Paleocene deep-water sediments and radiolarian faunas: Implications for evolution of Yarlung-Zangbo foreland basin, southern Tibet

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Received July 2, 2002

Abstract This is the first report on the Paleocene deep-water sequences and radiolarian faunas, which are distributed along the southern side of the Yarlung-Zangbo suture zone. The Zheba group is coined to indicate these Paleocene sequences which are subsequently divided into two lithostratigraphic units based on the lithology observed in the field. The lower unit characterized by the rhythmic cherts and siliceous shales is named the Sangdanlin formation, and the upper one composed mainly of flysches is termed the Zheya formation. The radiolarian faunas from the Zheba group are assigned to the RP1-RP6 zones of the Paleocene age. The Early Paleocene radiolarian assemblages have the potential to be established into the low latitude radiolarian zones and to fill in the gap between the Late Cretaceous and the Late Paleocene radiolarian zonations. The radiolarian dating provides a valuable tool for the regional correlation and reconstruction of the sedimentary environment of the Neo-Tethyan Ocean. The preliminary work shows that the Paleocene sequences accumulated in a foreland basin resulted from the southern Asian margin loading onto the northern Indian passive continental margin. The Yarlung-Zangbo foreland basin sequences deposited on the Indian passive continental margin also resulted in many good source-reservoir-covering assemblages for oil and gas resources.

Keywords: deep-water sediment, radiolarian, Paleocene, Yarlung-Zangbo foreland basin, Tibet.

Only a few Paleocene radiolarian assemblages have been reported, while the Early Paleocene zonal schemes remain poorly delineated. The Early Paleocene on-land radiolarians were described in the Hidaka melange belt of Japan and the North Island of New Zealand[1—3]. The Early Paleocene off-land radiolarians were only recovered in Deep Sea Drilling Project (DSDP) site 208 on the Lord Howe Rise of Tasman Sea[4,5]. These on-land and off-land faunal compositions have been used to establish the high-latitude Southern Pacific radiolarian zones[1,2,4,5]. The Late Paleocene on-land radiolarian assemblages recovered in the California of America and Cuba, and those of off-land extracted from DSDP Leg 10 in the Gulf of Mexico, DSDP sites 384 and 603 in Northwest Atlantic[6—11] are the bases of the Late Paleocene tropical radiolarian zonations.

The Paleocene to the very Early Eocene marine molasse sequences are widely exposed in the forearc basin in the northern sites of the Yarlung-Zangbo suture zone, such as Rujiao, Tsojiangding in southern Tibet (fig. 1) and Ladakh in northwestern India[12—14]. To the south of the Yarlung-Zangbo suture zone, Paleocene to Middle Eocene shallow marine carbonates and clastics are also widely distributed in the Tethyan Himalaya (fig. 1)[15—18]. Between the former two shallow marine basins, are there marine deposits in the Yarlung-Zangbo suture zone during the Paleogene? If yes, are they deep-water or shallow-water sedimentations? This paper introduces the newly discovered Early to Late Paleocene deep-water sediments and radiolarian faunas in the Saga region on the Indian passive continental margin (fig. 1). Field observations show that the Early Tertiary sequences are widely distributed on the southern side of the Yarlung-Zangbo suture zone. These Early Tertiary sequences may accumulate in a foreland basin[19] resulted from the loading of the Gangdese arc onto the Indian passive continental margin. The Paleocene tropical land-based radiolarian faunas are assigned to the RP1-RP6 zones of Paleocene age, and provide a valuable tool for reconstructing the collision processes of Indian and Asian plates.

