
Conodonts from the Induan-Olenekian boundary interval at Mud, Spiti

Orchard, M.J.¹ and Krystyn, L.²

¹ Geological Survey of Canada, 625 Robson St., Vancouver, BC, V6B 5J3, Canada.

morchard@nrcan.gc.ca

² Institut für Paläontologie-Geozentrum, A-1090 Wien, Althanstrasse 14, Austria. leopold.krystyn@univie.ac.at

Introduction

Two localities are candidates for the GSSP of the Induan-Olenekian boundary (IOB): West Pingdingshanensis in Chaohu, Anhui Province, China (Tong et al., 2004), and the Muth section, situated in the Lahul and Spiti district of the northern Himachal Pradesh State of India in the Western Himalayas (Krystyn et al., 2005). The former has been the subject of several studies in which its fauna and other features have been described (Tong, 2005; Tong & Zacharov, 2004; Tong et al., 2005, 2006a, b). The conodonts from Chaohu are summarised by Zhao et al. (2004; in press). In order to make comparisons between the two candidates, the conodont succession in Spiti is here summarized and compared with that from Chaohu.

The Lower Triassic in Spiti (Bhargava et al., 2004) is represented by the Mikin Formation (formerly Tamba Kurkur Fm.), which consists of three members named after their distinctive ammonoid fauna: 1) 3 m meters thick *Gyronites* beds (the former *Meekoceras* beds of Krafft); 2) 2 meters thick *Flemingites* beds (including the IOB beds); and 3) up to 10 m thick *Parahedenstroemia* beds. The Mikin Formation extends from Muth north-west along a tributary valley for several kilometers to the crest between the Pin and Parahio valleys. One of us (LK) sampled the continuously exposed beds at four sites on the northern valley slope, one 100 m above the village called M-03, and the others between 3900 and 4100m named M-04 to M-06. Strata covering the I-O boundary interval were assigned to beds 10 through 16, many of which were subdivided into sub-beds for sampling. A comprehensive geological description of the Muth site is to be found in Krystyn et al. (2004).

Ammonoid succession

The essential features of the ammonoid succession are described elsewhere (Krystyn, this volume). These can be summarized thus:

Bed 10 – assigned to the *Gyronites* (former *Meekoceras*) beds, and containing *Gyronites frequens* and *Himoceras*.

Beds 11-16 – assigned to the *Flemingites* beds and divided into the following layers:

Beds 11, 12A, 12B, 12C - the *Meekophiceras? vercherei* beds (0.4-0.6 m)

Beds 13A, 13B, 13C, 14A, 14B, 14C - the *Rohillites rohilla* Zone (0.9 m)

Beds 15A, 15B, 15C, 16A - the basal *Flemingites* – *Euflemingites* Zone (0.3m)

Conodont succession

Conodonts were recovered from a total of 21 samples (Table 1). A generally consistent conodont faunal succession was established in sections M-03 and M-04 in beds 12C, 13A, 13C, 14C, and 15 (A+B) with each showing a simultaneous appearance of *Ns. posterolongatus* Zhao & Orchard plus *Ns. waageni* Sweet sensu lato in bed 13, and a later appearance of *Ns. spitiensis* Goel in bed 15. Bed 11 showed some differences between M-03 and M-04 but they are not anomalous in the succession. Sections M-03 and M-06 yielded a similar fauna in bed 13B. Single samples from beds 10, 12A, 12B, 14A, 14B, and 16 in sections M-03 and M-04 showed no significant variance in terms of FADs and LADs.

The lowest horizon, bed 10, representing the *Gyronites* beds, contains a relatively diverse fauna consisting of three morphotypes of *Ns. dieneri* Sweet newly recognized by Zhao et al. (in press), plus *Ns. cristagalli* (Huckriede), and uncommon occurrences of *Ns. chii* Zhao & Orchard and *Ns. concavus* Zhao & Orchard. This association can be directly correlated with that at Chaohu, where the three morphotypes and the two new species recognized by Zhao et al. (in press) co-occur near the top of the *Prionolobus* – *Gyronites* Zone of both West and North Pingdingshan sections. Although the highest *Ns. concavus* occurs with *Ns. waageni eowaageni* Zhao & Orchard in both Chinese sections, no representative of the *Ns. waageni* group occurs at this level at Muth and therefore the conodont association of bed 10 is regarded as predating any prospective I-O boundary position.

