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UPPER DEVONIAN-LOWER CARBONIFEROUS CONODONTS FROM CHIANG DAO CHERTS, NORTHERN THAILAND

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Abstract. In Northern Thailand, radiolarites (radiolarian cherts) are very common and their study provides an important tool to understand the regional geology and moreover to localise the suture zone(s). Some of these deep and distal oceanic series yield conodonts which provide to obtain precise age datings. The present work is focused on the Upper Devonian and Lower Carboniferous conodonts from the Chiang Dao area (Chiang Mai province). The conodont faunas from these oceanic cherts display juvenile characters which are interpreted to be a result from a constraining environment.

Riassunto. Nel nord della Tailandia, le radiolariti (diaspri a radiolari) sono molto comuni e il loro studio rappresenta uno strumento importante per la comprensione della geologia regionale e per la localizzazione delle zone di sutura. Alcune di queste serie oceaniche distali profonde contengono conodonti il cui studio permette di ottenere delle datazioni precise. Il presente lavoro riguarda la tassonomia e l'interpretazione paleoambientale delle faune a conodonti del Devoniano Superiore e del Carbonifero Inferiore dell'area di Chiang Dao (Provincia di Chiang Mai). Le faune a conodonti provenienti da questi diaspri oceanici mostrano dei caratteri giovanili che sono qui interpretati come causati da fattori ambientali.

Introduction

Up to now, conodonts have not received much attention during micropalaeontological studies in Thailand and most reports contained only a note of their presence. They are mostly reported from limestones, because of the difficulty in recovering conodonts from cherts. But it appears that, although rare, conodonts can be important in improving the precision of dating of radiolarites (radiolarian chert). In addition, they are the only tool that can be used to precisely date the age of biozones developed from radiolarian remains.

Conodonts were first recorded from Thailand by Baum et al. (1970) who mentioned Triassic conodonts in the northern region (Lampang group). Triassic conodonts were also reported in Peninsular Thailand by Igo et al. (1988), Sashida & Igo (1992) and Sashida et al. (1993) from a limestone quarry at Khao Chiak. Ampornmaha (1995) reported and figured specimens from the same locality. Ordovician, Permian and Triassic conodonts were also reported from limestones of central Peninsular Thailand (Dill et al. 2004). Igo (1973) described Lower Carboniferous conodonts from a sequence of chert and shale exposed along the coast of Ko Yo, Songkla in Peninsular Thailand; Sashida et al. (1993) reported some conodonts from a black siliceous shale near Igo's locality.

In the northeastern part, Igo (1974) found Lower Permian conodonts that were then interpreted as Late Carboniferous in age (Fontaine et al. 1995; Mei & Henderson 2002). Viséan conodonts were mentioned by Chairangsee et al. (1990). In the western part, Ordovician conodonts were described from limestones in the Thong Pha Phum area (Agematsu et al. in press).

In northern Thailand, Hahn & Siebenhüner (1982) reported conodonts from the Lampang group (Triassic). Conodonts from Lampang and Ngao (Permian-Triassic) groups were described by Carey et al. (1995) in limestones of the Lampang-Ngao-Phrae area.

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Sashida et al. (1993) reported Lower Carboniferous conodonts from grey and green chert from the Chiang Dao Chert sequence.

While studying radiolarians in northern Thailand in 1989 and 1993, M. Caridroit and a Thai-German research team found co-occurring conodonts from samples of chert sequences in the Chiang Dao area. In January and February of 2003, three of us (CR, NW & MC) undertook a field survey in the area again to collect more siliceous and carbonate rocks in order to clarify the occurrence of radiolarians and conodonts for the detailed geology and age of these fossil-bearing rocks. Herein are presented the Upper Devonian – Lower Carboniferous conodont faunas from these three missions to the Chiang Dao area. The aim of this paper is to give an overview of conodonts from this country and to discuss their use in understanding the geology of northern Thailand. This report constitutes the first documentation of Upper Devonian and Lower Carboniferous conodonts from northern Thailand. This is also a first step in the age dating of chert bodies in this region.

Tectonic and geological setting of the Chiang Dao area

The Southeast Asian region, including Thailand, is now widely accepted as a "puzzle area", which comprises a complex assembly of allochthonous continental terranes, fragments, arcs, accretionary complexes, and suture zones (e.g. Metcalfe 2002). The tectonic history of this region is interpreted as one of rifting of continental terranes from Gondwana, their northwards drifting and their amalgamation and accretion to form Southeast Asia. These continental terranes drifted northward from Gondwana across the Tethys at different times. Based on this already accepted fundamental concept, several tectonic frameworks of Southeast Asia including mainland Thailand have been presented (e.g. Hutchison 1989; Metcalfe 1991; Mitchell 1992). Concerning the tectonic division of mainland Thailand, the following two continental terranes with Precambrian (?) basement have been recognized; namely, the western Shan-Thai (Sibumasu or Sinoburmalaya) and eastern Indochina Terranes (or block). The former is part of Cimmerian terranes, whereas the latter is included in Cathaysialand.

Palaeontological evidence is the significant key for age determination, biostratigraphic correlation, and also a powerful tool for facies interpretation as well as for palaeogeographic reconstructions. In particular, the radiolarian-bearing rocks such as cherts, fine-grained clastics, and limestones, which have been deposited in distal and proximal oceanic environments, can be used to infer the position of oceans that previously existed. They also have a high potential to elucidate palaeogeography, geodynamics and tectonics in this still debated region. Hence, the radiolarites are unique and excellent witnesses to indicate the existence of palaeo-oceans, and the age obtained by conodonts and radiolarians can be used directly to constrain the total life-span of ocean basins that once existed in the region.

The Chiang Dao area is part of the Shan-Thai block. This zone is located in the central part of northern Thailand, north from Chiang Mai city. The stratigraphy of Palaeozoic rocks in the area of Chiang Dao has been documented and reported by Baum et al. (1970), Bunopas (1981), and Chaturongkawanich et al. (1988). According to Bunopas (1981), the Palaeozoic formations include the following lithologic units: Cambrian to Ordovician: Hod Limestone and Pha Bong Quartzite; Silurian-Devonian or Carboniferous: Mae Hong Son Formation, Fang Chert ("Chiang Dao Chert", or section A, in this study), Pha Som Group, Don Chai Group and Mae Ko Complex; Carboniferous to Permian: Doi Kong Mu Formation, Fang Red-beds, Mae Tha Group and Phrae Group; and Permian Ngao Group.

Studied sections

The location and the log of studied sections are given on Fig. 1. They all come from the Chiang Dao area, in the north of Thailand.

