PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The Tibetan Plateau: Regional Stratigraphic Context and Previous Work

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The Tibetan plateau: regional stratigraphic context and previous work

By Yin Jixiang[1], Xu Juntao[2], Liu Chengjie[1] and Li Huan[1]

[1] *Institute of Geology, Academia Sinica, P.O. Box* 634, *Beijing, People's Republic of China*
[2] *Nanjing Institute of Geology & Palaeontology, Academia Sinica, Nanjing, People's Republic of China*

[One pullout]

A preliminary stratigraphic subdivision and correlation along the Qinghai–Xizang (Tibet) highway from Lhasa to Golmud and its adjacent areas is presented in this paper. The data used here are mainly observations on the 1985 Royal Society–Academia Sinica Geotraverse, together with published and unpublished accounts.

1. Introduction

Investigation of the stratigraphy along the Qinghai–Xizang (Tibet) highway from Golmud to Lhasa and its adjacent area started in the early 1950s. Field work in such a rugged and elevated region is extremely difficult, hence the level of understanding of the stratigraphy is obviously not comparable to that of other regions of China. This paper presents a preliminary stratigraphic subdivision and correlation along the Qinghai–Xizang (Tibet) highway from Lhasa to Golmud and its adjacent areas, as shown in the pullout (figure 23).

The data used here are mainly observations on the 1985 Royal Society–Academia Sinica Geotraverse, together with published and unpublished accounts. Some published and unpublished data from outside the area surveyed are briefly introduced where necessary. Unpublished data come from the following sources.

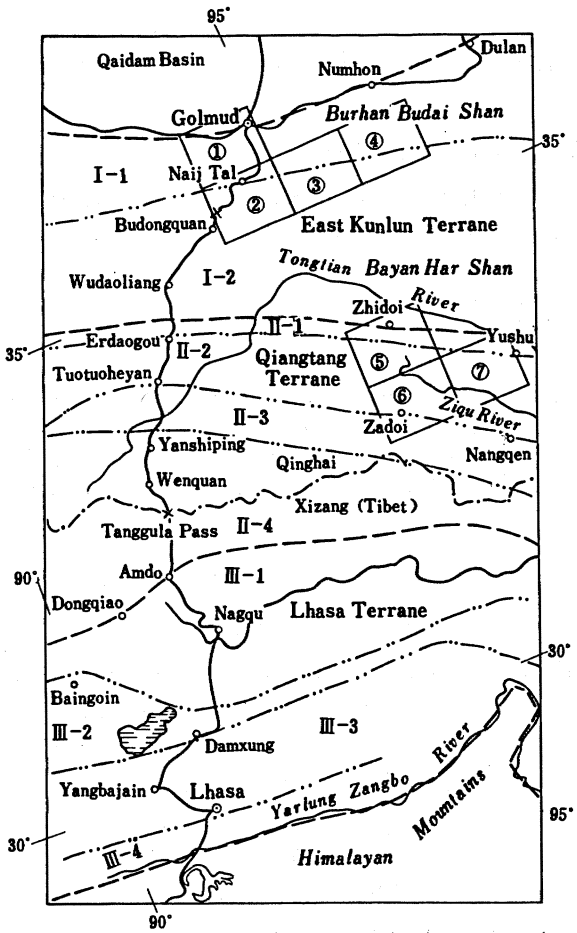
(1) The Bureau of Geology and Mineral Resources of Qinghai Province, 1981; Report on the Survey of Regional Geology, attached to the Geological Map of Qinghai Province (scale 1:200,000), People's Republic of China: Golmud City Sheet, J-46-(35); Naij Tal Sheet, I-46-(5); Zhidoi Sheet, I-46-(24); *ibid.* 1982; Aikengdeleisite Sheet, I-47-(1); Zadoi Sheet, I-46-(30); *ibid.* 1983; Dongwenquan Sheet, I-46-(6); Shanglaxiu Sheet, I-47-(25). The positions of these seven sheets and of the traverse routes are shown in figure 1.

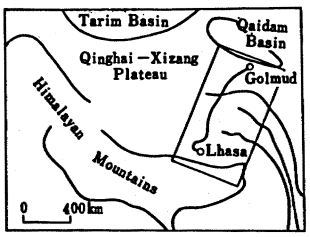
(2) Explanatory notes to the Geological Map of Qinghai Province (scale 1:1,000,000) (Zhang Qizhen & Zhang Yifu 1981).

Fossil locality numbers, e.g. B60, refer to Smith & Xu, this volume, Appendix, to which reference should be made for faunal lists.

2. Stratigraphy

Three major provinces can be recognized along the Geotraverse route: from north to south the Kunlun Terrane, the Qiangtang Terrane and the Lhasa Terrane. Figure 2 is a sketch map of the geology of the northern part of the Kunlun Terrane. For an alternative interpretation of the geology of this and other areas, see Leeder *et al.* (this volume) and the map of the Geotraverse compiled by Kidd *et al.* (this volume, Map, in pocket).





I. Stratigraphical Province of Kunlun: I-1, Burhan Budai sub-Region; I-2, Bayan Har sub-Region. II. Stratigraphical Province of Qiangtang: II-1, Zhidoi-Yushu sub-Region; II-2, Tuotuoheyan-Ziqu sub-Region; II-3, Kaixinling-Nangqen sub-Region; II-4, Tanggula Pass sub-Region. III. Stratigraphical Province of Lhasa: III-1, Dongqiao–Nagqu sub-Region; III-2, Baingoin-Nam Co sub-Region; III-3, Doilungdeqen-Lhunzhub sub-Region; III-4, Sangri sub-Region.

FIGURE 1. Stratigraphical provinces along the Qinghai–Xizang (Tibet) highway from Lhasa to Golmud and adjacent areas. 1–7 indicate the areas referred to in the unpublished reports relevant to this paper: 1. Golmud City Sheet, J-46-(35); 2. Naij Tal Sheet I-46-(5); 3. Dongwenquan Sheet I-46-(6); 4. Aikengdeleisite Sheet I-47-(1); 5. Zhidoi Sheet I-46-(24); 6. Zadoi Sheet I-46-(30); 7. Shanglaxiu Sheet I-47-(25).

3. Late Precambrian and Cambro–Sinian

The main development of supposed late Precambrian metamorphic rocks along the Geotraverse is in the Golmud–Naij Tal district in the Burhan Budai Mountains (figure 1). Sporadic occurrences of metamorphosed rocks here referred to the Cambro–Sinian are exposed in the southwestern Nyainqentanglha Mountains and south of Amdo (both in the Lhasa Terrane).

In the northern Burhan Budai Mountains, the lower unit, the Jinshuikou Group, is composed of medium-grade metamorphic rocks. The upper part, the Binggou Group, consists of medium to low-grade metamorphic rocks. They can be correlated with basement strata in the area of the Qaidam Basin and the Altun Mountains (Wang Yunshan & Chen Jiniang 1984). In the Daobangou Valley, 20 km south of Golmud, an incomplete section of the Binggou Group is unconformably overlain by Upper Devonian basal conglomerates; it is at least 1800 m thick. The lower part consists of grey and darkish-purple pebbly lithic greywackes, sericite-schists and phyllites with subordinate marbles, while the upper part consists mainly of laminated marbles, brecciated dolomitic marbles and dolomites with subordinate phyllites. The uppermost part of

