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Discovery of radiolaria from Upper Cretaceous Oceanic Red Beds in Daba, Kangmar and its paleogeographic implication

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ABSTRACT

A group of varicolored marine deposits, including red colored beds, are widespread in the Kangmar area, southern Tibet. They are lithologically similar to the Upper Cretaceous Oceanic Red Beds (CORBs) (the Chuangde Formation) outcropping at other localities in southern Tibet. At Daba locality, they are mainly composed of intercalated pelagic red clays and reddish colored pelagic limestones. Micropaleontologic study of the strata led to the discovery of radiolarians in siliceous rocks and siliceous limestones. Radiolaria preservation is mostly satisfactory and fifty-four species from forty-nine genera were identified. These allow recognition of three main radiolarian assemblages: *Cavaspongia califoniaensis — Xitus spicularius* assemblage, *Praeconocaryomma lipmanae — Clathropyrgus titthium* assemblage, and *Lithostrobus punctulatus — Lithocampe marinae* assemblage.

Occurrence of these radiolarian assemblages indicate a Campanian age of the CORBs at Daba, corroborated by co-occurring planktic foraminifers. Radiolarian and foraminiferal microfossil evidence and lithology of the strata indicate that the sediments were deposited at the lower continental margin of the Indian continental plate and in an adjacent abyssal oceanic basin.

The discovery of radiolarians from the CORBs at Daba area contributes to the paleogeographic interpretation of Late Cretaceous strata in southern Tibet and the Tethyan Himalaya. Unanswered is the remaining question: Was it the difference in palaeoceanography, such as ocean circulation, or plate tectonics, which resulted in the CORBs in the Tethyan Himalaya being younger than similar deposits in the western Tethys, where the deposition of this lithofacies had already begun in the Turonian? To answer this question more detailed biostratigraphic studies in southern Tibet are needed.

1. Introduction

The Himalayas are subdivided into a number of tectono-stratigraphic units, mostly separated by major thrusts and/or normal faults. Among these units, is the Tethyan Himalaya located between the Indus–Yarlung Suture Zone marked by the ophiolite belt to the north and the High Himalayas to the south. It is composed of a sequence of Early Paleozoic to Palaeogene sedimentary rocks including minor volcanics (Zhu et al., 2005; Mo et al., 2009). Directly south of the ophiolite belt, lies a broad belt of sedimentary mélange extending discontinuously for hundreds of kilometers in length along the strike and more than 10 km in width. This sedimentary mélange is in abrupt contact to the north with the ophiolite belt and to the south with a variety of marine sediments (Yang et al., 2002; Li and Shen, 2005). The Tethyan Himalaya can be further subdivided into the southern Tethyan Himalaya sub-belt and the northern Tethyan Himalaya sub-belt separated by a regional Tingri–Gamba thrust (corresponding to the Gyirong–Kangmar crustal fault) (Yu and Wang, 1990; Li et al., 2009a). The Tethyan Himalaya is composed of a thick metamorphic basement (>20 km) incorporating pre-Ordovician miogeoclinal clastic sedimentary rocks. Sedimentary environments and biotic composition of Paleozoic marine sedimentary strata in the Tethyan Himalayan belt are similar to those in North and South China. Middle and Late Carboniferous and Permian strata yield large, thick-shelled brachiopods and solitary corals characteristic of Gondwana-type strata in the Tethyan Himalaya. The northern and southern Tethyan Himalayan sub-belts started to differentiate during early Triassic time. Sedimentary environments within the Northern Sub-belt became diversified, while in the Southern Sub-belt marine sedimentation continued on the Indian continental plate margin (ASTSET, 1974).

The Cretaceous sedimentary strata of the southern Tethyan Himalayan sub-belt were deposited on the northern shelf of Greater India, while the sediments of the northern Sub-belt were laid down on the lower continental slope and in an adjacent Neotethyan oceanic basin (Yu and Wang, 1990). The currently used lithostratigraphic subdivisions and biostratigraphic zones based on radiolarian and planktic

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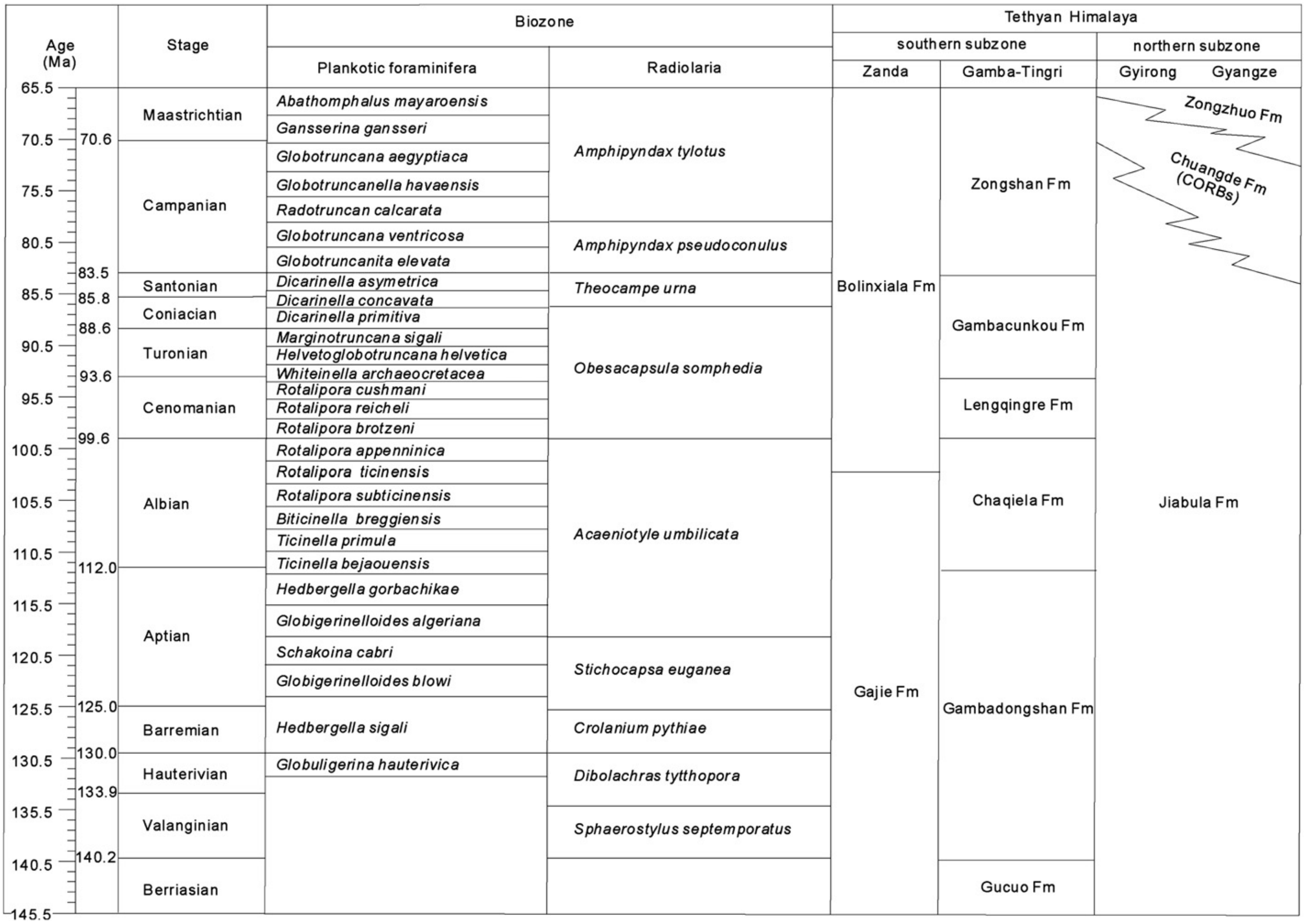


Fig. 1. Stratigraphic chart showing biostratigraphic zones and correlated lithostratigraphic formations for the Cretaceous in southern Tibet. Abbreviation: Fm = formation.

Fig. 2. Sketch map showing the location of the studied section in Kangmar, southern Tibet, China. ★ shows the location of the Daba section.