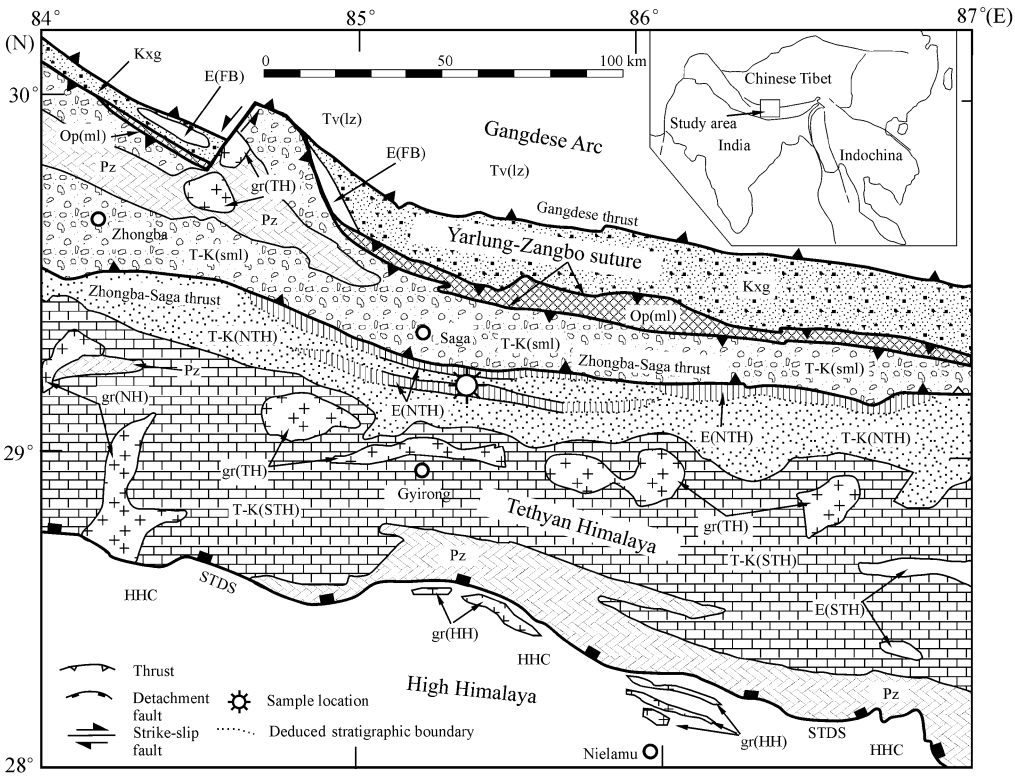

Fig. 1. Simplified tectonic map of the Yarlung-Zangbo suture zone and the location of the study area. E(NTH), northern subzone of Early Tertiary sequences in the Tethyan Himalaya; E(STH), southern subzone of Early Tertiary sequences in the Tethyan Himalaya; E(FB), Early Tertiary molasse sequences of Tsojiangding group in the Gangdese forearc basin; Kxg, Cretaceous flysch sequences of the Xigaze group in the Gangdese forearc basin; T-K(NTH), northern subzone of Late Triassic to Cretaceous sequences in the Tethyan Himalaya; T-K(STH), southern subzone of Late Triassic to Cretaceous sequences in the Tethyan Himalaya; Pz, Paleozoic continental shelf sequences; Tv(lz), Early Tertiary (65—40 Ma) Linzizong formation; gr(HH), high Himalayan leucogranites; gr(TH), Tethyan Himalayan leucogranites; HHC, high Himalayan crystalline rocks; Op(ml), ophiolite melange; T-K(sml), Late Triassic to Cretaceous sedimantary melange (accretionary prism); STDS, South Tibetan detachment system.

1 Geological setting

Two original basins of the Neo-Tethyan Ocean, the Indian passive continental margin and the

Gangdese forearc basins, are well exposed on the northern and southern sides of the Yarlung-Zangbo suture zone, respectively (fig. 1). The Mesozoic passive continental margin sequences are distributed between the Yarlung-Zangbo suture zone and the South Tibetan detachment system, which have been divided into two subzones. The deposits of the southern subzone, an Atlantic-type passive continental margin sequence, are mainly composed of ~5 km thick carbonates and clastics[15,16]. The northern subzone gradually changes from the southern one and is bounded on the north side by the Yarlung-Zangbo melange belt (fig. 1). The sequences of the northern subzone deposited on the Indian continental slope are mainly composed of siliceous clastics, shales and limestones[20—22]. Because of scarcity of large fossil records and lack of detail radiolarian biostratigraphic correlations, the ages of these strata remain poorly constrained, and the thicknesses are still unclear[20,21]. In the Gamba-Tingri areas of the southern subzone in the Tethyan Himalaya, the residual latest marine large foraminifera-bearing limestones and clastics can be estimated to persist to the Middle Eocene[16—18] (fig. 1).

The newly discovered Paleocene deep-water sequences deposited in the northern subzone of the Tethyan Himalaya (fig. 1) are 100 km apart from the Gamba-Tingri belt in longitudinal direction. The Sangdanlin section of these sequences had been reported by the Integrated Scientific Expedition of the Qinghai-Xizang Plateau, Chinese Academy of Sciences in 1966, which was thought to be of the Late Triassic age by Yin et al. (1988)[22]. Some radiolarians from the Sangdanlin section were first described by Sheng (1976)[23] in thin sections, and Li (1999)[24] redescribed these radiolarians in thin sections and related photomicrographs provided by Yin. Because of the limitation of observation in thin sections, the radiolarian faunas of the Sangdanlin section were mistakenly assigned to the Triassic[23] or Eocene to Miocene age[24].

In the Gangdese forearc basin, the late Early Cretaceous to Late Cretaceous flysches of the Xigaze group, 3.5—5 km thick, are unconformably overlain by the Paleocene to Early Eocene marine Tsojiangding group, which is composed of sandstones, conglomerates interbedded with some large foraminifera-bearing limestones[13].

The upper two basins are seperated by the Yarlung-Zangbo suture zone. It is popularly accepted that the onset of the collision between Indian and Eurasian plates is at 70—38 Ma (see ref. [25] and references therein).

Paleogeographic reconstructions for the Gamba-Tingri areas show that the Paleocene (65—55 Ma) paleolatitudes were 10°S—5°N[26,27]. The studied area is ~100 km apart from the Gamba-Tingri belt presently. Considering that there was a large-scale shortening of the crust (about 50% shortening) after collision[28], the two areas may be ~200 km apart during the Paleocene. Therefore, the studied area was located at the low tropic latitudes, and the approximate Paleocene paleolatitudes were 8°S—7°N.

