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Characteristics of Early Eocene radiolarian assemblages of the Saga area, southern Tibet and their constraint on the closure history of the Tethys

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Quantitative analysis of Early Eocene radiolarian assemblages discovered in the sedimentary mélange (accretionary prism) of the Saga area, southern Tibet provides new information to constrain the timing of Tethys closure and the initial collision of India and Eurasia. The radiolarian species of Saga include *Amphisphaera coronata* (Ehrenberg), *Buryella hannae* Bak & Barwicz-Piskorz, *Buryella clinata* Foreman, *Buryella tetradica* Foreman, *Calocycloma ampulla* (Ehrenberg), *Lamptonium fabaeforme constrictum* Riedel and Sanfilippo, *Lamptonium pennatum* Foreman, *Lithomespilus coronatus* Squinabol and *Lamptonium* (?) *colymbus* Foreman. The adequate and reliable correlation of these radiolarians specimens indicates that the assemblage is of Early Eocene in age. The age and depositional environment of these radiolarians testify that deep ocean basins existed between India Plate and Asia Plate during the Early Eocene. The complete closure of Tethys must have taken place at least after the Early Eocene.

Tibet, radiolarian, deep sea deposit, Early Eocene, Tethys

The age of the Tethys closure and India-Asia Plates collision are the keys for understanding the evolution of the Himalayan orogen and the formation of the Tibetan Plateau. However, the evolution history of the Tethys and time of collision between India and Asia Plates are still controversial. Existing estimates range from 70—65 Ma[1−4], 55—50 Ma[5−8] to 45—30 Ma[9−11]. These controversies are largely due to two fundamental reasons: (1) the closure processes of the Tethys and India-Asia Plates collision may have not been synchronous both spatially and temporally, that is, different regions may have occupied different tectonic positions in the same stage; (2) the ages on the closing and collision were mostly determined radiometrically, with little or no evidence from paleontology and stratigraphy. These dates thus lead to distinct views on the evolution of the Tethys. As the final disappearance of Tethys would coincide with the absolute retreat of seawater from Tibet, the transition from the latest marine to terrestrial facies would be one of the most direct proofs. Therefore, to determine the ages of Tethys closure and India-Asia Plates collision is to actually date the latest marine sediment in the region. In the past decade, much attention has been paid to studying the latest marine strata in the Yarlung Zangbo region. Somewhat curiously, the results are diverse from some other conclusions[1,2,12−15].

During our recent geological investigation in Sage area, southern Tibet, we discovered Early Eocene radiolarian assemblages in the sedimentary mélange of the

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Yarlung Zangbo suture, which provide direct constraint on the suturing between India and Asia Plates, and thus the closure of the Tethys. This paper presents detailed results of our paleontologic work on the radiolarians and discusses their significance in interpreting the timing of the collision between the India and Asia Plates.

1 Geological background and sampling

Saga area is situated in the middle part of the Yarlung Zangbo suture, southern Tibet, representing the trace of Tethys. From north to south, there are three tectonic units including the Gangdese forearc basins, Yarlung Zangbo suture and the northern subzone of the Tethyan Himalaya (Figure 1). Each unit is divided by thrusts. Furthermore, the Yarlung Zangbo suture can be divided into the ophiolitic mélange to the north and sedimentary mélange to the south, respectively. With width of 20—30 km, the sedimentary mélange distributes between the ophiolitic mélange zone and the northern subzone of the Tethyan Himalaya. The matrixes of the sedimentary mélange consist of the Triassic-Paleogene sandstones and mudstones. However, the tectonic blocks are composed of Paleozoic-Paleogene sandstones, limestones, cherts, basalts, amphibolites, gabbros and diabases. The blocks are different in size and lithology and the distribution is not systematic. The newly discovered Eocene radiolarians were found in this sedimentary mélange zone.

