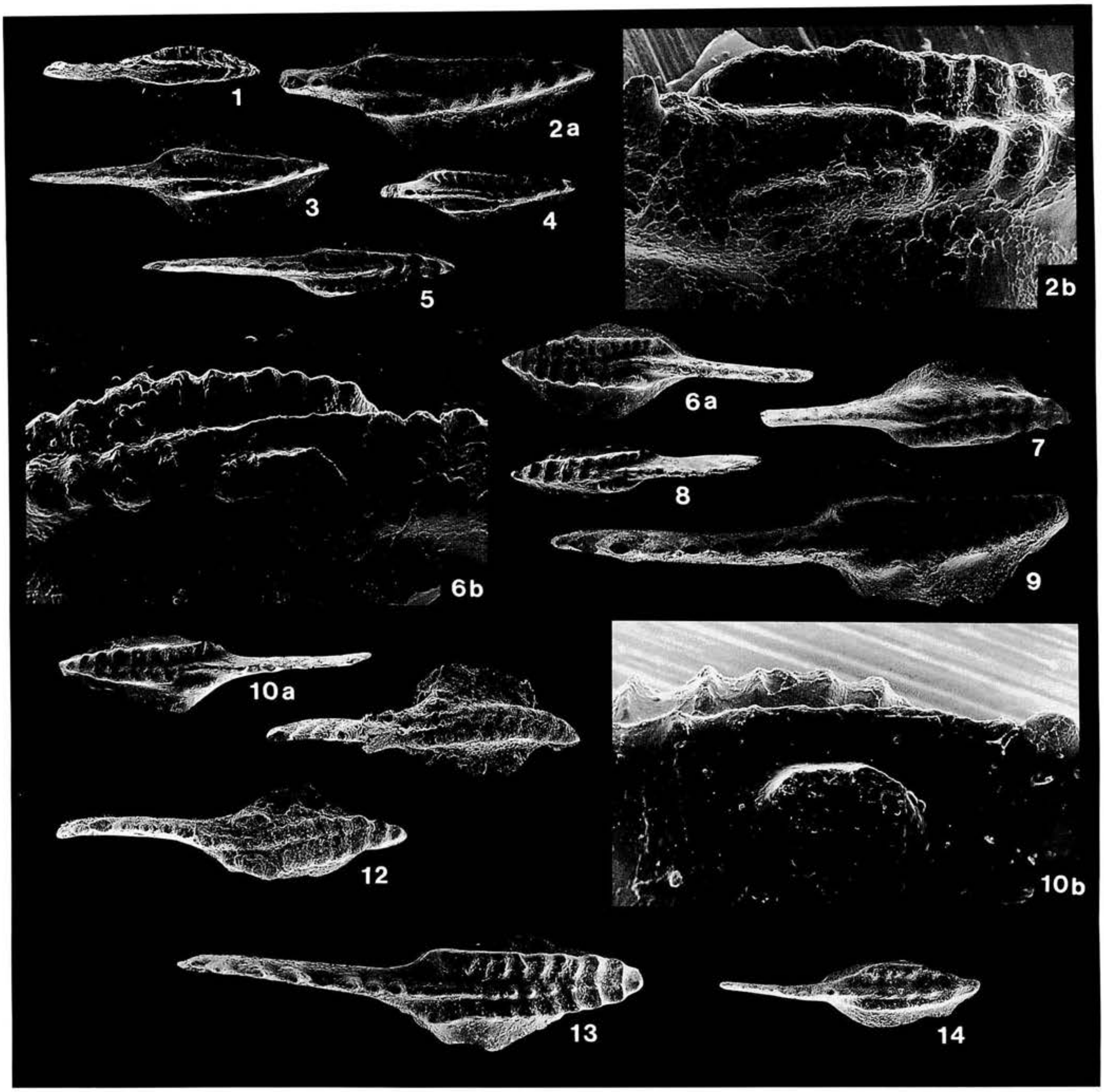


Figure 12. **1-5.** *Declinognathodus inaequalis* (Higgins). 1 : DESC-96006 from Loc. H 61.2, upper view, ×60, 2a, b : DESC-95349 from Loc. H 62.7, 2a : upper view, ×60, 2b : oblique upper view, x 180, 3 : DESC-95347 from Loc. H 62.7, upper view, ×60, 4 : DESC-95348 from Loc. H 62.8, upper view, ×60, 5 : DESC-95352 from Loc. H 66, upper view, ×60. **6-8.** *Declinognathodus noduliferus* (Ellison and Graves). 6a, b : DESC-95362 from Loc. H 62.8, 6a : upper view, ×60, 6b : oblique upper view, ×180, 7 : DESC-95365 from Loc. H 62.8, upper view, ×60, 8 : DESC-96007 from Loc. H 62.7, upper view, ×60. **9-12.** *Declinognathodus japonicus* (Igo and Koike). 9 : DESC-96008 from Loc. H 63.2, upper view, ×60, 10a, b : DESC-96009 from Loc. H 63.2, 10a : upper view, ×60, 10b : oblique upper view, ×300, 11 : DESC-95374 from Loc. H 63.5, upper view, ×60, 12 : DESC-95376 from Loc. H 63. 5, upper view, ×60. **13, 14.** *Neognathodus symmetricus* (Lane). 13 : DESC-95390 from Loc. H 70.5, upper view, ×60, 14 : DESC-95389 from Loc. H 68.8, upper view, ×60.

figs. 1, 2. ; Wang and Higgins, 1989, p. 285, pl. 8, figs. 4, 5 ; Nemirovskaya *et al.*, 1990, pl. 3, fig. 4.

Lochriea commutata (Branson and Mehl). Higgins, 1985, pl. 6.1, fig. 10 ; Varker and Sevastopulo, 1985, pl. 5.5, figs. 11, 12 ; Rexroad and Horowitz, 1990, p. 508, 509, pl. 2, figs. 18-23 [Pa element] ; Nemirovskaya *et al.*, 1994, pl. 2, fig. 1.