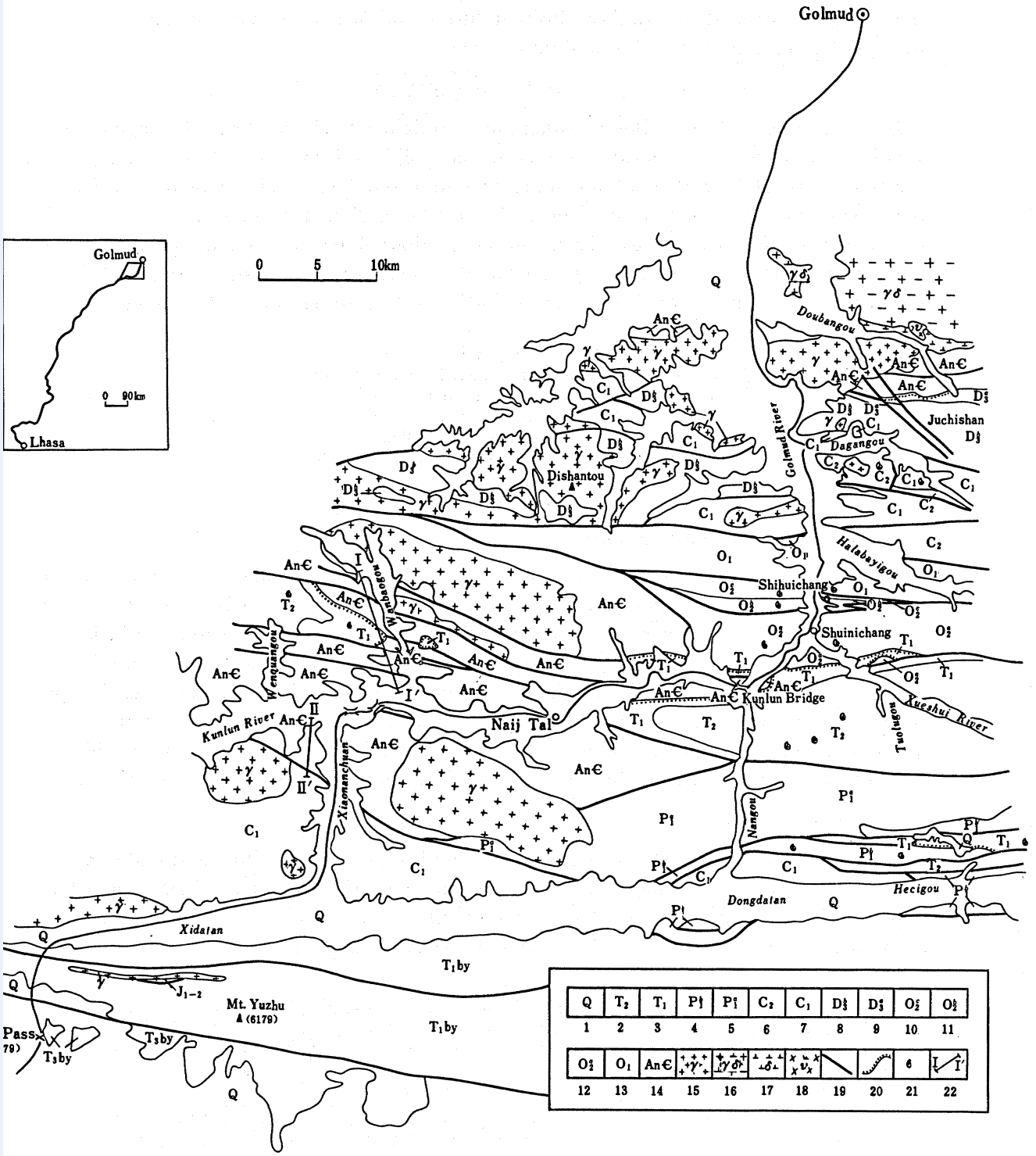


FIGURE 2. A sketch map of the geology of the Golmud–Naij Tal district showing the stratigraphy (modified from Golmud City Sheet and Naij Tal Sheet). 1. Quaternary (Q); 2. Naocangjianggou Formation (T_2); 3. Hongshuichuan Formation (T_1); 4. Carbonate Formation (P_1^b); 5. Clastic Formation (P_1^a); 6. Diaosu Formation (C_2^1), Sijiaoyanggou Formation (C_2^2); 7. Dagangou Formation (C_1); 8. Upper Member (Volcanics Member) of Juchishan Formation (D_3^b); 9. Lower Member (Clastics Member) of Juchishan Formation (D_3^a); 10. 'Fluxoturbidite Formation' (O_2^c); 11. Shihuichang Formation (O_2^b); 12. Shuinichang Formation (O_2^a); 13. Halabayigou Formation (O_1); 14. Binggou Group, Wanbaogou Group (An€); 15. Granite; 16. Granodiorite; 17. Diorite; 18. Gabbro; 19. Fault; 20. Unconformity; 21. Fossil localities; 22. Positions of sections.

the Group is intruded by granites. Stromatolites found nearby to the east suggest that the Binggou Group may be late Precambrian in age.

(*a*) *Wanbaogou Group*

In the southern Burhan Budai Mountains, possible late Precambrian belonging to the Wanbaogou Group is only locally exposed in the Naij Tal district. Its stratigraphy, age and correlation are all debatable because of the structural complexity and lack of fossil evidence in the type section in Wanbaogou Valley, 15 km NW of Naij Tal (Zhu Zhizhi *et al.* 1985; Li Guangcen & Lin Baoyu 1982). From our observations of the type section (figure 3 I–I′) and the principal reference section in Xiaonanchuan 20 km southwest of Naij Tal (figure 3 II–II′), the Wanbaogou Group is preliminarily divided into five formations in descending order as follows:

Fault

5. Clastic Formation (more than 1615 m in thickness)
4. Carbonate Formation (more than 330 m)
3. Green Schist Formation (235 m)
2. Volcanic Formation (more than 400 m)
1. Haematite-bearing Clastic Formation (more than 250 m)

Fault

(i) *Haematite-bearing Clastic Formation*

This formation is exposed only locally in the central Wanbaogou Valley. Its base is truncated by faulting; the topmost grey-white laminated marbles are conformably overlain by the Volcanic Formation. It consists mainly of phyllitic slates alternating with thin-bedded or lenticular dark grey marbles, greywackes and subordinate interbedded haematite-bearing clastics in the upper part. The haematite-bearing clastics include, in ascending order, feldspar-rich lithic greywackes, reddish-grey impure siliceous rocks, banded haematite-bearing quartzites, banded oolitic haematite units 3–5 cm in thickness, silty slates and red, silicified, dolomitic crystalline limestones as well as banded haematite-bearing calcite–quartz schists.

(ii) *Volcanic Formation*

In the Naij Tal district, the Volcanic Formation is repeated by folding and faulting. Dark grey basic volcanics and subordinate andesites dominate the lower part. In Xiaonanchuan (figure 3 II–II′), the formation has a conformable upper contact with the Green Schist Formation and the basal part is obscured by Quaternary deposits.

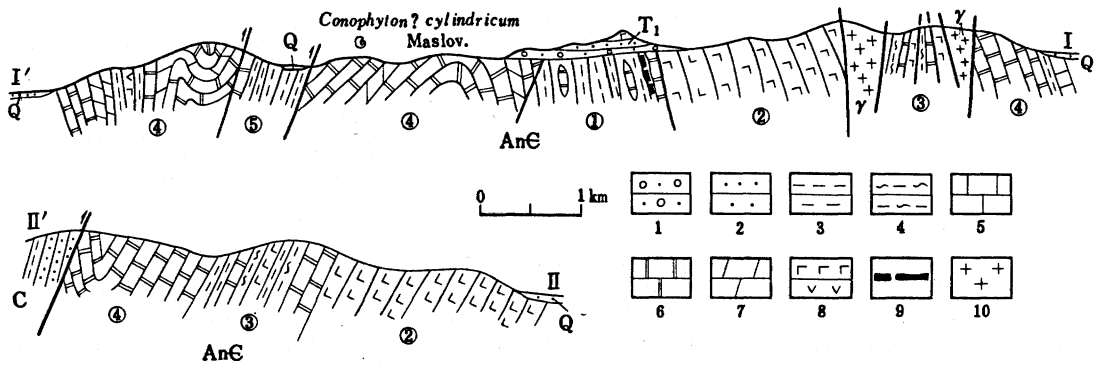


FIGURE 3. A section of the Wanbaogou Group in Wanbaogou, Xiaonanchuan, Naij Tal District and Golmud County (I–I′ Wanbaogou section, II–II′ Xiaonchuan section as shown in figure 2). 1. Conglomerate; 2. Sandstone; 3. Slate; 4. Green Schist; 5. Limestone; 6. Marble; 7. Dolomite; 8. Upper Basic volcanic rocks, Lower: Andesite; 9. Hematite; 10. Granite.

(iii) *Green Schist Formation*

The formation is well exposed in the Xiaonanchuan section and consists of grey-white laminated marbles, silicified marbles and ferruginous dolomitic marbles in the lower 80 m; grey-green laminated chlorite–quartz–schists and dark green actinolite–epidote–schists intercalated with basic volcanics in the middle 140 m; grey-green slate and subordinate laminated marbles form the upper 15 m.

(iv) *Carbonate Formation*

In Wanbaogou, the formation consists mainly of grey-white silicified marbles, calcareous dolomites, silicified dolomitic marbles and calcareous pisolitic micritic dolomites intercalated with subordinate quartzites. The basal and upper contacts are faulted. In the Xiaonanchuan, the top of the formation is overthrust by grey sandstones and slates of Carboniferous age, whereas the basal part is conformable on the Green Schist Formation.

(v) *Clastic Formation*

The lower and middle parts of the formation in Wanbaogou consist mainly of arenaceous slates intercalated with feldspar-rich lithic greywacke. The upper 30 m comprise dark grey thin cherts interbedded with siltstones and silicified marbles alternating with dark lenticular cherts and banded chert-bearing marbles as well as marbles with sparse, angular pebbles up to 40 cm in diameter of dark, yellowish pink and brown crystalline limestone. These represent debris flow deposits. The top and base are truncated by faulting.

The stromatolites *Conophyton* ? *cylindricum* Maslov, *Conophyton* cf. *miloradovici* Raaben and *Conophyton* sp. have previously been recorded from the Carbonate Formation in the Wanbaogou section (Zhu Zhizhi *et al.* 1985), who referred the Group to the late Precambrian. Similar fossils were also found in the same formation east of the Xiaonanchuan and north of Naij Tal, and suggest that the Wanbaogou Group may be roughly correlated with the Binggou Group. See discussion on the age of these beds, however, in Smith & Xu (this volume).

(*b*) *Nyainqentanglha Group*

A suite of paragneisses (the Nyainqentanglha Group) is best exposed in the southwestern Nyainqentanglha Shan. It is composed mainly of coarse-grained porphyritic–mica–gneiss and garnet–biotite granitic gneiss with subordinate amphibolite or hornblendite, reaching amphibolite facies (Li Pu 1955), locally decreasing to green schist facies. The age of the latest metamorphism of the Group, determined by whole rock Rb–Sr method, is 40–50 Ma, while the inherited age of zircon, determined by U–Pb method, is 1200–2000 Ma (Xu Ronghua, pers. comm.). It is assumed that the age of the main part of the Nyainqentanglha Group is Precambrian or, though with no geochronological evidence, Cambro–Sinian; the possibility of a part being younger cannot be ruled out (see Harris, Xu, Lewis, Hawkesworth & Zhang, this volume).

(*c*) *Amdo Schists*

A suite of thick meta-sediments, informally named the Amdo Schists, outcrops for 40 km along the traverse route between Amdo and Nagqu. The zircon age of metamorphosed granodiorites intruded into this Schist, determined by U–Pb method, is 531^{+5}_{-6} Ma (Xu Ronghua *et al.* 1985). This magmatism is possibly comparable with the Pan-African Event in Africa and Arabia (Gass 1982).

