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Discovery and significance of Cretaceous fossils from the Xigaze Forearc Basin, Tibet

Wan Xiaoqiao*, Wang Luo*, Wang Chengshan† and Luba Jansa‡
*China University of Geosciences, Beijing 100083, China, (e-mail: wanxiaoqiao@sky.cugb.edu.cn), †Chengdu Institute of Technology, Chengdu 610059, China and ‡Department of Geology, Dalhousie University, Halifax, N.S., Canada

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Abstract—The Xigaze Cretaceous forearc basin located between the Lhasa Block and Indus-Yarlung Suture was filled with flysch deposits during the mid-Cretaceous, as the Tethys oceanic crust was being subducted underneath Eurasia. The flysch comprises the Xigaze Group, dominated by the Angren Formation. Well preserved, newly discovered foraminifera within the Angren Formation constrain its age to late Albian to late Coniacian. Radiometric dating of the ophiolite belt impinging on the southern edge of the forearc basin yielded an age of 120 + 10 Ma, which implies that the deposition in the forearc basin occurred shortly after initiation of the subduction of the Neotethys.

Introduction

The Xigaze forearc basin formed at the southern active continental margin of the Lhasa Block. The basin stretches parallel to the Indus-Yarlung Suture Zone over an area of 550 km long and 20 km wide. To the north of the suture, the basin fill is represented by flysch deposits of the Xigaze Group. At the northern rim of the basin the Xigaze Group is in contact with Tertiary conglomerates and sandstones which overlie batholiths of the Gangdise Belt (Einsele *et al.* 1994). The southern edge of the basin is in tectonic contact with the Indus-Yarlung ophiolites.

The clastic sediments, evolution and facies architecture of the Xigaze forearc basin were studied in detail by Einsele *et al.* (1993; 1994) and Dürr (1996). As result of low metamorphic imprint and lack of fossils in the predominantly terrigenous strata the age of Xigaze group has been poorly known and suggested to range from early Albian to middle Cenomanian (Dürr 1996).

The present authors conducted detailed field study in the Xigaze area (Fig. 1) during 1992 and 1994, when samples for microfossil studies were collected. During recent study, the samples were found to contain well preserved foraminifera dominated by planktonic species, which constrain the age of the forearc sedimentary fill.

Hsu *et al.* (1995) proposed an alternative theory for the tectonic origin of the Zhanbo basin and of the ophiolites which they consider to be remnants of a collapsed back arc basin. Thus, new biostratigraphic data for the Xigaze Group are of increased importance for resolving the tectonic affinity of the Zhanbo basin.

Stratigraphy of the Xigaze forearc basin

The Cretaceous sediments of the Xigaze forearc basin are represented by the Xigaze Group (Wen Shixuan, 1974; Wu Haoruo *et al.*, 1977). This group was further subdivided into the Shangzugang and Angren Formations by Wang Shien (1988). The basal Shangzugang Formation outcrops discontinuously along the northern rim of the basin. It is formed by shelf carbonates, rich in larger foraminifera, corals and bivalves, indicating that the outer shelf was a shallow-water carbonate platform. The thickness of these beds is variable in different outcrops.

In the Xigaze region the Angren Formation represents the major sedimentary fill of the forearc basin. It comprises of thick flysch deposits dominated by conglomerates, volcaniclastic sediments, shales and siltstones with minor hemipelagic, carbonate-rich intercalations. Within the Angren Formation, Dürr (1996) recognized three fining upwards supercycles. Deep-cut channels at the base of these supercycles are infilled by coarse pebbly conglomerates with boulders up to $\frac{1}{2}$ m in size. The pebbles are predominantly andesites, with minor tonalites and granodiorites. Limestone pebbles are common (Dürr 1996). Cross-bedding within turbidites indicate southward transport. Lithofacies characteristics and sediment composition are suggestive of an upper–middle continental slope depositional environment.