Remarks.—This species has an unornamented platform that is broadly ovate in oral view and a carina that includes laterally expanded denticles with a curious polygonal pattern on part of its surface. The carina of *Lochriea commutata* is similar to that of *Neolochriea nagatoensis* in shape, but the denticles of the former are like thick needles, whereas those of the latter are less sharp and similar to spherical knolls.

This species was originally described by Branson and Mehl (1941) from the Chesterian Pitkin Limestone in North America. Grayson *et al.*, (1985) reported that it occurs together with *Declinognathodus noduliferus* in the Rhoda Creek Formation of Oklahoma, and ranges up to the uppermost part of their surveyed section (the *Declinognathodus noduliferus* Zone). In the Hina Limestone, this species is found commonly in the lower part of the *Declinognathodus noduliferus* Zone. In the Zhelvakovaya Valley section, this species also occurs with *D. noduliferus* in strata above the Mid-Carboniferous boundary (Nemirovskaya *et al.*, 1990). Therefore, the range of *Lochriea commutata* extends beyond the Mid-Carboniferous boundary.

Materials.—DESC-95289 from H 62.7, DESC-95291 from H 62.8, DESC-95293 from H 63.

Lochriea nodosa (Bischoff, 1957)

Figure 11-11

Gnathodus commutatus nodosus Bischoff, 1957, p. 23, 24, pl. 4, figs. 12, 13 ; Higgins, 1961, p. 213, pl. 10, figs. 7, 8 ; Koike, 1967, p. 297, pl. 1, fig. 19 ; Wirth, 1967, p. 207, pl. 19, figs. 13-18.

Gnathodus commutatus var. *nodosus* Bischoff. Higgins, 1961, p. 213, pl. 10, figs. 7, 8.