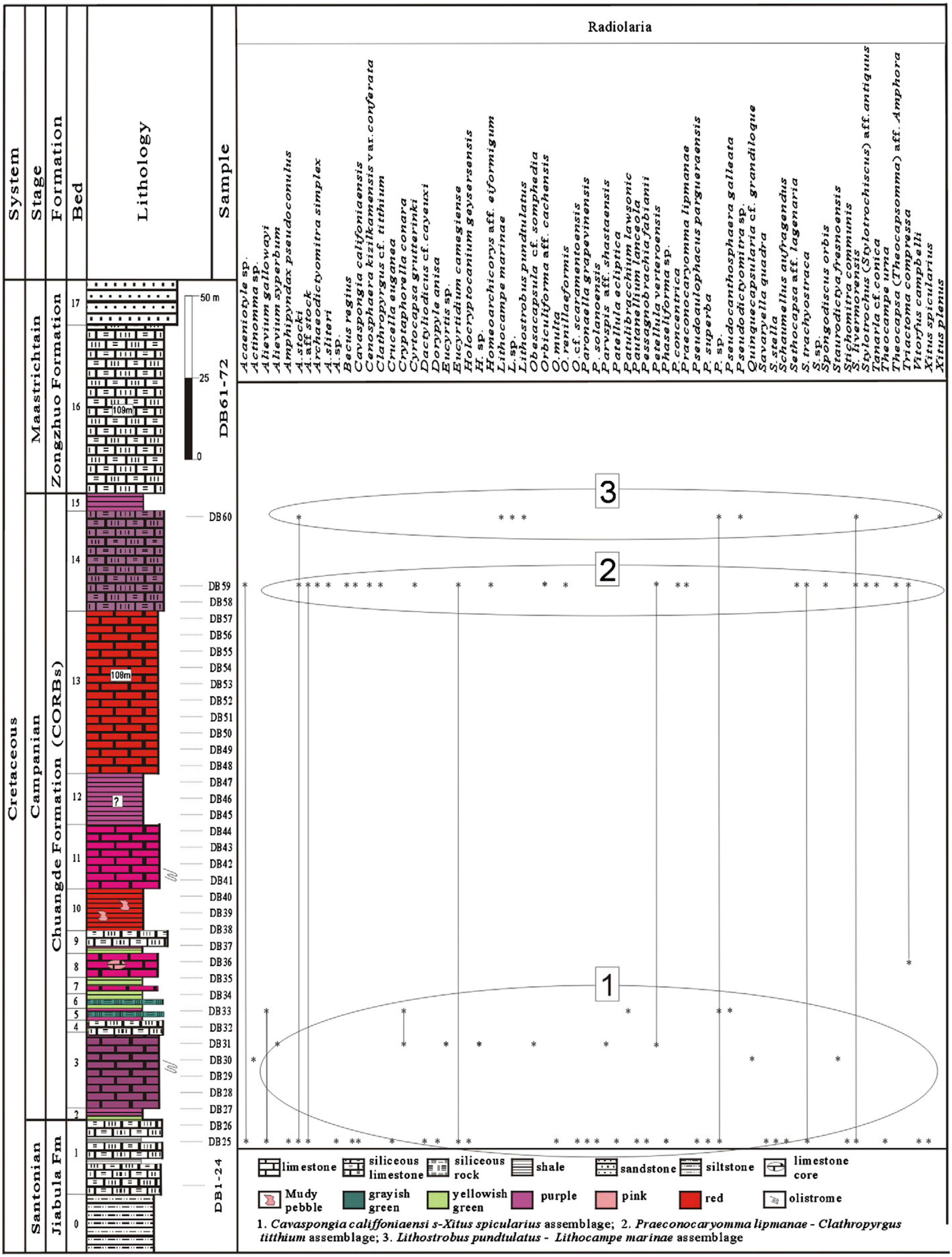


Fig. 3. The lithology and radiolarian range of the CORBs of the Daba section.

foraminiferal studies in the Tethyan Himalaya in southern Tibet are summarized in Fig. 1.

Radiolarian micropalaeontological studies have proven to be important in geological investigations of tectonically complex regions, such as of plate sutures zones (e.g., Yarlung Zangbo Suture Zone, in southern Tibet). This is because radiolarians can be preserved in a variety of oceanic sediments such as chert, siliceous mudstone, tuffaceous and flysch/flyschoid sediments, and micritic limestones, where other fossils may be lacking due to deposition below CCD, or destruction during sedimentary diagenesis and/or severe tectonic deformation. Radiolarian biochronology of Palaeozoic through Cenozoic time is reasonably well established, so that radiolarian fossils can be used as age-indicators and also can provide information about paleoceanographic conditions and paleogeography.

The Late Cretaceous sedimentary strata cropping out in Southern Tibet were involved in complex tectonics resulting in extensive faulting, folding and formation of complicated systems of nappes. Because of the complex geological structure of the Cretaceous strata in southern Tibet and the general lack of macrofossils, the microfossils, especially planktic foraminifera and radiolarians play an important role in regional biostratigraphy and geological investigations. A set of variegated marine deposits cropping out near Daba, Kangmar area (Fig. 2) was previously correlated with the Cretaceous Zongzhuo Formation, but without fossil evidence (TBGMR, 1983, 1993). They are lithologically similar to Cretaceous Oceanic Red Beds (CORBs) known from several other localities in southern Tibet (Wan et al., 2005a, 2005b; Wang et al., 2005; Li et al., 2009b).

We conducted field work in southern Tibet to investigate litho- and biostratigraphy of the CORBs at the Daba section at Kangmar. The latter area is tectonically situated in the northern Tethyan Himalayan sub-belt. In this paper, we present results of the study of Cretaceous radiolarians extracted from samples collected from the Chuangde Formation (equivalent to the CORBs) and from the top of the Jiabula Formation in Daba, Kangmar area, southern Tibet, with some of the species illustrated by scanning electron micrography. We discuss implications of these occurrences for the reconstruction of the paleogeography and paleoceanography of the Tethyan Himalayas.

2. Previous investigations

Cretaceous radiolarians of the Northern Tethyan Himalayan Sub-belt were the subject of several earlier studies (Li and Wu, 1985; Wu, 1988, 2007; Yang et al., 2002; Li et al., 2009b; Xu et al., 2009). Li et al. (2009b) first reported occurrences of Cretaceous radiolarians from the mélange directly south of the Yarlung–Zangbo Suture Zone (YSZ) at Saiqu, Sa'gya, the strata of which were previously considered to be part of the Triassic Xiukang Group. The three superposed radiolarian assemblages found, namely: *Holocryptocanium barbui–Dictyomitra turris*, *Thanarla veneta–Pseudodictyomitra pseudomacrocephala*, and *Dictyomitra magnifica–Dictyomitra turritum* assemblages document the presence of Upper Cretaceous strata at Saiqu.

The Upper Cretaceous strata at Daba section in Kangmar are composed of red limestone, siltstone, shale, siliceous chert and marlstone. Olistostromes/olistoliths and radiolarian fossils are abundant. The intercalated limestones are mainly micrites though a few packstones or grainstones could be rarely found. The micritic limestone and wackestone are mud-supported enclosing 5–25% well-preserved planktic foraminifers. Foraminiferal tests are mostly infilled with sparite. They are scattered within a red, occasionally gray-colored cryptocrystalline matrix. The packstone is grain-supported with 25–76% moderate to well preserved planktic foraminifers in a mainly red cryptocrystalline matrix. The grainstone occurs mainly in carbonate concretions. It is grain-supported with about 75–95% well preserved planktonic foraminifers and a minor gray cryptocrystalline matrix. The corrosion noted on some foraminifera and calcispheres suggests that the deposition was occurring below the lysocline (Li et al., 2009b), close to CCD. Turbidite beds are common in the underlying Jiabula Formation and are rhythmically banded and usually composed of siltstones intercalated with shales.

The planktic foraminiferal biozones recognized in CORBs of Daba section include *Globotruncanita elevata*, *Globotruncana ventricosa*, *Radotruncana calcarata*, *Globotruncanella havanensis*, and *Globotruncana aegyptiaca* zones, which indicate a Campanian age for the CORBs of the Daba section. Representative elements of the planktic foraminiferas include *Globotruncanita elevata*, *Globotruncana bulloides*, *Contusotruncana fornicata*, *Globotruncana arca*, *Radotruncana subspinosa*, *Globotruncana aegyptiaca* and *Heterohelix globulosa*.

