The age of the plant fossil assemblage in the Liuqu Conglomerate of southern Tibet and its tectonic significance*

FANG Aimin[1]**, YAN Zhen[1], LIU Xiaohan[2], PAN Yusheng[1], LI Jiliang[1], YU Liangjun[1], HUANG Feixing[2] and TAO Junrong[3]

(1. Laboratory of Lithosphere Tectonic Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China; 2. Institute of Tibet Plateau Research, Chinese Academy of Sciences, Beijing 100085, China; 3. Institute of Botany, Chinese Academy of Sciences, Beijing 100093, China)

Received April 20, 2005; revised May 12, 2005

Abstract The Liuqu Conglomerate, situated to the south of Yarlung Tsangbo Suture Zone (YTSZ), is a suit of molasse formed in a foreland basin of the Himalayan orogenic belt after the collision between the two plates of the Indian and Eurasion. It is of great significance in constraining the younger limit time of the collision of the two plates and providing stratigraphic evidence to reveal the post-collisional tectonic evolution and uplifting history of the Tibet plateau. However, the age of this molasse suit and its correlation to other synchronous strata distributed in southern Tibet have been in great disputes for a long time. Especially in recent years, argues on its ages are growing violently with the recognition of the great sedimentary tectonic significances of this molasse. During the field work carried out recently on this molasse suit, a lot of plant fossils were found preserved in fairly good conditions in the upper part of this strata, which is of great help in determining its age. By identification, the assemblage of the plant fossils belongs to a tropic to subtropic flora developed in the southern margin of the Northern Hemisphere supercontinent during the Middle to Later Eocene, which can provide good constraint on its formation age. This paper is to give a brief introduction of the plant assemblage and its age, and to discuss their tectonic significances.

Keywords: Liuqu conglomerate, plant fossils, age, Eocene, Tectonic implications.

The convergence and collision of the two plates of Indian and Eurasion has been one of the most important global geological events ever since Mesozoic Era, which not only resulted in the closure of the Tethyan ocean, but also caused the uplifting and formation of the magnificent Tibet Plateau. Therefore, it has always been one of the most important geological subjects to reveal the evolutionary history of this global event, and studies on the geology of the Tibet are kept being one of the hottest scientific subjects for a long time.

In convergent margins, accompanied with the formation and uplifting of the orogenic belts, a lot of basins will also develop and evolve during this process, and sediments and its sequences kept in these basins will record this geological process. There are many molasse basins distributed along the two sides of the Yarlung Tsangpo Suture Zone (YTSZ) (Fig. 1), in which a large quantity of molasse-type sediments are filled. These marine or terrestrial molasse suits are obviously formed during the evolution of the suture zone after the continent to continent collision of the Indian and Eurasion plates, and thus they contained a lot of geological information about the tectonic evolution of this region during the post-collision stage[1]. However, these molasses have not been well studied for a long time because of the limitation of the austere natural geographical conditions in Tibet Plateau, and as a result, the tectonic evolution of Tibet is fairly constrained by this situation. In recent years, the authors made a detailed study on the sequences, sedimentary environments and formation ages of the Liuqu Conglomerate, one of the most representative molasse suits in southern Tibet, and especially, found a large quantity of well-preserved plant fossils in the upper part of this molasse suit. Further identification indicates that they belong to an assemblage of Middle to Later Eocene in age. These findings provide not only concrete biostratigraphical evidence for further subdivision and correlation of the molasses outcropped in southern Tibet, but also new materials to constrain the collision age and tectonic evolution of the YTSZ.

* Supported by the Major State Basic Research Development Program of China (Grant No. 2002CB412600) and the Knowledge Innovation Program of the Chinese Academy of Sciences (Grant No. KZCX2- SW-119)

** To whom correspondence should be addressed. E-mail: fam@mail.igcas.ac.cn

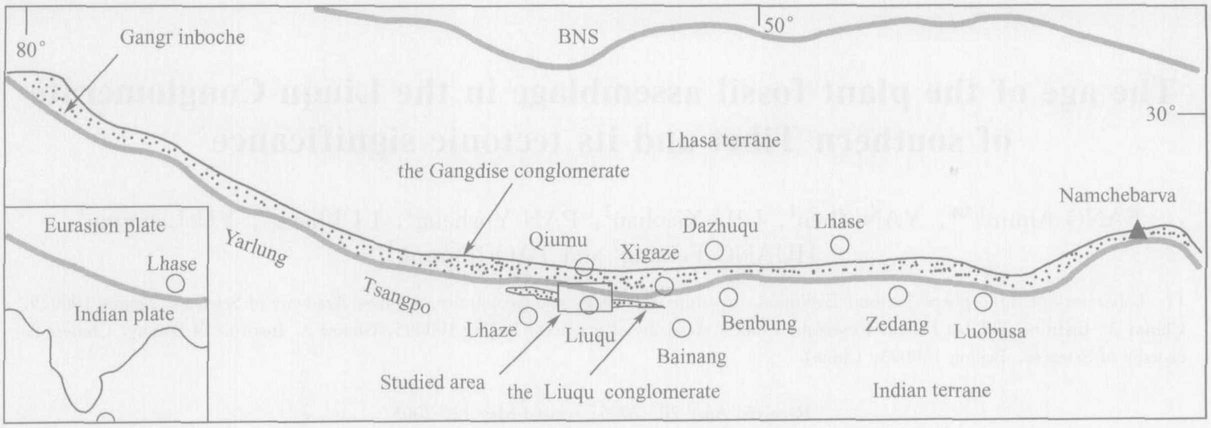

Fig. 1. Geological map showing the distribution of the conglomerates and the studied area.