2 Paleocene lithostratigraphy

The Paleocene deep-water sequences strike E-W on the southern side of the Yarlung-Zangbo melange zone (fig. 1). In order to distinguish them from the Cretaceous sequences in the studied area and the Early Tertiary shallow-water sequences in the Gamba-Tingri areas, the Zheba group was coined to indicate these Early Tertiary deep-water sequences. This group is subsequently divided into two stratigraphic units based on lithology observed in the field. The lower unit characterized by the rhythmic cherts and siliceous shales is named the Sangdanlin formation, and the upper one composed of flysches is termed the Zheya formation (Zheba, Zheya and Sangdanlin are the names of local villages near the stratigraphical sections). In this study, the Zheba group was described from upper to lower at two sites as given below (figs. 2 and 3):

Zheba section (fig. 2(a)): beds dipping steeply or reversely:

Early Tertiary Zheba group:

Zheya formation (not to the top):

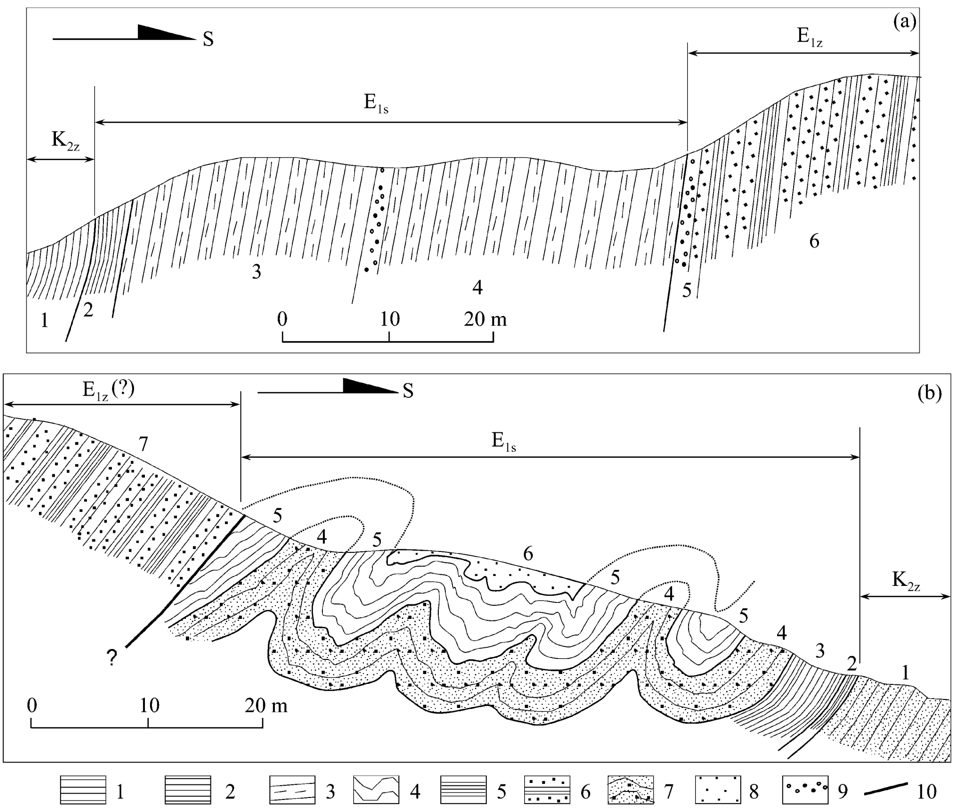

Fig. 2. Paleocene stratigraphic sections of Zheba group, southern Tibet. 1, Thick bedded chert; 2, thin bedded chert and siliceous shale; 3, porcellanite; 4, colour siliceous shale and chert; 5, grey, greenish chert; 6, flysch; 7, sandstone and shale; 8, lithic sandstone; 9, conglomerate; 10, fault. E_{1s}, Early Paleocene Sangdanlin formation; E_{1z}, Late Paleocene Zheya formation; K_{2z}, Late Cretaceous Zongzhuo formation; E_{1z} (?), no fossil, lithostratigraphic correlation with Zheya formation.