At the southern edge of the basin margin the lowermost beds have been placed in the Chongdui Formation by Wu Haoruo (1984). They are comprised by pelitic, siliceous and silty rocks with minor sandstone and conglomerates. Radiolaria are frequent in the siliceous rocks, and planktonic foraminifera occur in a thin bedded limestone intercalation within the upper part of the formation. The Chondui Formation only outcrops discontinuously between the forearc basin and the Indus-Yarlung ophiolite belt. In the Xialu Valley the reddish, bedded early Cretaceous radiolarites are conformably overlain by a sequence of black shales intercalated with greenish grey siltstone

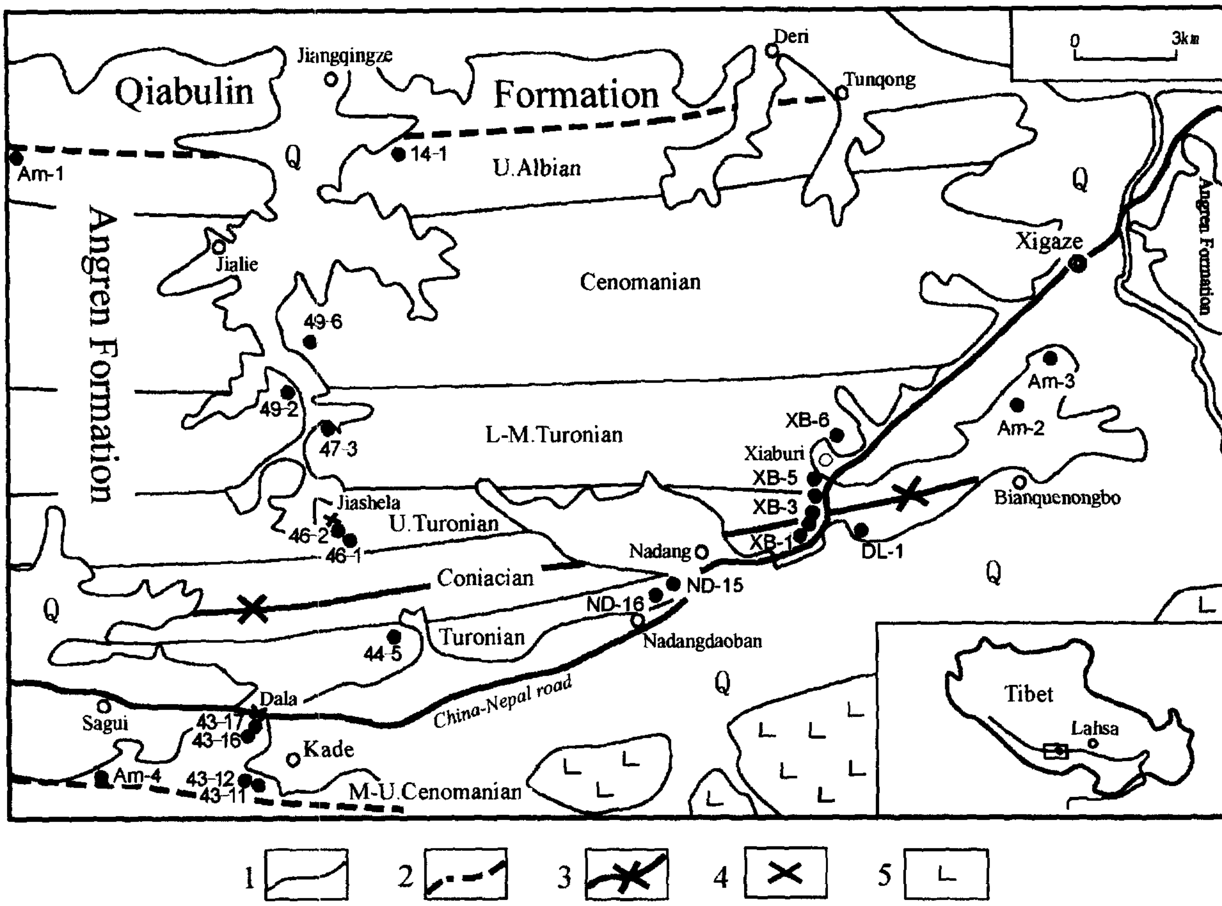

Fig. 1. Sketch map showing the fossil localities and stratigraphic boundaries. 1, Stratigraphic boundary; 2, fault; 3, axis of syclinorium; 4, pass; 5, lava.

turbidites, representing the toe of the forearc sedimentary prism.