The deposits and layers in the sedimentary mélange were comprehensively studied by several geologists[16−20]. Even to the present, however, the sequence, characteristics, ages, and the paleogeographical aspects are still being debated. The radiolarian cherts in the Sangdanlin area were previously reported by Sheng [17]. They were thought to be the Late Triassic and named Jilong Group[17, 18]. Several radiolarians in the Sangdanlin cherts were first described by Li[19] as Eocene-Miocene, but Ding[5] reinterpreted these cherts as Paleocene Sangdanlin Fomation and related its sequence to a foreland basin resulting from the southern Asian margin loading onto the northern Indian passive continental margin. The 1:250000 geological mapping termed the Sangdanlin cherts the Denggang Formation and assigned its age to Paleogene[20]. On the other hand, Chen et al.[21] and Qian[22] considered that the above sequences were emblematical tectonic mélange distributing in the south of the Yalung Zangbo Suture, based on deformation and structure studies.

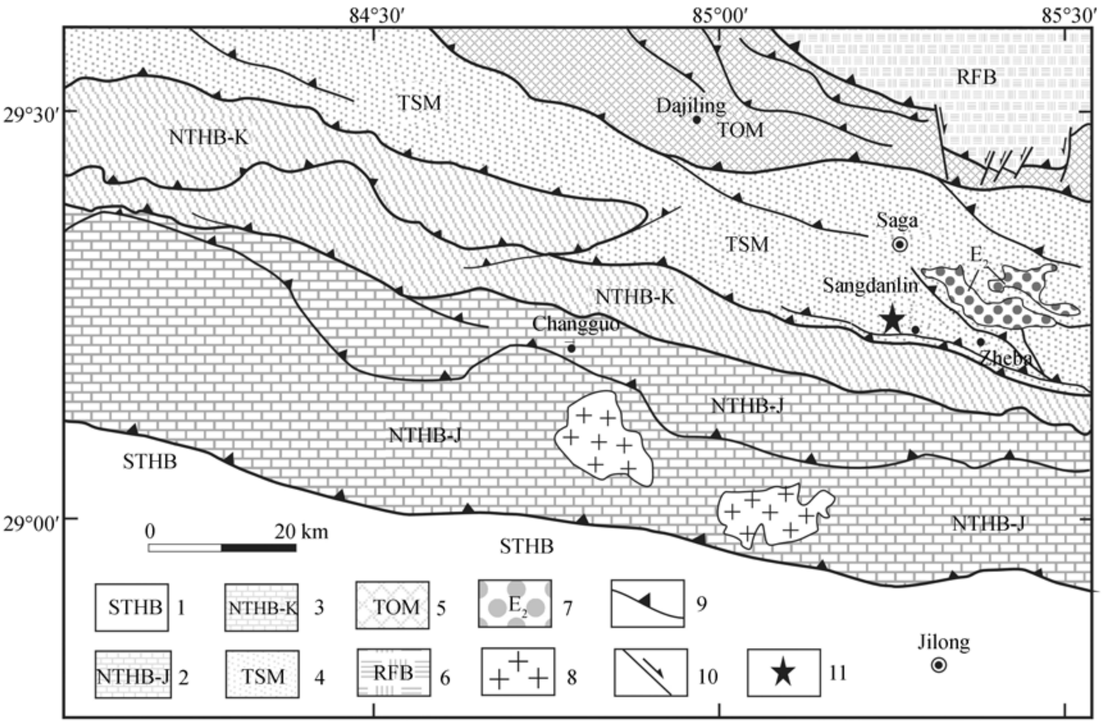

Figure 1 Simplified tectonic map of the study area. 1, Southern subzone of Jurassic sediments in the Tethyan Himalaya; 2, northern subzone of Jurassic sediments in the Tethyan Himalaya; 3, northern subzone of Cretaceous sediments in the Tethyan Himalaya; 4, sedimentary mélange (accretionary prism); 5, ophiolitic mélange; 6, Cretaceous sediments of the forearc basin; 7, Ecocene molasses; 8, granite; 9, thrust; 10, strike-slip fault; 11, location of radiolarian sample.