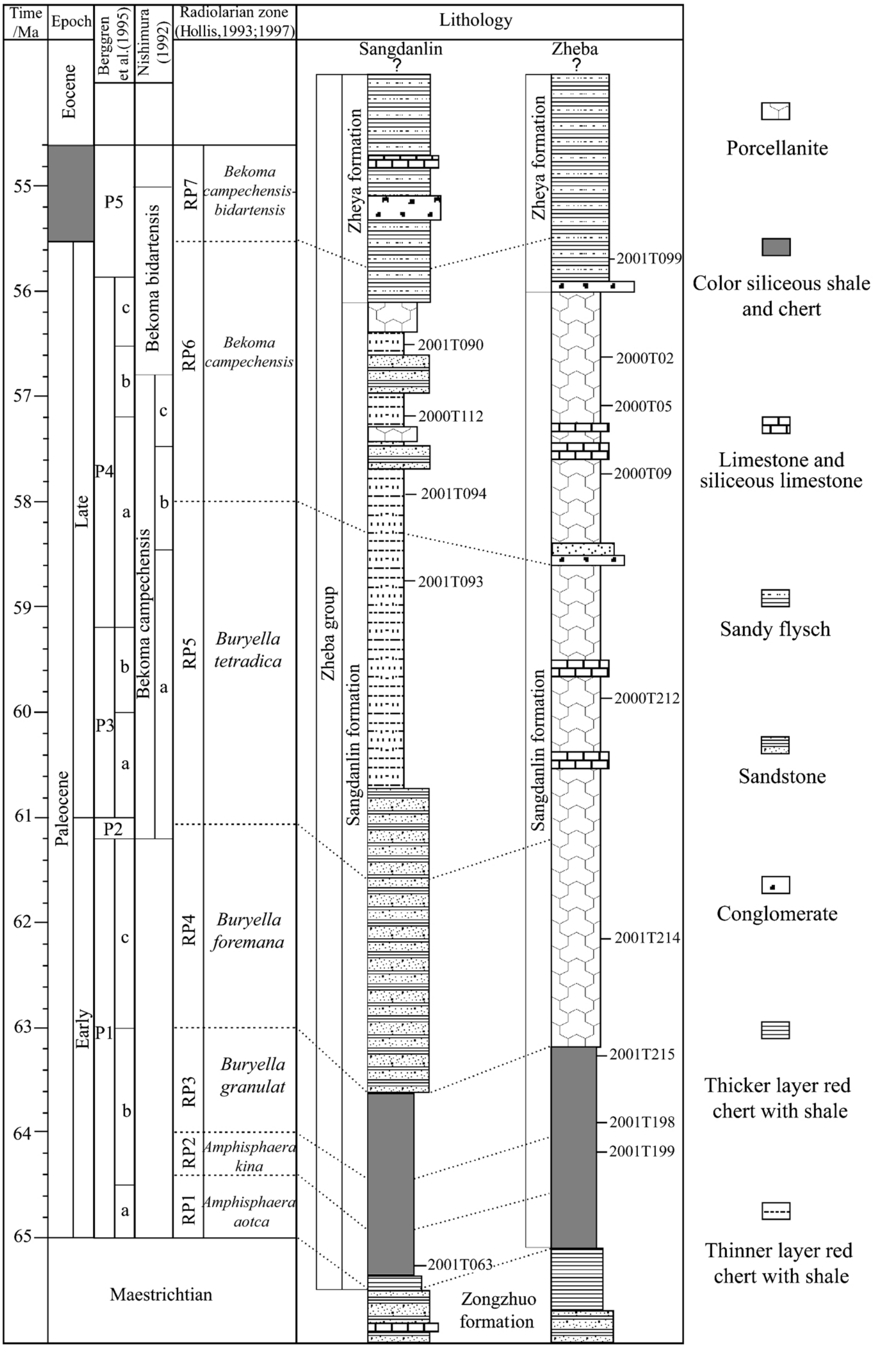

Fig. 3. Paleocene stratigraphy and correlation chart of the Zheba group, southern Tibet. Foraminifera zones are given based on ref. [29].

6. Grey pebble sandstones, shales and chert nodules. The pebbles in the pebble sandstones are cherts, shales and volcanic rocks. Radiolarians extracted from the chert nodules include *Bekoma campechensis*, *Lychnocanoma costata*, *Orbula comitata*, *Buryella tetradica*, *Podocyrtis turgida* et al. ＞300 m thick.

5. Fine conglomerates, the pebbles are cherts and volcanic rocks. 0.5 m thick.

— — — — Conformity — — — —

Sangdanlin formation:

4. Grey-white cherts, porcellanites and siliceous shales interbedded with some siliceous limestones and conglomerates. Radiolarians include *Bekoma campechensis, Lychnocanoma costata, Orbula comitata, Buryella tetradica, B. pentadica, B. petrusheskaya*, *Podocyrtis turgida*, *Tripocalpis simplex* et al. 20 m thick.

3. Grey-white cherts and siliceous shales. Radiolarians include *Buryella foremana*, *Buryella tetradica*, *Spongodiscus alvertus*, *Tripocalpis simplex*, *Buryella granulata*, *Buryella* cf. *tetradica* n. sp. and *Calocycletta tibeta* n. sp. et al. 26 m thick.

2. Red, purple cherts and siliceous shales. Radiolarians include *Amphisphaera aotea*, *Saturnalis kennetti*, *Amphisphaera goruna*, *Tripocalpis simplex*, *Amphipyndax stocki*, *Dictyomitra andersoni*, et al. 43 m thick.

— — — — Conformity — — — —

Late Cretaceous Zongzhuo formation (not to bottom):

1. Red, purple bedded cherts, siliceous mudstones and grey-white quartz sandstone. Radiolarians include *Amphipyndax stocki*, *Dictyomitra andersoni*, *Acanthocircus campbelli*, *Cornutella* n. sp. cf. *C. californica*, *Bathropyramis sanjoaquinensis* s. l. et al. Foraminiferas include *Abathomphalus intermedius* (Bolli), *Globotruncana arca* (Cushman) and *Globotruncanita stuarti* (de Lapparent). ＞500 m thick.