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4. Ordovician

The Ordovician, seen only around Naij Tal in the Kunlun Shan, was originally divided into two formations, the Shuinichang Formation (lower Upper Ordovician) and the Shihuichang Formation (upper Upper Ordovician) by Li Guangcen & Lin Baoyu (1982). New fossil evidence and structural interpretations lead us to propose the following revised subdivision (figure 4):

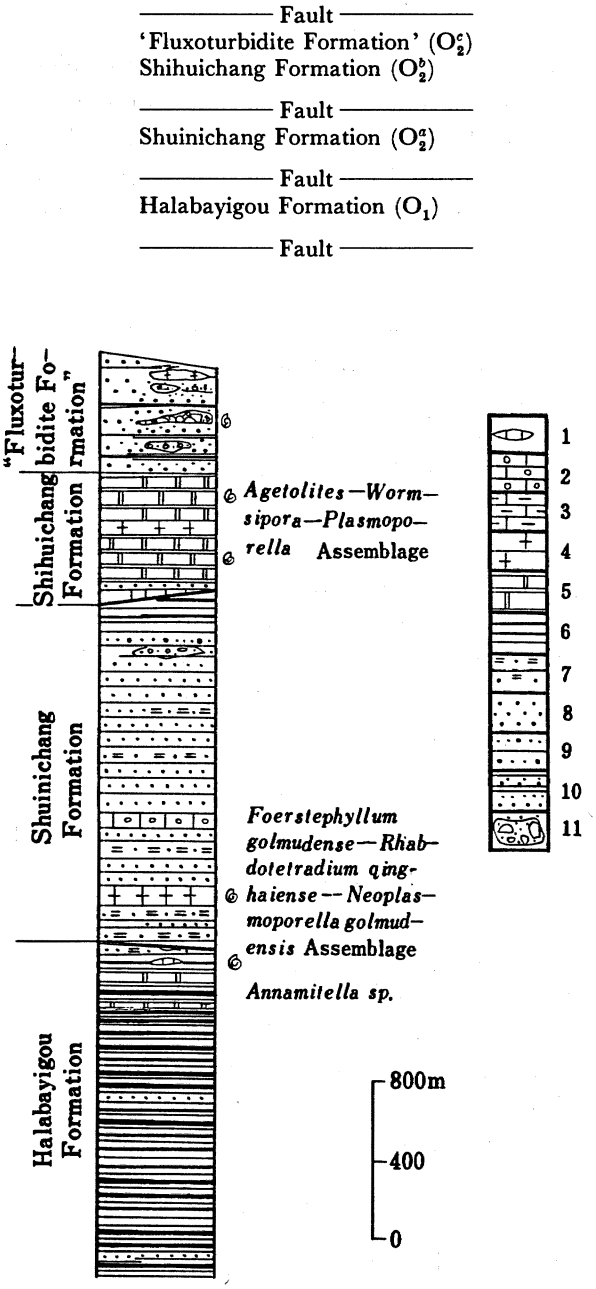

Figure 4. Generalized columns of the Ordovician in the Naij Tal district, Golmud County. 1. Lenticular limestone; 2. Oolitic limestone; 3. Argillaceous limestone; 4. Crystalline limestone; 5. Marble; 6. Slate; 7. Phyllite; 8. Graywacke, sandstone; 9. Pebbly sandstone; 10. Sandy turbidite; 11. Fluxoturbidite.

(i) *Halabayigou Formation* (O_1)

In the type section, situated on the eastern bank of the Golmud River north of Shihuichang, the main part of the formation is dominated by a monotonous flyschoid succession of grey slates alternating with thin-bedded sandstones. The upper part (about 150 m) is composed of phyllites and slates intercalated with subordinate dark limestones, oolitic limestones and marls as well as schistose brecciated marbles. The lower contact of the formation is not exposed and the upper contact is faulted. Li Guangcen & Lin Baoyu (1982) considered the Halabayigou Formation to be Silurian in age. However, one poor fragment of trilobite from the dark limestones at the top of the Formation indicates a possible early Ordovician age for these beds (loc. B100).

(ii) *Shuinichang Formation* (O_2^a)

The formation is best exposed along both banks of the Golmud River between Kunlun Bridge and Shihuichang; it is faulted against the Shihuichang Formation to the north and the Triassic or older sequences to the south (figure 2). The lower part of the formation is dominated by greywackes and phyllites intercalated with subordinate oolitic marbles, laminated marbles and dark grey crystalline limestones, they yield abundant corals (the '*Foerstephyllum golmudense* – *Rhabdotetradium qinghaiense* – *Neoplasmoporella golmudense* Assemblage'), dated as early late Ordovician (Li Guangcen & Lin Baoyu 1982; Lin Baoyu 1985). The middle part consists mainly of grey schistose feldspar-rich lithic greywackes and meta-lithic quartz greywackes intercalated with subordinate phyllites; the upper part consists of pebbly grits and feldspar-rich lithic greywackes interbedded in the topmost sequence with slates and schistose fluxoturbidites (50 m).

(iii) *Shihuichang Formation* (O_2^b)

This formation outcrops to the west of Shuhuichang and near the western bank of the Golmud River where it is mainly composed of laminated marbles and bioclastic crystallised limestones; some pyrite-bearing lithic quartz sandstones, arenaceous shales and silicified limestones are interbedded in the lower part. The contact with the overlying 'Fluxoturbidite Formation' in the north is conformable.

The limestones yield corals, bivalves and crinoids, some of which are poorly preserved indicating that they are not *in situ* fossils. The corals have affinities with the '*Agetolites–Wormispora–Plasmoporella* Assemblage'. Their age is late late Ordovician (Li Guangcen & Lin Baoyu 1982; Lin Baoyu 1985).

(iv) '*Fluxoturbidite Formation*' (O_2^c)

Along the western bank of the Golmud River, a suite of clastics with subordinate submarine mass-flow deposits, informally named the 'Fluxoturbidite Formation', rests conformably on the Shihuichang Formation. The lower sandy turbidites are intercalated with pebbly feldspar-rich lithic greywackes and calcareous shales with fragments of crinoid stems; the middle of the formation consists of fluxoturbidites and sandy turbidites. Two layers of thin-bedded crystallised limestone in the lower part yield a few corals and conodonts (B102). The top is faulted against Carboniferous strata to the north.

For a detailed sedimentalogical and palaeoenvironmental description of the Ordovician, see Leeder *et al.* (this volume).

Generally speaking, the Ordovician in the Naij Tal district has undergone low-grade metamorphism and strong deformation and has few fossil-bearing horizons. No section showing the complete sequence through the Ordovician has yet been established. The fossiliferous Upper Ordovician observed in this area may be correlated in lithology and fossils with the Tieshidasi Group in the Qimantage Mountains southwest of the Qaidam Basin and the Tanjianshan Group of the northern part of the Qaidam Basin (Xu Xian *et al.* 1982).

5. Silurian

No proven Silurian is found in the eastern Kunlun Terrane or the Qiangtang Terrane except in the 'Yidun–Zhongdian district' in the eastern part of the Qiangtang Terrane, where Middle and Upper Silurian strata are present. Outcrops of Silurian strata are, however, widespread in the Xainza district west of Nam Co in the Lhasa Terrane. The lower limestones yield corals, nautiloids, gastropods, stromatoporoids, brachiopods, bryozoa and crinoid stems of early and mid Silurian age. The upper part is mainly composed of sericite–chlorite phyllites alternating with quartzites. It is unfossiliferous but may be late Silurian in age as it rests conformably on the underlying Lower and Middle Silurian.

In the Xainza district, about 150 km SSW of Dongqiao, the Lower Silurian is represented by graptolitic shale and the Middle and Upper Silurian mainly by carbonates bearing cephalopods, corals and conodonts. It rests conformably on an Ordovician sequence and is disconformably overlain by the Devonian (Lin Baoyu 1983*a*; Xu Hankui *et al.* 1981).

6. Devonian

Devonian deposits along the Geotraverse route may be divided into two facies: terrestrial sediments cropping out at Daobangou 20 km south of Golmud in the Kunlun Terrane and marine deposits sporadically found to the west of Dongqiao in the northern part of the Lhasa Terrane. Only the former was observed.

(*a*) *Juchishan Formation*

Unmetamorphosed terrestrial clastic and volcanic rocks seen at Daobangou and Dishantou along the eastern and western banks of the Golmud River are here designated the Juchishan Formation after the Juchi Mountains south of Daobangou. The lower part of the Formation comprises basal conglomerate, slate, arenaceous mudstone, lithic feldspar-rich sandstone with subordinate siltstone intercalated with amygdaloidal andesite and meta-trachybasalt; the upper part is dominantly andesite intercalated with basalt and dacite, followed by purple massive rhyolite or perlitic rhyolite with subordinate sandstone, volcanic breccia and tuff. The basal conglomerate of the formation in the Daobangou section rests unconformably on the Precambrian Binggou Group while the volcanic rocks of the upper part (see Pearce & Mei, this volume) pass disconformably upward into the coarse clastic rocks or volcanic rocks of the Lower Carboniferous. The Juchishan Formation, whose age is inferred to be late Devonian (figure 5), can be roughly correlated, in sequence and lithology, with the Harzha Group in the Qimantage Mountains northwest of Golmud (Xu Xian *et al.* 1982).

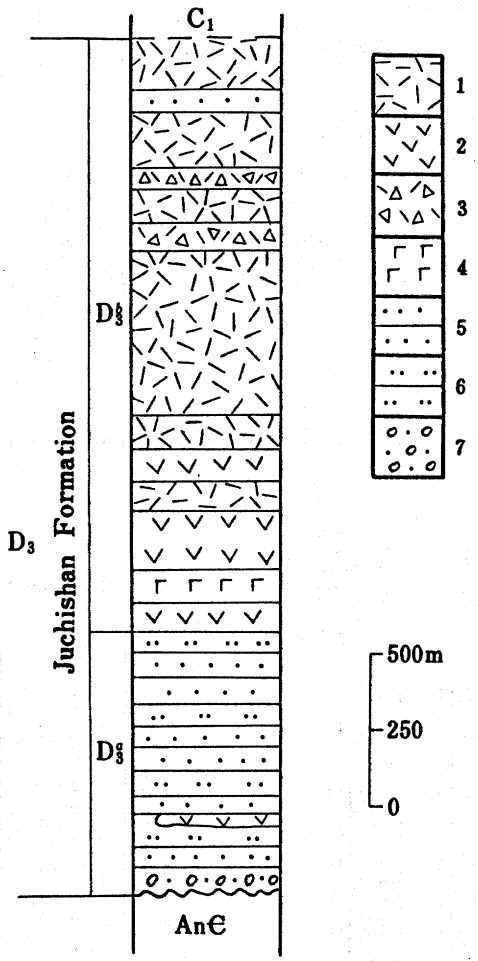

FIGURE 5. Columnar section of the Juchishan Formation at Juchi Mountain, south of Daobangou, Golmud County. 1. Rhyolite, perlitic rhyolite; 2. Andesite, dacite; 3. Volcanic breccia; 4. Basalt; 5. Sandstone; 6. Siltstone; 7. Conglomerate.

