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Nannofossil biostratigraphy of the Lower Cretaceous Shadui Formation (Northern Tethyan Himalayas, Southern Tibet)

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Abstract: Calcareous nannofossils of Aptian-Albian age were found in the basal part of the Shadui Formation, Northern Tethyan Himalayas, Southern Tibet. The predominantly shale strata are exposed near the northeastern tip of Yamdrock Tso Lake at the locality of Bangbu and they were previously considered to be of Late Cretaceous age. Occurrence of the nannofossil species *Prediscosphaera columnata* and *Cribrosphaerella ehrenbergii* indicates the Upper Aptian–Lower Albian Zone BC23. Nannofossil species of Late Albian, Cenomanian or younger Cretaceous age were not present in the studied part of the Shadui Formation. Nannofossils are badly preserved and hardly identifiable probably as a result of strong post mortem etching and dissolution during burial. The depositional setting of the Shadui Formation is interpreted as hemipelagic to pelagic. A horizon of dark shale in the lower part of the Shadui Formation may be stratigraphically correlated with ocean anoxic event OAE1b. The discovery of calcareous nannofossils at the Bangbu locality increases the stratigraphic precision in the correlation of Cretaceous strata between hemipelagic-pelagic facies and shelf depositional areas in the Tibetan Tethyan Himalayas.

Key words: Lower Cretaceous, Northern Tethyan Himalayas, Shadui Formation, biostratigraphy, oceanic anoxic event, calcareous nannofossils.

Introduction

Studies in biostratigraphy and chronostratigraphy of Mesozoic marine sedimentary strata in Tibetan Tethyan Himalayas are relatively scarce, in spite of geological studies of this region extending back more than a century, from early studies by Hayden (1907) and Douvillè (1916) to later research (e.g. Yang et al. 1962; Wang et al. 1976; Wu et al. 1977; Wu 1984, 1987; Xu et al. 1990; TBGMR 1993, 1994, 1997). The main reason is only occasional occurrence of macro- and microfossils in these Mesozoic sedimentary rocks. Within the Mesozoic System, the Upper Cretaceous strata have relatively higher bio- and chronostratigraphic resolution (Wan et al. 1993; Willems & Zhang 1993a,b; Willems et al. 1996; Shi et al. 2006), mainly based on foraminiferal, calcareous nannofossil and stable isotope studies (Wan et al. 2003; Li et al. 2006; Shi et al. 2006; Wendler et al. 2009). Most of the biostratigraphic research was conducted in the Gamba and Tingri, areas that tectonically belong to the paleoshelf of the Indian continental plate (Fig. 1). Six nannofossil zones and five additional biohorizons spanning Middle Albian up to Late Santonian age have been established in the Gamba area (Zhong et al. 2000). However, from the Cretaceous strata deposited on the deeper continental slope of the Indian plate and in the adjacent oceanic basin floor, as represented by areas of Northern Tethyan Himalayas (see Fig. 1), poor biostratigraphic data are available up to now. The exception is the Upper Cretaceous strata in the Gyangze area, where sediments were deposited on the lower continental slope, or at the transition into the deep oceanic trench (Li et al. 1999; Hu et al. 2008). Despite the overlying sediments being pelagic red beds intercalated with radiolarites and deposited below CCD (carbonate dissolution level), the presence of frequent limestone olistoliths and turbidites containing pelagic foraminifers allowed recognition of the Late Cretaceous age (Wang et al. 1983, 2000; Li et al. 2005; Hu et al. 2006).

Geological setting

The Tethyan Himalayas (Gansser 1964) tectonically belong to the Indian continental plate and are generally subdivided into Southern and Northern Tethyan Himalayas (see Fig. 1). The line of subdivision has been placed along the Gyrong-Kangmar thrust (Ratschbacher et al. 1994), or alternatively along the Gamba-Tingri fault (Wang et al. 1996). The Southern Tethyan Himalayas are characterized by shallow shelf sedimentary rocks of the Paleozoic, Mesozoic and Cenozoic (up to Eocene) age (Yang & Wu 1962; Xu et al. 1990; Willems et al. 1996), while the Northern Tethyan Himalayas are represented by sediments deposited on the continental slope and in the adjacent deep oceanic basin (Searle et al. 1987; Liu & Einsele 1994; Jadoul et al. 1998; Hu et al. 2008). The Bangbu section tectonically belongs to the deeper, Northern Tethyan Himalayas (see Fig. 1).