Sangdanlin section (fig. 2(b)): a complex syncline:

Early Tertiary Zheba group:

Zheya formation (not to the top):

7. Grey, greenish lithic sandstones, shales and conglomerates. Lithostratigraohic correlation with Zheya formation. ＞600 m thick.

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Sangdanlin formation:

6. Grey, greenish shales and lithic sandstones. 15 m thick.

5. Red, purple siliceous shales and cherts. Radiolarians include *Bekoma campechensis*, *Lychnocanoma costata*, *Orbula comitata*, *Buryella tetradica*, *B. pentadica*, *B. petrusheskaya*, *Podocyrtis turgida*, *Tripocalpis simplex* et al. 65 m thick.

4. Grey, greenish shales and sandstones. 50 m thick.

3. Grey, brown, red, purple shales, cherts and siliceous mudstones. Radiolarians include *Amphisphaera aotea*, *Amphipyndax stocki*, *Dictyomitra andersoni*, et al. 15 m thick.

2. Grey, greenish shales and cherts. 3 m thick.

— — — — Conformity — — — —

Late Cretaceous Zongzhuo formation (not to the bottom):

1. Metre-bedded quartzic sandstone interbedded with shales, chert and decimetre-bedded limestones. Radiolarians include *Amphipyndax stocki*, *Dictyomitra andersoni*, *Spongodiscus* sp., *Orbiculiforma renillaeformis* s.s., *Amphisphaera priva*, *Cornutella californica*, *Cornutella* n. sp. cf. *C. californica*, *Bathropyramis sanjoaquinensis* s. l. et al. ＞300 m thick.

3 Materials and methods

Samples were collected from the Paleocene Sangdanlin and Zheya formations. Cherts, porcellanites and siliceous shales were processed by the standard methods for radiolarian extraction. All the samples were broken into 2—5 cm pieces and placed in about 5% hydrofluoric acid. After 8—24 h, the samples were washed through 200 μm and 61 μm stainless-steel sieves. The dried residues (>61 μm fractions) were examined under binocular microscope. The well-preserved radiolarians were mounted on the Scanning Electron Microscope (SEM) stub using a thin brush, then coated with gold, observed and photographed using a SEM.

About 40% of the 322 samples contain Radiolarians, and only about 10% of the samples contain common to abundant and moderately to well-preserved radiolarians. More than 2700 SEM microphotographs were taken. In this work, 14 well preserved samples were selected (fig. 3), 13 genera, 19 species (including 3 new species) are shown here (table 1 and fig. 4).

Table 1 Distribution of representative radiolarians from the Paleocene Zheba group, southern Tibet

Taxa	01T199	01T198	01T215	00T214	00T212	00T209	00T205	00T202	01T099	01T063	01T093	01T094	00T112	01T090
Acanthocircus campbelli	R	R	R	R										
Amphisphaera aotea	C	C	R							F				
Amphisphaera goruna		C	C	C	C	R	F	F	F		F	R	F	F
Bathropyramis sanjoaquinensis	F	F	F	F	F					F		R		
Bekoma campechensis						C	C	C	C			A	A	F
Buryella n.sp. cf. *B. tetradica*	A	A	C	C	A	A	F			R				
Buryella foremanae				A	F									
Buryella granulata			C	C	F									
Buryella pentadica					C	C	F	F	F		F	A	C	F
Buryella Petrushevskaya							C	C	C		F	C	F	R
Buryella tetradica					A	A	F	C	C		F	A	A	C
Calocycletta tibeta n. sp.			C	C	C						F			
Cornutella n. sp. cf. *C. californica*	C	F	C	F	F					R	F			
Lychnocanoma costata					R	A	A	A	C			A	C	F
Orbula comitata					A	A	A	A	C		C	A	A	A
Podocyrtis turgida					F	C	A	A	A			A	C	C
Saturnalis kennetti	F	F	F	R	R					R				
Spongodiscus alveatus		F	F	C	C	F				R	F	F		
Tripocalpis simplex			R	C	C	F				R				

R, Rare, ＜5; F, few, 6—10; C, common, 11—25; A, abundant, ＞26 specimens.