Samples for this study were mainly collected from the CORBs and from the top of the Jiabula Formation cropping out at the Dada (Fig. 2), Kangmar region. The CORB's strata at the Dada locality are about 250 m thick. They comprise intercalated reddish and purple pelagic limestones, shales and siliceous shales. Pelagic limestones quantitatively dominate over intercalated shales in the outcrop (Fig. 3). CORBs have conformable contact with the underlying Lower Cretaceous Jibula Formation. The upper contact with overlying dark gray siliceous limestones of the lower part of the Zongzhuo Formation is also conformable.

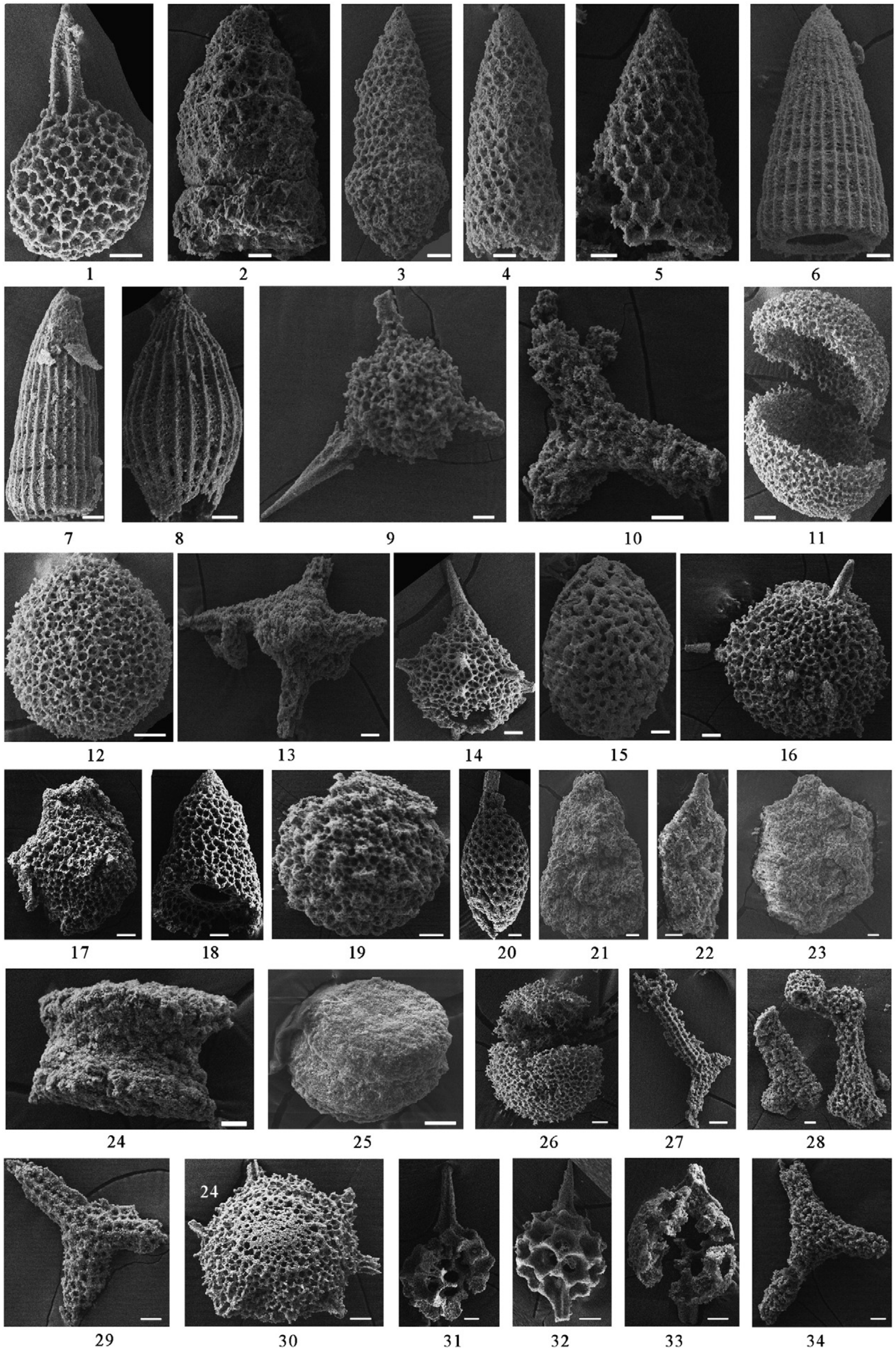
Identification of the genera and species of radiolarians and determination of their morphotypes from our study area were based on the shape of their skeletons, though some of them are poorly preserved and recrystallized, with quartz filling some of the fine skeletal structures, complicating the optical microscopy. In conclusion we comment on the paleoceanographic and paleogeographic implications of these radiolarian occurrences for the Cretaceous of southern Tibet and the Tethyan Himalayas.

3. Materials and methods

Seventy-two samples were collected from the Upper Cretaceous strata at the Daba section (28°43 54″E, 89°56 28″N), Kangmar, southern Tibet (Fig. 2) and thirty-eight samples of limestone, chert and siliceous shale were collected from the CORBs. Usually 1 kg from each sample was processed for radiolarians.

The processing and determination of the radiolarians were done in the laboratory of China University of Geosciences (Beijing). For freeing the radiolarians from the cherts and siliceous shales, the following procedures were applied: (1) The rocks were broken mechanically into small (centimeter-sized) pieces. (2) Broken pieces were then dissolved in diluted (5%) hydrofluoric acid (To remove the free radiolarians before they dissolve, it is advantageous to suspend the fragments above the bottom of the beaker). (3) Each sample was washed in distilled water and then examined to see if further treatment was required. (4) Encrusting iron oxides were removed by washing in a solution of 1% oxalic acid. (5) The free radiolarians were mounted on 22×40 mm glass slides for examination under transmitted light. (6) Representatives of each species were measured, gold-coated and photographed using a Scanning Electron Microscope (SEM).

Fig. 4. Scanning electron photomicrographs of representative species of identified radiolarian assemblages from the CORBs of Daba. 1. *Acaeniotyle* sp.; 2. *Amphipyndax pesudoconulus* (Pessagno); 3–4. *A. stocki* (Campbell and Clark); 5. *A.* aff. *stocki* (Campbell and Clark); 6–7. *Archaeodictyomitra simplex* Pessagno; 8. *A. sliteri* Pessagno; 9. *Becus regius* Luis; 10. *Cavaspongia* cf. *califoniaensis* Pessagno; 11–12. *Cenosphaera kizilkamensis* var. *conferata* Aliev; 13. *Crucella euganea* (Squinabol); 14. *Cytocapsa grutterinki* Tan Sin Hok; 15. *Phaseliforma* sp.; 16. *Dactyliodicus* cf. *cayeuxi* (Squinabol); 17. *Dorypyle anisa* (Foreman); 18. *Eucyrtidium camegiense* Campbell and Clark; 19. *Holocryptocanium geysersensis* (Pessagno); 20. *Homeoarchicorys* aff. *eiformigum* Empson-Morin; 21. *Lithocampe marinae* Gorbovetz; 22. *L.* sp.; 23. *Orbiculiforma* aff. *cachensis* Pessagno; 24–25. *O. multa* (Kozlova); 26. *O. renillaeformis* group (Campbell and Clark); 27. *Paronaella grapevinensis* (Pessagno); 28. *P. solanoensis* Pessagno; 29. *P.* sp.; 30. *Patellula ecliptica* Luis; 31–32. *Pautanellium lanceola* (Parona); 33. *P.* sp.; 34. *Pessagnobrachia fabianii* (Squinabol). Scale bar = 20 μm.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All radiolarian specimens examined during the present study are permanently deposited in the Fossil Identification Center of China University of Geosciences (Beijing), China.

4. The radiolarian assemblages

Lithological and paleontological features of the CORBs are summarized in Figs. 3–5. Abundant Cretaceous radiolarians were discovered from the CORBs of the Daba section. Radiolarian species identified are listed in Fig. 3 and radiolarian assemblages are illustrated in Figs. 4 and 5. The preservation of microfossils is satisfactory, though some specimens were filled by recrystallized quartz. Fifty-four species from forty-nine genera of radiolaria were extracted from cherts and siliceous limestones of the Chuangde Formation (CORBs) and from the top of the Jiabula Formation in Kangmar. The specimens were identified on the basis of their shape and ornamentation (see Figs. 3–5). Most of them are common elements of the Late Cretaceous radiolarian microfauna assemblages in the Tethyan ocean (Wu and Li, 1982; Wu, 1988, 1993, 2007; Li et al., 2009b).