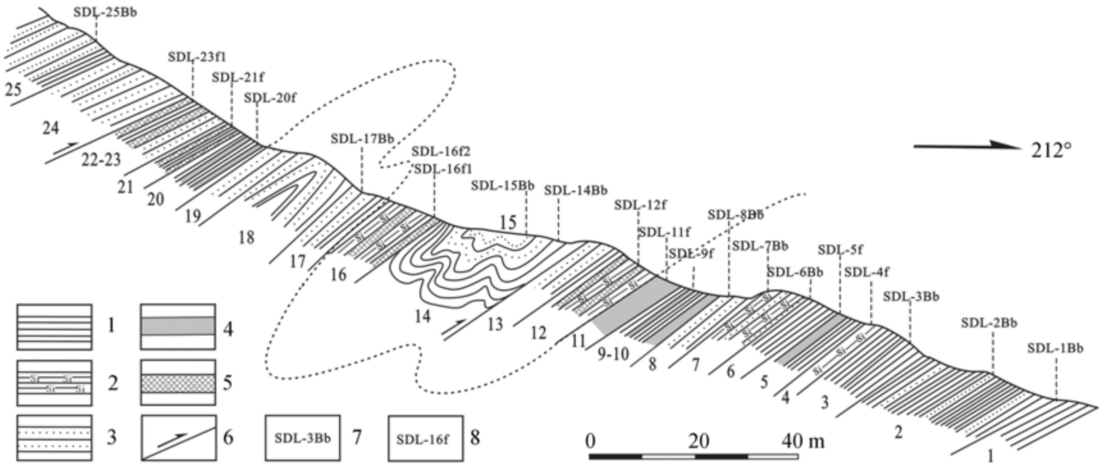

Figure 2 Fractional stratigraphic section and sampling sites of radiolarian fossils in Sangdanlin, southern Tibet. 1, Shale; 2, siliceous shale; 3, quartz-rich sandstone; 4, greyish green chert; 5, purple chert; 6, thrust; 7, position of petrologic samples; 8, position of radiolarian samples.

Sampling localities lie at the northwest part of the Sangdanlin Village in the south of the Saga County (Figure 1). The beds in the section are north dipping and have undergone intensively deformation. The contact relationships with the overlying and underlying strata are not clear. Two thrusts and reversed folds were recognized from this section (Figure 2). Because of lack of exact sedimentary structures that can determine the way-up of the bed, it's hard to identify the reversed part. This section can be divided into three stratigraphic units based on lithology observed in the field. To the south, rocks are mainly characterized by greyish green shales and thin fine quartz-rich sandstones; the middle part is composed of greyish green shales, purple cherts, siliceous shales as well as grey quartz-rich sandstones. The northern unit is composed entirely of medium-grain quartz-rich sandstones. The content of sandstone increases from south to north. The entire section is 230 m thick, and if the reversed parts were eliminated, the true thickness is about 85—90 m.

2 Sample processing and age determination of radiolarian assemblage

Ten samples for radiolarian identification were collected from the Sangdanlin sections (Figure 2). The microfossils processing and the identification were accomplished in the laboratory of Jagiellonian University, Poland. In order to make the radiolarian tests, each sample were broken into pieces of 1—2 cm across and dried at the temperature of 105℃. Samples were treated with hydrofluoric acid (10%) for 48 h. The residues were washed through a 61 μm sieve. The extracted radiolarians were then firstly examined under a binocular microscope. They were picked out manually from the residue. The best preserved specimens were mounted on Scanning Electron Microscope (SEM) stubs for more precise determination. More than 2000 SEM pictures were taken during the study. A great number of radiolarian fossils have been obtained in layer 11 greyish green siliceous shales (sample SDL-16f2) and layer 16 cherts (sample SDL-11f) of the Sangdanlin section. Radiolarians recovered from samples collected are Upper Cretaceous and Eocene in age. In this paper, only some important microfossil genera and species are described and illustrated (Figure 3).

Among greyish green siliceous shales (layer 11), recognized species are *Spongosaturninus* cf. *ellipticus* Campbell & Clark; *Pseudoaulophacus riedeli* Pessagno; *Orbiculiforma sacramentoensis* Pessagno and *Patellula planoconvexa* (Pessagno) (Figure 3, 1—5). By correlating this assemblage with the *Phaseliforma carinata* Subzone of Crucella easpartoensis Radiolarian Zone of Pessagno[23], the ages of these radiolarians in layer 11 can be assigned as the Late Cretaceous Campanian .