The Bangbu section is located approximately 20 km SW from Qingjie town, Shannan District, Southern Tibet. The Mesozoic sedimentary strata are exposed near the northeastern corner of the Yamdrock Tso (see Fig. 1). The base of the exposed strata is located at E 91°32′27.4″ latitude and N

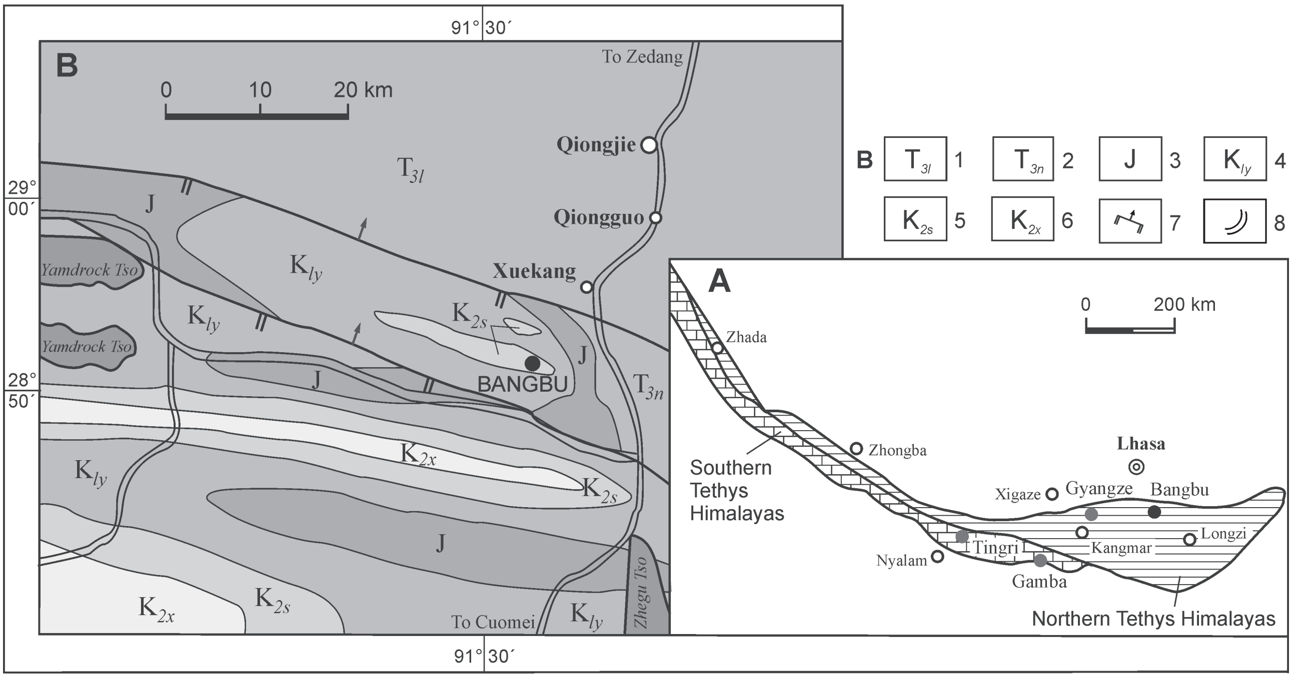

Fig. 1. A — Tethyan Himalayas, tectonic zones and significant localities of the Upper Cretaceous strata. **B** — Northern Tethyan Himalayas. Simplified geological map showing the location of the Bangbu cross-section (after Mao et al. 2003, modified). 1 — Upper Triassic Flysch, Langjiexue Group; 2 — Upper Triassic Flysch, Nieru Formation; 3 — Jurassic (unsubdivided); 4 — Lower Cretaceous, Yulangbaijia Group; 5 — Lower–Upper Cretaceous, Shadui Formation; 6 — Upper Cretaceous, Xieli Formation; 7 — thrust; 8 — road and/or path.