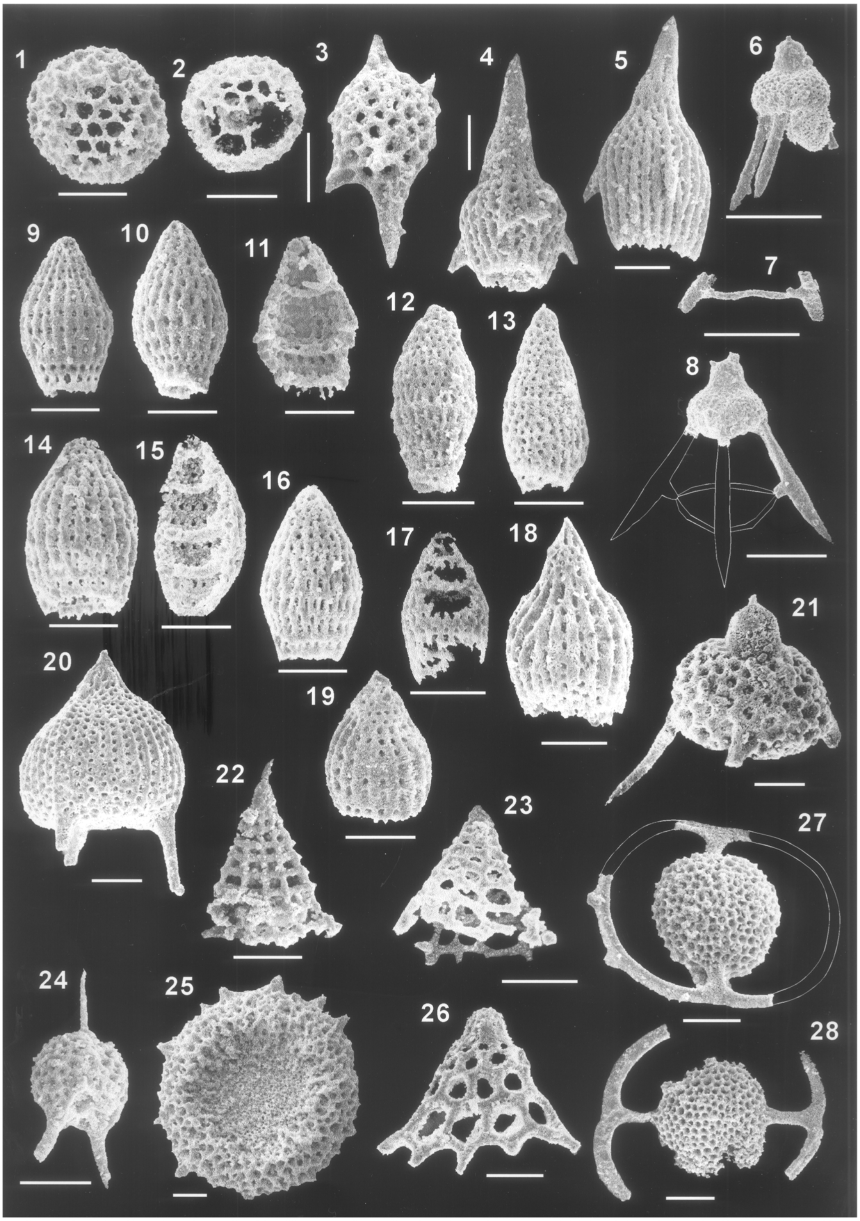

Fig. 4. Scanning electron microscopic images of selected radiolarians from the Paleocene sequences of the Zheba group, southern Tibet. Scale bars = 50 µm. 1, *Amphisphaera aotea* Hollis (2001T199); 2, *Amphisphaera aotea* Hollis, broken specimen showing detail of medullary shell (2001T199); 3, *Amphisphaera goruna* Hollis (2000T212); 4, *Calocycletta tibeta* n. sp. (2000T212); 5, *Calocycletta tibeta* n. sp. (2001T214); 6, *Bekoma campechensis* Foreman (2001T094); 7, *Bekoma campechensis* Foreman, broken foot of *Bekoma campechensis* (2001T094); 8, *Bekoma campechensis* Foreman (2001T094); 9, *Buryella tetradica* Foreman, (2000T09); 10, *Buryella tetradica* Foreman (2000T212); 11, *Buryella tetradica* Foreman, broken specimen showing detail of internal segmentation (2000T112); 12, *Buryella foremanae* Petrushevskaya (2000T212); 13, *Buryella granulata* Petrushevskaya (2001T199); 14, *Buryella pentadica* Foreman (2001T094); 15, *Buryella pentadica* Foreman, broken specimen showing detail of internal segmentation (2001T094); 16, *Buryella* cf. *tetradica* n. sp. (2000T199); 17, *Buryella* cf. *tetradica* n. sp. (2000T199), broken specimen showing detail of internal segmentation (2001T199); 18, *Podocyrtis turgida* Krasheninnikov (2000T09); 19, *Buryella Petrushevskaya* O'Connor (2000T09); 20, *Lychnocanoma costata* Nishimura (2000T09); 21, *Orbula comitata* Foreman (2000T09); 22, *Bathropyramis sanjoaquinensis* s. l. Campbell & Clark (2001T199); 23, *Bathropyramis sanjoaquinensis* s. l. Campbell & Clark (2000T212); 24, *Tripocalpis simplex* Nishimura (2000T212); 25, *Spongodiscus alveatus*, Sanfilippo & Riedel (2000T212); 26, *Cornutella* n. sp. cf. *C. californica* (2001T199); 27, *Acanthocircus campbelli* Foreman (2000T212); 28, *Saturnalis kennetti* Dumitrica (2000T212).

All materials are stored in the Institute of Geology and Geophysics, Chinese Academy of Sciences.

4 Paleocene radiolarian faunas

The selected Paleocene radiolarians from the Zheba group are listed in table 1 and illustrated in fig. 4. For age determinations, the zonal schemes of the Early Paleocene radiolarian assemblages established in South Pacific[1,2,4,5], and the Late Paleocene in the Gulf of Mexico and the Northwest Atlantic Ocean[6—11] were applied. Six radiolarian zones (RP1—RP6) have been identified, which are assigned to the ages from Early Paleocene to Late Paleocene.