1 Geological backgrounds of the studied area

The Liuqu Conglomerate is distributed discontinuously along the YTSZ, extending for about 150 km from west to east. It unconformably overlies the ophiolite to the north and the Triassic to Cretaceous sedimentary sequences of the Indian passive continental margin to the south, respectively. Lithologically, it is mainly composed of a set of striking purple red conglomerates of multi-sourced components, which are supposed to be originated from both the passive continental margin of the Indian plate and the ophiolite suit in the YTSZ. Yin1) first named it the "Liuqu Conglomerate" after the small village of Liuqu in Lhazi county in 1979 since the outcrops there are the best, but he did not describe it in detail at that time. During the 1980s, Yin et al. renamed it the "Liuqu Formation"[2] on the basis of systematic study on its lithologies and stratigraphic sequences, and they considered it to be the "outer molasse belt" of the YTSZ, which constitutes the conspicuous "paired molasse belts" distributed on both sides of the suture zone with the "inner molasse belt" of the Gangdese conglomerates. Since then, this molasse has become a research focus.

So far, the components of the conglomerates inside the molasse suit and their tectonic backgrounds, the sedimentary environments and ages of the molasses have been studied to different degrees[2—11], and some agreements on its sedimentary environments have been obtained. However, there are quite different opinions on its formation ages and correlations with other similar strata distributed in southern Tibet.

As early as 1968, Yin and Chan found some plant fossils in the red sandstones and conglomerates outcropped near Liuqu village during their first field investigation[2], which were identified as a Later Cretaceous flora by Guo[12]. In 1982, Yin and Liu found more plant fossils at three different sites from the upper parts of the Liuqu Conglomerates[2]. They also collected a lot of plant fossils which were identified later by Tao as an assemblage of Middle to Later Eocene flora[13]. Compared with the plant fossil assemblages found in the nearby Qiuwu and Mentu Formation and the middle Miocene Wulong Formation outcropped in Xigaze region, Yin et al.[2] considered that the age of the plant fossil assemblage in the Liuqu Conglomerates represented an earlier limit age of the molasses suit, while the younger limit one might extend into Oligocene. In the 1990s, Einsele et al.[5] thought that the Liuqu Conglomerate was formed during the Oligocene to Miocene based on analysis on the sedimentary facies of the Xigaze fore-arc basin as well as the regional stratigraphic correlations[5]. Recently, by synthesizing the former geological data on the Liuqu Conglomerate, Davis et al.[9] analyzed the sedimentary contacts between the conglomerate and its overlying and underlying strata, and they concluded that the Liuqu Conglomerate was formed in the Palaeogene by collision of an early island arc which resulted from inner-oceanic subduction of the Tethyan with the Indian plate. In general, it is obvious that opinions on the ages of the Liuqu Conglomerate are in great disputes, which almost covers the total Paleogene epoch. As a result, it is impossible to provide a valuable constrain on the younger limit time for the collision of the two plates of Indian and Eurasion.

1) Yin J.X. Guidance for Scientific Travel in South Tibet (in Chinese), part 2, 1980.

Therefore, the plant fossils should be studied in detail to provide some more accurate biostratigraphic evidence in determining its age and thereafter to constrain the collision time.

2 Sedimentary sequence of the Liuqu Conglomerate and the plant fossil outcrops

Strongly affected by the post-collisional tectonic movements in this region, both the ophiolite and the Mesozoic sedimentary sequences of the Indian passive margin have obducted over the Liuqu Conglomerate through steep-angled thrust belts in its north and south edges, respectively (Fig. 2). Furthermore, the ordinary successions of the Liuqu Conglomerate are interrupted by numerous folds and thrust faults, which brings a lot of difficulties in measuring its normal geological sections. On the basis of recovering its vertical sequences by getting rid of influences from the regional tectonic deformations, we divided the Liuqu Conglomerate into three parts according to their lithological assemblages and sedimentary characteristics:

Lower part: thick to mega-thick layered purple red coarse conglomerates intercalated with thin purple red mudstones and siltstones. Lithologically, the pebbles inside the conglomerates are mainly from chert and ultramafic rocks within the ophiolite suit and some flysch fragments. It unconformably overlies the ophiolite, and gradually changed upward into part two.

Middle part: purple, dark red coarse conglomerate intercalated with purple mudstones and siltstones. The pebbles inside the conglomerate are mainly from the Indian passive marginal sedimentary sequences, together with small parts of the chert and ultramafic rocks from the ophiolite.

Upper part: gray greenish and purple red conglomerates intercalated with mudstones and siltstones. With obvious cyclic characteristics, the pebbles inside the conglomerates are mainly from the Indian passive marginal sedimentary sequences, together with small parts of igneous rocks and fragments from the Yarlung Tsangpo ophiolite suit. It conformably overlies the strata of part two, and contacts with the Indian passive marginal sedimentary sequences by a thrust fault.

Vertically, the plant fossils are collected from the middle of the upper part of the Liuqu Conglomerate, which is about 150 m away to the south from the contact between the conglomerate and the Indian passive marginal sedimentary sequences. The spot where the plant fossils are found is located at about 4 km to the west of the village Liuqu, on a small hill near a bridge on the road from Xingjiang to Tibet (Fig. 2 (c)). All the plant fossils are picked up from thin mudstones that topped over thick coarse sandstones or pebbly sandstones, the sequences containing these plant fossils are subdivided as shown in Fig. 3.