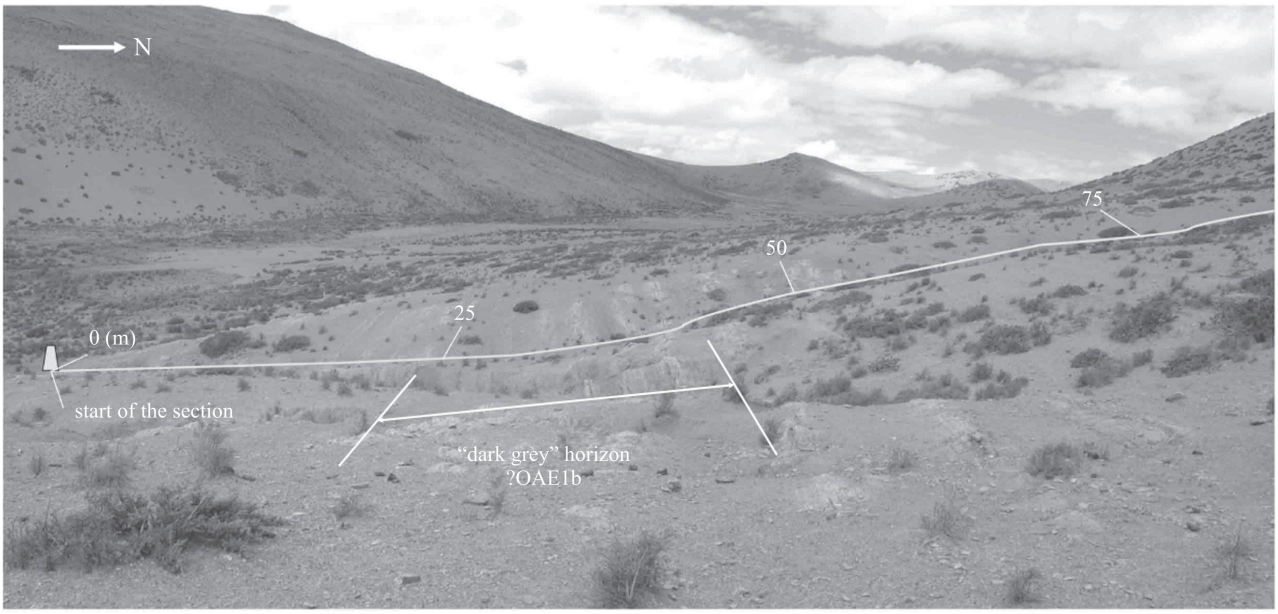

Fig. 2. Bangbu section, southwest from Qiongjie town, Southern Tibet.

28°50′49.2″ longitude, with the section continuing northward. This sedimentary succession (Fig. 2) was defined by Wang et al. (1983) as the Shadui Formation during early reconnaissance studies. It conformably overlies shale and sandstone of the Yulangbaijia Group (Wang et al. 1983), which is biostratigraphically undated due to the lack of fossils. The Shadui Formation terminates at the top of the mountain where it is eroded and covered by scree.

Strata of the Shadui Formation at the Bangbu locality are exposed in an 800 m thick profile. They comprise grey and dark grey silty shale and calcareous shale intercalated with thin-bedded and lenticular marlstone and mudstone. In the upper part of the exposed strata few fine-grained feldspathic-lithic sandstones and cherts are intercalated. Locally, calcareous shale is interbedded with thin-bedded marlstone and/or mudstone with an appearance of high-frequency cycles resembling Milankovitch orbitally forced cyclicity. Dark grey shale is a distinct feature of Bed 2 (Fig. 3). Fragments of brachiopods, foraminifers, rare radiolarians and ostracods found in this section from Beds 3, 5, 7 and 11, were interpreted as indicating an Early Cretaceous age (TBGMR 1997), or Late Cretaceous age (Mao et al. 2003). The later dating is based on nannofossils, namely an association of *Lithastrinus-Biscutum-Prediscosphaera* found in three samples (two samples from Bed 5 and one sample from Bed 8, see Fig. 3). This indicates that the Upper Cretaceous strata at Bangbu locality are much thicker than in the Tingri (Willems et al. 1996; Shi et al. 2006) and Gyangze areas (Li et al. 2005). Because during the field work small faults and folds indicating thrusting were noted and the possibility of tectonic duplication of parts of section was highly probable, only Beds 1 and 2 of the section have been remeasured and sampled for this study.

Methods

For nannofossil study, twenty-two shale samples (for location see Fig. 4) were investigated in the fraction of 2–30 μm, separated by decantation following the methodology described in Svobodová et al. (2004). Simple smear-slides were mounted by Canada Balsam and inspected at 1000× magnification, using an oil-immersion objective on a Nikon Microphot-FXA transmitting light microscope. Biostratigraphic data were interpreted applying Sissingh (1977) CC zones, Roth (1978) NC zones, and Bown et al. (1998) BC zones.

Results

Sedimentary rocks collected from the lower part of the Shadui Formation, Bangbu section, Beds 1 and 2 (Figs. 3 and 4) yielded few calcareous nannofossils, with a density from more than 15 specimens per 1 field of view of the microscope to less than 1 specimen per 10 fields of view of the microscope. The nannofossils were poorly preserved, strongly etched and mostly fragmented (Fig. 5), so the majority of them could not be identified. Assemblages are characterized by low species diversity, high numbers of *Watznaueria barnesiae*, and by the remains of outer rims of other placoliths. Biostratigraphically important species were scarce, irregular and usually fragmented (Table 1 and Fig. 5). Nannofossil species *Prediscosphaera columnata* (Fig. 5.1,2), *Lithastrinus floralis*, *Helenea chiastia*, *Zeugrhabdotus embergerii*, and *Lithraphidites carniolensis* were present only in few samples. The stratigraphically interesting species *Cribrosphaerella ehrenbergii* (Fig. 5.4,5) was found in samples LL-011 and LL-041 and a questionable specimen of *Rhagodiscus* cf. *achlyostaurion* (Fig. 5.11) exclusively in LL-041. Some of the samples did not provide any calcareous nannofossils (see Fig. 4 and Table 1).