Bed 11 yielded slightly different faunas at M-03 and M-04 although the long ranging *Ns. cristagalli* is common to both. At M-03, the latter species is accompanied by *Neospathodus dieneri*, but at M-04 *Ns. pakistanensis* Sweet and *Borinella nepalensis* (Kozur & Mostler) are dominant. This total fauna (+/- *Ns. dieneri*) is essentially the same throughout bed 12 at both sites, apart from a

single occurrence of *Eurygnathodus costatus* Staesche in collection M-04/12C. The conodont fauna of beds 11 and 12(A-C) at Muth, which is associated with the "Prioniolobus" vercherei ammonoid fauna, has no clear counterpart in Chaohu where *Borinella* is unknown. This may partly be explained by paleolatitudinal differences because the Spiti successions originated in higher latitudes compared with the equatorial ('Tethyan') Chaohu successions.

At Muth, the base of bed 13 marks the abundant appearance of *Ns. posterolongatus* and the FAD of *Ns. waageni* morphotype 1, both of which may have been formerly attributed to *Ns. waageni* and/or *Neospathodus novaehollandiea* McTavish. In this study, in addition to *Ns. posterolongatus*, 5 morphotypes of *Ns. waageni* are distinguished. Unlike the former species, all the morphotypes are characterized by round basal cavities. These are:

Morphotype 1 (Pl. 1, figs. 8-10). During growth, platform flanges are developed on the flanks of these elements, especially at the posterior end.

Morphotype 2 (Pl. 1, fig. 11). This corresponds to the holotype of *N. waageni* (= *N. w. waageni*) and has slightly reclined, subequal denticles forming an arcuate crest.

Morphotype 3 (Pl. 1, figs. 12). This small morphotype has a length to height ratio of about 1:1, upright denticles, and a variable basal margin that may be straight (as in *Ns. w. eowaageni* sensu stricto), upturned posteriorly, or upturned at both ends.

Morphotype 4 (Pl. 1, fig. 17, 18). In this form, there are a few posteriormost denticles that are abruptly smaller/lower than those to the anterior.

Morphotype 5 (Pl. 1, figs. 13-15). This form has an unusually large (sub)terminal triangular cusp.

Morphotype 6 (Pl. 1, fig. 16). This form has denticles that tend to radiate in a fan-like fashion from the base (= *Ns. aff. waageni* sensu Goel, 1977).

The first morphotype of *Ns. waageni* to appear in Spiti, in bed 13A, is morphotype 1, which mimics later growth stages of *Ns. pakistanensis* that have been called *Ns. novaehollandiea*. This underlies the suggestion (Orchard, in press) that *Ns. waageni* may have developed from *Ns. pakistanensis* by a decrease in relative length to height ratio, accompanied by upturning of the posterior basal cavity. An alternative derivation from *Ns. dieneri* morphotype 3 has been suggested by L. Zhao (pers. comm., 2006). *Neospathodus posterolongatus* is also thought to have developed from *Ns. pakistanensis*, in this case through the posterior elongation of the basal cavity (Orchard, in press). An argument against the origin of both *Ns. waageni* and *Ns. posterolongatus* in *Ns. pakistanensis* arises from the downturned posterior part of the latter species compared with upturning seen in both younger species. However, the basal profile is quite variable in morphotypes of both *Ns. pakistanensis* (in-

cluding *Ns. novaehollandiae*) and *Ns. waageni* and the suggested development is not precluded by that feature.

Most other morphotypes of *Ns. waageni* makes their appearances later: morphotype 2, which is regarded as the central morphotype of the species, may occur concurrently with morphotype 1 but certainly occurs in bed 13B together with morphotypes 3 and 4. Morphotype 5 appears in Bed 14A, and morphotype 6 appears in bed 15 (Table 1). The conodonts *Eurygnathodus costatus*, *Eu. hamadai*, *Discretella* sp., and *Spathicuspus?* n. sp. C also occur uncommonly in beds 13 and 14, which carry the *Rohillites rohilla* Zone ammonoid fauna. In Chaohu, most of the conodont fauna present in Muth beds 13 and 14 characterize the basal part of the "Flemingites – Euflemingites Zone", which leads to the suggestion that the *Rohilla* beds of Muth are equivalent to the lowermost part of the "Flemingites – Euflemingites Zone" in Chaohu. Both Bed 25 in West Pingdingshan and Bed 13A in Muth contain typical Induan species – *Ns. cristagalli* and *Ns. dieneri* – associated with typical Olenekian species – *Ns. posterolongatus* and *Ns. waageni* s. l.