3 The plant fossil assemblage in the Liuqu Conglomerate

Among all the samples collected in the field, we picked out about 30 blocks of them containing fairly well preserved plant fossils for further identification. The tectonic movements in this region are so strong that most compression fossils are destroyed, and therefore almost all the fossils we collected belong to impression ones. To enhance the reliability of the results from our identification and subdivision, we made the best use of the vein textures and shapes of the leaves preserved in our samples as major marks to compare with those in standard plant fossils identified in the references and the surrounding areas.

The majority of the plant fossils collected this time belong to leaf impressions, with a few fruit and seed impressions. By further identification, they belong to more than 14 species, which are subjected to 7 branches and 9 genus of the dicotyledon angiosperms. Compared with the plant assemblages first reported by Tao in 1988[13], the assemblages of the plant fossils found this time are quite different from each other[1)]. Although the amount of the plant fossils collected and its species identified are not enough to fully recover its paleo-flora, it also provides very important information to rebuild the paleobotanic evolutionary history in southern Tibet since most species of the plant fossils were extinct in this region and they are quite different from the present survived flora.

Specifically, the species that were identified this time include: *Platanus* cf. *comstoki*, *Platanus* sp., *Corylites megaphylla*, *Corylites* sp., *Populus gigantophylla*, *Ficus* sp., *Mallotus* sp., *Grewiopsis* sp., *Grewia* sp., *Cissites* sp., *Cornophyllum* cf.

1) Fang A. M., Yan Z., Liu X.H. et al. The flora of the Liuqu Formation in South Tibet and its climatic implications. Acta Palaeotologica Sinica (in Chinese), (In press).

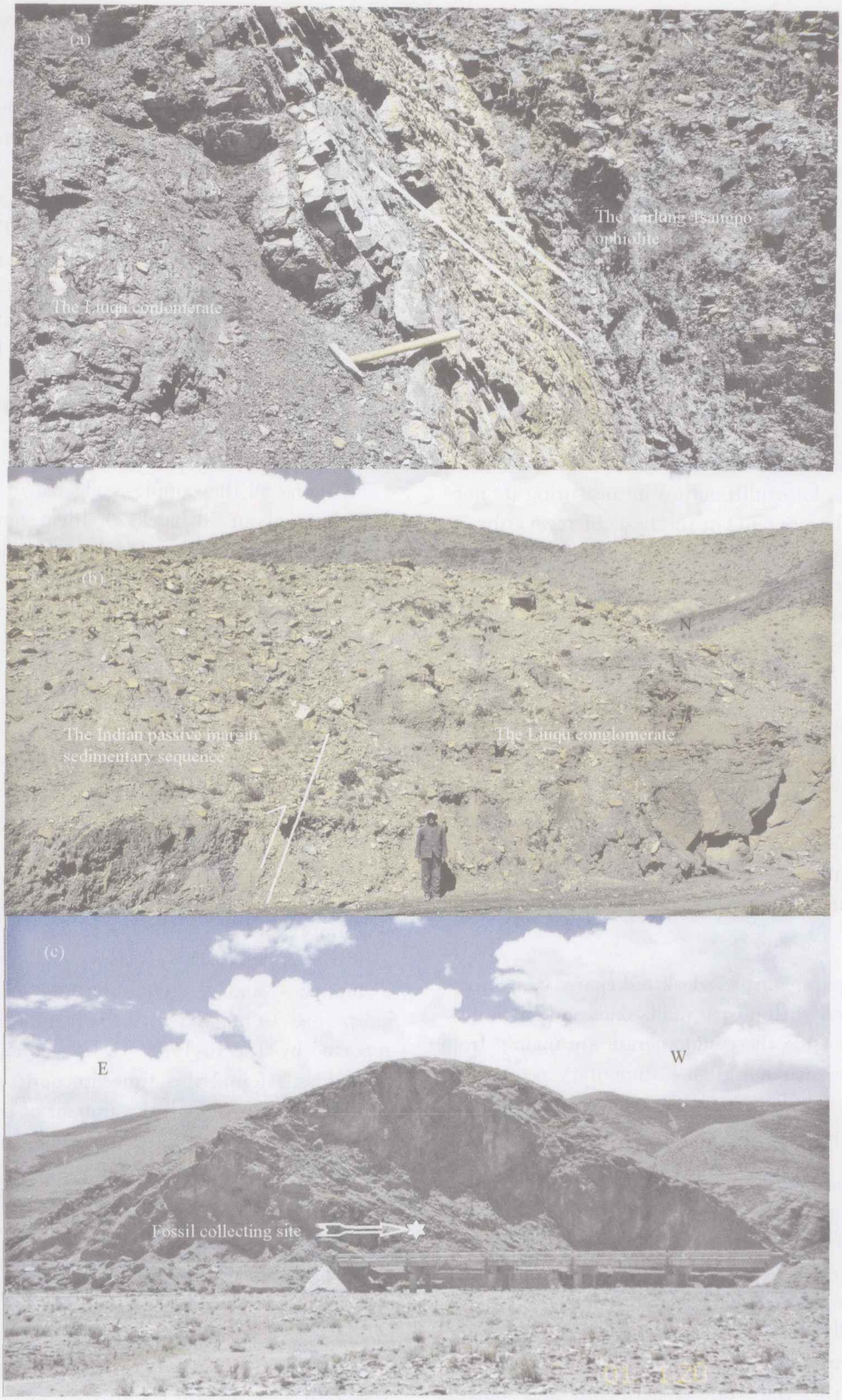

Fig. 2. Field pictures showing thrust contacts between the Liuqu Conglomerate and its surrounding terranes and the site where the plant fossils occurred. (a) Contact between the ophiolite and conglomerate; (b) contact between the conglomerate and the Indian passive marginal sedimentary sequences; (c) field section where plant fossils occurred.