Three radiolarian assemblages have been distinguished which in ascending order are: (1) *Cavaspongia califoniaensis–Xitus spicularius* assemblage; (2) *Praeconocaryomma lipmanae–Clathropyrgus titthium* assemblage;and (3) *Lithostrobus punctulatus–Lithocampe marinae* assemblage (Fig. 3). These assemblages were compared to radiolarian zones of Sanfilippo and Riedel (1985), referred to below, and which provide a broad indication of ages of the radiolarian assemblages recognized.

4.1. Cavaspongia califoniaensi–Xitus spicularius assemblage

These taxa occur in samples DB25-D33 collected from the top of the Jiabula Formation to the bottom of the Chuangde Formation, near the base of CORBs. Representative species of this assemblage include: *Acaeniotyle* sp., *Actinomma* sp., *Alievium gallowayi*, *A. syperbum*, *Amphipyndax pseudoconulus*, *A.stocki*, *A.* aff. *stocki*, *Becus regius*, *Cavaspongia califoniaensis*, *Crucella euganea*, *Cryptaphorella conara*, *Dactyliodicus* cf. *cayeuxi*, *Dorypyle anisa*, *Eucyrtis* sp., *Holocryptocanium geysersensis*, *H.* sp., *Obesacapsula* cf. *somphedia*, *Orbiculiforma multa*, *O.* cf. *sacramentoensis*, *Paronaella grapevinensis*, *P. solanoensis*, *Parvspis* aff. *shastaensis*, *Patellula ecliptica*, *Patulibracchium lawsonic*, *Pautanellium lanceola*, *P.* sp., *Pessagnobrachia fabianii*, *Petellula yerteroensis*, *Phaseliforma* sp., *Pseudoacanthosphaera galleata*, *Pseudoaulophacus* sp., *P. pargueraensis*, *P. superba*, *Quinquecapsularia* cf. *grandiloque*, *Savaryella quadra*, *S. stella*, *Schaumellus aufragendus*, *Sethocapsa* aff. *lagenaria*, *S. trachyostraca*, *Staurodictya fresnoensis*, *Stichomitra communis*, *S. livermorensis*, *Theocampe urna*, *Vitorfus campbelli*, and *Xitus spicularius*.

Among them, *Amphipyndax pseudoconulus*, *A.stocki*, *C. califoniaensis, Orbiculiforma multa*, *Patellula*, *Pseudoaulophacus*, *Stichomitra* and *X. spicularius* were reported to occur in an Upper Cretaceous radiolarian assemblage from the Russsian Platform (Moscow Basin) (Vishnevskaya and Wever, 1998). *Amphipyndax pesudoconulus* ranges from the top of the Santonian to the upper Campanian. *A. stocki* is frequent in Upper Cretaceous sediments. *C. califoniaensis* is stratigraphically limited to the Coniacian to Santonian. *Orbiculiforma multa* is common in Coniacian to Santonian sediments and occasionally occur in Turonian strata.

Therefore, the age of this radiolarian assemblage can be interpreted as late Santonian, and the CORBs strata at Daba should not be older than this.

4.2. Praeconocaryomma lipmanae–Clathropyrgus titthium assemblage

These taxa occur in sample DB59 from the upper CORBs (the Chuangde Formation). Representative species of this assemblage include: *Acaeniotyle* sp., *Archaeodictyomitra simplex*, *A. sliteri*, *Cenosphaera kizilkamensis* var. *conferata*, *Clathropyrgus titthium*, *Cytocapsa grutterinki*, *Eucyrtidium camegiense*, *Homeoarchicorys* aff. *eiformigum*, *Orbiculiforma renillaeformis* group, *Petellula verteroensis*, *Phaseliforma concentrica*, *Praeconocaryomma lipmanae, Sethocapsa* aff. *lagenaria*, *S. trachyostraca*, *Spongodiscus orbis*, *Stichomitra livermorensis*, *Stylotrochus* (*Stylotrochiscus*) aff. *antiquus*, *Tanarla* cf. *conica*, *Theocapsa* (*Theocapsomma*) aff. *amphora* and *Triactoma compressa*.

Among them, *Acaeniotyle*, *Archaeodictyomitra*, *Orbiculiforma*, *Praeconocaryomma lipmanae, Spongodiscus*, and *Stichomitra* were reported from the Upper Cretaceous of the Russsian Platform (Moscow Basin) (Vishnevskaya and Wever, 1998). *Praeconocaryomma lipmanae* ranges from Coniacian to Campanian. *Stichomitra livermorensis* is stratigraphically limited to the radiolarian zone 5 of the Bering region, of Late Campanian to Early Maastrichtian age (Vishnevskaya, 1986). *Clathropyrgus titthium* is limited to the Campanian (Sanfilippo and Riedel, 1985).

Therefore, this radiolarian assemblage indicates a Late Campanian age.

4.3. Lithostrobus punctulatus–Lithocampe marinae assemblage

These taxa occur in sample DB60 collected from the uppermost part of the CORBs (the Chuangde Formation). Representative radiolarian species in this assemblage include: *Amphipyndax stocki*, *Lithocampe marinae*, L. sp., *Lithostrobus pundtulatus*, *Orbiculiforma* aff. *cachensis*, *Pseuoaulophacus* sp., *Pseudodictyomitra* sp., *Stichomitra livermorensis* and *Xitus plenus*.

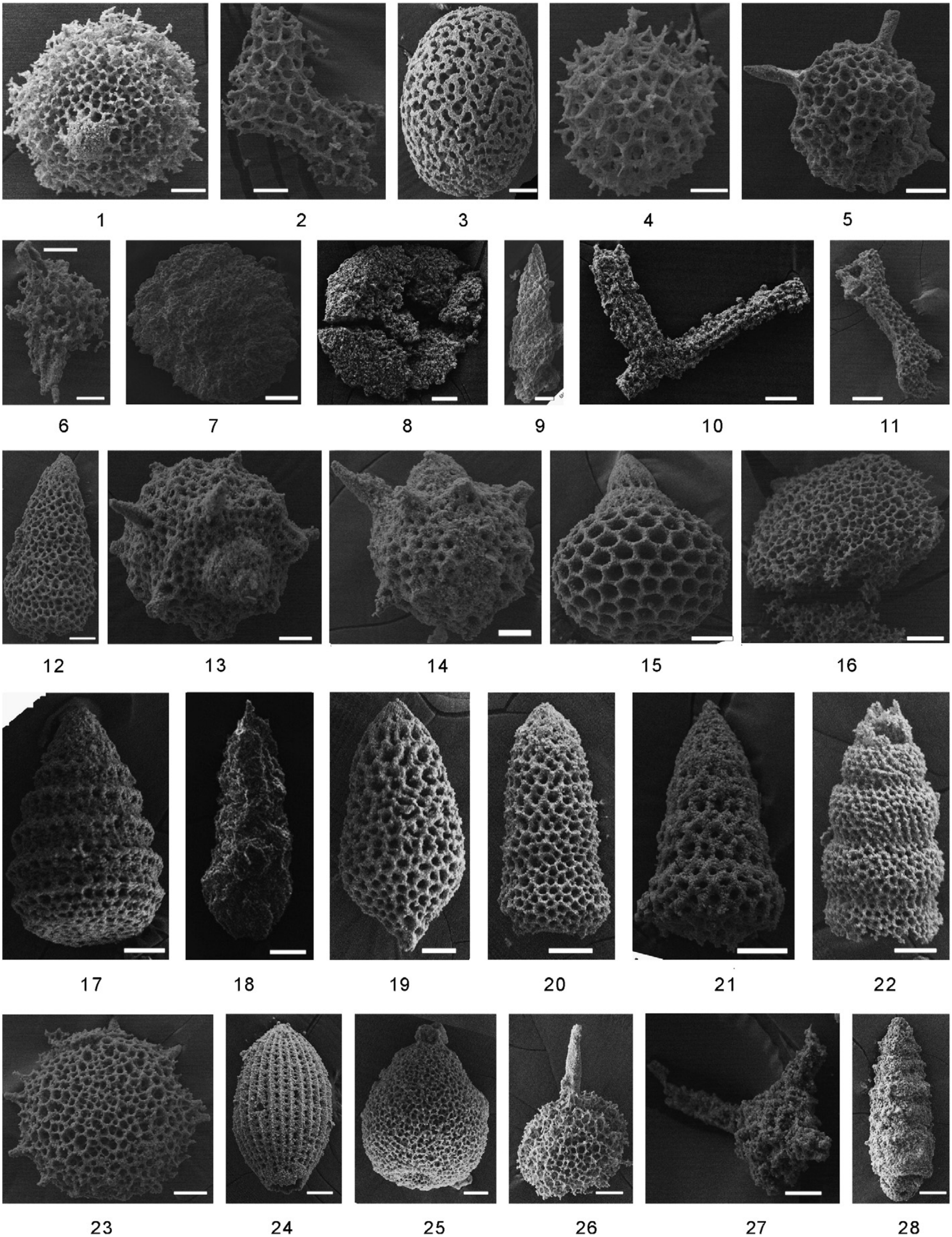
Among them, *Amphipyndax stocki*, *Lithocampe marinae*, *Lithostrobus*, *Pseuoaulophacus*, *Pseudodictyomitra*, and *Stichomitra livermorensis* were reported to occur in Upper Cretaceous radiolarian assemblages in the Russsian Platform (Moscow Basin) (Vishnevskaya and Wever, 1998). *A. stocki*, *L. pundtulatus* and *S. livermorensis* are also common elements of the radiolarian zones 4–6 of the Bering region and their range is Late Cretaceous (Vishnevskaya, 1986). *S. livermorensis* is stratigraphically limited to the radiolarian zone 5 of the Bering region, which has been interpreted as an age of Late Campanian to Early Maastrichtian. Therefore, this radiolarian assemblage indicates a Late Campanian age.