Radiolarians were moderately well preserved in the greyish green cherts layer 16 (sample SDL-16f2). The taxa include *Amphisphaera coronata* (Ehrenberg); *Buryella hannae* Bak & Barwicz-Piskorz, *Buryella clinata* Foreman, *Buryella tetradica* Foreman, *Calocycloma ampulla* (Ehrenberg), *Lamptonium fabaeforme constrictum* Riedel and Sanfilippo, *Lamptonium pennatum*

Foreman, *Lithomespilus coronatus* Squinabol, *Lamptonium* (?) *colymbus* Foreman and *Amphisphaera minor minor* (Clark & Campbell), *Lamptonium sanfilippoae* Foreman and *Lithelius minor* Jorgensen (Figure 3, 6—17). The biostratigraphic age determination of these deposits is based on the presence of radiolarian taxa widely distributing in the Lower Eocene low-latitude, such as: *Buryella clinata* Foreman, *Buryella tetradica* Foreman, *Calocycloma ampulla* (Ehrenberg), *Lamptonium sanfilippoae* Foreman, *Lamptonium fabaeforme constrictum* Riedel and Sanfilippo, *Lamptonium pennatum* Foreman, and *Lamptonium*(?) *colymbus* Foreman. These radiolarians are found in Cyprus[24] and Mexico Gulf[25]. According to Foreman[25] and Riedel et al.[26], these species are similar to *Buryella clinata-Thursocyrtis ampla*. Although the index species is not present herein, the co-occurrence of the above radiolarian specimens undoubtedly indicates that they are Early Eocene assemblages.

Besides the Paleogene marine sediments, a sequence of continental molasse lies 6—7 km away in the study area, northeast of the Sangdanlin Village (Figure 1). The molasse is composed of purple-grey conglomerates, conglomeratic sandstones and medium-coarse sandstones, and lays over the sedimentary mélange. The thickness of molasse is 294 m. Large Early Cretaceous