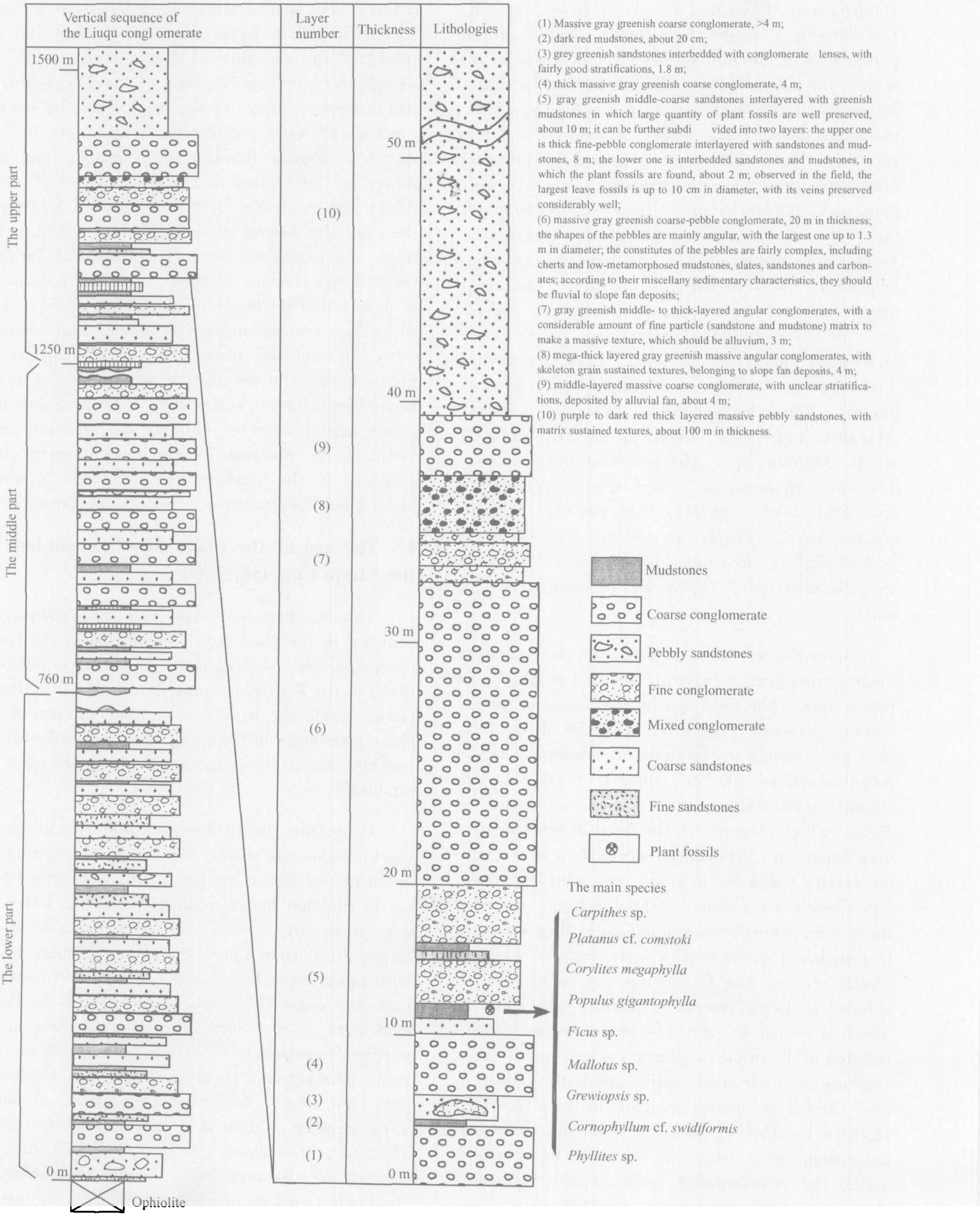

Fig. 3. Vertical sequences of the Liuqu Conglomerate and the plant fossils outcrops.

swidiformis, *Phyllites* sp. A, *Phyllites* sp. B, *Carpithes* sp.. Besides these species, Tao[13] also reported a lot of different species of plant fossils in the middle and upper parts of the Liuqu Conglomerate. In summary, the plant assemblages in the Liuqu Conglomerate include such species as follows: the fern species: Cyclosorus; the gymnosperm species: Ginkgoites; the angiosperm species: *Annona presanguinea*, *Caesalpinites* sp., *Cissites* sp., *Cornophyllum* cf. *swidiformis*, *Corylites megaphylla*, *Daphnogene polymorpha*, *Eucalyptophyllum obolongifolia*, *Eucalyptophyllum geinitzii*, *Eucalyptophyllum* sp. A, *Eucalyptophyllum* sp. B, *Evodia* sp., *Ficus protobenjamina*, *Ficus* sp. A, *Ficus* sp. B, *Grewia* sp., *Grewiopsis* sp., *Juglans sinustus*, *Lithocarpus angustus*, *Litseaphyllum presanguinea*, *Laurophyllum* sp., *Livistona tibetica*, *Magnolia inglefieldii*, *Magnolia* sp. A, *Magnolia* sp. B, *Mallotus* sp., *Melanorrhorea alaska*, *Milletia* sp., *Meliosma* sp., *Myrica* sp., *Nephelium* sp., *Platnus* cf. *comstoki*, *Platanus* sp., *Populus gigantophylla*, *Plafkeria rentonensis*, *Rhamnus preleptophylla*, *Rhamnus marginatus*, *Sapindus* sp., *Sabalites* sp., *Typha* sp., *Viburnum speciosum*.