Section A or "Chiang Dao chert"

Section A is located northeast of Chiang Dao, Chiang Mai province and crops out over a 2 km strike length along highway 107 from Chiang Mai to Fang city between km 106 and 108 (Fig. 1), positions 105647 for its base and 113662 for its top on Sheet 4848 III Ban Tha. This sequence was informally named "Fang Chert" by Bunopas (1981) but authors regarded the proper name as "Chiang Dao Chert" (see Wonganan et al. 2003 for detail of this new name). Kobayashi & Igo (1966) first reported the occurrence of graptolites from a black shale exposed at km 105.750. They assigned these fossils a Middle Ordovician to Early Silurian age. Subsequently, Jaeger et al. (1968, 1969) and Baum et al. (1970) studied graptolites from this point and revised the age of these fossils. According to them, these fossils indicate an Early Devonian (Gedinnian to Emsian) age. Bunopas (1981) also showed the same age for the "Fang Chert". Recently, the geologic age of the "Chiang Dao Chert" was determined by radiolarians (e.g. Caridroit 1991; Caridroit et al. 1990; Sashida et al. 1993; Wonganan et al. 2002, 2003). In the lower part of the sequence, the chert beds are of Late Devonian age, while the age of chert beds at the upper or north-

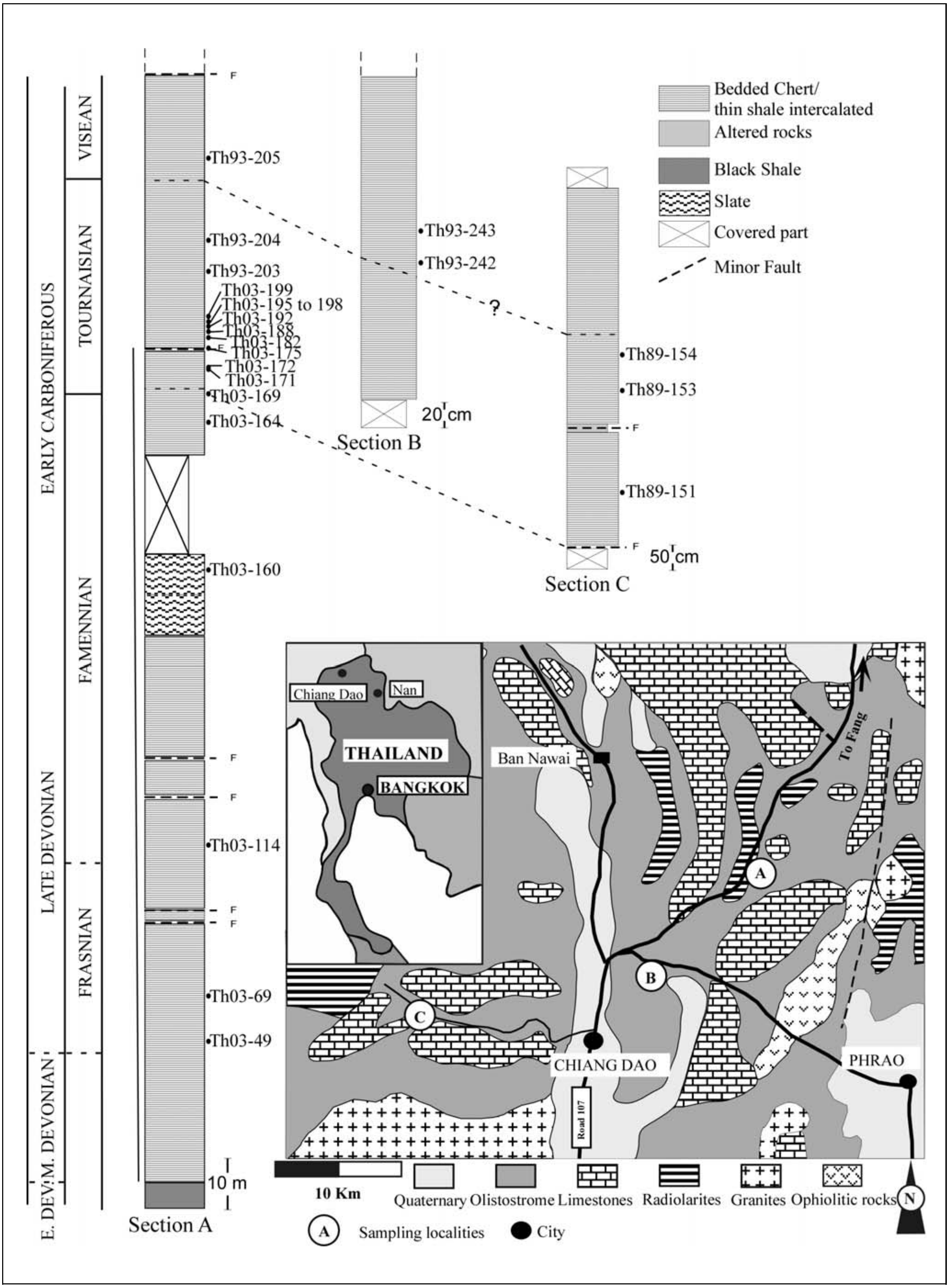


Fig. 1 - Stratigraphic logs of the sampled sections with their location on a simplified geological map of the Chiang Dao area. Horizons producing conodonts are indicated by a number.

ern part is reported as being late Early to Middle Permian. This sequence apparently becomes younger northward.

This section is characterised by huge radiolarite body whose base is made of several metres of siliceous black pelitic rocks. The radiolaritic facies commonly occurs together with thin intercalated shale. Chert rock from this area is dominantly grey to greenish grey in colour, but there are local variations to light grey, dark green, and reddish to black. The chert is mostly well stratified in layers, which vary from 3 cm to 10 cm in thickness, with an average close to 5 cm. The total thickness of such radiolarite bodies is estimated to be 200 m. Based on the presence of the facies itself (no limestone) and the duration of deposition (150 million years at least?), this chert body represents a very long time of continuous deep oceanic deposition (one of the longest known in the world).

A total of 194 samples were collected from the Devonian – Carboniferous part of this chert section, 17 of which yielded conodonts.

Section B

Section B is exposed in the area of Ban Huai Mae Yueng, between Doi Luang and Doi Nang in the Chiang Dao area, position 810467 on Sheet 4747 I Amphoe Chiang Dao. The section exposes well-bedded cherts of Early Carboniferous age; it is about 4 m in thickness and consists of grey to greenish grey, thin-medium chert beds, and very thin shale intercalations. Eight chert samples were collected from this section, two of them yielded conodonts.

Section C

The section is exposed at km 2.00 of Road 1150, position 011510 on Sheet 4847 IV Amphoe Phrao. This chert section is composed of a grey to greenish grey ribbon-chert sequence, with beds generally 3-5 cm thick, with intercalated thin layers of claystone or shale. Weathered cherts have yellow to white colours and are quite soft. The total thickness of this section could not be defined due to strong folding and faulting in the middle part, the uppermost and lowermost parts are also covered, but it is assumed that this sequence is about 14 m thick. No outcrop has been found which exposes strata conformably underlying the radiolarian chert. Microscopic study shows that the main component of this chert is mainly cryptocrystalline quartz associated with very fine clay minerals without carbonate components. Seven chert samples were collected from this section, three of them yielded conodonts. Based on the radiolarian faunas this section is thought to be Tournaisian in age.

Material and techniques

A total of 209 chert samples from the Chiang Dao area have been processed, 25 yielded conodonts. The weight of samples taken was about 100-200 gr.

The method of extraction is similar to that used for radiolarians. Samples are immersed in a 5% hydrofluoric acid solution. After 24 hours, the insoluble residue is washed gently through a 50 µm sieve and dried on a filter. In this study, to get enough elements, the process has been repeated three times. Radiolarians from these sections are currently under study.