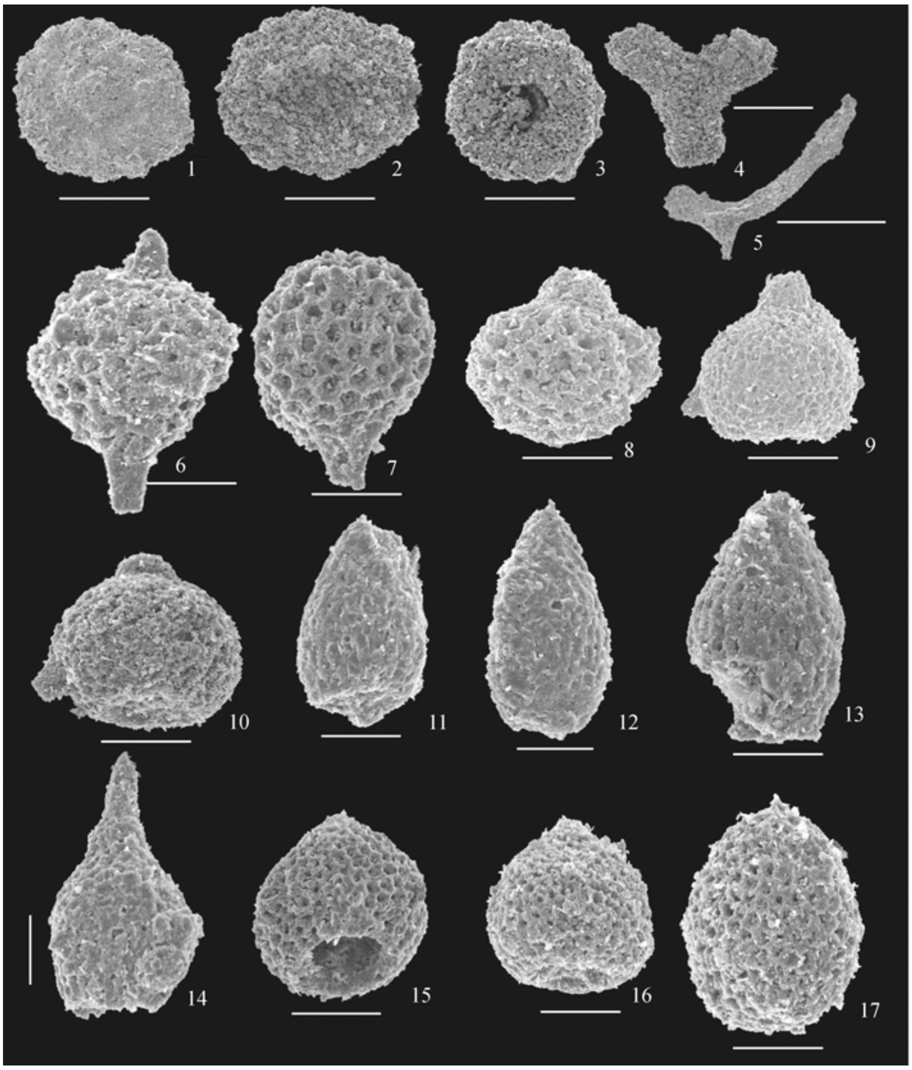

Figure 3 Scanning electron microscopic images of radiolarians of the Sangdanlin section. 1 and 2, *Patellula planoconvexa*, SDL11-1, ×200; 3, *Orbiculiforma sacramentoensis*, SDL11-1, ×300; 4, *Pseudoaulophacus riedeli*, SDL11-1, ×200; 5, *Spongosaturninus* cf. *ellipticus*, SDL11-1, ×200; 6 and 7, *Amphisphaera coronata*, SDL16-2, ×250; 8, *Calocycloma ampulla*, SDL16-2, ×300; 9 and 10, *Bekoma* sp., SDL16-2, ×250; 11, *Buryella hannae*, SDL16-2×300; 12, *Buryella clinata*, SDL16-2, ×300; 13, *Buryella tetradica*, SDL16-2, ×500; 14, *Lamptonium fabaeforme constrictum*, SDL16-2, ×300; 15, *Lamptonium pennatum*, SDL16-2×250; 16, *Lamptonium* (?) *colymbus*, SDL16-2×250; 17, *Lithomespilus coronatus*, SDL16-2, ×250.

radiolarians of the Barremian were found in the pebbles of conglomerates and conglomeratic sandstones. Radiolarians include *Praeconosphaera sphaeroconus* (Rust), *Mictyoditra thiensis* (Tan), *Archaeodictyomitra leptocostata* (Wu & Li), *Thanarla brouweri* (Tan), and *Hiscocapsa uterculus* (Parona). These pebbles indicate that the Early Cretaceous marine sediments are source of the molasse. Considering the sedimentary environment, the component of the pebbles as well as the unconformable contact with the mélange, it can be concluded that the deposits were developed in a molasse basin controlled by the India and Asia Plates collision. Tentatively, we applied ESR. dating to this suite of molassic deposits, and obtained 41.2—46.2 Ma (Lutetian) ages at the bottom of this deposits. The stratigraphic age not only demarcates the upper limit of the Tethysian sediments, but also indicates that the Early Eocene marine deposits at the Sangdanlin area are thus well constrained.

3 Discussion

3.1 Stratigraphic ages and depositional environment

Middle Triassic (Anisian)-Late Cretaceous (Turonian) radiolarians are well developed in the Yalung Zangbo Suture Zone[27]. However, Paleocene and Eocene radiolarians are rarely reported. There are conflicts on the ages of the radiolarians in the Sangdanlin section. Li[5] first described the Paleocene-Miocene radiolarians in thin sections and divided them into five assemblages. Because of the technical limitation in thin-section observations, the radiolarian faunas in Sangdanlin section did not arouse much attention. In fact, it has been questioned whether radiolarians of Eocene to Miocene age are present in the section. Our study, based on more abundant radiolarian faunas discovered in the Sangdanlin section, confirm the Early Eocene sediments in Saga area.

Modern radiolarian assemblage is thought to be a kind of pelagic or hemipelagic plankton. Its living space can be extended deep in the water column and often coexists with cherts. Although radiolarian cherts do not always accumulate in very deep oceanic basins (>3000 m) on the basis of the modern analogue, it is commonly thought that radiolarites deposits in various oceanic environment could be even deeper than 300—500 m[28]. It is generally accepted that bedded radiolarian cherts usually reflect a deep water environment far away from terrigenous influx, such as oceanic basin, island arc or rift basin. In general, the radiolarians in suture zone should reflect the age of paleo-ocean and ophiolites. The radiolarian fauna found in this study occurred in a gray-greenish laminated to thin-bedded cherts and siliceous shales. Horizontal laminations also well developed in the above rocks, without any shallow-water deposit marks and other fossils. These lines of evidence strongly point to deep-water setting environment for the Saga radiolarians.