7. CARBONIFEROUS

Carboniferous strata are widespread in the Kunlun, Qiangtang and Lhasa Terranes.

(*a*) *Golmud District, Kunlun Terrane*

Good sections of fossiliferous Carboniferous rocks are exposed near Dagangou and Halaguole in the mid Burhan Budai Mountains, though only the Dagangou section was examined (figures 6 and 7).

(i) *Dagangou Formation* (C_1)

The Dagangou section lies to the east of the Golmud River. The lower part of the formation (1012 m thick), consists mainly of terrestrial sandstones with subordinate rhyolite, basalt and tuff at different horizons. Some shallow-water sedimentary structures including cross-bedding and ripple marks were observed. The middle part is composed of white, medium- to thick-bedded quartzose sandstone, purple siltstone with subordinate pebbly sandstone and fine-grained conglomerate; medium-scale cross-bedding in sandstones of fluvial facies is common.

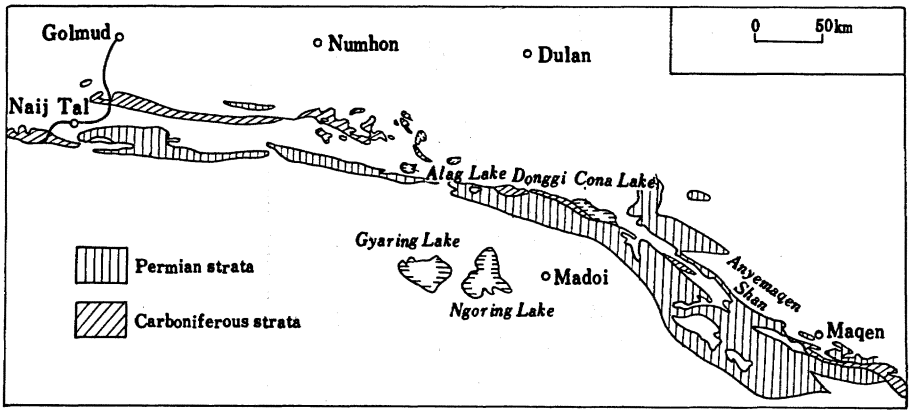

FIGURE 6. Sketch map of the distribution of the Carboniferous and the Permian in the Burhan Budai Mountains.

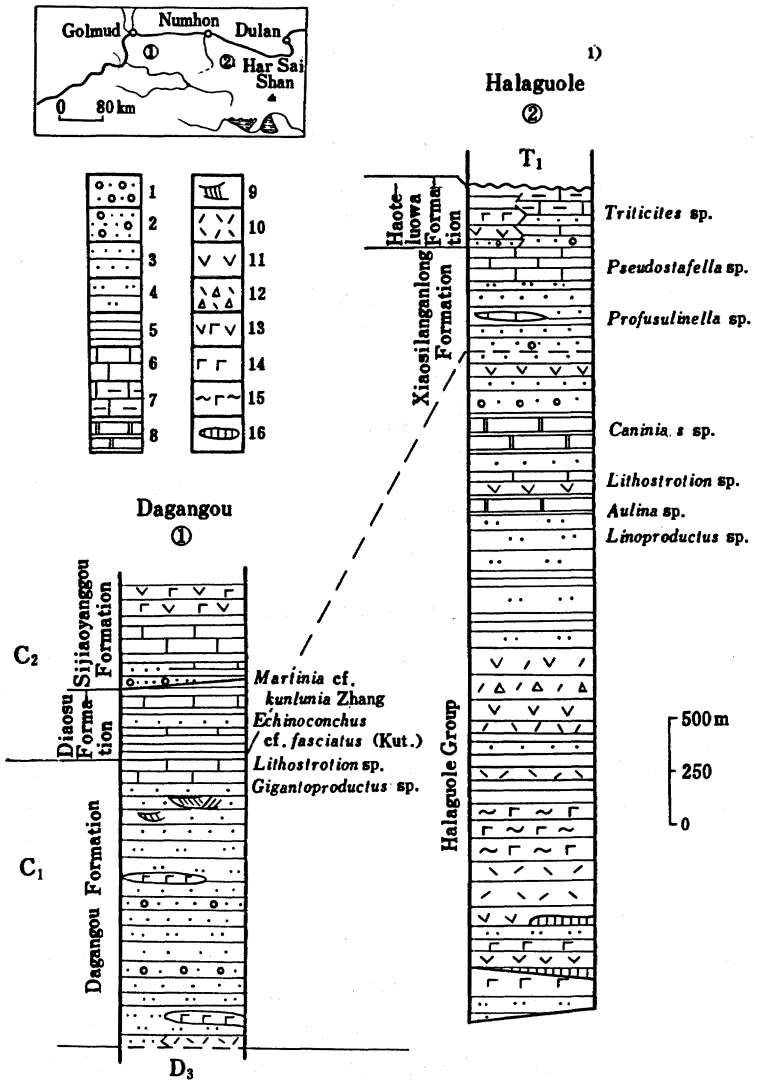

FIGURE 7. Correlation of columnar sections of the Carboniferous in the Burhan Budai Mountains. 1) Modified from Aikengdeleisite Sheet. 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4. Siltstone; 5. Shale; 6. Limestone; 7. Argillaceous limestone; 8. Marble; 9. Cross-bedding; 10. Rhyolite; 11. Andesite; 12. Tuffaceous breccia; 13. Andesite-basalt; 14. Basalt; 15. Metamorphosed intermediate-basic volcanic rocks; 16. Siliceous rock.

The upper part, about 60 m thick, consists of grey, medium-bedded limestones, with sporadic reefs intercalated with subordinate carbonaceous shale or thin coal seams yielding brachiopods, corals and a few trilobites and crinoid stems (loc. B108) indicating a late Visean age.

(ii) *Diaosu Formation* (C_2^1, 380 m)

The Diaosu Formation rests conformably on the Dagangou Formation. The lower 140 m consists of arenaceous shale interbedded with thin-bedded sandstone, carbonaceous shale and thin-bedded bioclastic limestones yielding brachiopods (loc. B108); the upper part is characterised by a rhythmic succession which is in turn succeeded upwards by a succession of thin-bedded conglomerate, sandstone, shale and limestone intercalated with subordinate rhyolite at higher levels. The succession yields brachiopods, corals, fusilinaceans and conodonts (loc. B108, first limestone unit).

The Carboniferous succession in the Dagangou section is in turn succeeded upwards by a sequence of terrestrial, alternating marine and terrestrial and neritic deposits representing a transgressive succession. The fossil assemblages of the Dagangou Formation are predominantly benthonic and fixed fauna, while those of the Diaosu Formation and the Permian Sijiaoyanggou Formation include larger benthic foraminifera.

A flyschoid sequence exposed in Xiaonanchuan southwest of Naij Tal shows a southward increase in metamorphic grade from greenschist in the north to low amphibolite facies in the south (near the Xidatan Fault). The sequence has tectonic contacts both to the north and to the south and the thicknesses seen is estimated at over 2000 m. Some spores and pollen, the '*Laevigatosporites–Reinshospora* Assemblage', have been reported, although not described or figured, from the lower part of the sequence in Xiaonanchuan. Based on this assemblage, the age is considered to be 'Middle and Late Carboniferous' (Zhu Zhizhi *et al.* 1985). Lithologically the sequence is roughly similar to the Halaguole Group to the east near Numhon, so it is taken to be early Carboniferous in age, although it may be Cambro–Ordovician (see Leeder *et al.*, this volume).

(*b*) *Tuotuoheyan–Zadoi District, Qiangtang Terrane*

Carboniferous strata are mainly developed in the Zadoi and Qamdo districts east of the traverse route. However, a tectonic slice, previously referred to the Lower Permian, was discovered at Kaixinling. The strata, about 300 m thick, consist of thick-bedded or massive limestones with fusulinaceans (loc. B60). *Quasifusulina longissima* is a species found in the Mapingian in Hunan, Guizhou, Zhejiang, Gansu and Ningxia Provinces; it is also found at the top of the Taiyuan Formation in Shanxi Province. The fusuline-bearing strata are referred to the late Carboniferous of Chinese workers (mid Lower Permian of non-Chinese workers).

Several good Permo–Carboniferous sections are found in the Zadoi and Qamdo districts. To the west of Qamdo, the Lower Carboniferous is composed mainly of carbonates in the lower part and thick coal-bearing clastic rocks in the upper part. The Permian is carbonates; the contact of the Lower Carboniferous with the underlying Devonian is conformable, that of the early Permian with the overlying late Permian disconformable (Dong Deyuan & Mu Xinan 1984). In the Zadoi district, between Kaixinling and Qamdo, the Lower Carboniferous is composed of limestones intercalated with coal, gypsum and purple clastics with intermediate-acidic volcanics at different levels; it yields early Carboniferous corals and brachipods. The early Permian (late Carboniferous of Chinese workers) consists mainly of purple clastic rocks intercalated with subordinate carbonates with intermediate-basic and intermediate-acidic

volcanic rocks and bears Lower Permian fusulinaceans (Zadoi Sheet). The Carboniferous is disconformable on the underlying Devonian; the contact with the overlying Permian is obscure.

(*c*) *Lhasa District, Lhasa Terrane*

Carboniferous sediments are widespread in the Lhunzhub district and are also sporadically exposed to the south of Jang Co in the north of the Lhasa Terrane. So far, fossiliferous Lower Carboniferous has only been found in the Maizhokunggar district 60 km northeast of Lhasa where it is composed mainly of quartzose sandstones alternating with slates and subordinate limestones bearing the coral *Kueichowphyllum* sp. It is over 600 m thick (Li Pu 1955).