The next significant conodont appearance in both the Spiti and Chaohu successions is *Neospathodus spitiensis* Goel, which appears in Bed 15 at Muth and in Bed 26 at West Pingdingshan, both of which are assigned to the *Flemingites – Euflemingites* Zone. These levels in the two candidate sections are similar also in the presence of *Ns. waageni* s.l. and *Discretella*, and in the absence of the other conodont taxa known from deeper levels. The holotype and all figured paratypes of *Ns. spitiensis* came from Smithian levels at Khar in Spiti (Goel, 1977), and records of the species from questionable Dienerian strata is unsubstantiated. In North America, the species *Ns. conservativus* (= *Conservatella* Orchard 2005), a homeomorph of *Ns. spitiensis*, characterizes co-eval strata of the *Euflemingites romunduri* Zone along with its associates *Ns. waageni* and *Ns. posterolongatus*.

Summary and comparisons with Chaohu

In Spiti, the I-O boundary interval can be divided into three conodont zonal intervals by reference to the FADs of *Ns. ex gr. waageni* + *Ns. posterolongatus*, and of *Ns. spitiensis*. Together with the older *Ns. pakistanensis* +/- *Ns. dieneri*, these taxa provide an evolutionary continuum (Orchard, in press). The intervals are characterized by:

- 1) Strata dominated by *Ns. dieneri*, *Ns. cristagalli*, *Ns. pakistanensis*, and *Bo. nepalensis*, with uncommon *Ns. chii* and *Ns. concavus* restricted to the interval. This interval corresponds to *Gyronites* and *Meekophiceras?*-bearing beds 10-12.
- 2) Strata above the FAD of *Ns. posterolongatus* + *Ns. ex gr. waageni*, which are initially associated with elements of the underlying bed. This interval in beds 13-14 belongs to the *Rohillites* Zone.
- 3) Strata above the FAD of *Ns. spitiensis*, assigned to the

Flemingites–*Euflemingites* Zone of beds 15-16.

Compared with Chaohu, Zone 1 of Muth can be broadly correlated with the upper part of the *dieneri* Zone. The absence of *Borinella* and rarity of *Ns. pakistanensis* at these levels in the Chinese sections represents a major difference between the two successions. The FAD of *Ns. posterolongatus* can be recognized in both areas: in West Pingdingshan, Chaohu it falls in Bed 25 at 0.03 m below the appearance of *Flemingites* (Zhao et al., in press) compared with a position close to the base of the *Rohillites* Zone in Muth. A further difference about these levels is the order of appearance of *Ns. waageni* morphotypes 2 and 3. In West Pingdingshan: the appearance of *Ns. w. eowaageni* (~morphotype 3) is slightly earlier (top bed 24) than *Ns. w. waageni* (~morphotype 2, base bed 25), whereas the two forms appear either concurrently or in reverse order at Muth. The other morphotypes of *Ns. waageni* have not yet been differentiated in the Chaohu sections, and nor is it clear to what extent these morphotypes are variants related to growth or intraspecific variation. Use of an undifferentiated *Ns. waageni* may be a preferred datum for both correlation and definition. The base of Zone 3, identified by the FAD of *Ns. spitiensis*, begins in bed 15 in Muth and in bed 26 in the West Pingdingshan section. In both cases it corresponds to the *Flemingites* – *Euflemingites* Zone. There is good correspondence between the two areas in both ammonoid and conodont faunas at these levels.