Specimens are deposited at Laboratoire de Paléontologie et Paléogéographie du Paléozoïque (LP3), Université de Lille 1, France.

Age of conodont faunas

A total of about 140 conodont elements were recovered. The average number of conodonts per sample varies from 1-2 to 25. Details on conodont species are given in Table 1. The zonation used here is the Late Devonian Standard Zonation of Ziegler & Sandberg (1990) and the post-*Siphonodella* Zonation of Lane et al. (1980).

Section A has been referred to the Frasnian-Viséan, section B to the Viséan and section C to the Tournaisian.

Section A

Frasnian: in the Chiang Dao Chert, the first sample which yielded conodonts is sample Th03-49, at about 27 metres from the beginning of the chert sequence that overlays the black shales. Conodonts found are *Palmatolepis eureka* and *Polygnathus* sp., whose co-occurrence gives an age of late Frasnian (Early *rhenana* to *linguiformis* zones)

Two other samples, Th03-69 and Th03-114, yielded some isolated conodonts but no platform elements were found.

Famennian: *Palmatolepis regularis, Palmatolepis minuta loba*, *Palmatolepis glabra prima* and *Palmatolepis adamantea* were extracted from sample Th03-160, which indicates an early Famennian age (Upper *crepida* Zone). From the same age, sample Th03-164 yielded only one platform element identified as *Palmatolepis glabra prima*.

Tournaisian: sample Th93-203 in section A yielded a fauna including *Scaliognathus anchoralis europensis*, *Sc. anchoralis fairchildi* and *Polygnathus bischoffi*, whose co-occurrence represents the late Tournaisian *anchoralis* Zone. Sample Th93-204 is characterized by the co-occurrence of *Pseudopolygnathus triangulus* and *Scaliognathus anchoralis fairchildi*, which indicates also the late Tournaisian *anchoralis* Zone. Samples Th03-172 and Th03-195 to Th03-198 yielded *Polygnathus communis communis*, *Polygnathus* and/or *Lochriea saharae*. These four samples cannot give a precise age dating; they should be Tournaisian in age, before the

Section		Section A (Chiang Dao Chert)																	Section B			Section C		
sample number		Th03-49	Th03-69	Th03-114	Th03-160	Th03-164	Th03-169	Th03-171	Th03-172	Th03-188	Th03-192	Th03-195	Th03-196	Th03-197	Th03-198	Th93-203	Th93-204	Th93-205	Th93-242	Th93-243		Th89-151	Th89-153	Th89-154
conodont species																								
P. eureka	Pa	3																						
	Sb	2																						
Polygnathus spp.	Pa	4										1	1											
Palmatolepis spp.	Pa	1																						
	M				3																			
	S				3																			
P. regularis	Pa				8																			
P.glabra prima	Pa				2																			
P. minuta loba	Pa				10																			
P. adamantea	Pa				1																			
P. minuta minuta	Pa				2	1																		
Pol. purus	Pa						1?					4		1										
Pol. communis communis	Pa							1	3		1?	2			2									
	Pb							1																
	M											3												
	Sa											2?												
	Sb										1?	1?												
Hindeodus sp. indet.	Pa							1								1	1	2						
L. saharae	Pa														1									
Sc. anch. europensis	Pa															1								
Sc. anch. fairchildi	Pa															2	1							
	Sc															8	2							
Pol. bischoffi	Pa															1								
Pol. triangulus	Pa																3							
Gn. homopunctatus	Pa																	1						
Gn. austini	Pa																	1						
H. cristulus	Pa																		1					
Gn. praebilineatus	Pa																		1					
Gn. bilineatus	Pa																			1				
Gnathodus sp. indet.	Pa																					1	2	1
gen. indet.	Pa	2		2								3	1			1	1							
element indet.			3			2				2		1	3	1		8	9	4						

Tab. 1 - Distribution of conodont taxa from productive horizons of sampled sections.

anchoralis Zone, as the series appears to be continuous. Samples Th03-169, Th03-171, Th03-188, Th03-192 and Th03-196 yielded only fragmentary elements or ramiform elements and so no precise age dating could be assigned to these samples.

Viséan: sample Th93-205 yielded elements of G*nathodus homopunctatus* and *Gnathodus austini* indicating early to middle Viséan age.

Section B

Viséan: at section B, sample Th93-242 yielded *Gnathodus praebilineatus* and *Hindeodus cristulus*, which indicate an early to middle Viséan age. Sample Th93-243 yielded *Gnathodus bilineatus*, which is late Viséan to earliest Namurian aged (*bilineatus* Zone).

Section C

Specimens from the genus *Gnathodus* were found in samples Th89-151, Th89-153 and Th89-154. The poor preservation of these specimens makes it impossible to identify the species. According to radiolarian data (Wonganan 2005), this section is Tournaisian.

Depositional environment and implications

Radiolarites, radiolarians and palaeoenvironment

The Radiolaria are unicellular planktonic predators living in all marine domains; their skeleton is made of opal usually transformed into quartz (always if older than Cretaceous). So, their presence or absence in a marine sediment or rock is related to their preservation (before, during and after sedimentation).

Radiolarites are biogenic sediments mainly made of radiolarian skeletons; they are often holosiliceous or partly carbonated (if deposited over the CCD) and sometimes called radiolarian cherts.

Radiolarites can be observed as several meter thick intercalations in terrigenous or calcareous platform series and correspond to a deepening (local or due to isostasy). It is the case of the Carboniferous lydite rocks in South France which are sometimes called phtanites (as in Ardennes, Belgium or in Armorican massifs, Western France). If the sedimentation rate is very low (little terrigenous sedimentation), radiolarites can be found as a single bed inside a detritic sequence (as in the Maizuru Zone s.l. in Japan, Caridroit and De Wever 1986).

In these two examples, radiolarites are not indicators of palaeo-oceanic deposits (only indicators of marine deposits).

The third case is thick radiolarites that represent a very long period of sedimentation: several tens of millions of years. In Japan, such radiolarites are usually associated with ophiolites and are, for example, continuous from Upper Carboniferous to Jurassic times (e.g. for the Upper Tamba belt, Caridroit et al 1987). These ones clearly represent deep and very distal oceanic deposits.

In Northern Thailand, the radiolarites are similar to the Japanese ones but, if ophiolites are commonly present, true contact between ophiolites and radiolarites is not observed (due to the poor outcrop conditions which are related to the tropical weathering). The radiolarites are dated from the Middle Devonian to the Early Upper Triassic (about 200 my in duration). The Chiang Dao chert outcrop itself is a continuous radiolarite body dated from the Middle Devonian to the Middle Permian (150 my). The upper part is made of altered radiolarites which did not yield fossils (probably Upper Permian and Triassic). In the same area, Upper Permian and Triassic radiolarites have been described (e.g. Wonganan 2005).

In spite of the lack of true and observed contact between the radiolarites and oceanic crust, such very long biogenic radiolarite deposits, without any calcareous beds, can clearly only represent deep and very distal oceanic sedimentation during a period of around 200 my.