Biostratigraphy

The biostratigraphic study resulted only in general information because of extremely poor nannofossil preservation. The presence of *Prediscosphaera columnata* indicates Zone BC23 that Bown et al. (1998) correlated with the Lower Albian. However, this species is reported below the proposed base of the Albian (Kennedy et al. 2000). Apparently Zone BC23 spans the Aptian-Albian boundary (Bralover et al. 1995).

Nevertheless, the scarce presence of *Cribrosphaerella ehrenbergii* may highlight the Lower Albian. Erba (1988) mentioned the first occurrence of *C. ehrenbergii* in the Lower Albian above the first *P. columnata* from the Umbrian-Marchean Basin, Central Italy (Tethyan Province), but Bown et al. (1998) reported it from the Upper Albian and correlated it with the Boreal ammonite Zone "inflatum". The species range in Italy is more relevant to the Tethyan Himalayas than its Boreal first occurrence.

The biostratigraphic significance of *Rhagodiscus* cf. *achlyostaurion* is questionable. Cobianchi et al. (1997) marked its first occurrence in the Upper Albian in the "Amadeus" level in the Scisti a Fucoidi Formation, whereas Bralower (1992) and Bown et al. (1998) placed it in the Upper Aptian. However, the badly preserved material from the Shadui Formation makes it difficult to differentiate species *R. achlyos-*

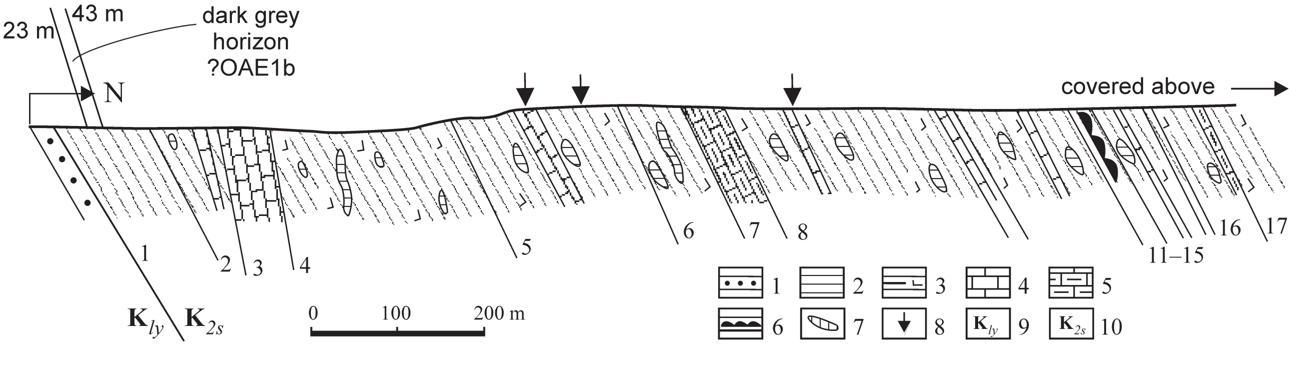

Fig. 3. Lithostratigraphic profile of the Shadui Formation at Bangbu locality (after Mao et al. 2003, modified) with marked Beds 1–17. Beds no. 1 and 2 are the intervals investigated during this study. **1** — sandstone; **2** — shale; **3** — calcareous shale; **4** — micritic mudstone; **5** — marlstone; **6** — chert; **7** — lenticular limestone; **8** — position of samples reported by Mao et al. (2003); **9** — Lower Cretaceous, Yulangbaijia Group; **10** — Lower–Upper Cretaceous, Shadui Formation.