As above mentioned, the age span of the three radiolarian assemblages recognized is late Santonian to Late Campanian. Based on the identification of radiolarian species and their correlations to radiolarian biozones, the CORBs (the Chuangde Formation) at Daba section are accordingly of Campanian age. As for *S. trachyostraca*, it is usually limited to the Valanginian to Santonian but occurred in samples DB25 and 59 of the Dada section, which should originate from the underlaid older strata.

5. Implications of the radiolarian occurrences for the Late Cretaceous paleogeography of the Tethyan Himalaya

Regional paleontology and sedimentologic studies of Cretaceous strata exposed in the southern Tethyan Himalaya document that their deposition occurred mainly on the northern Indian passive continental margin. The Upper Cretaceous strata from the southern

Fig. 5. Scanning electron photomicrographs of representative species of radiolarian assemblages from the CORBs of Daba. 1. *Petellula verteroensis* (Pessagno); 2. *P.* sp.; 3. *Phaseliforma* aff. *concentrica* (Lipman); 4. *Praeconocaryomma lipmanae* Pessagno; 5. *Pseudoacanthosphaera galeata* Luis; 6. *P. superba* (Squinabol); 7–8. *Pseudoaulophacus* sp.; 9. *Pseudodictyomitra* sp.; 10. *Savaryella quadra* (Foreman); 11. *S. stella* Luis; 12. *Schaumellus aufragendus* Empson-Morin; 13–14. *Sethocapsa trachyostraca* Foreman; 15. *S.* aff. *lagenaria* Wu and Li; 16. *Spongodiscus orbis*(Campbell and Clark); 17. *Stichomitra communis* Squinabol; 18–21. *S. livermorensis*(Campbell and Clark); 22. *S.* sp.; 23. *Stylotrochus* (*Stylotrochiscus*) aff. *antiquus* Campbell and Clark; 24. *Tanarla* cf. *conica* (Aliev); 25. *Theocapsa* (*Theocapsomma*) aff. *amphora* Campbell and Clark; 26. *Triactoma compressa* (Squinabol); 27. *Vitorfus campbelli* Pessagno; 28. *Xitus spicularius* (Aliev). Scale Bar = 20 μm.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Tethyan Himalaya record deposition from shallow to deep shelf environments while the time-equivalent stratigraphic units in the northern Tethyan Himalaya indicate deposition on a deeper continental slope and in the adjacent deep oceanic basin (Yu and Wang, 1990; Liu, 1992; Willems, 1993; Liu and Einsele, 1994; Willems et al., 1995; Jansa and Hu, 2009; Li et al., 2009a). The fauna of these two sub-belts are quite distinct, reflecting different bio- and litho-facies: a planktic assemblage, including ammonoids, belemnites, radiolaria and planktic foraminifera occurs in the northern sub-belt; while a mixed assemblage of both benthic and planktic faunas/flora (including ammonoids, bivalves, gastropods, echinoids, corals, ostracoda, planktic and benthic foraminifera and calcareous nannofossils) occurs in the southern sub-belt (Wan and Hao, 1993).

Regionally, the Upper Cretaceous strata in the western part of the Tethyan Himalaya are represented by a broad variety of lithofacies and of biota. In the upper part of the Chikkim Formation in Spiti and the Bolinxiala Formation in Zanda, which contain bioclastic grainstones and packstones, benthic foraminifera and signs of bioturbation are abundant (Bertle and Suttner, 2005; Li et al., 2009a). This suggests deposition on shallow carbonate platforms built on a shelf, with the depth episodically above the fair-weather wave base (Li et al., 2009a). The presence of sandy limestone beds, large benthic foraminifera, abundant vertical burrows and hard grounds in Spiti (Bertle and Suttner, 2005) favors an inner shelf location. In contrast, the abundance of bioclastic wackestone and packstone with bivalves, calcispheres, rotalid foraminifera, and spicules in Zanda (Li et al., 2009a) indicates a middle to outer shelf depositional environment. In northern Zanskar, the Shillakong Formation is mainly composed of shale and marly limestone with occasional olistostromes which were interpreted as deep-water deposits by Fuchs (1982), but most likely represent a slope environment (Li et al., 2009a).

In the eastern part of the Southern Tethyan Himalaya, the Upper Cretaceous Zongshan Formation in the Gamba region contains abundant grainstone layers that show low-angle cross stratification, and enclose a broad variety of fauna, such as benthic foraminifera, echinoids, calcispheres, oysters, gastropods and abundant rudist and coral-rudist reefs (Li et al., 2009a), suggesting deposition on the outer shelf, or outer shelf margin (Li et al., 2011; Masse and Philip, 1981). The Upper Cretaceous strata of the eastern Northern Tethyan Himalaya represented by sections in Kangmar, Gyangze, and Sa'gya areas are in contrast composed of pelagic red limestone, siltstone, pelagic red shale, cherts, siliceous shales, marlstone, intercalated abundant olistostromes, and turbidite beds. Microfossils present are predominantly radiolarian and planktic foraminifera (Wan et al., 2005a, 2005b; Li et al., 2009a, 2009b; Li et al., 2011). Such features are consistent with the deposition at the lower continental slope and in deep oceanic basin environments, with some of the sediments being deposited below CCD (Yu and Wang, 1990; Liu, 1992; Liu and Einsele, 1994).

As in the Late Cretaceous CORB's lithofacies, the Late Cretaceous radiolarian occurrences are restricted to the Northern Tethyan Himalayan Sub-belt and are rare, even if not entirely missing, in the Southern Tethyan Himalayan Sub-belt.