3.2 Tectonic attributes of radiolarian stratum

The tectonic attributes of radiolarian-based stratum directly constrain the tectonic evolution of the study area. Namely, whether the radiolarian stratum was part of normal deposition in a foreland basin[5] or abundant in the Tethyan Ocean would have distinct implications. The Sangdanlin section comprises asynchronous deposits in ages, such as Triassic, Cretaceous, Paleocene, and Eocene[5,17,19], based on the radiolarians discovered by us and others. This has led to the different age and strata division, including the Late Triassic Jilong Group[18] and the Paleocene Sangdanlin Formation[5]. Our newly discovered Eocene radiolarians assemblage in the same section indicates that this marine stratum is made up of various deposits in age and environment, and is characterized by non-Smith stratigraphy. We also noticed that the tight-reversed folds and thrusts are common in this marine stratum suggesting that they undergone intensive deformation, similar to the mélange of the Yalung Zangbo suture in structure style[21, 22]. For instance, two episodes of reversed and layer-paralleled thrusts can be distinguished in the range of 200 m from the Sangdanlin section. These tectonic imprints indicate that this section is one of the tectonic slices in the sedimentary mélange, south of the Yalung Zangbo Suture.

Previous work restricted the Zheba Group in the Paleocene and was assigned to the deposits of foreland basin[5], the lower cherts were named the Sangdanlin Formation and the upper clastic rocks were the Zheya Formation. In this study, we re-investigated the lower cherts in the Zheba area, and found abundant Late Barremian to Early Aptian radiolarians of Early Cretaceous. The main species are *Archaeodictyomitra lacrimula* (Foreman), *Archaeodictyomitra leptocostata* (Wu & Li), *Archaeodictyomitra mitra* Dumitrica, *Hiscocapsa grutterinki* (Tan), *Praeconosphaera sphaeroconus* (Rust), *Pseudodictyomitra lanceloti* Schaaf, *Pseudodictyomitra lodogaensis* Pessagno, *Thanarla brouweri* (Tan), *Thanarla pacifica* Nakaseko and Nishimura. These radiolarians indicate that the lower part of the Zheba Group was Cretaceous in age. Moreover, the cherts and clastic rocks are usually divided by faults and disorderly in sequence. The top and bottom boundaries of the section cannot be identified in the field. The thickness of sediments distinguished from the wedge-shaped structure in foreland basin. Structure analysis reveals that Zheba Group comprised large tectonic blocks and underwent intricately deformation, similar to the Sangdanlin section.

From the peculiarities above, it can be inferred that the cherts in study areas vary in age, and are remnants of the Tethyan Ocean which were mixed during subduction of the Tethyan crust and perched in sedimentary mélange as tectonic blocks. The rock associations and deformation style indicate the existence of the Tethyan Ocean along the Yalung Zngbo Suture.

In addition, Wan et al.[29] reported the Early Eocene foraminiferal marine stratum at Zhongba, west of our study area, and named it the Jialazhi Formation covered by the Middle Eocene Gangdese Group. Li[14] found a sequence of mid-late Eocene (50－40 Ma) marine sediments at Zhepure in Tingri area. These localities share the same tectonic features with the Saga area; indicating that the Tethyan Ocean developed along these regions during Early Eocene.

4 Conclusions

The discovery and documentation of Early Eocene radiolarian assemblages in the Saga area suggest that the Sangdanlin section is made up of multiple deposits of contrasted ages and is probably a large block within a tectonic mélange. The existence of deep-sea deposits in Saga area extends the duration of the Tethys Ocean to Early Eocene. The main implication of this finding is that India-Asia Plates collision must have taken place after Early Eocene. These new observations provide significant evidence for understanding the timing of the Tethys closure and constraining the entire collision of India-Asia Plates blocks.

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