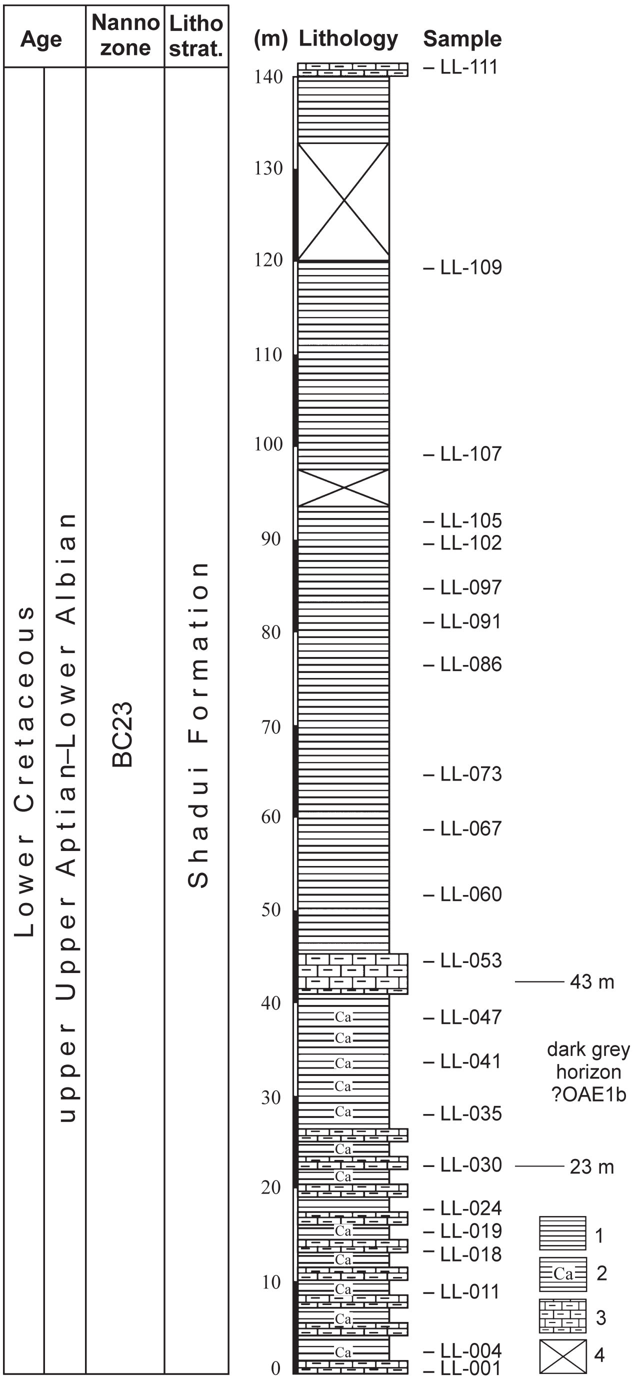

Fig. 4. Bangbu section, lower part of the Shadui Formation. Lithostratigraphic column of Bed 1 and Bed 2 with indication of collected samples. **1** — shale, **2** — calcareous shale, **3** — marlstone, **4** — outcrop covered. Nannoplankton zone after Bown et al. (1998), lithostratigraphy after Wang et al. (1983).

taurion from *R. angustus*, the first occurrence of which is known also from the Aptian. Nannofossil species with their first occurrences in the Upper Albian, Cenomanian or younger Cretaceous stages have not been found here.

The basal part of the Shadui Formation, dated at the Bangbu locality by nannofossils as Late Aptian to Early Albian, may be in part the chronostratigraphic equivalent of the Upper Gambadongshang Formation in the Gamba area, Southern Tethyan Himalayas (Zhong et al. 2000), that spans the interval Early–Middle Albian, Zone *Prediscosphaera cretacea* (Zhong et al. 2000).

Discussion

The scarcity or even complete absence of calcareous nannofossils in sedimentary strata at the Bangbu locality may be explained by two different causes:

1. Post mortem dissolution near or below the carbonate compensation depth (CCD). In that case, their scarce presence or even absence would indicate deposition in a bathyal or abyssal paleoenvironment.

2. Carbonate dissolution and etching occurring during sediment burial as a result of liberation of organic acids during decomposition of organic matter enclosed in the sediments, or during low grade metamorphosis as a result of deep burial and subsequently accentuated by overthrust tectonics resulting from tectonic compression during and after the Indian-Asian continental collision.

The studied sediments contained mostly dissolution and mechanically more resistant nannofossil species, represented by placoliths (generally disc-like in form) of genera *Watznaueria* and *Parhabdolithus*, or cubic-shape nannofossils of the group Polycyclolithaceae, genus *Eprolithus*. A similar mode of nannofossil preservation with signs of strong etching was observed, for example, in the Albian and Cenomanian black shales of the Outer Western Carpathians (Svobodová et al. 2004; Švábenická 2006; Skupien et al. 2009), where etching was interpreted as the result of carbonate dissolution caused by the releases of carbon dioxide during oxidation of organic matter. The presence of micritic mudstone intercalated within shales in Bed 3 (see Fig. 3) of the Shadui Formation indicates that dissolution is not related to deposition below CCD, but most probably is the result of deep burial and dissolution by organic acids. The prevailing shale lithology of the Shadui Formation, the presence of nannofossils, and the occurrence of radiolarians observed in the upper part of the formation suggest a hemipelagic-pelagic depositional environment.