According to the distribution of their survived modern corresponding species, we tried to rebuild the palaeo-flora of the fossil assemblages found in the Liuqu Conglomerate. The survived species of the *Mallotus* grow mainly in the tropic to subtropic zones of Asian nowadays, and in China, they are only distributed to the south of the Yangz River. As for the *Ficus*, which occurred in the fossil assemblage as a very important component, their modern corresponding species also grow in tropic and subtropic zones. The *Grewia* are mainly presented in tropic regions of the eastern hemisphere, and in China, they are mainly distributed in its southwestern region; while its similar species, the *Grewiopsis* are now only distributed in tropic regions of Africa. The *Cissites*, which is similar to modern *Cissus*, are widely distributed in the tropic to subtropic zones, and in China they mainly occur in its southwestern and Taiwan island. As for the species occurring in the assemblages reported by Tao[13], most of them also belong to components of a tropic to subtropic flora, among which the representative ones include *Magnolia*, *Annona*, *Lintseaphyllum*, *Laurophyllum*, and *Lithocarpus*. Furthermore, the *Nephelium* and *Sapindus* are also distributed in the tropic to subtropic zones. The species belonging to *Eucalyptophyllum* are distributed in tropic zones of America and the tropic to subtropic zones of Australia nowadays. Although the genetic subdivision of the *Eucalyptus* is still in dispute, they are also supposed to be components of a tropic and subtropic flora. As for the species in Palmae branch, the *Livistona* and *Sabalites* are distributed in the tropic zones of Asia, Africa and Australia, respectively. And in China, there are also several species of Palmae living in the tropic or seasonal rain forests in the areas of Taiwan, Guangdong, Hainan, southern Tibet and Yunnan. It is obvious that the paleoclimate and paleoflora reflected by these two assemblages are almost similar to each other. In summary, it can be concluded that most of the components in the plant fossil assemblages in the Liuqu Conglomerate belong to a tropic flora although a few may belong to subtropic or temperate ones (such as the *Platanus*), which are geographically subjected to the southern margin of the Northern Hemisphere supercontinent, but not the Gondwana.

4 The age of the plant fossil assemblage in the Liuqu Conglomerates

Totally, there are 39 species of the angiosperm identified in the plant fossil assemblage in the Liuqu Conglomerates. Most of these species have also been found in the Paleogene strata outcropped in different places around the world. Therefore, the age of the plant assemblage in the Liuqu Conglomerates can be roughly inferred by comparing it with other plant assemblages.

Comparing the plant fossil assemblage in the Liuqu Conglomerate with that occurred in the interlayers of Indian Deccan basalts[14], there are only 4 genera in common between them, while the latter belongs to an early Eocene flora and contains 29 species of the dicotyledon (include leaf and timber fossils) with more tropic flora components and without any temperate ones. However, compared with the Paleogene flora of the North America and Asia in the northern heimisphere[15,16], the ratios of the species' similarities between them increase more. For examples, the *Ficus*, *Mallotus*, *Magnolia*, *Annona*, *Litseaphyllum*, *Laurus*, *Sapindus*, *Corylites*, *Platanus*, *Grewiopsis*, *Cornophyllum* and *Sabalites*, etc. that occurred in the plant assemblages of the Liuqu Conglomerate are the common components of an early Tertiary flora in the northern heimisphere. Among them, the *Corylites* have occurred in the Paleogene Paskapoo Formation outcropped in western Atberta of North America and the later Paleocene to early Eocene Xianchen Formation outcropped in Linbao of Henan Province in China. The Grewiopsis has occurred in the late Cretaceous strata outcropped in Wyoming of Northern American, and it also occurred in the Paleogene Kamnatka Formation outcropped in Russian together with *Populus giantophylla*, *Cornophyllum*, etc. Furthermore, comparing the plant fossil assembalge in the Liuqu Conglomerate with those occurred in the Paleogene Qiuwu and Mentu formations that outcropped in the adjacent regions in southern Tibet, there are about 13 species of 10 genera in common among them although the latter two assemblages contain more species from the *Eucalyptophyllum* and have majority components with small leaves. Therefore, the ratios of similarities between these assemblages are much higher than those outcropped elsewhere, which demonstrates that they might be the contemporaneous flora with considerable degrees of affiliation. Furthermore, most components occurred in the Liuqu Conglomerate belong to a Paleogene flora in the Northern Hemisphere, and some of them belong to Createaceous and Paleocene. However, there are no species lived later than Paleogene in it. According to paleoclimatic studies, the global cooling tendency began in Oligocence, and the corresponding changes occurred in plant assemblages should also obey this tendency, i.e. there should be some comparatively cold components occurred in the Oligocene flora. However, no such plant fossils have been found in the Liuqu Conglomerate so far, which demonstrates that the age of this plant assemblages should be older than Oligocene. As a conclusion, we think that the plant assemblages occurred in the Liuqu Conglomerate should belong to Eocene, most probably the middle to late Eocene, which is identical to the results obtained by Tao[13].

5 Tectonic implications

5.1 Regional correlations of the inner and outer molasse belts and their tectonic situations

According to the regional tectonic skeleton of south Tibet (Fig. 1), a large scale of ophiolite zone (the Yarlung Tsangpo sututre zone), a maga-arc belt (the Gangdise — Ladaka volcanic arc), and a forearc basin between them (the Xigaze forearc basin) had been formed during the northward subduction of the Tethyan ocean ever since Jurassic. After that, the subsequent collision of the two plates of Indian and Eurasion not only resulted in the tectonic emplacement of the ophiolite, but also built the paired molasse belts on each side of the suture zone[2]. The inner one, located to the north of the suture zone, is discontinuously distributed along the southern foot of the Ladaka — Gangdese mountain chains, in which the famous Hindustan River molasse and the Gangdese Conglomerates are included; while the outer one, represented by the Liuqu Conglomerate, is located to the south of the suture zone, and extends from Renbung to Lhaze discontinuously. These two molasse belts are supposed to be formed during the uplifting process of the Hymalayan orogenic belt in a same tectonic background, and the existence of them not only provides concrete evidence for the collision of the two plates of Indian and Eurasion, but also offer us invaluable materials in disclosing the tectonic evolution after the collision of the two plates. However, the spatial distribution of the strata in these two molasse belts and their sedimentary environments and formation ages are different from each other since they are situated in different tectonic positions and have experienced different stages of evolution, which also resulted in the disputes in their stratigraphic correlations and subdivisions.