The type section of the Pondo Group at Urulung village west of Pondo is predominantly composed of diamictites, i.e. pebbly arenaceous mudstone, pebbly siltstone and pebbly sandstone intercalated with siltstone, mudstone and lenticular conglomerate. The basal part is intruded by granites and the topmost part grades conformably into the early Permian Urulung Formation; it is more than 1000 m thick. Pebbles within the diamictites are of diverse composition, dominantly quartzite with subordinate limestone, slate and granite. The diamictites generally appear to be massive and structureless but some sedimentary structures including bioturbation, graded bedding and pseudo-dropstones may be seen, suggesting that part of the

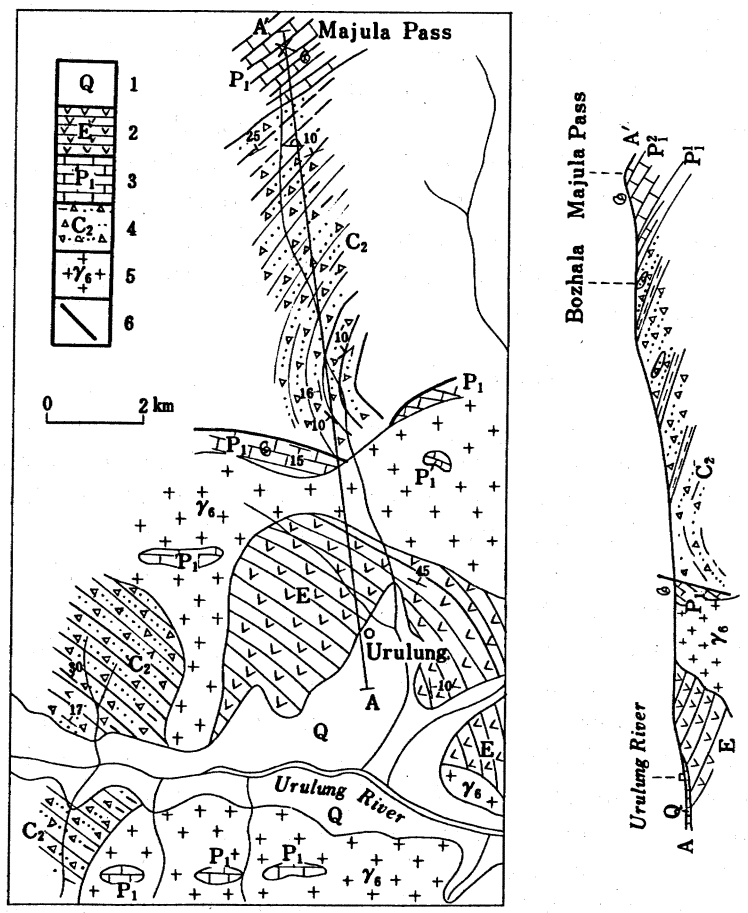

FIGURE 8. A section of the Pondo Group at Urulung village, west of Pondo town, Lhunzhub County. (From Yin Jixiang & Wan Chuanfen, in press.) 1. Quaternary deposits; 2. Volcanic rocks (Linzizong Formation); 3. Limestone (Urulung Formation and Lobadoi Formation); 4. Diamictite (Pondo Group); 5. Granite; 6. Fault.

diamictites originated as submarine gravity current deposits. Fossils from the upper part, on the whole, belong to the '*Bandoproductus* Fauna' which may be compared, in horizon and characteristics, with the '*Stepanoviella* Fauna' which occurs in Kashmir and Australia (Chen Chuzhen & Wang Yujing 1984). Exposures of the Pondo Group on the East Hill of Damxung City, 26 km northwest of Urulung village, are fossiliferous (locs. B17–21); the fossils suggest a late Carboniferous/early Permian age (figure 8).

8. Permian

Permian strata are widespread in the Kunlun, Qiangtang and Lhasa Terranes.

(*a*) *Golmud District, Kunlun Terrane*

(i) *Sijiaoyanggou Formation*

The base of this formation was not observed. However, other work indicates that it lies conformably on the Diaosu Formation (The Compiling Group of the Charts of Stratigraphical Units Sequences of Qinghai 1980). The lower part of the formation, exposed on the southern bank of the lower Dagangou Valley near the Golmud River, mainly consists of siltstone and pebbly sandstone intercalated with carbonates. The top is truncated by a fault; about 284 m is seen. The upper part is dominantly composed of andesitic basalts. The age of these basalts is questionable: for an alternative interpretation, see Smith & Xu, and Leeder *et al.*, this volume.

(*b*) *Naij Tal District, Kunlun Terrane*

The Permian forms an E–W trending belt in the western part and a NW–SE trending belt in the southeastern part of the southern Burhan Budai Mountains and is developed immediately to the south of the Carboniferous. It forms the bulk of the strata exposed in the Anyemaqen Mountains between Alag Lake and Maqen and extends westwards to Naij Tal (figure 6). In the eastern part of the outcrop, between Alag Lake and Maqen, the Permian sequence is associated with a number of small ultramafic bodies which have long been believed to be ophiolites; this belt has been regarded as the Southern Kunlun Suture (Li Baotian 1984). In the western part of the outcrop, between Alag Lake and Naij Tal, the Permian contains a great deal of basic, intermediate-basic and intermediate-acid volcanic rocks; no ultramafic rocks have been found. In the Naij Tal district, the Lower Permian succession is well-exposed at Nangou south of Kunlun Bridge, along the southern bank of the Xueshui River and the Tuolugou as well as along both banks of the Dongdatan Valley, while fossiliferous Upper Permian is found only along the Upper Xueshui River and in the Xugui district to the east of the Geotraverse route. No true flysch sediments typical of deep water facies have been found in the Permian of the Kunlun Shan despite its tremendous thickness (figure 9). A generalized Permian sequence in the Naij Tal district is as follows.

Overlying beds	Neogene red beds
	Unconformity
Upper Permian (after 'Dongwenquan Sheet')	
Upper Part	Carbonates and calcirudite intercalated with tuff; carbonates yield early late Permian Araxoceratid ammonoids and the brachiopods *Neophricodothyris* cf. *asiatica* (Chao), *Waagenites* sp. and *Buxtonia* sp.
Lower Part	Conglomerate and pebbly sandstone with subordinate thin-bedded limestone.

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Paraconformity

Lower Permian (after 'Dongwenquan Sheet' and 'Naij Tal Sheet')

Carbonate Rock Formation (P_1^b) or (P_2^a)	Bioclastic limestone intercalated with subordinate calcareous shale and quartzose sandstone, limestone yielding fusulinaceans: *Verbeekina*, *Schwagerina*, *Neoschwagerina* and *Sumatrina*; corals: *Iranophyllum* and *Wenzelella* etc. (log. M855/7). The sequence is generally intensely deformed. (This formation is considered by non-Chinese workers to be of early late Permian age on forams.)
Clastic Rock Formation (P_1^a)	
Upper Part	Limestone alternating with slate and phyllite intercalated with lenticular conglomerate and thin-bedded limestone.
Lower Part	Schistose sandstone and conglomerate, schistose rhyolitic brecciated lava, rhyolite and tuff intercalated with siltstone, pebbly sandstones and subordinate dolomite.