Gnathodus nodosus (Bischoff). Higgins and Bouckaert, 1968, pl. 2, fig. 2 (only) ; Rhodes *et al.*, 1969, p. 104, 105, pl. 19, figs. 16a-20c ; Igo, 1973, p. 194, pl. 29, figs. 14-17 ; Igo and Kobayashi, 1974, p. 421, pl. 56, figs. 8-12 ; Watanabe, 1975, p. 164, pl. 14, figs. 12-16 ; Metcalfe, 1980, p. 304, pl. 38, fig. 2 ; Metcalfe, 1981, pl. 6, figs. 1-5.

Paragnathodus nodosus (Bischoff). Higgins, 1985, pl. 6.1, fig. 9 ; Li *et al.*, 1987, pl. 1, fig. 7 ; Riley *et al.*, 1987, pl. 2, figs. 10, 11, 13, 14 ; Wang *et al.*, 1987a, p. 131, pl. 1, figs. 3-5 ; Haikawa, 1988, pl. 7, figs. 8, 9 ; Wang *et al.*, 1987b, pl. 1, fig. 9, pl. 2, fig. 10 ; Wang and Higgins, 1989, p. 285, 286, pl. 8, figs. 6, 7 ; Nemirovskaya *et al.*, 1990, pl. 3, figs. 3, 9 ; Kulagina *et al.*, 1992, pl. 29, fig. 13.

Lochriea nodosa (Bischoff). Nemirovskaya *et al.*, 1994, pl. 1, fig. 8, pl. 2, fig. 6.

Remarks.—This species differs from *Lochriea commutata* in having a platform ornamented with several nodes or ridges. Recently, Nemirovskaya *et al.* (1994) stated that *L. commutata* and *L. cracoviensis*, both having simple unornamented platforms, are the earliest representatives of the genus *Lochriea*. They also stated that *Lochriea* species with ornamented platforms first appear during the late Visean or earliest Serpukhovian, and may be valuable for correlation. They recognized eight species in total of *Lochriea* with ornamented platforms : *L. mononodosa*, *L. nodosa*, *L. cruciformis*, *L. multinodosa*, *L. monocostata*, *L. costata*, *L. ziegleri*, and *L. senckenbergica*.

Among the Japanese *Lochriea* specimens, species with ornamented platforms are less common. Their biostratigraphic significance is unclear at present. In this study, I treat these forms with ornamented platforms from the Hina Limestone as *L. nodosa*.

Material.—DESC-95281 from H 61.2.

Genus ***Neognathodus*** Dunn, 1970

Type species.—*Polygnathus bassleri* Harris and Hollingsworth, 1933

Neognathodus symmetricus (Lane, 1967)

Figures 12-13, 14

Gnathodus bassleri symmetricus Lane, 1967, p. 935, pl. 120, figs. 2, 13, 14, 17, pl. 121, figs. 6, 9.

Gnathodus wapanuckensis (Harlton). Koike, 1967, p. 300, pl. 1, figs. 22-25.

Gnathodus bassleri (Harris and Hollingsworth). Webster, 1969, p. 29, pl. 5, fig. 14 (only).

Neognathodus bassleri (Harris and Hollingsworth). Dunn, 1970, p. 336, pl. 64, figs. 1a-c, 12 (only).

Neognathodus bassleri symmetricus (Lane). Lane and Straka, 1974, p. 96, figs. 37. 22, 31, 32, 37-39, figs. 39. 16-18, 21-24.

Neognathodus symmetricus (Lane). Grayson, 1984, p. 51, pl. 2, fig. 7 ; Li *et al.*, 1987, pl. 1, fig. 6 ; Wang *et al.*, 1987a, p. 130, pl. 3, figs. 6, 7, pl. 7, figs. 3, 4, 8, 12, pl. 8, figs. 2-5 ; Wang *et al.*, 1987b, pl. 2, fig. 6, pl. 3, fig. 4 ; Wang and Higgins, 1989, p. 282, 283, pl. 2, figs. 1-4 ; Grayson *et al.*, 1990, p. 377, 378, pl. 3, fig. 23 ; Nigmadganov and Nemirovskaya, 1992, pl. 4, figs. 1, 7.