It has long been recognized that microfossil assemblages in sediments reflect the paleoenvironmental and paleoclimatic conditions at the time of deposition, and in addition they are also important paleoecologic indicators. Much attention has been devoted to paleoclimatic and paleoecologic studies using calcareous microfossils, such as foraminifera and nannofossils. Early investigators (e.g. Phleger et al., 1953) examined foraminiferal assemblages in Pleistocene cores from the North Atlantic, and determined that biogeographic faunal provinces migrated in response to changing climatic conditions. Subsequent investigators have successfully utilized Quaternary foraminiferal assemblages for paleoceanographic interpretations (e.g., Berger, 1968; Ruddiman, 1971). But, in contrast, much less is known about the biogeography and paleobiogeography of siliceous microfossil groups — diatoms, radiolarians, and silicoflagellates. Mandra (1969) and Jendrzejewski and Zarillo (1972) made some progress using silicoflagellates; Jousé et al. (1963), Donahue (1970) and Burckle (1972) have utilized diatoms; and Casey (1971), Nigrini (1967, 1971), Sachs (1973) and Johnson and Knoll (1973) have examined the potential use of radiolarians as paleoclimatic indicators. Major progress has been achieved during the past several decades toward a better understanding of both the biostratigraphic importance of radiolaria and their significance as paleoecologic indicators. Ecologic studies have been mainly restricted to the Cenozoic (Casey, 1963, 1971, 1972; Nigrini, 1967; Goll and Bjørklund, 1971, 1974; Petrushevskaya, 1971; Casey et al., 1972; Renz, 1976; Bjørklund, 1977), but not much progress has been made in the environmental aspects of Mesozoic radiolaria. The first attempt to analyze distribution patterns of Mesozoic radiolarian populations was made by Empsom-Morin (1984). After studying the depth and latitude distribution of radiolaria in Campanian (Late Cretaceous) tropical and subtropical oceans, the author (ibid) drew a conclusion that the radiolarian faunal composition showed three basic responses to the environment: (1) morphotypes present, (2) diversity, and (3) abundance. Although abundance is influenced by localized productivity and sedimentation rates, numbers of radiolaria tend to increase with the depth in any given depositional basin. The author further pointed out that most of the forms were restricted to low and intermediate paleolatitudes, but some species such as *Penobrachium* were present only at high latitudes. Similarly Goll and Bjørklund (1974) concluded that some modern radiolaria species in the South Atlantic are latitudinally restricted. Takahashi (1991) studied the flux, ecology and taxonomy of the radiolaria in the Pacific and Atlantic and concluded that because significant numbers of nassellarian and phaeodarian species are deep-water dwelling forms, the diversity of radiolarians increases with increasing depth in the mesopelagic zone. The highest standing stock of living radiolaria is generally found at the vicinity of the thermocline (e.g., Renz, 1976; Takahashi, 1991). The advantage of using radiolaria in open, deep oceanic sedimentary environments is that the preservation of siliceous microorganisms such as radiolaria in deep sea sediments is little affected by water depth and is therefore controlled by biological productivity and related rate of sediment accumulation (Renz, 1976), and is not influenced by the CCD, as calcareous microfossils are. The siliceous oozes are generally more extensive in the equatorial and polar siliceous belts than in other latitudinal regions, which reflects both siliceous productivity in the overlying waters and indirectly carbonate dissolution on the sea-floor.

In southern Tibet, radiolarians are widespread in the Upper Cretaceous of the Northern Tethyan Himalaya Sub-belt and are particularly common in the Yarlung–Zangbo Suture Zone (YSZ), and the adjacent sedimentary mélange belt, which are remnants of the Neotethyan oceanic basin. However, only occasionally do radiolaria occur in the Southern Tethyan Himalaya Sub-belt (Fig. 6).

The sedimentary strata within the Yarlung Zangbo Ophiolite Zone contain abundant radiolaria-bearing sediments, such as chert and siliceous mudstone. Radiolarian dating has been used extensively to determine the timing of the ophiolite belt formation and of the geologic processes associated with the Neo-Tethys oceanic basin closure (Wu, 1988; Yang et al., 2002; Ding, 2003; Li et al., 2007). In the YSZ, both the Xialu Chert to the north and the Chongdui Formation to the south are rich in radiolarians (Li and Wu, 1985; Wu, 1988, 2007). Radiolarian assemblages of Middle and Late Jurassic and Early and Late Cretaceous ages have been discovered from the Xialu cherts (Wu, 1988, 1993, 2007). This indicates that radiolarian ooze deposition was widespread in bathyal depths of the Neotethys ocean, at least from the Middle Jurassic to Late Cretaceous (Cenomanian) (Wu, 2007). Indirectly, these occurrences provide clear evidence that the depth of the Neotethys oceanic basin was already in excess of 4500–5000 m. Directly south of the suture zone occurs the sedimentary mélange zone including flysch and other pelagic–hemipelagic

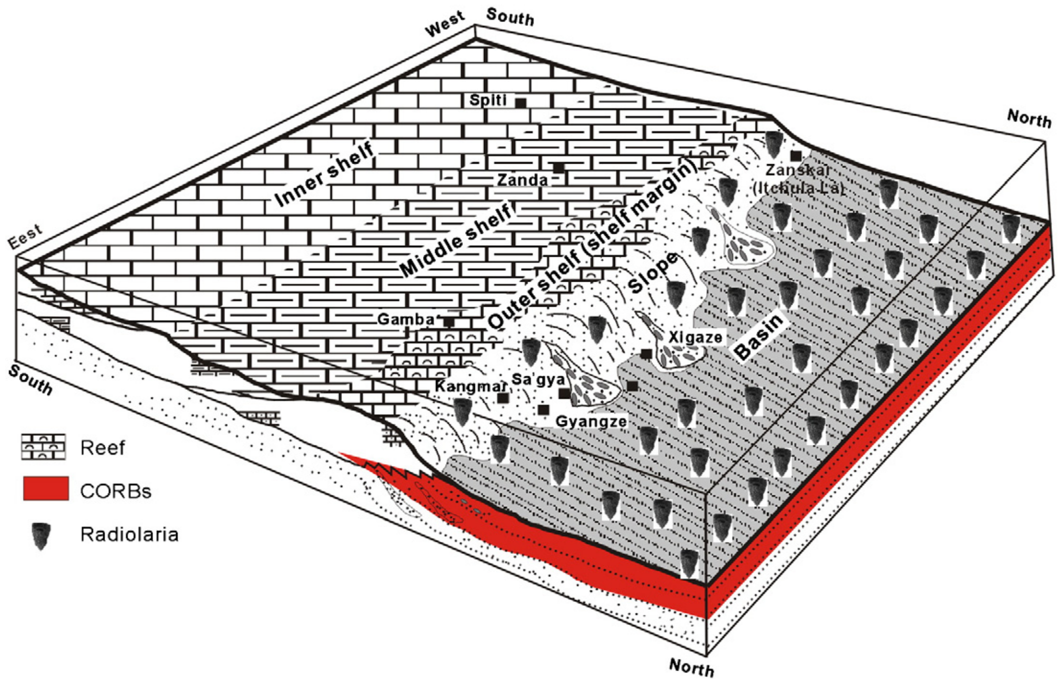

Fig. 6. Schematic biopaleogeographic reconstruction of the Late Cretaceous depositional environments of the Tethyan Himalaya.

sediments also rich in radiolarians. Middle Triassic to Late Cretaceous radiolarians have been reported from chert and/or siliceous mudstone blocks, or sheets from the mélange (Wu and Li, 1982; Yang et al., 2002; Li et al., 2009b). Wu and Li (1982) reported the presence of Late Cretaceous Turonian radiolarian assemblages in cherts from the olistostromes of the Zongzhuo Formation, near Gyangze. Later on, Sun et al. (2002) described Late Cretaceous Santonian–Campanian radiolarian assemblages from the chert of the mélange at Zongba. Late Cretaceous radiolarian assemblages from cherts of the mélange of the Zongzhuo Formation in Sagya were recently discovered by Li et al. (2009b).

At Sangdalin section located at the southern boundary of YSZ, within the sedimentary mélange belt lie the youngest, early Cenozoic CORBs in southern Tibet, with radiolaria present in chert and siliceous red mudstones (Wang et al., submitted for publication). They are of Early Eocene (Ypresian) age.

The Daba section at Kangmar discussed in this paper is one of the most southern CORBs-bearing localities in southern Tibet, from where the Late Cretaceous radiolarian assemblages were reported. However, in the Cretaceous strata of the Southern Tethyan Himalaya Sub-belt, only occasional radiolarian fossils have been found.

6. Discussion and conclusions

The CORBs are a useful Late Cretaceous lithostratigraphic "marker", present not only in southern Tibet, but globally widespread from New Zealand westward to Asia (southern Tibet, Iran), Turkey, Greece, southern Europe and the North Atlantic oceanic basin (Chen et al., 2007; Jansa and Hu, 2009). In southern Tibet such strata are comprised of intercalated noncalcareous abyssal, red colored mudstones, variably interbedded with pelagic marlstones, limestone, calcareous turbidites, radiolarian cherts and common olistostoliths. Such strata were named the Chuangde Formation in southern Tibet (correlative with CORBs, Wang et al., 2005). The CORB's occurrence was reported from Gyangze (Li et al., 1999; Wan et al., 2005a, 2005b), Sagya (Li et al., 2009b) and Gyirong-Sagya areas (Wan and Ding, 2002).