Fault

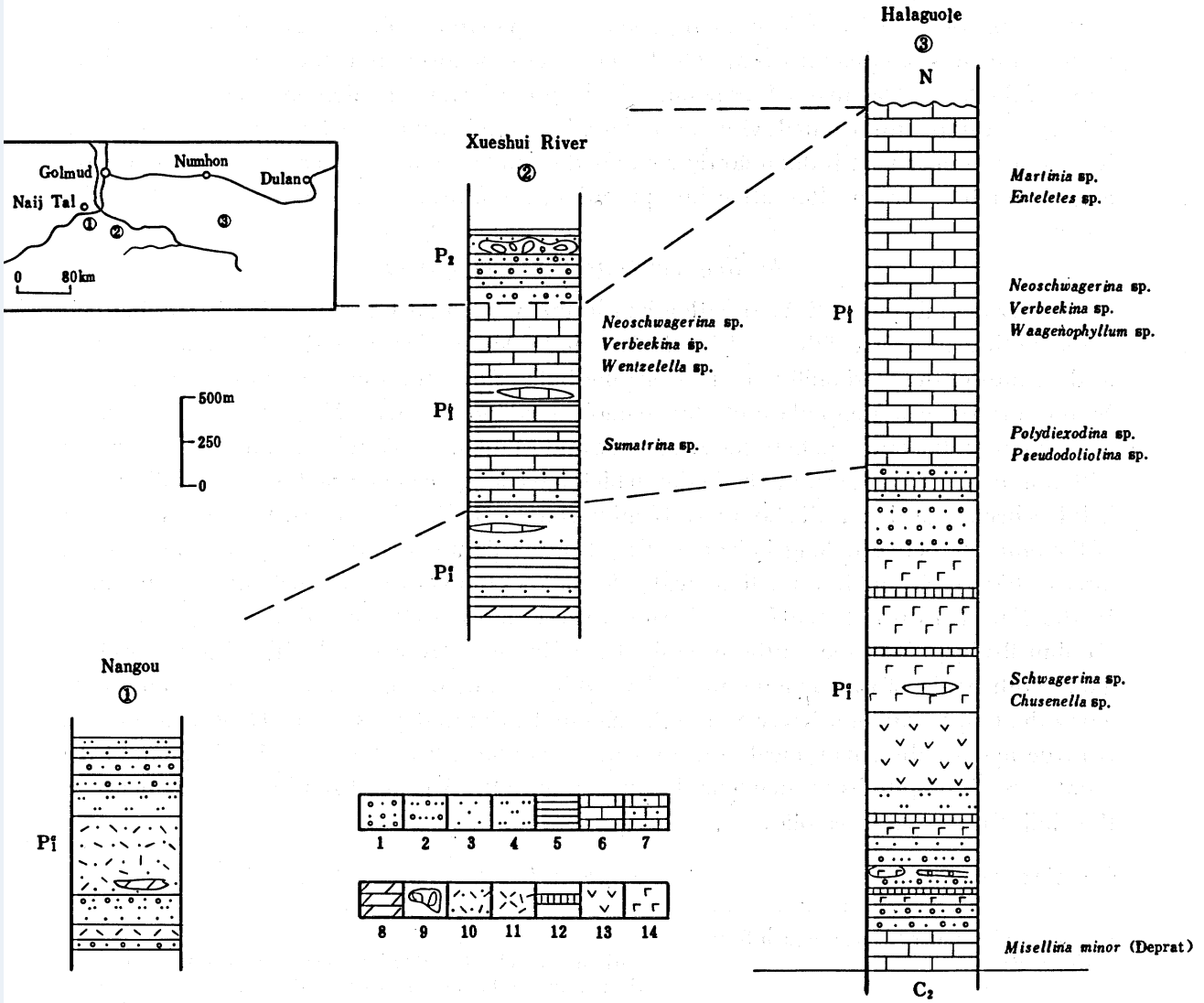

FIGURE 9. Correlation of the Lower Permian in the Burhan Budai Mountains. (1) After Naij Tal Sheet; (2) After Dongwenquan Sheet; (3) After Aikengdeleisite Sheet. 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4. Siltstone; 5. Slate; 6. Limestone; 7. Arenaceous limestone; 8. Dolomite; 9. Calcirudite; 10. Tuff; 11. Rhyolite; 12. Siliceous rocks; 13. Andesite; 14. Basalt.

In the Halaguole district to the south of Numhon, the Lower Permian is predominantly basic and intermediate volcanic rocks. The fossiliferous limestone at the bottom the upper Lower Permian rests conformably on the fossiliferous topmost limestone of the lower Lower Permian (of non-Chinese usage).

(*c*) *Wuli–Kaixinling District, Qiangtang Terrane*

The core of the Kaixinling–Nangqen anticlinorium is formed of Permian. Good sections mostly occur in the Zadoi or Nangqen districts east of the Geotraverse route. However, several small, incomplete and faulted sections of the same strata are exposed in the Wuli–Kaixinling district (figure 10).

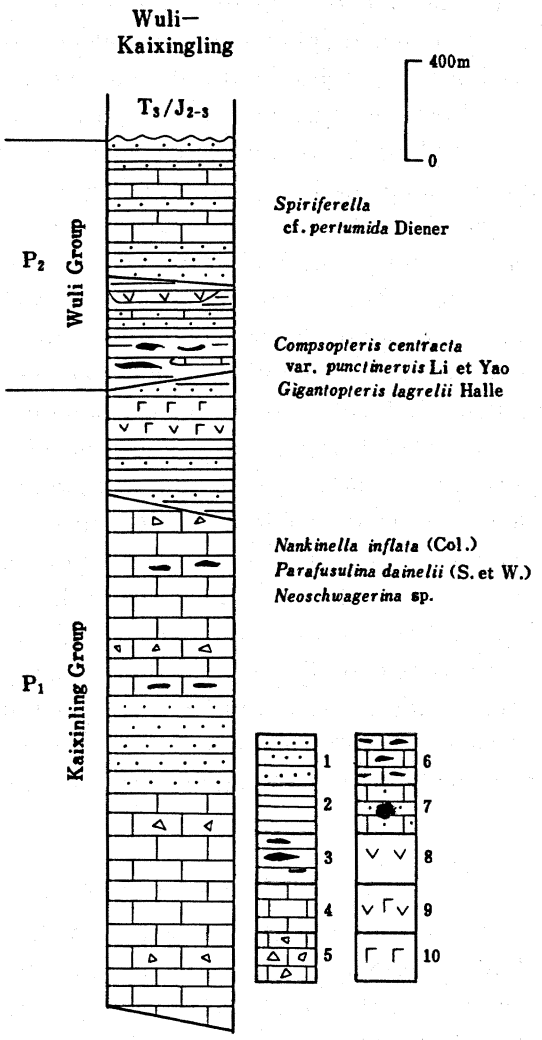

FIGURE 10. Columnar section of the Permian in the Wuli–Kaixinling district. 1. Sandstone; 2. Shale, mudstone; 3. Coal series; 4. Limestone; 5. Brecciated limestone; 6. Arenaceous limestone; 7. Cherty limestone; 8. Andesite; 9. Intermediate-basic volcanics; 10. Basalt.

(i) *Kaixinling Group* (P_1) or (P_2^a)

The Kaixinling Group includes the lower Carbonate Rock Formation which is faulted against the upper Volcanic Rock Formation. The limestones and sandstones of the thick Carbonate Rock Formation bear fusulinaceans (loc. 60), suggesting a Lower Permian (Chinese usage) or lower Upper Permian (non-Chinese usage) age. Among them, *Verbeekina verbeeki*,

Neoschwagerina haydeni, *N. craticulifera* and *Parafusulina multiseptata* belong to the *Neoschwagerina* and *Yabeina–Neomisellina* zones of the Maokouan stage; the age is inferred to be late early Permian (early late Permian of Western authors). The Volcanic Rocks Formation (at least 380 m) is composed of grey, green and purple basic and intermediate volcanic rocks in the lower part and amygdaloidal basalts intercalated with sandstone and slate in the upper part.

(ii) *Wuli Group* (P_2)

The lower Coal-bearing Clastic and Volcanic Rock unit of the Group is 288–534 m thick at Kaixinling coal mine and at the East Hill of Wuli and is dominantly composed of carbonaceous shale intercalated with coal, sandstone, andesite, bioclastic calcareous sandstone and dark grey thin-bedded limestone as well as silty mudstone at different levels. Carbonaceous sandstones from the East Hill of Wuli yield brachiopods, bivalves and gastropods (loc. B59). In addition, some brachiopods, bivalves and plant fossils were collected from Kaixinling (loc. B66). The following plant fossils from the same locality have previously been reported: *Gigantopteris nicotianaefolia* Schenk, *G. largrelii* Halle, *Lobatannularia ensifolia* Halle, *Calamites* cf. *gigae* Brogn., *Asterophyllites* sp., *Pecopteris arborescens* Goeppert, *P.* (*Ptychocarpus*) *ascuata* Halle, *Cladophlebis* sp., *Taeniopteris multinervis* Weiss, etc. (Pan Guan 1957). Brachiopods from both Wuli and Kaixinling belong to the same fauna but the horizon of the fossils from Wuli is probably slightly lower than that of the same fossils from Kaixinling. The fauna suggests a late Permian age.

The limestones, sandstones and shales of the overlying Carbonate Rocks Unit exposed to the east of Wuli is conformable on the Coal-bearing Clastic and Volcanic Rocks Unit; it reportedly yields the brachipods *Perigegarella* cf. *castellata* Wang and *Spiriferella* cf. *pertumida* Diener (The Compiling Group of the Charts of Stratigraphic Units Sequences of Qinghai 1980).

The Permian of the Kaixinling–Wuli district is comparable in fauna and lithology to that of the Qamdo district to the east except that the upper part of the Upper Permian exposed at Wuli is mainly composed of carbonates while it is volcanic in Qamdo. The palaeofloral assemblage of the Wuli Group is essentially allied to that of the Tuoba Formation in the Qamdo (Li Xingxue *et al.* 1982) and the Yushu districts (He Yuanliang & Zhang Shanzhen 1984) as well as that of the Ryaggor Caka Formation to the west in the Amugang-Mayingangri region. All may be referred to the late Permian Cathaysian flora (Li Xingxue & Yao Zhaoqi 1983).

(*d*) *Lhasa District, Lhasa Terrane*

Lower Permian strata are widespread in the Lhasa district and are unconformably overlain by Mesozoic strata. The Lower Permian may be divided into two formations, the lower Urulung Formation (limestones and sandstones) and the overlying Luobadoi Formation. The Lielonggou Formation is Upper Permian. These formations have been investigated in detail by the Scientific Expedition to the Xizang (Tibet) Plateau of the Chinese Academy of Sciences in the 1970s and a summary of these formations from published data is as follows.

(i) *Urulung Formation* (P_1^1)

This formation (40 m) has yielded Artinskian brachiopods, corals and bryozoa: *Fluctuaria* cf. *mongolica* (Denier), *Transennatia gratiosus* (Waagen), *Cancrinella cancriniformis* (Tsch.) (brachiopods), *Praewentzelella* cf. *multiseptata* (Enderle) (coral).

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(ii) *Luobadoi Formation* (P_1^2)

The formation (about 640 m thick) is conformable on the Urulung Formation and is composed of limestones intercalated with subordinate siltstone and marble; it has yielded the Kungurian fusilinaceans *Neoschwagerina globularis* Wang, Sheng et Zhang, *N. margaritae* Deprat, *Yabeina shiraiwensis* Ozawa, and the corals *Iranophyllum minor* Wu and *Ipciphyllum percicum* (Douglas) (Chen Chuzhen & Wang Yujing 1984). The upper part of the formation is absent.

(iii) *Lielonggou Formation* (P_2)

The lower part of the formation is truncated by faulting. The upper part passes conformably into or is paraconformable with the overlying Chaqupu Group of early and mid-Triassic age. It is mainly composed of sandstone intercalated with thin-bedded or lenticular andesite and andesite–basalts at different levels. The grain size of the sandstone increases upward in the upper part of the sequence and fragments of plant fossils appear representing a prograding sequence. It contains brachiopods, bivalves and bryozoa (loc. B11); the formation has been referred to the Upper Permian by Sun Dongli *et al.* (1981).

A coal-bearing clastic rock sequence more than 700 m thick exposed in the Xiagangjiang district (84° 15′ E, 30° 26′ N) in the western part of the Lhasa Terrane has been reported as displaying a 'mixed flora' of the Eurasian and Gondwanan Continents (Li Xingxue *et al.* 1985). However, neither typical elements of the Gondwanan flora nor those of the Cathysian flora were found in the 'mixed flora', which showed both features unique to the Lhasa Terrane and features relating the Terrane to the Cathaysian palaeolandmass to the northeast and Gondwanaland to the south.