Description.—Platform is almost symmetrical in oral view and consists of prominent straight carina and two well developed parapets. Carina is nodular and extends near posterior end of platform. Two parapets are ornamented by transversely ridged nodes.

Remarks.—This species differs from *Neognathodus bassleri* in being a nearly symmetrical platform and in having the carina centered between the margins of the platform.

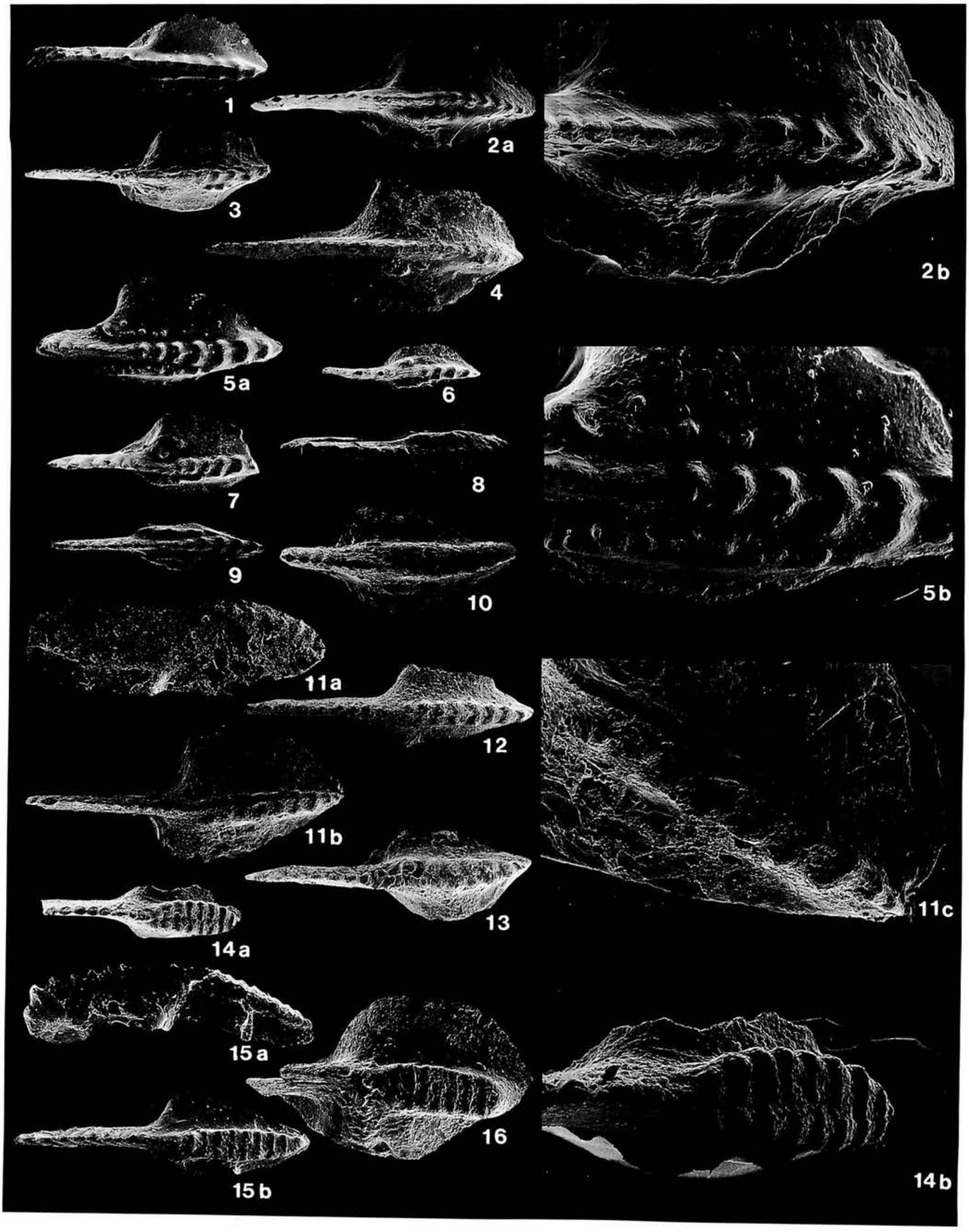
The specimens of *Gnathodus wapanuckensis* described by Koike (1967) from the Kodani Formation of the Atetsu Limestone have a narrow symmetrical platform, and are here assigned to *Neognathodus symmetricus*.