Depositional environment (Northern Thailand)

Ribbon-bedded radiolarites from the Chiang Dao area contain very little and fine terrigenous detritus. These continuous, siliceous and biogenic sediments are the evidence of an oceanic realm that must have been opened between the Shan-Thai and the Indochina continental terranes and whose size must have been rather large and deep to avoid important detritic and/or carbonaceous sedimentation. Palaeontological data can constrain the age of these palaeo-oceanic sediments and hence the opening and closure times of the palaeo-ocean.

The occurrence of black shale containing Lower Devonian graptolites may indicate that the Palaeo-Tethys opened before early Early Devonian time, which is compatible with the subsequent occurrence of Middle Devonian radiolarites. The closure of this ocean, in the northern Thailand segment, could not take place before the latest Triassic (probably Early Jurassic) according to radiolarian data (Wonganan 2005). According to our data and several paleogeographic models (e.g. Metcalfe 1998, see fig. 2), this ocean would have a width of at least several hundred kilometres (as for instance the present Red Sea) during the Devonian, and several thousands of kilometres during the time of maximum opening (Carboniferous and Permian). Thus, cherts from our study would have been deposited in a deep basin several thousands of kilometres distant from the carbonate platform.

Features of the conodont fauna

The conodonts recovered from the Devonian and Carboniferous interval in the Chiang Dao cherts are not

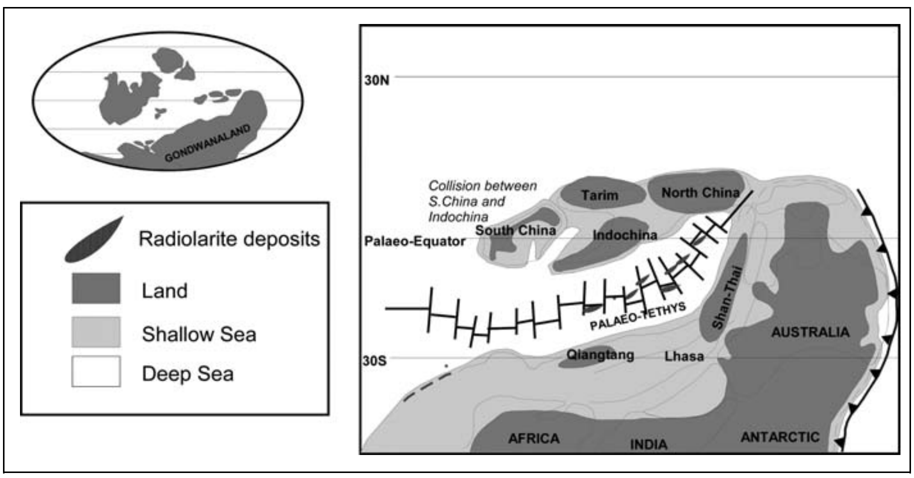


Fig. 2 - Palaeogeographic map for Late Devonian - Early Carboniferous times (modified after Metcalfe 1998).

abundant enough to establish a precise biofacies. However, the assemblages found are informative as to the palaeoecological significance of these faunas. The ecology of conodont communities, and particularly their bathymetric distribution, has been studied by several researchers for the Devonian and Carboniferous period (see Zhuravlev & Tolmacheva 1995 for references). In our samples, the Upper Devonian faunal association is composed of genera *Palmatolepis* and *Polygnathus*, which are found mainly offshore. No genera characteristic of the shallow-water biofacies (e.g. *Icriodus* or *Pelekysgnathus*) were recovered. In the Lower Carboniferous, fauna is composed of *Polygnathus communis communis* which is found in many environments and so is considered to be ubiquitous (Lane et al. 1980). Other genera are *Hindeodus, Gnathodus, Pseudopolygnathus, Scaliognathus* and *Lochriea. Hindeodus* and *Scaliognathus* are nektonic, and were found to live in the outer platform (Sandberg & Gutschick 1984). *Gnathodus* is interpreted as living in an open marine/outer shelf environment (Higgins et al. 1991) and, according to its geographic and stratigraphic distribution as a nektonic, deep water, conodont (Baxter 2002). *Pseudopolygnathus* is considered to be nektonic (Baxter 2002) but is often absent in the basin (Higgins et al. 1991; Lane et al. 1980). *Lochriea* often occurs together with *Gnathodus* and may have the same habitat. Again, genera characteristic of shallow-water biofacies are totally missing from the assemblages. Fauna is nektonic and seems to be similar to the fauna deposited on the outer shelf/ continental slope of the carbonate platform. However, one important feature of this fauna is that most of the conodonts extracted from these radiolarites have a smaller size than the ones usually extracted from limestones, with a length around 500 μm. A very few larger platforms of mature size are present but they are very scarce compared to the total of platform elements. This reduction in size is accompanied by a display of juvenile characters for some of the specimens.

Palaeoecological interpretation

Two possibilities can be considered: either the population recovered from our samples presents effectively a dwarfism related to its living environment (distal colonisation), or the elements found have been transported for long distances, on the order of several thousand kilometres (taphonomic bias).

Considering the last hypothesis, because of the deep and very distal setting of the deposits, the presence of the conodont elements tends to be interpreted as indicating a taphonomic cause: the elements are the remains of decomposing conodont carcasses that floated on the ocean, or they were consumed by predators. This hypothesis has been developed by Tolmacheva & Purnell (2002) who found clusters and isolated elements of conodonts in Lower Ordovician cherts from Kazakhstan. The elements (and clusters) were interpreted as the results of predation, with predators that preferred to eat smaller animals. But no remains of other macrophagous animals were found in that case and in the present study, and no conodont clusters were found in the thin sections made from our samples. In addition, if the conodonts recovered from our radiolarite samples are effectively the result of predation, this would imply that there were predators able to have daily displacements of several thousand kilometres.

The elements can be the result of post-mortem transportation by current activity, with a preferential transportation of smallest (and lightest) elements. Hydrodynamic studies (Broadhead et al. 1990, McGhoff 1991) demonstrated that lightest elements are transported farther from the carbonate platform. The assemblages found are composed of specimens that characterize the continental slope domain. The fauna would therefore result from a selective transportation of the fauna from the platform. To confirm or invalidate this hypothesis, we must consider the area of deposition of the sediments. As explained previously, during the Devonian/Carboniferous times, radiolarites are deposited far (several thousand of kilometres) from the platform. Studies by Broadhead et al. (1990) indicate that with a horizontal current of 10 cm/s, the lateral displacement is about 9 km for a *Palmatolepis* element (platform element) at 1000 m depth. To transport the conodont elements for thousands of kilometres, the currents must have been very significant. It seems therefore that synsedimentary, post-mortem transportation of conodont elements could not be responsible for this chert assemblage.

The other possibility is that conodonts effectively inhabited the oceanic domain where their elements have been recovered, and the fauna would therefore be characterized by an offshore biofacies with a decrease in size of the conodont elements (the result of a reproductive or feeding adaptation?). Adult specimens with such juvenile characters may be considered as a progeny of the species inhabiting the oceanic domain. The organisms would have had an early maturation in the context of r-selection, response to a more selective and constraining environment. Dwarfism (or progeny) as a survival mechanism has been reported for conodonts after extinction events (Girard 1996; Girard et al. 2004; Renaud & Girard 1999). We can assume that conodonts had the same adaptative strategy in difficult environments (biotic or abiotic factors). Abiotic (oxygen content, temperature, salinity) or biotic (rarefaction of prey, change in the size of the prey) factors can reduce the ontogenesis (progenese) or decrease the size of the individuals.