An important horizon of dark grey to black shale containing nannofossils of the Late Aptian to Early Albian age was found within Bed 2 (see Fig. 3). Similar horizons in the

Fig. 5. Calcareous nannofossils of the Bangbu locality (Bed 1 and Bed 2), Shadui Formation, Northern Tethyan Himalayas, Tibet. **PPL** — plane-polarized light, **XPL** — cross-polarized light. For magnification see fig. 2. **1, 2** — *Prediscosphaera columnata* (outer rim); LL-018. **3** — *Prediscosphaera ponticula* (fragment); LL-035, XPL. **4, 5** — *Cribrosphaerella ehrenbergii*; LL-041, 4 — PPL, 5 — XPL. **6** — *Flabellites oblongus*; LL-004, XPL. **7, 8** — *Broinsonia matalosa*; LL-041, XPL, 7 — 0°, 8 — 10°. **9, 10** — *Helenea chiastia*; XPL, 9 — LL-011, 10 — LL-047. **11** — *Rhagodiscus* cf. *achlyostaurion*; LL-041, XPL. **12** — *Rhagodiscus angustus*; LL-41, XPL. **13** — *Hexalithus* sp.; LL-011, XPL. **14** — *Hayesites irregularis*; LL-011, XPL. **15, 16** — *Hayesites* sp.; LL-047. **17, 18** — *Stoverius achylosus* (fragments); LL-041, XPL. **19** — *Cyclagelosphaera argoensis*; LL-004, XPL. **20** — *Watznaueria barnesae*; LL-043, XPL. **21** — *Watznaueria britannica;* LL-041, XPL.