4.1 *Amphisphaera aotea* zone (RP1)

The interval is from the first appearance of *Amphisphaera aotea* to that of *A. kina*[1,2]. In sample 2001T063 from the Sangdanlin formation, abundant *A. aoteo* and a few of Cretaceous taxa were extracted. The Cretaceous taxa include *Amphipyndax stocki, Dictyomitra andersoni*, *Spongodiscus* sp., et al. However, the diversity and abundance of the Cretaceous taxa are low. Furthermore, abundant Late Maestrichtian foraminiferas have been identified in the upper part of the Zongzhuo formation. They include *Abathomphalus intermedius* (Bolli), *Globotruncana arca* (Cushman) and *Globotruncanita stuarti* (de Lapparent), which are assigned to the Gansserina gansseri zone of the Late Cretaceous age (68—66 Ma)[30]. The first Paleocene radiolarian assemblage is indicated by the occurrence of *Amphisphaera aotea*, which was first recovered in the Early Paleocene Mead Hill formation in New Zealand[1,2]. *Amphisphaera aotea* mainly ranges from RP1 to RP2 zones, rarely persists to the low RP3 zone. So sample 2001T063 is assigned to the RP1 zone of very Early Paleocene age.

4.2 *Amphisphaera kina* zone (RP2)

The interval is from the first appearance of *Amphisphaera kina* to that of *Buryella granulata*[1,2]. In this work, no *A. kina* has been confirmed. Abundant well-preserved *Amphisphaera aotea* with the first occurrence of *Saturnalis kennetti* and *Amphisphaera goruna* were extracted from sample 2001T199. *A. aoteo* mainly occurs in RP1 and RP2 zones, and is very rare in the low RP3 zone in New Zealand. *Amphisphaera goruna* first occurs in the low *Amphisphaera kina* zone[2]. So, sample 2001T199 is assigned to the *Amphisphaera kina* zone.

4.3 *Buryella granulata* zone (RP3)

The interval is from the first appearance of *Buryella granulata* to that of *Buryella foremana*[1,2]. Sample 2001T198 contains abundant *Buryella granulata, Buryella* cf. *tetradica* n. sp., *Calocycletta tibeta* n. sp. and *Tripocalpis simplex. Amphisphaera aotea* appears last in this sample. Sample 2001T198 is assigned to the *Buryella granulata* zone.

4.4 *Buryella foremana* zone (RP4)

The interval is from the first appearance of *Buryella foremana* to that of *Buryella tetra-*

dica[1,2]. Sample 2000T214 contains a few of *Buryella foremana* and abundant *Spongodiscus alvertus*. In New Zealand, *Spongodiscus alvertus* first appears in the lower part of *Buryella foremana* zone. Other species of this assemblage include *Tripocalpis simplex*, *Buryella granulata* and *Buryella* cf. *tetradica* n. sp. The co-occurrence of *Buryella foremana* and *Spongodiscus alvertus* indicates that sample 2000T214 should be assigned to the *Buryella foremana* zone.

4.5 *Buryella tetradica* zone (RP5)

The interval is from the first appearance of *Buryella tetradica* to that of *Bekoma campechensis*[1,2]. Samples 2000T212 and 2001T093 contain abundant well-preserved *Buryella tetradica*, *B. pentadica*, *B. petrusheskaya* and *Podocyrtis turgida*. *B. pentadica* first appears in the upper part of the *Buryella tetradica* zone in New Zealand, and *B. petrusheskaya* also first appears at the upper part of the *Buryella tetradica* zone at the Ocean Drilling Project (ODP) site 1121[1,2,5]. Abundant taxa include *Spongodiscus alvertus*, *Buryella* cf. *tetradica* n. sp. and *Tripocalpis simplex*. The co-occurrence of *Buryella tetradica* and *B. petrusheskaya* without *Bekoma campechensis* suggests that samples 2000T212 and 2001T093 be assigned to the *Buryella tetradica* zone.

4.6 *Bekoma campechensis* zone (RP6)

The interval is from the first appearance of *Bekoma campechensis* to that of *Bekoma bidartensis*[1,2,8]. Samples 2000T02, 2000T05, 2000T09, 2001T090, 2001T094, 2001T099 and 2000T112 contain abundant and well-preserved *Bekoma campechensis*, *Lychnocanoma costata*, *Orbula comitata*, *Buryella tetradica*, *B. pentadica*, *B. petrusheskaya*, *Podocyrtis turgida* and *Tripocalpis simplex*. *Buryella foremana*, *Saturnalis kennetti* and *Cornutella californica* disappear in these samples. *Bekoma campechensis* is the index species of the *Bekoma campechensis* zone, which rarely persists to the Eocene[8—10]. Thus, samples 2000T02, 2000T05, 2000T09, 2001T090, 2001T094, 2001T099 and 2000T112 are assigned to the *Bekoma campechensis* zone of Late Paleocene age. Some radiolarian assemblages could be assigned to the very Early Eocene age.