Thus, we interpret the studied assemblages as the remains of conodont associations that were living in a deep and very distal oceanic area, and which show a reduction in size resulting from their constraining environment.

Systematic palaeontology

Conodonts studied here are only Pa elements, other elements are only mentioned (Table 1). The preservation is often poor as hydrofluoric acid is used, some elements remain uncertain as their ornamentation is lacking.

Genus *Palmatolepis* Ulrich & Bassler, 1926

Type species: *Palmatolepis perlobata* Ulrich & Bassler, 1926

Palmatolepis eureka Ziegler & Sandberg, 1990

Pl. 1, figs 1-2

1990 *Palmatolepis eureka* Ziegler & Sandberg, p. 63-64, pl. 9, fig. 9-13.

Description. Smooth rounded platform without lateral lobe. The carina is high with partly fused denticles. It is straight to slightly curved. No carina is present posterior to the central node.

Remarks. Note the extremely small size (320 & 420 µm length) and the poor preservation of the specimens, adding difficulties for their taxonomic assignment. However, the outline and the carina are characteristic of the species.

Stratigraphic range. Early *rhenana* zone to *linguiformis* Zone.

Palmatolepis adamantea Metzger, 1994

Pl. 1, fig. 4

1963 *Palmatolepis* n. sp. A Helms, text-fig. 2, fig. 40.

1981 *Palmatolepis* n. sp. Helms & Ziegler in Clark et al., p. W98-W99, text-fig. 62, fig. 61.

1994 *Palmatolepis adamantea* Metzger, p. 626, pl. 17, fig. 13-15,18-20.

Description. Conodont with a diamond-shaped platform outline. The outer lobe is small, almost undeveloped. The inner lobe is not developed. The posterior tip is turned upward. There is a small free blade (about 1/5 of the total length of the platform). The carina is moderated in hight and is sigmoid. It is absent after the central node. There is no apparent ornamentation of the platform.

Stratigraphic range. Early to Late *crepida* Zone.

Palmatolepis minuta loba Helms, 1963

Pl.1, figs 5-6

1963 *Palmatolepis minuta loba* n. subsp. Helms, pl. 2, fig. 13-14, pl. 3, fig. 12, text-fig. 2, fig. 39.

Description. Very small element (less than 500 µm length) with a smooth triangular platform. The free blade is very high and is about half of the total length of the unit. The carina decreases in hight, and is not distinguishable anymore posterior to the central node.

Remarks. The elements resemble specimens of *P. minuta loba* figured by Sandberg & Ziegler (1973, pl.5, fig.1-2). They resemble specimens of *P. parva* figured by Klapper et al. (1994, fig. 7: 8-12, 18) but differ slightly in having a more sigmoid blade-carina. The specimen figured on Pl. 2, Fig. 6 resembles *P. rhomboidea* in having a bulge at the anterior end of the inner platform.

Stratigraphic range. Late *crepida* Zone to Early *rhomboidea* Zone.

Palmatolepis minuta minuta Branson & Mehl, 1934a

Pl. 1, fig. 7

1934a *Palmatolepis minuta* Branson & Mehl, p. 236-237, pl. 18, fig. 1, 6-7.

1962 *Palmatolepis minuta minuta* - Ziegler, p. 65-67, pl. 3, fig. 1-10

1999 *Palmatolepis minuta* - Schülke, p. 41-43, pl. 5, fig. 15-27. [see for synonymy]

Description. The specimens have a small, subovate platform, without outer lobe. The blade-carina is high anteriorly and decreases toward the central node, and continues posteriorly. The platform is unornamented. The posterior margin is rounded.

Remarks. *P. minuta minuta* have different outlines, with a more or less marked outer lobe. The specimens found here resemble the lectotype of Branson & Mehl (1934a, pl. 18, fig. 1).

Stratigraphic range. Late *triangularis* to the *trachytera* Zone.

Palmatolepis regularis Cooper, 1931

Pl. 1, figs 8-9

1931 *Palmatolepis regularis* Cooper, p. 242, pl. 28, fig. 36.

1962 *Palmatolepis* cf. *regularis* - Ziegler, p. 75-77, pl. 6, fig. 20-24.

1999 *Palmatolepis* cf. *P. regularis* - Schülke, p. 45-46, pl. 10, fig. 8-12. [see for synonymy]

2004 *Palmatolepis regularis* - Klapper et al., p. 381, pl. 7, fig. 28, 31.

Description. Small elements with the anterior part of the blade free. This free blade is short, sometimes absent. The carina is not well marked and forms a sigmoid shape with the blade. It extends until the posterior tip. The platform is smooth and asymmetrical; the outer part has a lateral lobe slightly or not marked, and is slightly larger than the inner part. A secondary carina is not visible on our specimens.

Stratigraphic range. Early *crepida* Zone to Early *rhomboidea* Zone

Palmatolepis glabra prima Ziegler & Huddle, 1969

Pl. 1, figs 10-11

1969 *Palmatolepis glabra prima* n. subsp. Ziegler & Huddle, p. 379-380.

1999 *Palmatolepis glabra unca* Sannemann - Schülke, p.37-38, pl. 4, fig. 1-11. [see for synonymy]

Description. Specimens have a smooth platform with a rounded and convex inner parapet and no or a small developed outer lobe. The outer platform joins the carina more anteriorly than the inner one. The carina is sigmoidal. The preservation of the specimens does not allow the identification of a posterior carina. Pa elements represent the morphotype 1 as defined by Sandberg & Ziegler (1973).

Stratigraphic range. Late *crepida* Zone to the Late *marginifera* Zone.

Genus *Polygnathus* Hinde, 1879

Type species: *Polygnathus dubius* Hinde, 1879

Polygnathus purus Voges, 1959

Pl.1, figs 12-16

1959 *Polygnathus pura* Voges, pl. 34, fig. 21-33.

Remarks. Specimens with no depression posterior to the basal cavity and a large, plane and smooth platform are assigned to *P. purus*. The specimens from our samples have also a more or less triangular outline that distinguish them from *P. communis communis*.

Stratigraphic range. *praesulcata* Zone to *isosticha-crenulata* Zone.

Polygnathus communis communis

Branson & Mehl, 1934

Pl. 1, figs 17-20

1934b *Polygnathus communis* Branson & Mehl, p. 293, pl. 24, fig. 1-4

Remarks. Smooth oral surface. The platform is leaf-shaped and slightly convex on the lateral view. The inner part of the platform joins the carina more anteriorly than the outer. Both sides of the platform join the carina convexly then concavely. The carina is composed of about 10-14 denticles fused on 2/3 of their height. Carina is straight on the anterior part and slightly inclined towards inner side on the posterior part. Carina reaches the posterior edge of the platform. Height of the carina decreases posteriorly. Free blade is high. Its length is about 1/3 of the total length of the specimen. In aboral view: the basal cavity is small; a small inflexion is present posterior to the basal cavity but no clear depression is visible. Specimens are however regarded as *P. communis communis* and no as *P. purus* because of the smallest size of the platform and the upturned edges of the platform. They can be considered as transitional between *P. communis communis* and *P. purus*.