Biostratigraphic study indicate that the Xigaze Group encompasses all three of the above mentioned formations. Both the southern and northern rims of the Xigaze group contain broadly synchronous sedimentary deposits, even though they are represented by different lithofacies (Fig. 2) and support Einsele *et al.*'s (1994) tectonic interpretation of the area as partially eroded large synclinorium.

Radiometric dating of the ophiolites in the Yarlung-Zhanbo ophiolite belt located at the southern edge of the forearc basin provided an age of 120 ± 10 Ma (Gopel *et al.* 1984). Intercalated ash layers and tuffites in the forearc sediments yielded and age of ca.110 m.y. (Schärer *et al.*, 1994; Coulon *et al.* 1986). The development of the forearc basin thus constrains the onset of subduction of the Neotethys to early Albian. Our study of the sedimentary facies and tectonostratigraphic development of the Xigaze Group leads us to a view that it corresponds closer to the Andean type subduction, as represented by the central Peru forearc, than to a backarc as suggested by Hsu *et al.* (1995). Considering the relatively small accretionary prism, most of the sediments from the oceanic plate and the trench had to be subducted beneath, rather than accreted to the continental margin.

The foraminifera in the Angren formation

The newly discovered microfossils, mainly foraminifera were found mostly in light colored hemipelagic marls and shales intercalated within the Angren Formation. Nineteen foraminiferal species of 13 genera were recognized, including 14 species of 6 genera of planktonic foraminifera. Fossil localities are shown in Fig.1, and sections with samples studied are summarized below.

Section from Kade to Jiangqingze

43-11: Light grey shale, yielding foraminifera *Globigerinelloides ultramicra* (Subbotina), *Hedbergella delrioensis* (Carsey), *H. planispira* (Tappan), *Rotalipora cushmani* (Morrow), *Anomalina* sp., *Lenticulina* sp.

43-12: Greyish yellow silty shale, with a few *Dorothia* sp.

43-16: Light grey nodular limestone and marl yielding *Hedbergella* sp.

43-17: Light grey nodular limestone and marl yielding *Anomalina* sp.

44-5: Greyish yellow marl with abundant planktonic foraminifera dominated by *Globigerinelloides ultramicra* (Subbotina), *Hedbergella delrioensis* (Carsey), *H. holmdelensis* Olsson, *Whiteinella baltica* (Douglas &