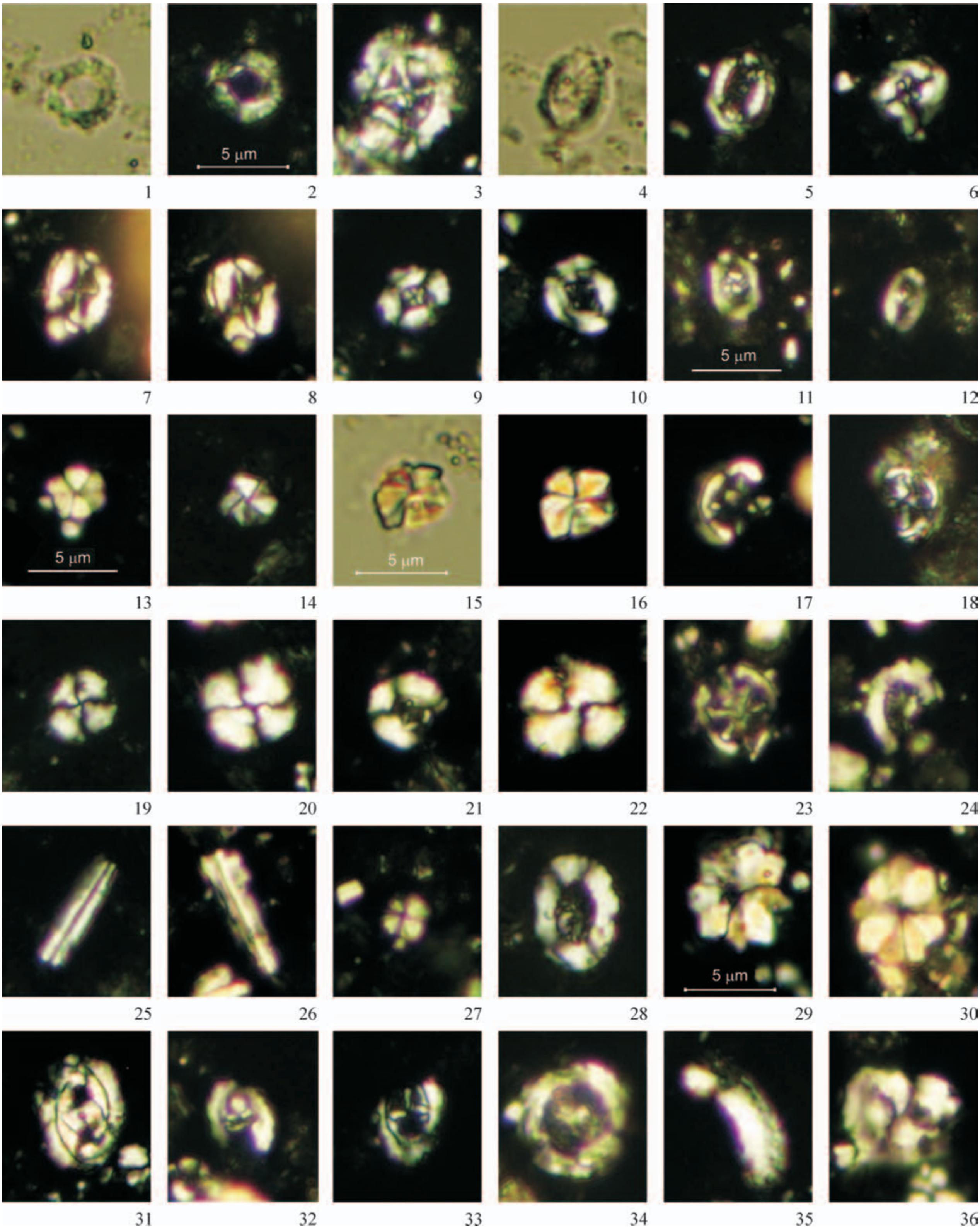

Fig. 5. (Caption continued from preceding page.) **22** — *Watznaueria biporta*; LL-004, XPL. **23** — *Corollithion acutum* (fragment); LL-041, XPL. **24** — *Cretarhabdus conicus* (fragment); LL-041, XPL. **25** — *Lithraphidites carniolensis* (fragment); LL-035, XPL. **26** — *Lithraphidites* cf. *moray-firthensis;* LL-011, XPL. **27** — *Discorhabdus* sp.; LL-011, XPL. **28** — *Retacapsa surirella*; LL-004, XPL. **29, 30** — *Eprolithus floralis*; XPL, 29 — LL-011, 30 — LL-035. **31** — *Zeugrhabdotus embergerii*; 31 — LL-018, XPL. **32** — *Zeugrhabdotus diplogrammus*; LL-041, XPL. **33** — *Staurolithites* sp. (fragment); LL-047, XPL. **34** — Circular remnant of nannofossil specimen; LL-011, XPL. **35** — *Manivitella pemmatoidea* (fragment of the broadly elliptical specimen); LL-041, XPL. **36** — *Haqius circumradiatus*; LL-041, XPL.

Table 1: Bangbu section, lower part of the Shadui Formation, Northern Tethyan Himalayas. Distribution of calcareous nannofossils and biostratigraphic interpretation. Abundance of nannofossil taxa: **VR** = very rare (<1 specimen per 10 fields of view), **R** = rare (1–9 specimens per 10 fields of view), **F** = few (>1 specimen per field of view). Estimates of the abundance of nannofossils in samples: **M** = moderate (>10 specimens per field of view), **L** = low (10–1 specimens per field of view), **VL** = very low (<1 specimen per field of view), **f** = fragments.

Age (Bangbu Section)	nannozones: Sissingh (1977)	nannozones: Roth (1978)	nannozones: Bown et al. (1998)	Oceanic anoxic event (Ogg et al. 2006)	Lithostratigraphic unit	Sample No.	sample abundance	*Chiastozygus litterarius*	*Cretarhabdus conicus*	*Cretarhabdus striatus*	*Cyclagelosphaera argoensis*	*Discorhabdus* cf. *ignotus*	*Diazomatolithus lehmanii*	*Eprolithus floralis*	*Flabellites oblongus*	*Haqius circumradiatus*	*Hayesites irregularis*	*Helenea chiastia*	*Lithraphidites carniolensis*	*Manivitella pemmatoidea*	*Prediscosphaera columnata*	*Prediscosphaera ponticula*	*Retacapsa angustiforata*	*Retacapsa surirella*	*Retacapsa* sp.	*Rhagodiscus angustus*	*Staurolithites crux*	*Staurolithites* sp.	*Watznaueria barnesiae*	*Watznaueria biporta*	*Watznaueria britannica*	*Watznaueria fossacincta*	*Zeugrhabdotus diplogrammus*	*Zeugrhabdotus embergerii*	*Cribrosphaerella ehrenbergii*	? *Hexalithus* sp.	*Lithraphidites* cf. *moray-firthensis*	*Prediscosphaera spinosa*	*Stoverius achylosus*	*Rhagodiscus* cf. *achlyostaurion*	*Broinsonia* sp.	*Biscutum constans*	*Broinsonia matalosa*	*Corollithion acutum*	*Cribrosphaerella ehrenbergii*	*Cyclagelosphaera* cf. *margerelii*	*Grantarhabdus coronadventis*	*Zeugrhabdotus elegans*
?					Shadui Formation	LL - 111	VL																						VR																			
						LL - 109	barren of calcareous nannofossils																																									
						LL - 107	barren of calcareous nannofossils																																									
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late Late Aptian–Early Albian	CC8	NC8	BC23			LL - 097	VL																						R																			
						LL - 091	L											VR	f						VR			VR	R					VR														
						LL - 086	VL		f					VR			VR	VR	f	VRf					VR				R					R							?							
						LL - 073	VL							VR															R			VR																
						LL - 067	L							VR					f										R					f														
						LL - 060	barren of calcareous nannofossils																																									
				dark horizon ?OAE1b		LL - 053	L											VR	f	VRf				VR	VR		VR		F	R	VR	VR		R												VR		
						LL - 047	L			f					VR		?	R	f			f	VR	VR				R	F	R				VR			VR		f		VR							
						LL - 041	M		VR		VR	VR		R	VR		VR	VR	f	VRf	VR	f	VR			VR	R		F	VR		VR	VR	VR	VR		R	VR	f	VR	VR	VR		VR	VR	VR	f	VR
						LL - 035	L		VR			VR		F				VR	Ff		VR				R	VR	VR		F	VR				R							VR							
						LL - 030	VL		VR					VR															R																			
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						LL - 019	barren of calcareous nannofossils																																									
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						LL - 011	M		VR			VR		R	VR	VR	VR	VR	f		f			VR			VR		F	VR	VR	VR	VR	VR	VR	VR	R	f	f									
						LL - 004	M	VR	?	f	VR	R	VR	R	VR	VR	VR	R	f	Rf	VR	f	?	VR	VR	VR	VR	f	F	VR	VR	VR	?	R														
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Western Tethys are considered to represent anoxic ocean event OAE1b, also known as the Urbino level by Italian geologists (Luciani et al. 2007), stratigraphically placed in the Early Albian, or the "Paquier" organic-rich event of the lowermost Albian age, of French geologists (Herrle et al. 2003; Tsikos et al. 2004), which are isotopically demonstrated by isotopic positive shift of $^{13}C_{org}$ (age correlations sensu Ogg et al. 2006). Both of these horizons are mentioned in the literature as OAE1b. Erba (2004) correlates OAE1b with the lowermost Albian. The "Paquier" event falls in Roth's (1978) nannoplankton Zone NC8 as does the age of the black shale horizon within the lower part of the Shadui Formation. If the black shale horizon within Bed 2 at Bangbu locality corresponds to the "Paquier" event, that Herrle et al. (2003) related to a period of extreme monsoonal forcing, then it would demonstrate the expansion of the latter event into the Eastern Tethys, although current available literature concludes that the "Paquier" event is known only from the Tethys-Atlantic region (Tsikos et al. 2003).