9. Triassic

Triassic sediments are widely distributed in the Kunlun and Qiangtang Terranes but occur only sporadically in the Lhasa Terrane (figure 11).

(*a*) *Naij Tal Region, Kunlun Terrane*

(i) *Burhan Budai Subregion*

This subregion lies to the north of the major Xidatan–Xugui–Maqen fault. The Lower Triassic Hongshuichuan Formation, 1346 m in thickness (figure 12), has a lower part mainly composed of conglomerate, lithic feldspathic sandstone, pebbly sandstone and siltstone reportedly resting unconformably on Ordovician and Precambrian (Wanbaogou Group) sediments. The reputed basal conglomerate, 100 m thick, consists of pebbles and boulders of sandstone, tuff, quartzite, limestone and granite; they range in diameter from 4 cm to 1 m and are well-rounded or subrounded. The upper part is calcareous. The Middle Triassic Naocangjiangou Formation is over 2000 m thick. The lower part is composed of quartzose feldspathic sandstone intercalated with siltstone and slate, the upper part is mainly composed of slate with siltstone and sandstone interlayers, the top is unseen. Thick intermediate-acid volcanics are intercalated in the middle part of the Hongshuichuan Formation and in the lower part of the Naocangjiangou Formation about 150 km east of Golmud.

The early Triassic brachiopod *Pseudospiriferina* cf. *tsinghaiensis* Yang et Ti has been reported

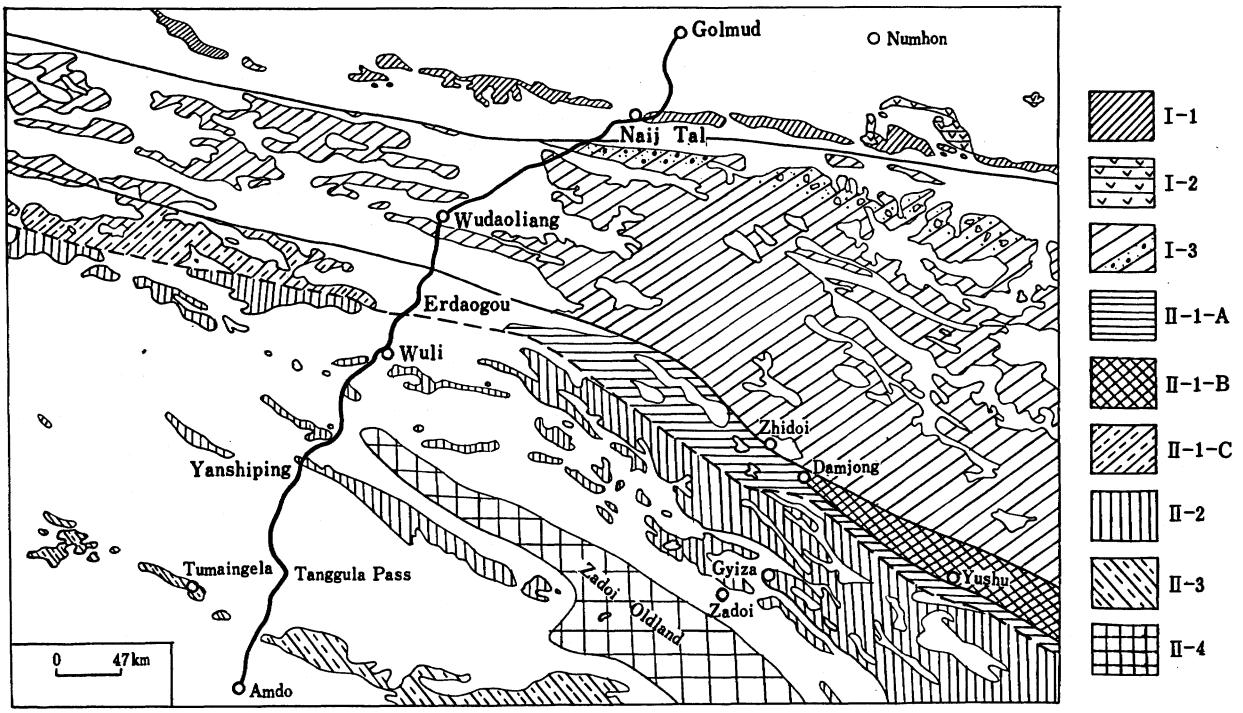

FIGURE 11. Distribution of Triassic sediments in the Kunlun and the Qiangtang Terranes. I. The East Kunlun Terrane: I-1, The Lower to Middle Triassic marine sediments in Burhan Budai Mt.; I-2, The Triassic terrestrial sediments–Babaoshan Group in Burhan Budai Mt.; I-3, The Triassic flysch–Bayan Har Group in Burhan Budai Mt. II. The Qiangtang Terrane: II-1-A, The Triassic Baitang Group is dominated by calc-alkaline volcanics; II-1-B, 'Ophiolite-Island arc complex belt'; II-1-C, Alterations of terrestrial and marine coal-bearing clastics (island arc belt); II-2, Triassic sediments in 'Back-arc basin'–Gyiza Group; II-3, Alternations of terrestrial and marine coal-bearing clastics–Tumain-gela Formation at the southern margin of Qiangtang Terrane; II-4, The uplift region–'Zadoi oldland' during Triassic.

from the upper part of the Hongshuichuan Formation in the West Hill of Wanbaogou Valley. The Anisian bivalve *Posidonia* cf. *bosniaca* Bittner and the ammonoid *Leiophyllites* sp. were previously found from the Naocangjiangou Formation 10 km west of Wanbaogou. Ladinian sediments have not yet been found from the Burhan Budai Mountains (see Naij Tal Sheet). Abundant brachiopods, bivalves and ammonoids were found in supposed equivalents of the Hongshuichuan and the Naocangjiangou Formations in the eastern Burhan Budai Mountains; the assemblages display features of a mixture of typical Tethyan and Boreal faunas (Sun Dongli & Ye Songling 1982; The Research Group on the Triassic of the Wuhan Geological College and Qinghai Institute of Geology 1979; Yin Hongfu & Ling Qiuxian 1986; He Yuanliang & Yin Jiarun 1983; Wang Yigang & Chen Guolong 1984). Late Permian brachipods were collected (loc. B91) during the Geotraverse from greyish-white limestone probably equivalent to the middle part of the original Hongshuichuan Formation.

The terrestrial coal-bearing clastics (Babaoshan Group) yield abundant plant fossils similar to the late Triassic '*Dictyophyllum–Clathropteris* flora' of South China (Wu Shunqing & Wu Xiangwu 1982; Wu Shunqing 1983) and the brackish water bivalve *Utschamiella*, suggesting that a brief late Triassic transgression took place in this area.

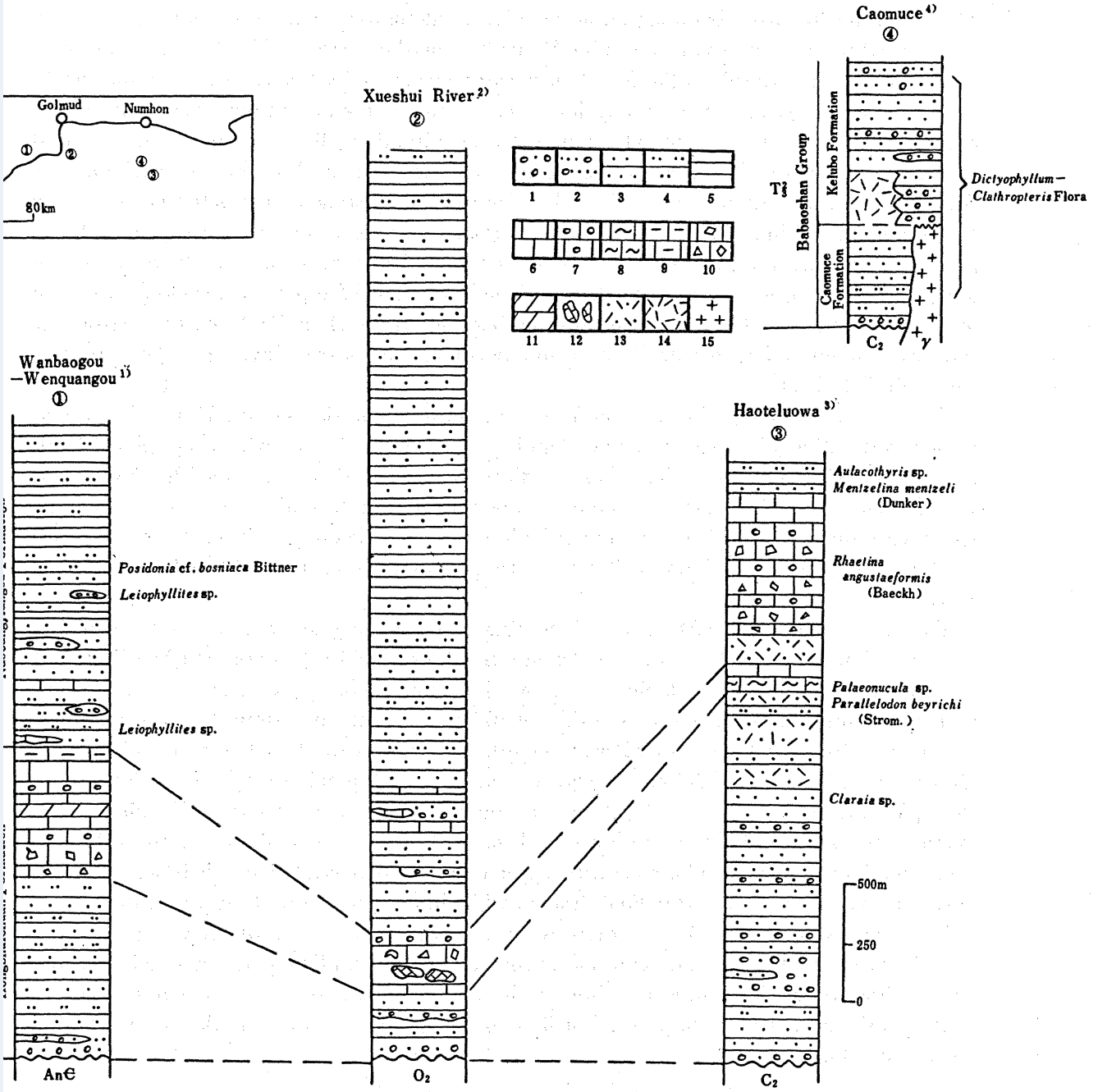

FIGURE 12. Correlation of columnar sections of Triassic sediments in the Burhan Budai Mountain area. 1) Modified from Naij Tal Sheet, Wanbaogou section and Wenquangou section. 2) *Ibid.*, Xueshuihe section. 3) and 4) Modified from Aikengdeleisite Sheet. 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4. Siltstone; 5. Shale, slate; 6. Limestone; 7. Oolitic limestone; 8. Argillaceous banded limestone; 9. Argillaceous limestone; 10. Brecciated limestone; 11. Dolomite; 12. Calcirudite; 13. Tuff; 14. Rhyolite; 15. Granite.