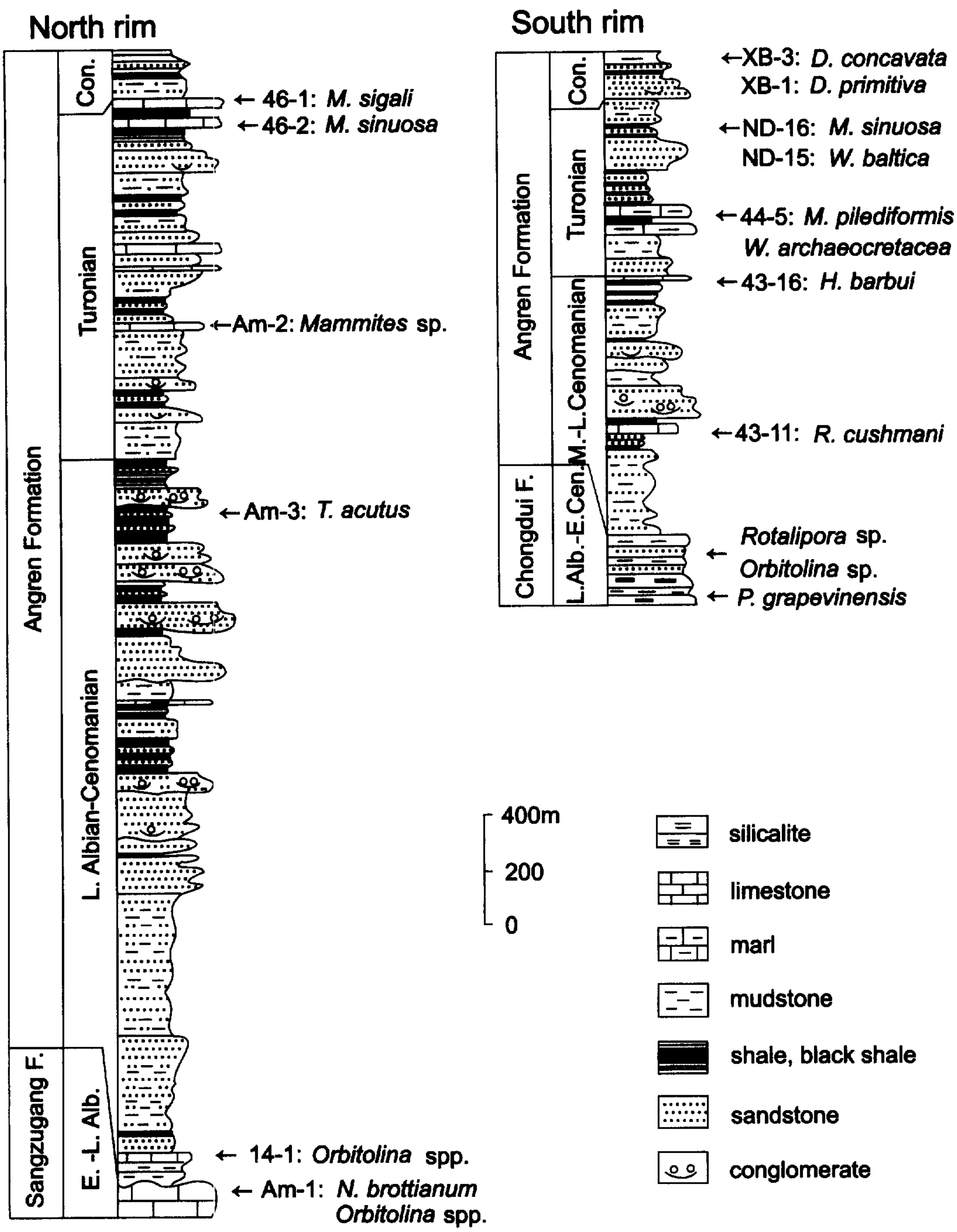

Fig. 2. Subdivision and biostratigraphy of the Xigaze forearc basin deposits.

Rankin), *W. archaeocretacea* (Pessagno), *Dicarinella* sp., *Marginotruncana sigali* (Reichel), *M. renzi* (Gandolfi), *M. pilediformis* Lamolda, *Heterohelix reussi* (Cushman).

46-1: Light grey marl intercalation in black shale yielding few specimens of *Marginotruncana sigali* (Reichel), *Anomalina* sp.

46-2: Thin bedded marl intercalation in dark grey limestone, with *Marginotruncana sigali* (Reichel), *M. sinuosa* Porthault.

43-7: Greyish yellow marl containing abundant planktonic foraminifera dominated by *Globigerinelloides ultramicra* (Subbotina), *Hedbergella delrioensis* (Carsey), *Whiteinella archaeocretacea* Pessagno, *W. baltica* Douglas & Rankin, *W.* sp. *Marginotruncana sigali* (Reichel), *M. schneegansi* (Sigal), *M. pilediformis* Lamolda, *Heterohelix reussi* (Cushman).

49-2: Greyish yellow silty shale, yielding few benthonic foraminifera tests of *Valvulineria* sp., *Textularia* sp.

49-6: Greyish yellow siltstone yielding few benthic foraminifera *Valvulineria* sp., *Textularia* sp.