The presence of pelagic, red, noncalcareous mudstones reflect deposition below the carbonate compensation depth (CCD), in an abyssal depth setting, similar to modern deep sea red clays of the Pacific Ocean. The intercalated, thin-bedded fine grained limestones and marlstones usually represent turbidites and fine grained turbidite tails, derived from the upper reaches of the continental slope and transported into the adjacent deep basin, where the basin floor was below CCD. The radiolarians retrieved from the Chuangde Formation (CORBs) of Daba, Kangmar, southern Tibet indicate Late Cretaceous Campanian age of the strata, similar to the other locations of CORBs in southern Tibet. The CORBs deposition in southern Tibet coincides with the Campanian diversity peak in the occurrence of planktic foraminifera (Li et al., 2009a; Li et al., 2011).

Radiolaria microfossils are abundant in pelagic sediments of the Yarlung Zangbo ophiolite zone and in the sedimentary mélange and bathyal sediments to the south of the ophiolite zone. However, only a few radiolarians had been reported so far from the Cretaceous shelf deposits of the Southern Tethys-Himalaya Sub-belt. The current status of radiolarian studies in southern Tibet is not as advanced as in such regions as western North America, Russia, Europe, Philippines and Japan. To establish the radiolarian biostratigraphic zonation and rebuild the evolutionary history of the Neo-Tethys ocean, more detailed and systematic studies of the radiolarian paleobiostratigraphy is needed.

We consider an important conclusion of our study for paleogeographic and plate tectonic reconstructions of Neo-Tethys, that all known localities of CORBs in southern Tibet provide clear evidence that deposition was occurring near the boundary of the continental slope/rise and adjacent abyssal basin. This implies that all of the open ocean floor of the Neo-Tethys was subducted, and only the sedimentary cover of the deep continental margin of the Indian continental plate escaped a similar fate. An important caveat to such an interpretation is that it indicates that both the mélange and ophiolite belt zones of YZS are tectonically displaced and were "pushed up" onto the lower reaches of the Asia continental plate.

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References

ASTSET (Academic Sinica Tibet Scientific Expedition Team), 1974. Reports on scientific expeditions to Mountain Qomolama area (1966–1968) – Geology. Science Press, Beijing. 299 pp. (in Chinese).

Berger, W.H., 1968. Planktonic foraminifera: selective solution and paleoclimatic interpretation. Deep Sea Research 15, 31–34.

Bertle, R.J., Suttner, T.J., 2005. New biostratigraphy data for the Chikkim Formation (Cretaceous, Tethyan Himalaya, India). Cretaceous Research 26, 882–894.

Bjørklund, K.R., 1977. *Actinomma haysi*, n. sp., its Holocene distribution and size variation in Atlantic Ocean sediments. Micropaleontology 23 (1), 114–126 pl.1.

Burckle, L.H., 1972. Diatom evidence bearing on the Holocene in the South Atlantic. Quaternary Research 2, 323–326.

Casey, R.E., 1963. Studies on the ecology of planktonic foraminifera and radiolaria off the southern California coast. Journal of Paleontology 37 (4), 977 (Abstract).

Casey, R.E., 1971. Distribution of polycystine radiolaria in the oceans in relation to physical and chemical condition. In: Funnell, B.M., Riedel, W.R. (Eds.), The Micropaleontology of Oceans. Cambridge University Press, pp. 151–160.

Casey, R.E., 1972. Neogene radiolarian biostratigraphy and paleotemperatures: Southern California, the experimental Mohole, Antarctic core E 14–8. Palaeogeography, Palaeoclimatology, Palaeoecology 12, 115–130.

Casey, R.E., Price, A.B., Swift, C.A., 1972. Radiolarian definition and paleoecology of the late Miocene to early Pliocene in Southern California. In: Stinemeyer, E.H., Church, C.C. (Eds.), Proc. of the Pacific Coast Miocene biostratigraphic symposium. Soc. Econ. Pal. Min., Annual Mtg., Pacific Sect., 47th, March 9–10, pp. 226–238.

Chen, X., Wang, C., Hu, X., Huang, Y., Wang, P., Luba, J., Zeng, X., 2007. Cretaceous oceanic red beds, distribution, lithostratigraphy and paleoenvironments. Acta Geologica Sinica 81 (6), 1070–1086.

Ding, L., 2003. Paleocene deep-water sediments and radiolarian fauna: Implications for evolution of Yarlung-Zangbo foreland basin, soutern Tibet. Science in China, Series D 46 (1), 84–96 (in Chinese with English summary).

Donahue, J.G., 1970. Pleistocene diatoms as climatic indicators on North Pacific sediments. In: Hays, J.D. (Ed.), Geological Investigations of the North Pacific: Geol. Soc. Amer. Memoir, 126, pp. 121–138.

Empsom-Morin, K.M., 1984. Depth and latitude distribution of radiolaria in Campanian (Late Cretaceous) tropical and subtropical oceans. Micropaleontology 30 (1), 87–115.

Fuchs, G., 1982. The geology of Western Zanskar. Jahrbuch der Geologischen Bundesanstalt 125, 1–50.

Goll, R.M., Bjørklund, K.R., 1971. Radiolaria in surface sediments of the North Atlantic Ocean. Micropaleontology 17 (4), 434–454.

Goll, R.M., Bjørklund, K.R., 1974. Radiolaria in the surface sediments of the South Atlantic. Micropaleontology 20 (1), 38–75.

Jansa, L., Hu, X.M., 2009. Cretaceous pelagic black shales and red beds of the North Atlantic: origins, paleoclimate and paleoceanographic implications. In: Hu, X.M., et al. (Ed.), Cretaceous oceanic red beds: stratigraphy, composition, origins, and paleoceanographic and paleoclimatic significance: SEPM Special, 91, pp. 59–72.

Jendrzejewski, J.P., Zarillo, G.A., 1972. Late Pleistocene paleotemperature oscillations defined by silicoflagellate changes in a subarctic deep-sea core. Deep Sea Research 19, 327–329.

Johnson, D.A., Knoll, A.J., 1973. Radiolaria as paleoclimatic indicators: Pleistocene climatic fluctuations in the equatorial Pacific Ocean. Technical report (prepared for the National Science Foundation under Grant GA-36825), pp. 1–30.

Jousé, A.P., Koroleva, G.S., Negaeva, G.A., 1963. Stratigraphical and paleogeographical investigations in the Indian sector of the Southern Ocean. Okeanologii 8, 137–161.

Li, G.B., Jiang, G.Q., Hu, X.M., Wan, X.Q., 2009a. New biostratigraphic data from the Cretaceous Bolinxiala Formation in Zanda, southwestern Tibet of China and their paleogeographic and paleoceanographic implications. Cretaceous Research 30 (4), 1005–1018.

Li, G.B., Wan, X.Q., Liu, W.C., Bucher, H., Li, H.S., Goudemand, N., 2009b. A new Cretaceous age for the Saiqu "mélange", southern Tibet, evidence from radiolaria. Cretaceous Research 30 (1), 35–40.

Li, G.B., Jiang, G.Q., Wan, X.Q., 2011. The age of the Chuangde Formation in Kangmar, southern Tibet of China: implications for the origin of Cretaceous Oceanic Red Beds (CORBs) in the Northern Tethyan Himalaya. Sedimentary Geology 235, 111–121.

Li, W.Z., Shen, S.Z., 2005. Faunas from the Permian limestone blocks at the Yarlung Zangbo suture zone in southern Xizang (Tibet) and its paleogeographical implications. Geological Review 51 (3), 225–233 (in Chinese with English summary).

Li, H.S., Wu, H.R., 1985. Some radiolarian fossils from the Cretaceous Chongdui Formation, southern Tibet. Acta Micropalaeontologica Sinica 2 (1), 62–74 (in Chinese with English summary).

Li, X.H., Wang, C.S., Wan, X.Q., Tao, R., 1999. Verification of stratigraphic sequence and classification for the Chuangde section of Gyangze, southern Tibet. Journal of Stratigraphy 23, 303–309 (in Chinese with English summary).

Li, Y.L., Wang, C.S., Hu, X.M., Bak, M., Wang, J.J., Chen, L., Li, X.H., 2007. Early Eocene radiolarian fauna of southern Tibet and its time-control on the closure of Tethys. Science Bulletin 52 (12), 1430–1435 (in Chinese).