The inner molasse belt — the Gangdese Conglomerate: it was first put up by Heim and Gansser[17], who named the molasse deposits developed at the foot of the Kailas Mount the Gangdese Conglomerate (the Kailas Congl.). After that, Liu et al. renamed it the "Gangdese Group", [18] which refers to the Cretaceous — Oligocence molasse suits that were formed in the foreland depressions of the Gangdese Mountains during its uplifting process resulted from the formation and evolution of the volcanic arc. Generally, these molasses are composed mainly of terrestrial deposits with a certain number of marine interlayers in its lower part. Regionally, the "Gangdese Group" is discontinuously distributed along the Yarlung Tsangpo suture zone in southern Tibet, and it also extends into the Indoburman Ranges[19]. By comparison[2, 11], the Gangdese Conglomerate corresponds to such outcrops as the coal series of the Qiuwu and Giabulin formations, the Mala Conglomerates, the foraminiferous conglomerate occurred in the Cuojiangding geological section, and the mottle and red colored conglomerates that distributed in Dazhuqa and Luobusa to the east of the Kailas Mount. And to the west of the Mount Kailas, it corresponds to the Mentu formation outcropped in Arli region and the

Middle Eocene — Miocene Indus River molasses[20,21]. Totally, the inner molass belt narrowly extends from the east to the west for more than 1000 km, as a large scale of striking tectonic belt accompanied with the Yarlung Tsangpo suture zone marking the collision belt of the two plates of Indian and Eurasion. Tectonically, the Kailas conglomerate is situated to the north of the suture zone in the front belt of the obduction plate, and it disconformably overlies the Gangdese volcanic arc and the sedimentary sequences of the Yigaze forearc basin. Lithologically, it is a suit of molasse formed in the front region of the Gangdese Mountains with close genetic relationship to the Xigaze forearc basin sequences. And normally, it is rich in the granitic and igneous pebbles in its lower part, and the granitic, igneous, cherts and a few ophiolite pebbles in its middle to upper parts. As for the ages of the "Gangdese Group", the conglomerates outcropped in different regions have different ages[5,6,10,22—26], which demonstrates that the collision of the two plates and the uplifting of the Gangdese Mountain chain should happen spatially in a certain time order.

The outer molasse belt: as represented by the Liuqu Conglomerate, this molasse belt is located to the south of the Yarlung Tsangpo suture zone, with a total thickness of more than 1800 m. Spatially, the outer molasse belt is mainly distributed in the Xigaze region, extending from the east of Bainang county to the west of Sagui county. However, it may also extend east far into the Shannan region of southern Tibet, and even to the western Burma. And to the west, there are also some sporadic outcrops of conglomerates in Arli and Ladakh regions[2] that might belong to this belt. Among these outcrops, the conglomerate exposed around the small village Liuqu is the best one, which is up to 6 km in total width. The Liuqu Conglomerate is a set of thick purple red terrestrial molasse, which is distinguished from the conglomerates that make the inner molasse belt by its abundance in ophiolitic and chert pebbles but scarcity in the granitic pebble, which also demonstrates that the conglomerates in the two molasse belts are formed in different sedimentary basins with different sources.

Compared with the inner molasse belt, the outer one is not only on a much less scale, but also with a relatively simple constitutions. Tectonically, the Liuqu Conglomerate is situated to the south of the suture zone in the front of the subduction plate of Indian. It was formed in the oblique-slip basins in front of the Indian passive margin during the emplacement of the ophiolite, so its sources originally come from both of the Indian passive margin to the south and the ophiolite to the north.

5.2 The ages of the molasse belts and their constrains to the collision time of the two plates

Although most researchers agree that the collision of the Indian plate with Eurasion commenced in Cretaceous and ended in Paleogene[8], there are still great disputes on the exact time of the final contact between the two plates occurred at different regions along the YSSZ. For example, biostratigraphic evidences from the upper most marine strata formed before the collision and the lower most molasse formed after the collision show that this final contact might prolong into the Eocene[1,2,11]. Theoretically, as direct evidence, the sedimentary records of the upper most marine strata and the lower most molasses found within the suture zone can provide the most rigorous constrains on the time of the collision since this process should happen during the shift from marine to terrestrial sedimentary environments between the two plates, i.e. the collision should happen earlier than the formation of the lower most terrestrial molasses, while later than the upper most marine strata. Therefore, it is one of the most important approaches to find and date these special sedimentary units inside the suture zone.