Stratigraphic range. Famennian to *anchoralis* Zone.

Polygnathus triangulus (Voges, 1959)

Pl. 2, figs 7-9

1959 *Pseudopolygnathus triangula triangula* Voges, p. 304-305, pl. 35, fig. 7-13.

1985 *Polygnathus triangulus* - Belka, p. 41, pl. 13, fig. 2-4.

1993 *Pseudopolygnathus triangulus* - Perret, p. 280, fig. 92a-d, pl. 6, fig. 6,11-14.

Description. Carmini-planate element with a triangular outline, symmetrical (or near symmetrical) platform. The free blade is about half the length of the unit. The platform is ornamented with strong spaced ridges that enlarge toward the margins. The carina bears more than 12 partly fused denticles, which have a sub-triangular shape.

The basal cavity is wide, rounded, flat and just near the anterior end of the platform.

Remarks. Specimens with a wide basal cavity are often assigned to the genus *Pseudopolygnathus*. However, the expanded basal cavity can be a characteristic of immature elements of *Polygnathus* species (see Purnell 1992). No specimens exceeding 650 μm in total length were found in this study. As no mature specimen was found, the specimens could effectively be juveniles of the genus *Polygnathus.* They can resemble immature specimens of *P. bischoffi*. But, based on the morphological features such as the triangular shape of the platform, the elements will be maintained here as the *P. triangulus* species.

Stratigraphic range. *duplicata* Zone to *anchoralis* Zone.

Polygnathus bischoffi Rhodes, Austin & Druce, 1969

Pl. 2, fig. 15

1969 *Polygnathus bischoffi* - Rhodes, Austin & Druce, p. 184-185, pl. 13, fig. 8-11c.

Description. The platform is more or less triangular, slightly arched on lateral view. The anterior edges are perpendicular to the blade, the lateral edges are parallel to the carina on the 2/3 anterior of the platform then they reach the carina just before the posterior tip. The platform is ornamented by delicate ridges confined to margins. The free blade is high, and represents about 1/3 of the total length of the element. The carina is low and is convex posteriorly. It is composed of more than 20 discrete fused denticles. The basal cavity is circular and located in the posterior zone of the anterior half of the platform.

Stratigraphic range. Early *crenulata* Zone to *anchoralis* Zone.

Genus *Lochriea* Scott, 1942

Type species: *Spathognathodus commutatus* Branson & Mehl, 1941.

Lochriea saharae Nemyrovska, Perret-Mirouse & Weyant, 2006

Pl. 1, fig. 22.

2002 *Lochriea saharae* nomen nudum – Nemyrovska, Perret-Mirouse & Weyant, p.47.

2006 *Lochriea saharae* sp. nov. – Nemyrovska, Perret-Mirouse & Weyant.

Description. Carmini-scaphate element with a small oval platform, asymmetrical. Ornamentation is lacking. The carina is straight with 14 large and separated nodes of about equal size. The anterior free blade is about one third of the total length of the element. The basal cavity does not extend to the posterior tip.

Remarks. The specimen is poorly preserved but no ornamentation seems to have been present. The subrectangular lateral profile of this specimen and its expanded cup, near the posterior tip but without reaching it, assigns it to *L. saharae*. In the original description of *L. saharae*, the carina is slightly curved anteriorly, that feature does not appear in our specimen.

Stratigraphic range. Early- through mid-Viséan.

Genus *Scaliognathus* Branson & Mehl, 1941

Type-species: *Scaliognathus anchoralis* Branson & Mehl, 1941

Scaliognathus anchoralis europensis Lane & Ziegler, 1983

Pl. 2, fig. 1.

1941 *Scaliognathus* Branson & Mehl, p. 102, pl. l7, fig. 21.

1957 *Scaliognathus anchoralis* - Bischoff, p. 53-54, pl. 1, fig. 8,11-14.

1980 *Scaliognathus anchoralis* morphotype 2 - Lane, Sandberg & Ziegler, p. 138, pl. 1, fig. 1-2.

1983 *Scaliognathus anchoralis europensis* - Lane & Ziegler, pl. 2 fig. 1-3; pl. 4, fig. 6.

Description. Anchor-shaped platform. The anterior limb is broad, long and straight. The lateral processes are as long, or slightly shorter, than the anterior limb. They are wide and curved anteriorly at about 70° to the anterior limb. On the anterior limb, there is a prominent median carina consisting of large discrete denticles. Lateral processes bear denticles inclined posteriorly. They are subequal in size except one higher near the extremity. The specimen bears nodes along the axis. A prominent posteriorly directed cusp is also present. The basal cavity is large and triangular. It is prolonged by a basal groove that extends into the anterior and lateral limbs.

Stratigraphic range. *anchoralis* Zone.

Scaliognathus anchoralis fairchildi Lane & Ziegler, 1983

Pl. 2, figs 2-4

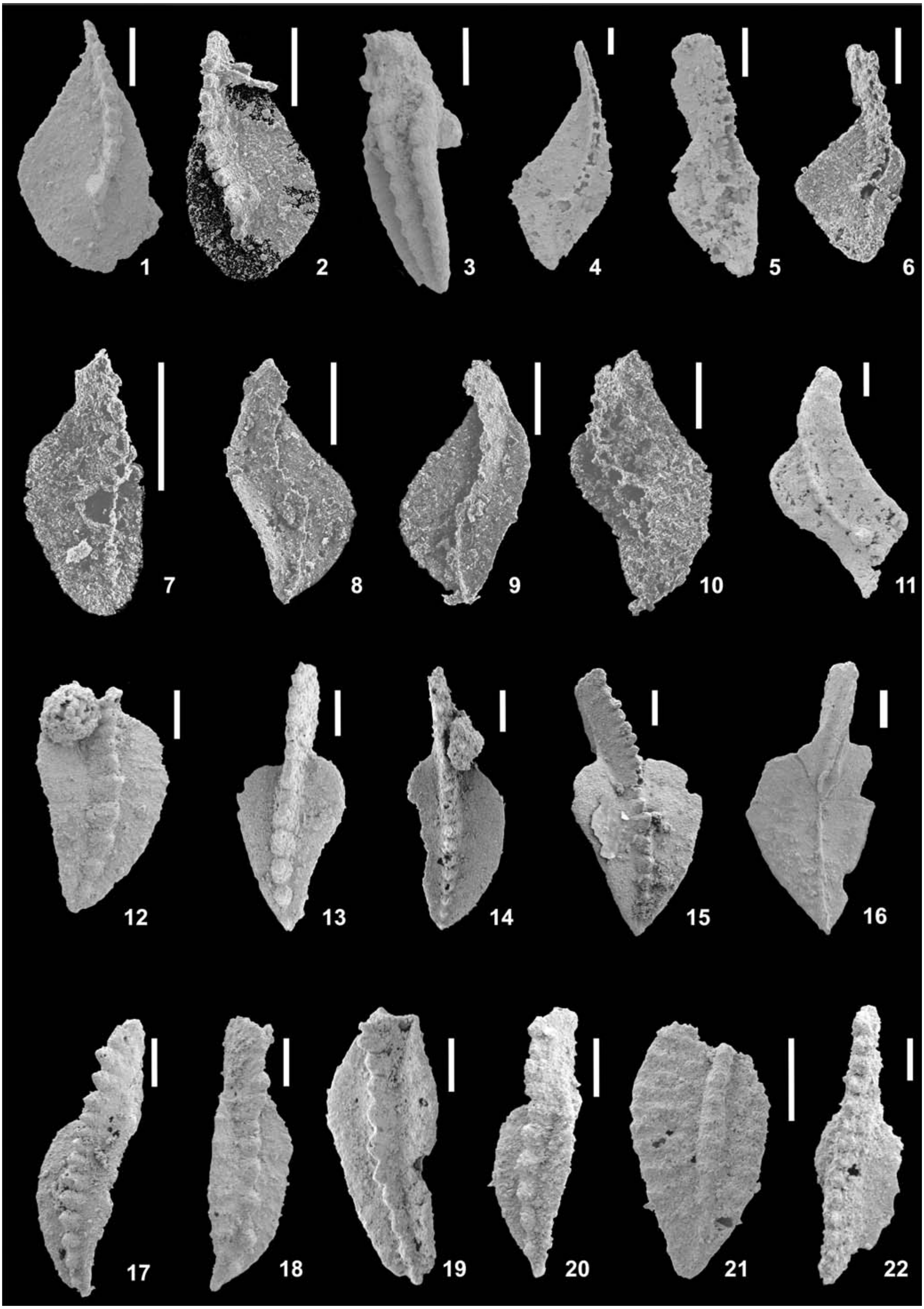
1980 *Scaliognathus anchoralis* morphotype 1 – Lane, Sandberg & Ziegler, p. 151-152, pl. 1, fig. 5-7.