14-1: Greyish green shale intercalated with bioclastic packstone, with abundant benthic faunas as bivalves, corals, crinoids and foraminifera. Foraminifera are dominated by *Orbitolina* spp., *Textularia* sp., corals are *Montlivaltia* sp. and *Epistreptophylum* sp.

Section from Nadang to Deri

ND15: Greyish yellow marl, rich in foraminifera: *Whiteinella archaeocretacea* Pessagno, *W. baltica* Douglas & Rankin, *Marginotruncana sigali* (Reichel).

ND16: Greyish yellow marl contain a few foraminifera such as *Marginotruncana sinuosa* Porthault.

Section south from Xiaburi

DL-1: Greyish yellow calcareous mudstone, yielding a few specimens of *Hedbergella delrioensis* (Carsey).

XB-1: Yellowish grey marl yielding many planktonic foraminifera: *Dicarinella primitiva* (Dalbiez), *Marginotruncana sigali* (Reichel), *Lenticulina* sp.

XB-2: Yellowish marl intercalated in black shale with few specimens of *Lenticulina* sp.

XB-3: Yellowish grey marl yielding abundant foraminifera: *Whiteinella archaeocretacea* Pessagno, *W. baltica* Douglas & Rankin, *Dicarinella primitiva* (Dalbiez), *D. concavata* (Brotzen), *Marginotruncana sigali* (Reichel), *M. schneegansi* (Sigal), *Heterohelix reussi* (Cushman).

XB-4: greenish shale containing rich foraminiferal microfauna such as *Hedbergella delrioensis* (Carsey), *Marginotruncana sigali* (Reichel), *M. schneegansi* (Sigal), *Heterohelix reussi* (Cushman).

XB-5: greenish shale containing few tests of *Marginotruncana* sp.

XB-6: greenish grey shale with a few specimens of *Lenticulina* sp.

Other fossils rarely found in the Angren Formation are ammonites and radiolarians. An ammonite identified as *Mammites* sp. by Wen Shixuan (1974) was found south of city Xigaze (Fig.1, Am-2). An ammonite belonging to Brancoceratidae was reported by Xiao Xuchang (1984) from south of Sagui (Fig.1, Am-4). Wiedmann and Dürr (1995) described from the Angren Formation the ammonite *Mortoniceras* (*M.*) *pricei intermedium* Spath, which was found 30 Km east of the city Xigaze; and *Turrilites* (*T.*) *acutus* Passy at 3.5 km south of the city (Fig.1, Am-3). Furthermore, they identified the ammonite *Neophlycticeras* (*N.*) *brottianum* (D'Orbigny) from a pebble in the conglomerate derived from the Shangzugang Formation, about 20 km west of the city Xigaze (Fig.1, Am-1). Radiolaria were described from pelagic limestones of the same stratigraphic horizon as the sample 43-16. The radiolaria are represented by *Holocryptcantium barbui* Dumitrica, *Gongylothorax siphonofer* Dumitrica, *Archaeodictyomitra* sp., *Pseudodictyomitra pachicostata* Pessagno, *Cenellipsis botryoides* Rust, *Acaeniotyle diaphorogona* Foreman and *Patulibrachium* sp. (Yin Jixiang *et al.*, 1988).

Biostratigraphy of the Angren formation

Previous biostratigraphic studies by Bassoullet *et al.* (1984) reported foraminiferal assemblage of an Albian to Turonian age from the Xigaze Group, southwest of the city Xigaze. Other authors, such as Wang Shien (1988), Yin Jixiang *et al.* (1988), referred the Angren Formation to late Early Cretaceous–Late Cretaceous age. Wiedmann and Dürr (1995), from studies of three ammonites from the Xigaze Group, suggested early late Albian to middle Cenomanian age for the sedimentary strata. The foraminiferal assemblages here described are evenly distributed through the Angren Formation and therefore they provide better biostratigraphic control.