References

- Bhargava, O.N., Krystyn, L., Balini, M., Lein, R., Nicora, A. 2004. Revised litho- and sequence stratigraphy of the Spiti. International Meeting and Field Workshop on Triassic Stratigraphy of the Himalayas (Spiti, India), June, 25 – July, 6. *Albertiana*, 30: 21-39.
- Krystyn, L., Balini, M., Nicora, A. 2004. Lower and Middle Triassic stage boundaries in Spiti. International Meeting and Field Workshop on Triassic Stratigraphy of the Himalayas (Spiti, India), June, 25 – July, 6. *Albertiana*, 30: 39-53.
- Krystyn, L., Bhargava, O.N. and Bhatt, K.D., 2005: Muth (Spiti, Indian Himalaya) – a Candidate Global Stratigraphic Section and Point (GSSP) for the base of the Olenekian stage. *Albertiana*, 33: 51-53.
- Orchard, M.J. In press. Conodont diversity and evolution through the latest Permian and Early Triassic upheavals. *Palaeogeography Palaeoclimatology Palaeoecology*.
- Tong, J. 2005. Studies on the Triassic in Chaohu, Anhui Province, China. *Albertiana*, 32: 57-63.
- Tong, J., Hansen, H.J., Zhao, L., Zuo, J. 2005. High-resolution Induan-Olenekian boundary sequence in Chaohu, Anhui Province. *Science in China (Series D)*, 48: 291-297.
- Tong, J., Wu, S., Li, Z., Guo, G., Zhang, J. 2006(a). Lower Triassic bivalves from Chaohu, Anhui province, China. *Albertiana*, 34: 42-51.
- Tong Jinnan, Zakharov, Y.D. 2004. Lower Triassic ammonoid zonation in Chaohu, Anhui Province, China. *Albertiana*, 31: 65-69.
- Tong Jinnan, Zakharov, Y.D., Orchard, M.J., Yin Hongfu., Hansen, H.J. 2004. A candidate of the Induan-Olenekian boundary stratotype in the Tethyan region. *Albertiana*, 29: 13-28.
- Tong, J., Zacharov, Y., Yu, J. 2006(b). Some additional data to the Lower Triassic of the West Pingdingshan Section in Chaohu, Anhui province, China. *Albertiana*, 34: 52-59.
- Zhao Laishi, Orchard, M. J., Tong Jinnan. 2004. Lower Triassic biostratigraphy and speciation of *Neospathodus waageni* around the Induan-Olenekian boundary of Chaohu, Anhui Province, China. *Albertiana*, 29: 41-43.
- Zhao, L., Orchard, M.J., Tong, J., Sun, Z., Zuo, J., Zhang, S., Yun, A. In press. Lower Triassic conodont sequence in Chaohu, Anhui Province, China and its global correlation. *Palaeogeography Palaeoclimatology Palaeoecology*.

Plate

- 1, 2. *Neospathodus chii* Zhao & Orchard. Sample M04-10.
3. *Neospathodus dieneri* Sweet. Morphotype 1 Zhao & Orchard. Sample M03-11.
4. *Neospathodus concavus* Zhao & Orchard. Sample M04-10.
5. *Neospathodus cristagalli* (Huckriede). Sample M04-10.
6. *Neospathodus dieneri* Sweet. Morphotype 2 Zhao & Orchard. Sample M03-11.
7. *Neospathodus dieneri* Sweet. Morphotype 3 Zhao & Orchard. Sample M04-10.
- 8-10. *Neospathodus waageni* Sweet. Morphotype 1. Sample M03-13A.
11. *Neospathodus waageni waageni* Sweet (=Morphotype 2). M03-14A.
12. *Neospathodus waageni eowaageni* Zhao & Orchard (=Morphotype 3). Sample M03-14A.
- 13, 14. *Neospathodus waageni* Sweet. Morphotype 5. Sample M04-15B.
15. *Neospathodus waageni* Sweet. Morphotype 5. Sample M03-16.
16. *Neospathodus waageni* Sweet. Morphotype 6. Sample M03-15.
- 17, 18. *Neospathodus waageni* Sweet. Morphotype 4. Sample M03-16A.
- 19, 20. *Neospathodus pakistanensis* Sweet. Sample M03-13A.
- 21, 22. *Neospathodus posterolongatus* Zhao & Orchard. Sample M03-13.
- 23, 24. *Neospathodus spitiensis* Goel. Sample M03-15.