Liu, G., 1992. Permian to Eocene sediments and Indian passive margin evolution in the Tibet Himalaya. Tübinger Geowissenschaftliche Arbeiten (A)13, 268.

Liu, G., Einsele, G., 1994. Sedimentary history of the Tethyan basin in the Tibet Himalayas. Geologische Rundschau 83, 32–61.

Mandra, K.T., 1969. Silicoflagellates: a new tool for the study of Antarctic Tertiary climates. Antarctic Journal US 4, 172–174.

Masse, J.P., Philip, J., 1981. Cretaceous coral-rudistid buildups of France. In: Toomey, D.F. (Ed.), European Fossil Reef Models. SEPM Special Publications 30, 399–426.

Mo, X.X., Zhao, Z.D., Yu, X.H., Dong, G.C., Li, Y.G., Zhou, S., Liao, Z.L., Zhu, D.C., 2009. Cenozoic syn-collisional and post-collisional igneous rocks in the Tibetan Plateau. Geological Publishing House. 396 pp., platesI-VII (in Chinese).

Nigrini, C., 1967. Radiolaria in pelagic sediments from the Indian and Atlantic Oceans. Bulletin of the Scripps Institute of Oceanography 11, 1–125.

Nigrini, C., 1971. Radiolarian assemblages in the North Pacific and their application to a study of Quaternary sediments in core v20-130. In: Hays, J.D. (Ed.), Geological Investigations of the North Pacific": Geol. Soc. Amer. Memoir, 126, pp. 139–183.

Petrushevskaya, M.G., 1971. Radiolyarii v planktone i v donnykh osadkakh. Geokimiya kremnesema. Nauka, Moscow, pp. 219–245.

Phleger, F.B., Parker, F.L., Pierson, J.F., 1953. North Atlantic foraminifera. Repts. Swed. Deep-Sea Exped. (1947–1948), 7, pp. 3–122.

Renz, G.W., 1976. The distribution and ecology of radiolaria in the Central Pacific: plankton and surface sediments. University of California Press, Berkeley and Los Angeles. 267 pp.

Ruddiman, W.F., 1971. Pleistocene sedimentation in the equatorial Atlantic: stratigraphy and faunal paleoclimatology. Geological Society of America Bulletin 82, 283–302.

Sachs, H.M., 1973. North Pacific radiolarian assemblages and their relationship to oceanographic parameters. Quaternary Research 3, 73–88.

Sanfilippo, A., Riedel, W.R., 1985. Cretaceous radiolaria. In: Bolli, H.M., Saunders, J.B., Perch-Nielsen, K. (Eds.), Plankton Stratigraphy. Cambridge University Press, London, pp. 575–630.

Sun, L.X., Zhang, Z.L., Fan, Y.G., Jia, J.C., Li, J.H., 2002. Discovery of radiolarians from the Cretaceous Chert of Zongba, Tibet. Geological Bulletin of China 21 (3), 172–174.

Takahashi, K., 1991. Radiolaria: flux, ecology, and taxonomy in the Pacific and Atlantic. Ocean Biocoenosis Series 3, 176 pls.63.

TBGMR (Tibet Bureau of Geology and Mineral Resources), 1983. A report on the regional Report of Geological Mapping (Xigaze-Yadong, 1:1000000). Unrepublished report. 286 pp.(in Chinese).

TBGMR (Tibet Bureau of Geology and Mineral Resources), 1993. Regional Geologic Records of Xizang (Tibet) Autonomous Region. Geological Publishing House, Beijing. 459 pp. (in Chinese).

Vishnevskaya, S.V., 1986. Middle to late Cretaceous radiolarian zonation of the Bering region, U.S.S.R. Marine Micropaleontology 11, 139–149.

Vishnevskaya, S.V., Wever, P.D., 1998. Upper Cretaceous radiolaria from the Russian Platform (Moscow Basin). Revue de Micropaleontologie 41 (3), 235–265.

Wan, X.Q., Ding, L., 2002. Discovery of the latest Cretaceous planktonic foraminifera from Gyirong of southern Tibet and its chronostratigraphic implications. Acta Palaeontologica Sinica 41, 89–95 (in Chinese with English abstract).

Wan, X.Q., Hao, Y.C., 1993. A preliminary correlation between the Cretaceous calcareous nannofloras and foraminifera of southern Tibet. Revista Espanola de Micropaleontologia XXV 1, 41–56.

Wan, X.Q., Li, G.B., Si, J.L., 2005a. The distribution and ages of Late Cretaceous–Paleocene oceanic red beds in southern Tibet. Earth Science Frontiers 2, 31–37 (in Chinese, English abstract).

Wan, X.Q., Lamolda, M.A., Si, J.L., Li, G.B., 2005b. Foraminiferal stratigraphy of Late Cretaceous red beds in southern Tibet. Cretaceous Research 26, 43–48.

Wang, C.S., Hu, X.M., Sarti, M., Scott, R.W., Li, X.H., 2005. Upper Cretaceous oceanic red beds in southern Tibet: a major change from anoxic to oxic, deep-sea environments. Cretaceous Research 26, 21–32.

Wang, J., Hu, X., Jansa, L., Huang, Z, submitted for publication. Provenance of the Upper Cretaceous–Eocene sandstones in the Sangdanlin section, south-central Tibet: constraints on timing of India–Asia connection. Journal of Geology.

Willems, H., 1993. Sedimentary history of the Tibet Tethys Himalaya continental shelf in south Tibet (Gamba, Tingri) during Upper Cretaceous and Lower Tertiary (Xizang Autonomous Region, P R China). Berichte, Fachhereich Geowissenschaften, Universität Bremen, 38, pp. 49–183.

Willems, H., Wan, X., Yin, J., Dongdui, L., Liu, G., Dürr, S., Gräfe, K.-U., 1995. The Mesozoic development of the N-Indian passive margin and of the Xigaze Forearc Basin in southern Tibet, China. Excursion Guide to IGCP 362 Working-Group Meeting "Integrated Stratigraphy": Berichte, Fachbereich Geowissenschaf- ten, Universität Bremen, 64, p. 113 S.

Wu, H.R., 1988. Jurassic and Cretaceous radiolarian fossils from Xialu chert, the Yarlung Zangbo ophiolite zone, southern Tibet. Bulletin of Institute of Geology, Academia Sinica 3, 191–212 (in Chinese).

Wu, H.R., 1993. Upper Jurassic and Lower Cretaceous radiolarians of the Xialu chert, Yarlung Zangbo ophiolite belt, southern Tibet. Micropaleontology Special Publication 6, 115–136.

Wu, H.R., 2007. The Cretaceous radiolarian "*Turbocapsula costata* Zone" and age of the Chert sequences in Yarlung Zangbo Suture Zone, southern Tibet. Acta Micropalaeontologica Sinica 24 (4), 370–373.

Wu, H.R., Li, H.S., 1982. Radiolaria from the olistostrome of the Zongzhuo Formation, Gyangze, southern Xizang (Tibet). Acta Palaeontologica Sinica 21 (1), 64–74 (in Chinese with English abstract).

Xu, R.K., Zheng, Y.Y., Feng, Q.L., Shan, L., Wei, J.H., Zhang, X., Zhang, G.Y., Ma, G.T., Pang, Y.C., 2009. Radiolarian chert and island-Arc volcanic rocks in Xiapugou, Tibet: records of Neo-Tethys intra-oceanic subduaction system? Earth Science - Journal of China University of Geosciences 34 (6), 884–894.

Yang, Q., Matsouka, A., Wang, Y.J., 2002. Progress in radiolarian micropaleontological studies in southern Tibet. Acta Micropaleontlogica Sinica 19 (2), 105–111.

Yu, G.M., Wang, C.S., 1990. Sedimentary geology of the Xizang (Tibet) Tethys. Geological Memoir, Series 3, 12. Geological Publishing House. 187 pp. (in Chinese with English summary).

Zhu, T.X., Zhou, M.K., Feng, X.T., Zou, G.F., Li, J.Z., Zhuang, Z.H., Jiang, X.S., Wang, J., Chen, Y.M., Pan, Z.X., 2005. Phanerobiotic multiple strata and basinal evolution of northern Himalayan area. Geological Publishing House. 205 pp., platesI-IV (in Chinese).