5 Discussion and conclusions

The existences of the Paleocene deep-water sequences and radiolarian faunas were first confirmed on the southern side of Yarlung-Zangbo suture zone in this work. The radiolarian faunas extracted from the Zheba group range from RP1 to RP6 zones of the Paleocene age (65—55 Ma), which are generally similar to those of New Zealand of the Southern Pacific. However, the very Early Paleocene radiolarian assemblages show slightly different from the latter. The southern Tibet Early Paleocene radiolarian compositions have only a few of Cretaceous taxa. This may imply that the radiolarians in the Zheba group might have suffered from a mass extinction on the Cretaceous/Tertiary Boundary (KTB), the majority of Cretaceous taxa could not persist into the Paleocene.

The Zheba group, conformably deposited on the Zongzhuo formation on the Indian passive continental margin, is mainly composed of radiolaria-bearing cherts and flysches[20—22]. But the lithology of the Zheba group is very different from the latter which is dominated by large amounts of foraminifera-bearing quartzic sandstones and limestones. The time of the transition from the shallow-water sedimentary environment to the deep-water one may indicate the onset of the Asian continent loading onto the Indian continental margin and of the synchronously flexural subsidence of the Yarlung-Zangbo foreland basin. The Sandanlin formation may be accumulated in the central trench of the foredeep region. During the period of the deposition of the Zheya formation, the orogenic fold-thrust belt migrated to the northern part of the study area. The Zheya formation accumulated in the wedge-top depozone. Our own field work confirms the earlier observation result[16] that there is an unconformity at the KTB in the Gamba-Tingri areas of the Tethyan Himalaya. This is indicated by the conglomerates and pebble sandstones. The pebbles of the conglomerate are mainly silt sandstones, shales, cherts and rarely limestones. This unconformity indicates the forebugle depozone in the Gamba-Tingri areas or just north of it. In this scenario, the flexural subsidence and the unconformity of the Yarlung-Zangbo foreland basin imply that the onset of the collision between the Asian and the Indian continents was ~65 Ma ago.

Another possible time of the collision between Indian and Asian plates is at the beginning of the Zheya formation accumulation (~55 Ma). The Sangdanlin formation probably accumulated in the subduction trench prior to the collision, while the Zheya formation may probably be accumulated in the foredeep depozone resulted from the Asian continent loading the northern margin of Indian continent. The forebugle probably was in the High Himalaya and the back-bugle was probably situated at the present southern flank of Himalaya. The Eocene Zhepure[15—17] limestones, sandstones and shales in the Gamba-Tingri areas probably accumulated in front of the High Himalayan forebugle. The conglomerates deposited at the KTB indicate the regressive sediments.

The evidence from the foreland basin alone cannot confirm the time when the Asian continent collided with the Indian continent. The fact that the Linzizong formation unconformably deposited on all the pre-Cretaceous strata and granites suggests that the collision between Indian and Asian continents was perhaps triggered at the KTB[31] in the middle part of the Yarlung-Zangbo suture zone.

During the period of deposition of the Zheba group, the southern side of the Yarlung-Zangbo suture zone was a foreland basin system, the Indo-Burma region to the east and the Pakistan-Persian Gulf region to the west of the study area were marginal ocean basins. The Paleocene sequences of the Yarlung-Zangbo foreland basin system depositing on the Indian passive continental margin resulted in many good source-reservoir-covering assemblages for oil and gas resources. This geologic setting is similar to that of the Zagros foreland basin system. This new discovery leads us to suggest a reevaluation of the potential of gas and oil resources in the region of the foreland basin sequences preserved in the Tethyan Himalaya.

The following conclusions can be drawn from the lithostratigraphy and radiolarian dating:

(1) The newly named Zheba group, which is well exposed on the southern side of the Yarlung-Zangbo suture zone, represents the Early Tertiary deep-water sediments. This group is com-

posed of the lower Sangdanlin formation dominated by cherts and siliceous shales and the upper Zheya formation characterized by flysches.

(2) The radiolarian faunas from the Zheba group are assigned to the RP1—RP6 zones (65—55 Ma) of the Paleocene age. The Early Paleocene radiolarian assemblages of the Zheba group have the potential for establishing the low latitude radiolarian zones to fill in the gap between the Late Cretaceous and the Late Paleocene radiolarian zonations.

(3) The Paleocene radiolarian dating provides a valuable tool for regional correlation and reconstruction of the sedimentary environments in the Yarlung-Zangbo orogenic belt. Furthermore, this work provides a new on-land marine KTB in the Neo-Tethyan Ocean, which is a potential base for the study on mass extinction and extraterrestrial impact.

Acknowledgements The author thanks Wan Xiaoqiao for the identification of foraminifera. This work benefits from discussions with Li Hongsheng, Wu Haoruo and Yin Jixiang. The author thanks Pan Yusheng, Xu Ronghua and Wan Xiaoqiao for their assistance in the field. Critical reviews by Feng Qinglai and an anonymous reviewer helped the author to improve the paper. This work was supported by the Chinese National Key Project (Grant No. 1998040800) and the Chinese Academy of Sciences Key Project (Grant No. KZCX2-SW-119).

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