The oldest fossil assemblage in the Angren Formation is represented by sample 14-1. The corals are of Middle Jurassic to Cretaceous age and the larger foraminifera *Orbitolina* spp. is of Aptian–Albian age in this region. The ammonite *Neophlycticeras* (*N.*) *brottianum* which belongs to the *Mortoniceras inflatum* Zone (Wiedmann and Dürr 1995) occurs underneath the sample 14-1 and is considered to be of an early late Albian age. Accordingly, the sample 14-1 is younger than early late Albian and its age is constrained by the occurrence of orbitolinids to the late Albian. Therefore, the earliest deposits of the Angren Formation is of late Albian age. The sample 43-11 from the southern rim of the basin contains a rich foraminiferal assemblage which includes *Rotalipora cushmani*, considered to be an index fossil for Middle to Upper Cenomanian (Caron 1985). This implies that the oldest age of the Angren Formation outcropping at the southern basin rim is middle Cenomanian.

Samples 43-16 and 43-17 yield a few foraminifera and many radiolaria of early late Cretaceous age (Yin Jixiang *et al.*, 1988). From the stratigraphic position of beds we suggest that they are of late Cenomanian age. Sample 44-5 yielded an abundant foraminiferal fauna. Among them, *Whiteinella archaeocretacea* mostly occurs in Turonian; *Marginotruncana renzi* in the middle Turonian to Coniacian; *Marginotruncana pilediformis* in the middle Turonian (Lamolda 1977), which brackets the age of the sample as middle Turonian.

Sample 47-3 is similar to sample 44-5 in both lithology and fossil assemblage. Both probably belong to the same layer comprising rims of the synclinorium (Einsele *et al.* 1994) and is of a middle Turonian age.

Strata become younger towards the axis of the synclinorium as determined by the sample 46-2, where the first occurrence of *Marginotruncana sinuosa* indicates late Turonian age. No Coniacian fossils have been found here.

Toward the east, the youngest strata of the Angren Formation crop out near Xiaburi. Sample XB-1 contains many foraminifera, in which *Dicarinella primitiva* is a zonal fossil of the early Coniacian. This zonal indicator suggests an early Coniacian age for the sample XB-1. Sample XB-3 contains the foraminifera *Dicarinella concavata*, which is a zonal fossil for the late Coniacian (Caron 1985). The fossil assemblages in the samples XB-4 and XB-5 are similar to sample 47-3, and are of middle Turonian age. Ammonite *Mammites* sp. (Am-2) also occurs within this middle Turonian layer. Northward, *Turrilites* (*T.*) *acutus* (AM-3) of middle Cenomanian age was found by Wiedmann and Dürr, (1995) as a reworked specimen in a pebble of conglomerate. It documents continuous carbonate deposition at the northern outer shelf to the late Cenomanian, or early Turonian. Thus we conclude that the sample XB-3 dates the youngest bed of the Angren Formation to be of late Coniacian age.

Fossils found in the Angren Formation indicate that it was deposited during the late Albian to late Coniacian time.

The new foraminiferal data allow us to suggest the following biostratigraphic zonation for the Angren Formation: late Albian *Orbitolina* assemblage; middle–