1983 *Scaliognathus anchoralis fairchildi* Lane & Ziegler, pl. 1, fig. 2-4; pl. 3 fig. 3.

PLATE 1

Scale bar represents 100 µm.

Fig. 1-2	- *Palmatolepis eureka* Ziegler & Sandberg, 1990. Oral view, sample Th03-49, nos. COT1 and COT2.
Fig. 3	- *Polygnathus* sp. Oral view, sample Th03-49, no. COT3.
Fig. 4	- *Palmatolepis adamantea* Metzger, 1994. Oral view, sample Th03-160, no. COT4.
Fig. 5-6	- *Palmatolepis minuta loba* Helms, 1963. Oral view, sample Th03-160, nos. COT5 and COT6.
Fig. 7	- *Palmatolepis minuta minuta* Branson & Mehl, 1934. Oral view, sample Th03-160, no. COT7.
Fig. 8-9	- *Palmatolepis regularis* Cooper, 1931. Oral view, sample Th03-160, nos. COT8 and COT9.
Fig. 10-11	- *Palmatolepis glabra prima* Ziegler & Huddle, 1969. Oral view, sample Th03-160, no. COT10 and sample Th03-164, no. COT11.
Fig. 12-16	- *Polygnathus purus* Voges, 1959. 12-15: Oral view, 16: Aboral view. 12-13: sample Th03-195, nos. COT12 and COT13; 14: sample Th03-172, no. COT14; 15-16: sample Th03-197, no. COT15.
Fig. 17-20	- *Polygnathus communis communis* Branson & Mehl, 1934. Oral view. 17: sample Th03-172, no. COT16; 18: sample Th03-195, no. COT17; 19: sample Th03-171, no. COT18; 20: sample Th03-198, no. COT19.
Fig. 21	- *Polygnathus* sp. Oral view, sample Th03-195, no. COT20.
Fig. 22	- *Lochriea saharae* Nemyrovska, Perret-Mirouse & Weyant, 2006. Oral view, sample Th03-198, no. COT21.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Description. The specimen has straight lateral processes that give a T-shaped element. Postero-lateral limbs are straight to slightly curved anteriorly. The lateral processes and the anterior limb are thin, bar-type, with high, separated denticules inclined posteriorly. The posterior limb is well developed on the specimen figured on Pl. 2 Fig. 4. Basal cavity covers much of the lower surface.

Stratigraphic range. *anchoralis* Zone.

Genus *Gnathodus* Pander, 1856

Type species: *Gnathodus bilineatus* (Roundy, 1926)

Gnathodus austini Belka, 1985

Pl. 2, fig. 10

1985 *Gnathodus austini* Belka, p. 38, pl. 4, fig 2-3, 7-8, 10-11.

Description. The carina is high and thin until the posterior extremity. The blade has the same length as the platform. Cusps are fused on half of their high; they're straight, partly inclined. The second and third cusps are more important. The parapet is short with a single node at its anterior end. The basal cavity is narrow, deep, asymmetrical and lanceolate.

Remarks. The presence of a distinct high node on the anterior part of the parapet assigns this specimen to the species *G. austini*. Only one specimen was found and of very small size.

Stratigraphic range. Late *anchoralis* Zone to *bilineatus* Zone.

Gnathodus homopunctatus Ziegler, 1960

Pl. 2, figs 11, 14.

1960 *Gnathodus homopunctatus* Ziegler, p. 39, pl. 4, fig. 3.

2004 *Gnathodus homopunctatus* - Bermúdez-Rochas, Sarmiento & Rodríguez, p. 49-52, pl. 7, fig. 1-6, 8-9, 11. [see for synonymy]

Description. The platform is symmetrical. Its oral surface bears some discrete and scattered nodes. The carina is high and slender. Blade denticles are about 15 in number and blunted. The lateral outline is rectangular.

Remarks. It differs from *G. symmutatus* by the presence of nodes laterally.

Stratigraphic range. *texanus* Zone to *bilineatus* Zone.

Gnathodus praebilineatus Belka, 1985

Pl. 2, fig 16.

1985 *Gnathodus praebilineatus* Belka, p. 39, pl. 7, fig. 4-8.

1999 *Gnathodus praebilineatus* - Meishner & Nemyrovka, p. 438, pl. 1, fig. 2-3, 5, 7, 9-10, 14, 17, pl. 2, fig. 5, 7, 11, 16, pl. 3, fig. 20-21. [see for synonymy]

Description. Pa element composed of an inner parapet not completely developed. The outer platform is short, a little bit larger than the parapet. It reaches the carina at an angle of about 50° in both anterior and posterior part. Some discrete nodes are present on the platform but no particular arrangement can be distinguished. The carina is high and simple (does not extend posteriorly) and is composed of completely fused denticles that cannot be discriminated.

Remarks. Our specimen has very few characters and is very small (400 µm length) and therefore can be considered as a juvenile of the species. No ridges are present on the parapet, nodes are scattered and the specimen has a slender platform, and so it seems to be closer to *G. praebilineatus* than *G. bilineatus*. But, as no mature specimen was found, this remains doubtful.

Stratigraphic range. Early *austini* Zone to Early *bilineatus* Zone.

Gnathodus bilineatus (Roundy, 1926)

Pl. 2, fig. 17

1926 *Polygnathus bilineatus* Roundy, pl. 3, fig. 10a-c.