Materials.—DESC-95389 from H 68.8, DESC-95390 from H 70.5.

Genus ***Neolochriea*** gen. nov.

Type species.—*Neolochriea hisaharui* Mizuno gen. et sp. nov.

Diagnosis.—Scaphate pectiniform elements with free


1
2a
2b
3
4
5a
5b
6
7
8
9
10
11a
11b
11c
12
13
14a
14b
15a
15b
16

blade, smooth platform, and nodular carina. Blade is about half element length and possesses low denticles. Platform is oval or elliptical in form. Carina is long, ornamented with weakly nodes or ridges, and extends to posterior end of platform. Basal cavity is large.

Remarks.—*Neolochriea* gen. nov. differs from *Lochriea* Scott, 1942 in having a long and pointed posterior platform, from *Ferganaegnathodus* Nemirovskaya and Nigmadganov, 1993 in having a nodular carina, and from *Idiognathoides* Harris and Hollingsworth, 1933 in absence of a sulcus at the anterior part of the platform. The following four species are referable to the genus *Neolochriea*: *N. nagatoensis*, *N. hisayoshii* sp. nov., *N. hisaharui* sp. nov., and *N. koikei* sp. nov. I have recovered these *Neolochriea* species from other seamount limestones in the Akiyoshi Terrane of southwest Japan, such as the Akiyoshi, Taishaku, Atetsu, and Omi Limestones. All of the *Neolochriea* species appear between the last occurrence of *Lochriea* species and the first occurrence of *Idiognathoides* species. Therefore, *Neolochriea* gen. nov. may derive from *Lochriea* and evolve into *Idiognathoides* during the Early Pennsylvanian.

Etymology.—From *neo* (Greek) meaning "new" and *lochriea*, referring to the genus *Lochriea*, therefore "new" *Lochriea*.

Geological age.—Earliest Late Carboniferous or earliest Pennsylvanian.

Neolochriea hisaharui sp. nov.

Figures 13-10—13

Gnathodus commutatus nagatoensis Igo and Koike, 1965, p. 89, pl. 9, fig. 10 (only); Koike, 1967, p. 297, pl. 1, fig. 18 (only).

Diagnosis.—Blade is as long as platform or slightly longer than it and continues as a carina. Carina bends slightly on the anterior part of the platform and straightens on the posterior end. Long straight carina continues to posterior end of platform as narrow, low, and node-like denticles. Outer and inner surfaces of platform are smooth.

Description.—In upper view, the unit is elliptical and pointed at posterior end of platform. Long blade continues posteriorly as a carina. Carina is long, relatively thick, straight, rising above smooth platform, and ornamented with two rows of nodes. A very shallow groove curves between the rows toward the posterior part of the carina. The groove vanishes about two-thirds of the distance from the anterior part of the carina, where the nodes fuse into a single row.

In lateral view, blade is high and long. Denticles of blade are very low. One of the anterior denticles is slightly higher and pointed. Underside of platform is flat and upper side is slightly arched.

In aboral view, the basal cavity is deep and widely flaring anteriorly.

Remarks.—*Neolochriea hisaharui* sp. nov. is similar to *N. nagatoensis*, but can be distinguished from the latter by the difference in width of the carina. This new species has a thickened carina with a very shallow groove, whereas *N. nagatoensis* has a narrow carina without the groove. Among the specimens illustrated as *N. nagatoensis*, one specimen of Igo and Koike (1965, pl. 9, fig. 10) and another specimen of Koike (1967, pl. 1, fig. 18) have a thickened carina with a shallow groove. They are considered to be identical with the present new species.