The age of the upper most marine strata: the marine Upper Cretaceous — Paleogene strata are well developed in southern Tibet, and they are distributed mainly in the regions of Gamba and Tingri with fairly stable successions and lithologies. Among them, the marine strata outcropped in Gamba area are the most integrity, which can be subdivided from bottom to the top into the Gamba Group, Zongshan Formation, Jidula Formation, Zongpu Group and Zhepuno Formation, respectively. And the upper most marine stratum, the Zhepono Formation, was supposed to be deposited in Middle Eocene[27,28]. However, Qian et al.[29] thought the upper most marine strata in south Tibet was the Eocene conglomerates outcropped in the section of Cuojiangding, whose opinion was supported by Yin et al.[30] since they had found large quantity of the Eocene marine foraminifera faunas in it. Furthermore, in the section of Sandanlin near Sagui, Li[31] first reported a Later Eocene — Oligocene radiolarian faunas in the cherts of the section, which means that the upper most marine strata in southern Tibet should be much younger than what the previous researchers thought. However, Ding[32] doubted Li's result about the age of the marine strata in the Sangdanlin section because it is only based on the radiolarian fossils picked up from several thin-sections. He thought that the latest radiolarian faunas from the deep water deposits preserved in the Sangdanlin section was formed in Paleocene in the foreland basins that developed in front of the Indian passive margins, and thus he deduced that the collision between India and China along the middle part of the YSSZ should happen between the boundary of the Cretaceous and Paleocene. Nevertheless, recently we systematically analyzed the radiolarian faunas in the cherts from the Sandanlin section and found that the youngest ones belong to Middle Eocene (Fang et al., in prepare), which provides concrete evidence to show that the upper most marine strata in southern Tibet might be younger than Paleogene. Furthermore, we also found some Eocene foraminifera in the marine successions of the Gangdese conglomerate1), which is coincident with those found in the Cuojiangding section reported by Yin et al.[29] Therefore, according to the upper most marine strata in southern Tibet, the final collision between India and China should at least last into Eocene.

The age of the earliest terrestrial molasse: the occurrence of the terrestrial molasse within the YSSZ represents the closure of the Tetheyan ocean and the beginning of the continent to continent collision between China and India, so the ages of the oldest terrestrial molasse indicate the younger limit time of the collision. Therefore, the molasse outcropped along the two sides of the YSSZ provides very good constrains on this process.

As for the ages of the inner molasse belt, different researchers have quite different opinions. Zhang et al.[22] studied the foraminifera in the thin limestone interlayers within the conglomerates exposed in the southern pass of the Mount Mala, about 110 km northwest away from Zhongba, and considered it to be the Eocene strata; Liu et al.[18] also found a lot of Paleogene and Eocene foraminifera in the conglomerates outcropped in the Cuojiangding section near Zhongba, and thought its older limit as Early Eocene; Gen et al.[23] studied the plant fossils in the coal series of Qiuwu and Mentu formation, and considered them to be the Cretaceous — Eocene strata, while Qian et al.[10] thought that they are formed during the Late Paleocene — Oligocene; the Geological Bureau of the Tibet[26] considered that the Qiuwu and Giabulin formations are Eocene and Oligocene — Miocene, respectively. However, Wu[25] thought these two formations were formed in Late Cretaceous on the basis of the radiolarian faunas inside them, which is almost coincident with the results of Liu et al.[24]. Einsele et al.[5] studied the sequence of the Xigaze basin and thought that the Qiuwu Formation was formed during the Eocene to Oligocene; Wang et al.[7] considered that the Qiuwu Formation was formed in Eocene. Recently, Aitchison et al.[11] synthesized the different conglomerate units that can be correlated with the "Gangrinboche conglomerates", and thought that they were formed during the Oligocene to Miocene. According to the above data, although the ages of the conglomerate units preserved in the inner molassees belt cover a fairly long time span, most of them are concentrated in Eocene, reflecting that the time for the peak of the collision between India and China should happen at this period.

As for the ages of the conglomerate units preserved in the outer molasse belt, there are also quite different opinions as mentioned above. However, those constrained by the plant fossil assemblages are concentrated mainly in the Middle to Late Eocene[13]. The age obtained from the plant assemblages proposed in this paper can confirm this conclusion. Combined with analysis on the ages of the upper most marine strata outcropped in southern Tibet, we think that the closure of the Tethyan ocean in this area should happen in Middle Eocene.

Acknowledgements The authors would like to thank Prof. Wang Kaiyi, Mark Quigley, Liu Qin and Cao Jing for their help in the field works, and thank Prof. Ding Lin for his useful suggestions.

References

1 Rowley D. B. Age of initiation of collision between India and Asia: A review of stratigraphic data. Earth and Planetary Science Letters, 1996, 145: 251—270.

2 Yin J., Sun X., Sun Y. et al. Stratigraphy on the molasses-type sediments of the paired molasses belts in the Xigaze region, South Xizang. In: Monograph of Institute of Geology, Chinese Academy of Sciences (in Chinese) (No.3). Beijing: Science Press, 1988, 158—176.

1) Yan Z., Fang A. M. and Pan Y. S. Sedimentary environment of the Dajin conglomerate in Tibet, age of foraminiferan assemblages and their tectonic significance. Progress in Natural Science (in press).

3 Pal D., Srivatstava R. A. K. and Mathur N. S. Tectonic framework of the miogeosynclina sedimentation in Ladakh Himalaya: a critical analysis. Himalayan Geology, 1978, 8(1): 500—522.

4 Wang L. C. and Wang D. A. The division of the sedimentary facies of the subside belt of Yalunzambu river - Xiangquanhe and its deposit model. In: The Sedimentary Rocks in South Tibet (in Chinese). Beijing: Science Press, 1981, 1—51.

5 Einsele G., Liu B., Dürr S. et al. The Xigaze froearc basin: evolution and facies architecture (Cretaceous, Tibet). Sedimentary Geology, 1994, 90: 1—32.

6 Wang C. and Liu Z. Xigaze Forearc Basin and Yaluzangbu Suture in the Tibet (in Chinese), 1st ed. Beijing: Geological Publishing House, 1999, 1—237.