Confirmation of the potential synchroniety of the black shale horizon within Bed 2 at Bangbu locality with the "Paquier" event requires detailed carbon and oxygen isotope analyses of the Bangbu sequence, neither of which is currently available.

Conclusion

The calcareous nannofossils found in sedimentary strata at the Bangbu locality, Northern Tethyan Himalayas, Southern Tibet are badly preserved and hardly identifiable as a result of strong etching and dissolution that occurred during sediment burial. The Late Aptian to Early Albian age, Zone BC23 is proven by the presence of the species *Prediscosphaera columnata* and scarce *Cribrosphaerella ehrenbergii*. Nannofossil species that first occur in the Late Albian, Cenomanian or in younger Cretaceous stages were not found. The horizon of dark grey to black shales (Bed 2) in the lower part of the Shadui Formation suggests the presence of anoxic ocean event OAE1b in Southern Tibet.

The discovery of calcareous nannofossils at the Bangbu section in Northern Tethyan Himalayas allows more precise biostratigraphic dating of the sediments, with a zonal resolution for the Late Aptian and Early Albian stage and thus assists in the intercorrelation of shelf and hemipelagic to pelagic strata of Mesozoic age in Southern Tibet.

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Appendix

List of calcareous nannofossils mentioned in the text, in alphabetical order of genera epithets.

Biscutum constans (Górka) Black
Broinsonia matalosa (Stover) Burnett
Chiastozygus litterarius (Górka) Manivit
Corollithion acutum Thierstein
Cretarhabdus conicus Bramlette & Martini
Cretarhabdus striatus (Stradner) Black
Cribrosphaerella ehrenbergii (Arkhangelsky) Deflandre
Cyclagelosphaera argoensis Bown
Cyclagelosphaera margerelii Noël
Diazomatolithus lehmanii Noël
Discorhabdus ignotus (Górka) Perch-Nielsen
Eprolithus floralis (Stradner) Stover
Flabellites oblongus (Bukry) Crux
Grantarhabdus coronadventis (Reinhardt) Grün
Haqius circumradiatus (Stover) Roth
Hayesites irregularis (Thierstein) Applegate et al.
Helenea chiastia Worsley
Lithraphidites carniolensis Deflandre
Lithraphidites moray-firthensis Jakubowski
Manivitella pemmatoidea (Deflandre) Thierstein
Prediscosphaera columnata (Stover) Perch-Nielsen
Prediscosphaera ponticula (Bukry) Perch-Nielsen
Prediscosphaera spinosa (Bramlette & Martini) Gartner
Retacapsa angustiforata Black
Retacapsa surirella (Deflandre & Fert) Grün
Rhagodiscus cf. *achlyostaurion* (Hill) Doeven
Rhagodiscus angustus (Stradner) Reinhardt
Staurolithites crux (Deflandre & Fert) Caratini
Stoverius achylosus (Stover) Perch-Nielsen
Watznaueria barnesiae (Black) Perch-Nielsen
Watznaueria biporta Bukry
Watznaueria britannica (Stradner) Reinhardt
Watznaueria fossacincta (Black) Bown
Zeugrhabdotus diplogrammus (Deflandre) Burnett
Zeugrhabdotus elegans (Gartner) Burnett
Zeugrhabdotus embergerii (Noël) Perch-Nielsen