Neolochriea hisaharui sp. nov. is similar to *Gnathodus glaber* described by Wirth (1967) from the Quinto Real of the Western Pyrenees in Spain, but the former differs from the latter in having an elliptical platform and a relatively thick carina. In *N. hisaharui* sp. nov. the carina is ornamented by two rows of nodes, but in *G. glaber* the carina comprises only a single narrow row of nodes.

Etymology.—The specific name is dedicated to Professor Hisaharu Igo, Department of Astronomy and Earth Sciences, Tokyo Gakugei University, who has contributed much to the progress of Late Paleozoic conodont taxonomy and biostratigraphy in Japan.

Materials.—Holotype: DESC-95326 from H 65.5; Paratypes: DESC-95323 from H 65.5, DESC-95324 from H 65.5, DESC-95325 from H 65.5.

Neolochriea hisayoshii sp. nov.

Figures 13-5—9

Gnathodus opimus Igo and Koike, 1965, p. 89, pl. 9, figs. 5-8 (only).

Diagnosis.—Blade is almost as long as carina, and continues onto a carina. Long and straight carina bends slightly on the anterior part of the platform and straightens on the posterior end. Carina continues to posterior end of unit, forming a long narrow row of low node-like denticle. Outer and inner sides of carina are ornamented with parapet-like row of nodes. Outer and inner surfaces of platform are smooth.

Description.—In upper view, unit is elliptical and pointed at

Figure 13. **1-4.** *Neolochriea nagatoensis* (Igo and Koike). 1: DESC-95301 from Loc. H 64, upper view, ×60, 2a, b: DESC-95300 from Loc. H 64, 2a: upper view, ×60, 2b: upper view, ×180, 3: DESC-95302 from Loc. H 64, upper view, ×60, 4: DESC-95303 from Loc. H 64, upper view, ×60. **5-9.** *Neolochriea hisayoshii* sp. nov. 5a, b: holotype, DESC-95313, from Loc. H 64.5, 5a: upper view, ×60, 5b: upper view, ×180, 6: paratype, DESC-95310 from Loc. H 64.5, upper view, ×60, 7: paratype, DESC-95312 from Loc. H 64.5, upper view, ×60, 8: paratype, DESC-95316 from Loc. H 66, upper view, ×60, 9: paratype, DESC-95311 from Loc. H 64.5, upper view, ×60. **10-13.** *Neolochriea hisaharui* sp. nov. 10: paratype, DESC-95325 from Loc. H 65.5, upper view, ×60, 11a-c: holotype, DESC-95326 from Loc. H 65.5, 11a: lateral view, ×60, 11b: upper view, ×60, 11c: upper view, ×180, 12: paratype, DESC-95324 from Loc. H 65.5, upper view, ×60, 13: paratype, DESC-95323 from Loc. H 65.5, upper view, ×60. **14-16.** *Neolochriea koikei* sp. nov. 14a,b: holotype, DESC-95334 from Loc. H 67.5, 14a: upper view, ×60, 14b: upper view, ×180, 15a, b: paratype, DESC-95335 from Loc. H 68.5, 15a: lateral view, ×60, 15b: upper view, ×60, 16: paratype, DESC-95336 from Loc. H 68.5, upper view, ×60.

the posterior end of the platform. The long blade extends onto a carina. The carina is flanked by parapet-like row of nodes in both sides. The inner row of nodes fuses to the carina at posterior part of carina. The outer row of nodes fades out in the middle part of the carina.

In lateral view, blade is high and long. Denticles of blade are low and rounded. The anterior part of the blades is slightly higher and pointed.

In aboral view, large basal cavity is present.

Remarks.—*Neolochriea hisayoshii* sp. nov. differs from *N. hisaharui* sp. nov. in having a row of nodes on both the inner and outer sides of the carina.

Igo and Koike (1965) reported *Gnathodus opimus* from the Uzura quarry of the Akiyoshi Limestone. Among the specimens which they illustrated, four specimens (Igo and Koike, 1965, pl. 9, figs. 5-8) have parapet-like nodes on both side of the carina. They are considered to be identical with the present new species.