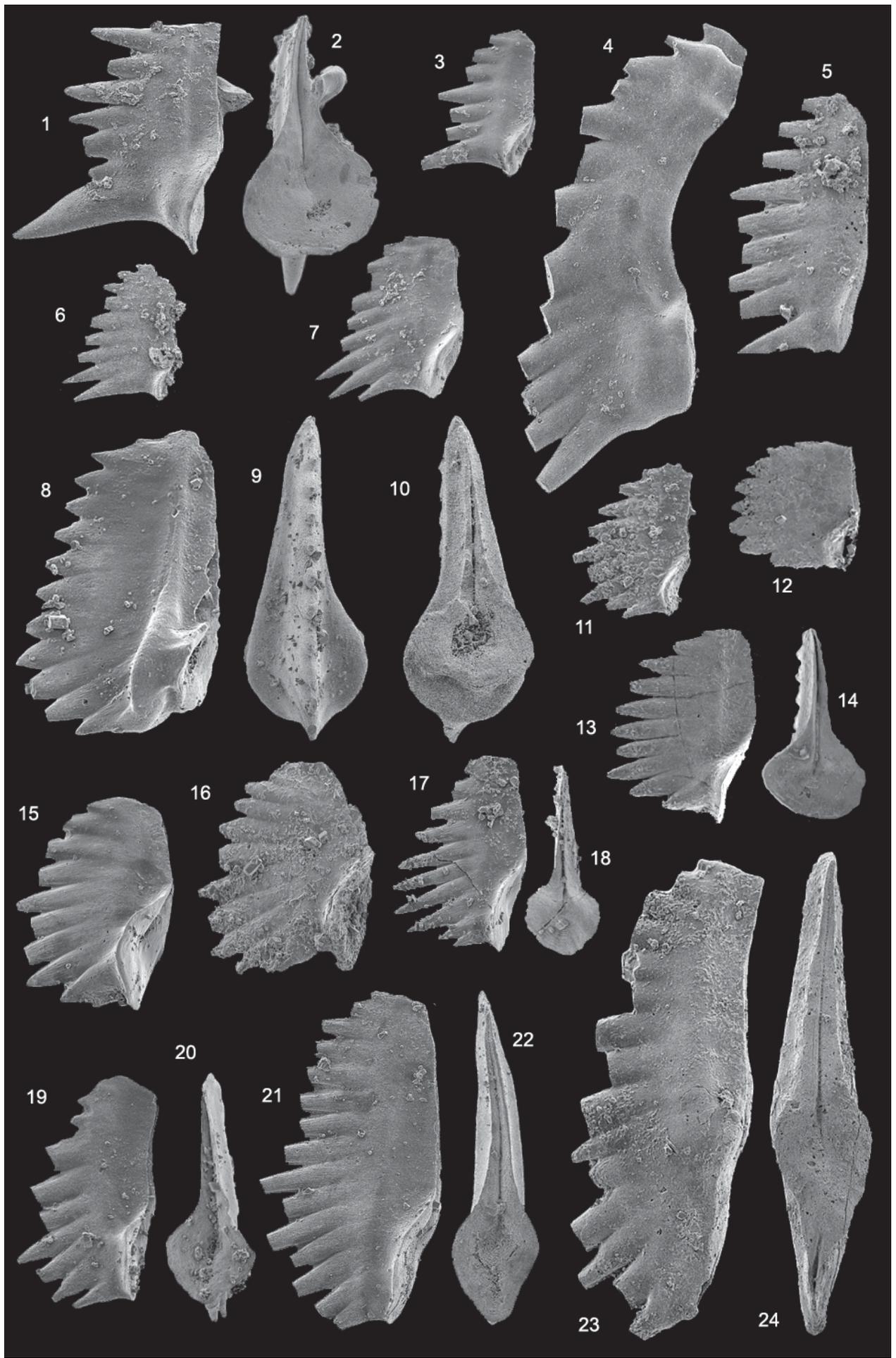


Table 1: Conodont assemblages from the Muth section.

	04/10	03/11	04/11	04/12A	03/12b	03/12c	04/12c	03/13a	04/13a	04/13b	06/13b	03/13c	04/13c	03/14a	04/14b	03/14c	04/14c	04/15a	04/15b	03/15	03/16a	
<i>N. cristagalli</i>	X	X	X	X	X		X	X	X													
<i>N. dieneri</i> M1	X	X			X			X														
<i>N. dieneri</i> M2	X	X					X		X													
<i>N. dieneri</i> M3	X																					
<i>N. chii</i>	X	?																				
<i>N. concavus</i>	X																					
<i>N. pakistanensis</i>			X	X	X	X	X	X	X	X			X									
<i>N. postetrolongatus</i>				X	X	X	X	X	X	X	X		X	X								
<i>Bornella nepalensis</i>			X	X	X	X	X	X	X	X				X								
<i>Ng. ex gr. carinata</i>								X														
<i>Discretella discreta</i>								X														
<i>N. waageni</i> M1								X													X	X
<i>N. waageni</i> M2								X													X	X
<i>N. waageni</i> M3										X											X	X
<i>N. waageni</i> M4														X							X	X
<i>N. waageni</i> M5														X							X	X
<i>N. waageni</i> M6																					X	X
<i>Spathicuspus?</i> n. sp. C																						
<i>Eurygnathodus hamadai</i>																						
<i>Eurygnathodus costatus</i>							X															
<i>N. spitenensis</i>									X												X	X
<i>N. sp. nov. U</i>																					?	X
<i>N. sp. nov. S</i>																					?	X