1939 *Gnathodus bilineatus* - Cooper, p. 388, pl. 42, fig. 59, 60.

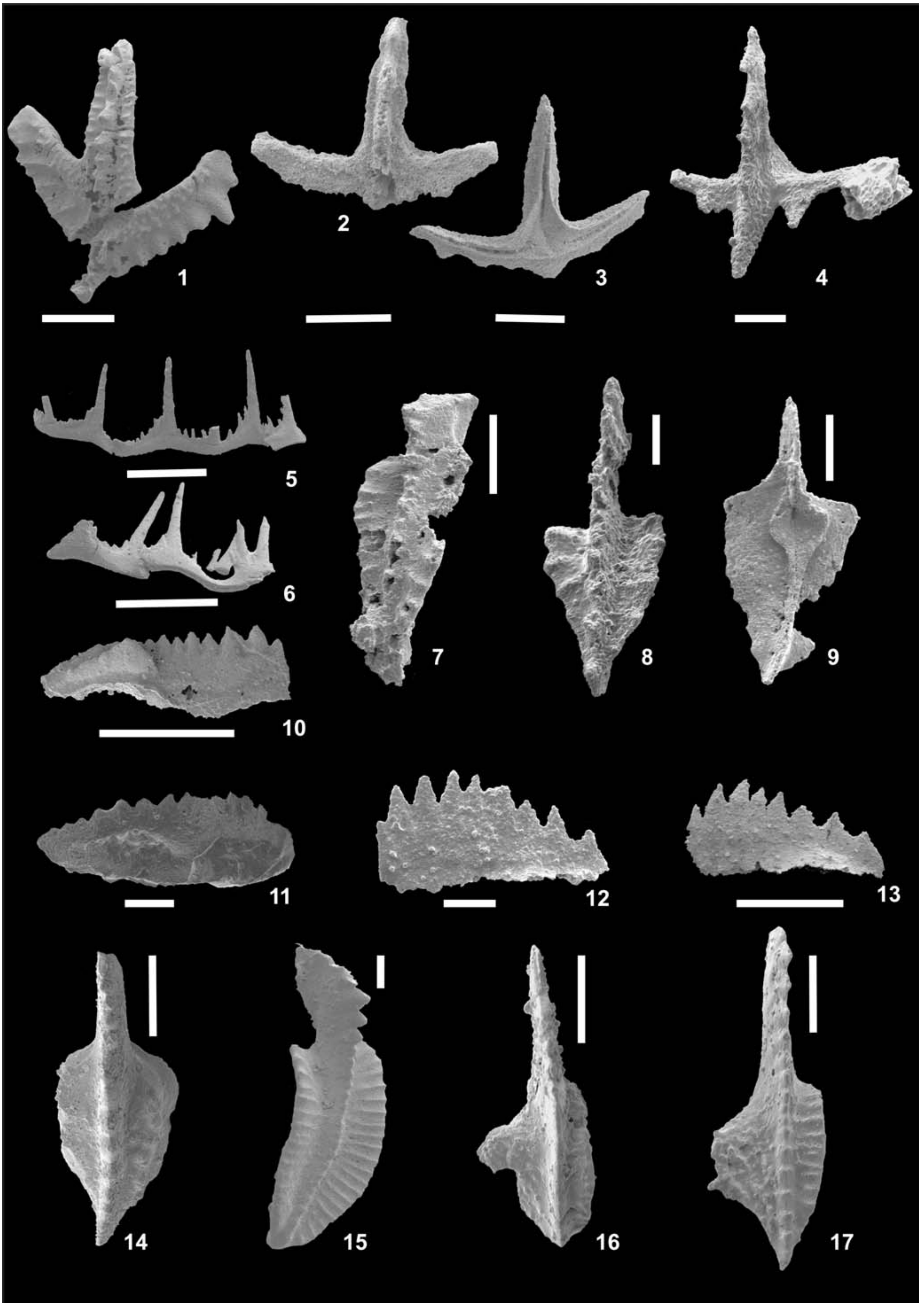
2004 *Gnathodus bilineatus* - Bermúdez-Rochas, Sarmiento & Rodríguez, p. 44-48, pl. 5, fig. 1-5. [see for synonymy]

Description. Pa element with an asymmetrical platform. The parapet is short and narrow. It bears 11 ridges that do not all extend from the outer margin to

PLATE 2

Scale bar represents 100 µm.

Fig. 1	- *Scaliognathus anchoralis europensis* Lane & Ziegler, 1983. Oral view, sample Th93-203, no. COT22.
Fig. 2-4	- *Scaliognathus anchoralis fairchildi* Lane & Ziegler, 1983. 2: Oral view, sample Th93-203, no. COT23, 3: Aboral view, sample Th93-204, no. COT24; 4: Oral view, sample Th93-203, no. COT25.
Fig. 5-6	- *Scaliognathus anchoralis*, Sc element. Lateral view, sample Th93-203, nos. COT26 and COT27.
Fig. 7-9	- *Polygnathus triangulus* (Voges, 1959). Oral view, sample Th93-204, nos. COT28, COT29 and COT30.
Fig. 10	- *Gnathodus austini* Belka, 1985. Lateral view, sample Th93-205, no. COT31.
Fig. 11, 14	- *Gnathodus homopunctatus* Ziegler, 1960. 11: Lateral view, 14: Oral view, sample Th93-205, no. COT32.
Fig. 12-13	- *Hindeodus* sp. Lateral view. 12: sample Th93-203, no. COT33; 13: sample Th93-204, no. COT34.
Fig. 15	- *Polygnathus bischoffi* Rhodes, Austin & Druce, 1969. Oral view, sample Th93-203, no. COT35.
Fig. 16	- *Gnathodus praebilineatus* Belka, 1985. Oral view, sample Th93-242, no. COT36.
Fig. 17	- *Gnathodus bilineatus* (Roundy, 1926). Oral view, sample Th93-243, no. COT37.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the carina. It joins the carina at almost 90° on the anterior part and at low acute angle in the posterior part of the element. The parapet ends posteriorly just before the tip of the carina. The outer platform is triangular, more or less rounded, and is quite short. It is covered by discrete nodes that might be arranged in 3 lines at about an angle of 45° to the carina but it is difficult to clearly see their arrangement as the specimen is not well preserved. The carina is straight and composed of 16 triangular denticles partly fused.

Remarks. The specimen is assigned to *G. bilineatus* and not *G. praebilineatus* due to the ridges of the parapet well developed and the nodes that seem to arrange in concentric lines. It corresponds to an early ontogenic stage of the species.

Stratigraphic range. *bilineatus* Zone.

Conclusion

This paper points out the importance of dating the long duration radiolarite deposits which are one of the main evidences of the presence of an ocean. Throughout Asia, palaeontological is becoming more and more numerous and should be an important key to understanding Gondwana dispersion and the closure of Palaeotethys. Conodonts have a great potential for compensating the lack of age dating with radiolarians and thus helping in the understanding of the palaeogeography and tectonic history of northern Thailand. Moreover, the study of conodonts in cherts will bring out new clues for the understanding of the palaeoecological habits of these organisms.

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