Neolochriea hisayoshii sp. nov. is similar to *Ferganaegnathodus ferganaensis* described by Nemirovskaya and Nigmadganov (1993) from the Gażskaya Formation (Lower Bashkirian) of Middle Asia, but the former differs from the latter in possessing a denticulate carina.

Etymology.—The specific name is dedicated to Professor Emeritus Hisayoshi Igo, Institute of Geoscience, University of Tsukuba, who has led conodont study in Japan.

Materials.—Holotype: DESC-95313 from H 64.5; Paratypes: DESC-95310 from H 64.5, DESC-95311 from H 64.5, DESC-95312 from H 64.5, DESC-95316 from H 66.

Neolochriea koikei sp. nov.

Figures 13-14—16

Diagnosis.—Blade is as long as platform or slightly longer than it, almost straight, and attaches onto the carina in a straight line and continues as a long thick carina. The carina expands laterally on the posterior end of the platform to form a transverse ridge. Outer and inner surfaces of the platform are smooth.

Description.—In upper view, the platform is elliptical and pointed at posterior end. Long blade continues as a thick carina. Carina expands into a long, elliptical flat surface that is ornamented with transverse ridges and joined with the blade in a straight line. A longitudinal sulcus or groove is absent at the anterior part of the platform.

In lateral view, the attachment part between blade and platform is slightly arched. Blade is high and platform is lower than blade. Denticles of blade are low and pointed. Under and upper side of platform is almost flat.

In aboral view, a typical gnathodid basal cavity is present.

Remarks.—*Neolochriea koikei* sp. nov. differs from *Neolochriea hisaharui* sp. nov. in having a thick and wide carina. The carina of the former species has remarkable transverse ridges and is washboard-like.

Neolochriea koikei sp. nov. closely resembles *Idiognathoides convexus* described by Ellison and Graves (1941) from the Dimple Limestone (Lower Pennsylvanian), but the latter differs from the former in having a longitudinal sulcus at the anterior of the platform. *I. pacificus* described by Savage and Barkeley (1985) from the Klawak Formation (Lower Pennsylvanian) of Alaska also resembles *N. koikei* sp. nov., but the former differ from the latter in having a short groove at the anterior of the platform. *N. koikei* sp. nov. has neither a sulcus nor groove. Considering the resemblance and stratigraphic ranges among these species, I suppose that *N. koikei* sp. nov. may evolve into these *Idiognathoides* species.

Etymology.—The specific name is dedicated to Professor Toshio Koike, Institute of Geology, Yokohama National University, for his active research on conodont biostratigraphy.

Materials.—Holotype: DESC-95334 from H 67.5; Paratypes: DESC-95335 from H 68.5, DESC-95336 from H 68.5.

Neolochriea nagatoensis (Igo and Koike, 1965)

Figures 13-1—4

Gnathodus commutatus nagatoensis Igo and Koike, 1965, p. 89, pl. 9, figs. 9, 11-12 (only); Koike, 1967, p. 297, pl. 1, fig. 17 (only).

Gnathodus nagatoensis Igo and Koike. Igo and Kobayashi, 1974, p. 421, pl. 56, figs. 14, 15.

Description.—In upper view, platform is broadly ovate and consists of a prominent, slightly bending carina. Oral surface of platform is smooth. The long blade attaches to the platform and continues as a carina. Only inner side adjacent to the carina is ornamented with a row of nodes. The nodes form a line along the carina and fuse at the posterior part of the platform.

Remarks.—*Neolochriea nagatoensis* resembles *Lochriea commutata*, but the former differs from the latter in having a row of nodes on the inner side of carina. *N. nagatoensis* also resembles *N. hisayoshii* sp. nov., but the former differs from the latter in having the nodes on only one side of the carina. Considering the resemblance of form and the appearance of these species, I suppose that *N. nagatoensis* may derive from *L. commutata* and evolve into *N. hisayoshii* sp. nov.

Materials.—DESC-95300 from H 64, DESC-95301 from H 64, DESC-95302 from H 64, DESC-95303 from H 64.

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