Fig. 3. SEM photomicrographs of Cretaceous foraminifera from Xigaze, Tibet. All specimens are deposited in the China University of Geosciences (Beijing). (1) *Hedbergella delrioensis* (Carsey) dorsal side; Sample ND15. ×160. (2) *Hedbergella planispira* (Tappan) 2a. dorsal side; 2b. ventral side. sample 4311. ×160. (3) *Hedbergella holmdelensis* Olsson 3a. dorsal side; 3b. ventral side. sample4311, ×160. (4) *Whiteinella inornata* (Bolli) 4a. dorsal side; 4b ventral side. Sample ND3 × 80. (5) *Whiteinella archaeocretacea* Pessagno 5a. dorsal side; 5b. ventral side. Sample 445. ×80. (6) *Whiteinella baltica* Douglas & Rankin 6a. dorsal side; 6b. ventral side. Sample 445 × 80. (7) *Dicarinella concavata* (Brotzen) 7a. dorsal side; 7b. ventral side. Sample XB3 × 80. (8) *Dicarinella primitiva* (Dalbiez) 8a. dorsal side; 8b. ventral side. Sample XB1 × 80. (9) *Marginotruncana sigali* (Reichel) 9a. dorsal side; 9b. ventral side. Sample XB3 × 80. (10) *Marginotruncana pilediformis* Lamolda 10a. dorsal side; 10b.ventral side. Sample XB3 × 80. (11) *Marginotruncana sinuosa* Porthault 11a. dorsal side; 11b.ventral side. Sample XB3 × 80. (12) *Marginotruncana renzi* (Gandolfi) 12a. dorsal side; 12b.ventral side. Sample445 × 80. (13) *Marginotruncana schneegansi* (Sigal) 13a. dorsal side 13b. ventral side. Sample462 × 80. (14) *Heterohelix reussi* (Cushman) Sample XB3;. ×80. (15) *Heterohelix moremani* (Cushman) Sample 445;. ×80. (16) *Lenticulina* sp. Sample XB6; ×80.

late Cenomanian *R. cushmani–H. barbui* assemblage; Turonian *Mammites* assemblage; middle Turonian *M. pilediformis–W. archaeocretacea* assemblage; late Turonian *M. sinuosa–M. sigali* assemblage; early Coniacian *D. primitiva* assemblage; and late Coniacian *D. concavata* assemblage.

Discussion

The newly described microfossils document that the faunas from both rims of the Xigaze forearc basin is broadly time correlative. This supports interpretation of the tectonic structure of the studied area as a large synclinorium (Yin Jixiang *et al.*, 1988; Dürr 1996; Einsele *et al.* 1994). The sediments of the forearc basin are older at both the northern and southern rim of the synclinorium, and become progressively younger toward the synclinorium axis. Geographically, the synclinorium axis crosses south of the Jiashela Pass, and continues eastward to the south of Xiaburi (Fig.1).

The youngest strata found occur at the locality XB-3. The southern edge of the Angren Formation is in fault contact with the Indus–Yarlung ophiolite belt, where remnants of the underlying Chongdui Formation are scattered along the fault. At the Xialu valley Early Cretaceous radiolarites are conformably overlain by thin-bedded clastics and turbidites of the Chongdui Formation. The Chongdui Formation represents distal foreslope deposits of late Albian to early Cenomanian age which overlie deep sea radiolarites. It thus signifies that during late Albian, the oceanic deposits below the CCD were in contact with, and thus proximal to, a continental margin situated to the north. The Angren Formation overlies the Chongdui Formation conformably.

The flysch deposits in the northern part of the basin are considerably thicker than those of the southern rim, and were deposited mainly on a forearc slope. The age of the Angren Formation along the north rim of the basin is late Albian to late Coniacian (Fig. 3).

In the Sangsang region, west from the Angren town (Liu Chengjie *et al.*, 1988), the Angren Formation is conformably overlain by shallow marine deposits of the Padana Formation. Therefore, the stratigraphic position of the Padana Formation indicates a possibly Santonian age for the formation. If that is the case, than it would indicate that the forearc basin at this time either had been more or less filled by flysch deposits, or was tectonically uplifted, as deposition continued in a shallow marine setting.

The presence of calcareous tests of planktonic foraminifera in marl intercalations within the Xigaze Group are strong evidence for the deposition occurring above the CCD. Supported by sedimentological and lithofacies indicies the Xigaze Group was deposited on a forearc slope.

Conclusion

Newly discovered foraminifera in the Xigaze Group sedimentary deposits indicate late Albian to late Coniacian age for the forearc deposits. This allow us to conclude that a forearc basin at the southern edge of the Lhasa Block developed from late Albian to late Coniacian. The Aptian age of the Indus–Yarlung ophiolites (Gopel *et al.* 1984) indicates that the development of the forearc basin began early after initiation of the subduction of Neotethys. The new biostratigraphic data constrains the initiation of subduction of the Neotethys to early Albian.

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