7 Wang C. S., Liu Z. and Hebert R. The Yarlung-Zangbo paleo-ophiolite, southern Tibet: implications for dynamic evolution of the Yarlung-Zangbo Suture Zone. Journal of Asian Earth Sciences, 2000, 18: 651—661.

8 Yin A., Harrsion T. M., Murphy M. A. et al. Tertiary deformation history of southeastern and southwestern Tibet during the Indo-Asian collision. Geological Society of America Bulletin, 1999, 111: 1644—1664.

9 Davis A. M., Aitchison J. C., Zhu B. D. et al. Paleogene island arc collision-related conglomerates, Yarlung Tsangpo suture zone, Tibet. Sedimentary Geology, 2002, 150: 247—273.

10 Qian D. Y. The ages of the coal series Qiuwu Formation and the Molasses outcropped along the mountain chain from Ladakal to Gandese. Monograph of the Geology of the Tibet Plateau (in Chinese), 1985, 16: 229—241.

11 Aitchison J. C., Davis A. M., Zhu B. D. et al. New constraints on the India-Asia collision: the Lower Miocene Gangrenboche conglomerates, Yarlung Tsangpo suture zone, SE Tibet. Journal of Asian Earth Sciences, 2002, 21: 251—263.

12 Guo S. X. The plant fossils in the Xigaze Group of the Mount Qomolangma region. In: Scientific Survey Report in Mount Qomolangma Region (1966—1968), Paleontology (in Chinese) (No. 1). Beijing: Science Press, 1975, 411—423.

13 Tao J. R. Plant fossils from Lepuqu Formation in Lhaze County, Xizang and their paleoclimatological significances. In: Monograph of Institute of Geology, Chinese Academy of Sciences (in Chinese) (No.3). Beijing: Science Press, 1988, 223—238.

14 Lakhanpal R. N. Tertiary floras of India and their bearing on the historical geology of the region. Taxon, 1970, 19(5): 657—694.

15 Wolfe J. A. Paleogene Floras from the gulf of Alaska region. U.S. Geol. Surv. Prof., 1977, 1: 1—30.

16 Manchester S. R. Leaves and fruits of Davidia (Cornales) from the Paleocene of North America. Systematic Bot., 2002, 17(2): 368—382.

17 Heim A. and Gansser A. Central Himalaya-Geological observations of Swiss expedition in 1936. Societe Helvetique Science Naturelle Memoire, 1939, 73: 1—245.

18 Liu C., Yin J., Sun X. et al. Late Cretaceous-Early Tertiary marine sequences-the non-flysch deposits of the Xigaze forearc basin in South Xizang. In: Monograph of Institute of Geology, Chinese Academy of Sciences (in Chinese) (No.3). Beijing: Science Press, 1988, 130—157.

19 Brunnschweiler R. O. On the geology of the Indoburman Ranges (Arakan coast and Yoma, Chin hill, Naga hill). J. Geol. Soc. Aust., 1966, 13: 137—194.

20 Searle M. P. Stratigraphy, structure and evolution of the Tibetan-Tethys zone in Zanskar and the Indus suture zone in the Ladakh Himalaya. Trans. R. Soc. Edinb. Earth Sci., 1983, 73: 205—219.

21 Frank W., Gansser A. and Trommsdorff V. Geological observations in the Ladakh area (Himalayas) - A preliminary report. Schweiz. Mineral. Petrogr. Mitt., 1977, 57: 89—113.

22 Zhang B. and Mu X. Discovering of the marine Tertiary in the north of the Yarlung Zangbu (Xizang). Acta Stratigraphica Sinica (in Chinese), 1979, 3: 65—66.

23 Gen G. C. and Tao J. R. The Tertiary paleobotany of Tibet. Monograph on the Tibetan Geology (in Chinese), 1982, 3: 212—223.

24 Liu Z. F., Wang C. S. and Li X. H. Stratigraphic research on Giabulin Formation in the Xigaze region, Xizang (Tibet). Journal of Chengdu Institute of Technology, 1996, 23(2): 56—63.

25 Wu, H. R. Northern region of Tethys-Himalayas. In: Chinese Academic Institute (Compilers), Stratigraphy in Xizang (Tibetan) Plateau (in Chinese). Beijing: Science Press, 1984, 115—119.

26 Bureau of Geology and Mineral Resources of Xizang Autonomous Region. Regional Geology of Xizang (Tibet) Autonomous Region (in Chinese). Beijing: Geological Publishing House, 1993, 1—303.

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

28 Wen S. X. The strata (Cretaceous, Tertiary) of the Mount Qomolangma region. In: Scientific Survey Report in Mount Qomolangma Region (1966—1968), Geology (in Chinese). Beijing: Science Press, 1974, 148—183.

29 Qian D. Y., Gu Q. G. and Zhang B. G. New data on the age of the Anren Formation in the Xigaze group of Tibet. Geo. Sinic. (in Chinese), 1982, 3(4): 329—331.

30 Yin J. X., Sun X. and Wen C. F. Xigaze group- the flysch successions of the Xigaze forearc basin in south Xizang. In: Monograph of Institute of Geology, Chinese Academy of Sciences (in Chinese) (No.3). Beijing: Science Press, 1988b, 96—118.

31 Li H. Discovery of Paleogene radiolarite in South Tibet: A late report of discovery. In: Proceedings of the Third National Stratigraphical Conference of China (in Chinese). Beijing: Geological Publishing House, 2000, 354—358.

32 Ding L. Paleocene deep-water sediments and radiolarian faunas: Implications for evolution of Yarlung- Zangbo foreland basin, southern Tibet. Science in China (Series D), 2003, 46(1): 84—96.