(ii) *Bayan Har Subregion*

The Bayan Har Subregion is situated between the Qiangtang Terrane, the Yangtze Terrane and the Burhan Budai-West Qinling Mountains. The Triassic sediments in the subregion are composed mainly of fairly monotonous sandstones and shales. They outcrop sporadically over

150 km in the area from Budongquan to Beiluheyan along the Geotraverse route and are well represented by the sections at Coal-mine Valley and on the northern side of the Kunlun Shan Pass. On the southern side of the Xidatan, the sequence contains 'exotic blocks' of sandstone, limestone, granite, conglomerate and slate, which range in diameter from several cms to tens of metres; they are arranged mainly along the schistosity. Some limestone blocks are reported to bear Carboniferous–Permian fossils similar to those from the Burhan Budai Mountains. Break-ups are seen between the blocks and the matrixes suggesting later structural deformation (Li Guangcen & Lin Baoyu 1982; Zhu Zhizhi *et al.* 1984; see also Coward *et al.*, this volume, figure 4). These we interpret as olistostromes. A previous discovery of the ammonoids *Meekoceras* and *Mesohedenstroemia* from an equivalent horizon in the East Wenquan region close to the east of Xidatan indicates that these olistostrome-bearing strata of mid–late early Triassic age represent the lower Bayan Har Group in the northern part of the 'Bayan Har Fold System' (see Naij Tal Sheet).

The bivalve *Halobia* has been found from the sandstone and slates of the Upper Bayan Har Group in the Wudaoliang area (The Compiling Group of the Charts of Stratigraphical Units Sequences of Qinghai 1980). The Triassic sediments at the southern margin of the 'Bayan Har Fold System' in the Zhidoi area are composed mainly of distal turbidites with a typical Bouma sequence intercalated with cherts and pelagic limestones yielding *Halobia*. They are thrust southward on the Upper Triassic Baitang Group (Yin Jixiang, unpublished field mapping, 1967).

The 'Bayan Har Fold System' is a thick Triassic terrigenous sequence of clastic turbidites (Zou Dingbang *et al.* 1984) without volcanics. Small granitoid intrusives (213 Ma K–Ar age for the granodiorite at Wudaoliang) occur. The major fauna recorded is Tethyan-type planktonic thin-shelled bivalves and other plankton. The paraconformity between the lower Bayan Har Group and the Upper Permian has been seen only south of Maqen (The Research Group on the Triassic of Wuhan Geological College and Qinghai Institute of Geology 1979; Wang Yigang & Sun Dongli 1985). Based on the aeromagnetic survey (Cai Zhenjing 1984), magmatism and deep faulting are not well-developed in the region where Triassic sediments occur, implying a hardened basement. It is probable that there is a Palaeozoic basement in the northern part of the Bayan Har Fold System, while in its southern part, nearer to the 'Litian Lake–Jinsha River Suture Zone', there is an accretion prism or subduction complex. The asymmetry of the Triassic sedimentation in the Bayan Har and Songpan–Garze fold systems, with shallow-water characteristics in the north and northeast and abyssal or bathyal deposits to the south (Zhang Qinwen 1981; Liu Baotian 1984) suggests that the Bayan Har Group represents a forearc basin.

(*b*) *Tuotuoheyan–Zadoi District, Qiangtang Terrane*

(i) *Zhidoi–Yushu Subregion*

This subregion, 18–45 km in width, lies at the northern or northeastern margin of the Qiangtang Terrane. In its western part, west of Erdaogou towards Xijir Ulun Lake, thick Triassic sandstones and siltstones with carbonaceous shale and coal seams are exposed; they are associated with serpentinised ultrabasic rock in Chawuma Mountain 60–70 km west of Beiluheyan (Zhang Qizhen & Zhang Yifu 1981). Late Triassic bivalves and plants have been reported.

The Triassic in the Zhidoi area (the middle part of the subregion) is called the Baitang

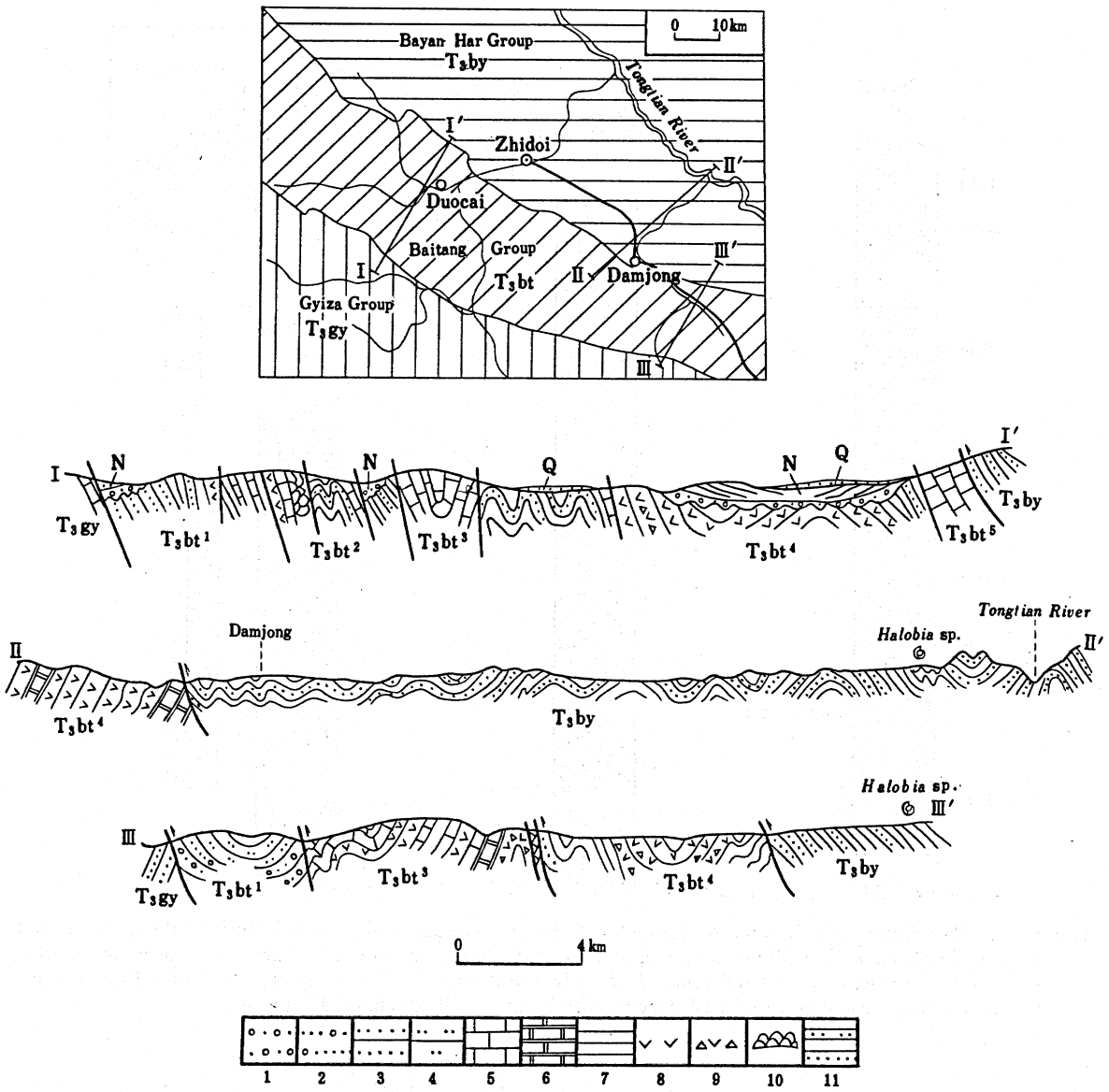

FIGURE 13. Sections of the Baitang Group in Duocai–Damjong, Zhidoi County, Qinghai Province. 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4 Siltstone; 5. Limestone; 6. Marble; 7. Shale and slate; 8. Andesite; 9. Volcanic breccia; 10. Pillow lava; 11. Flysch.

Group; it has yielded late Triassic brachiopod, bivalve, coral, ammonoid and gastropod faunas of Tethyan type (Zhao Rongli 1982). The Group contains enormous amounts of volcanics and outcrops around Damjong–Duocai in Zhidoi County, where it was surveyed by some Chinese stratigraphers after the Joint Geotraverse (figure 13).

At Duocai (figure 13, I–I′), the Baitang Group can be subdivided into five suites separated from each other by faults; the first four of these occur in the Songmorong–Yangzhilong section at Damjong village (figure 13, III–III′). These sections suggest that the volcanic component increases and carbonates decrease eastwards (figure 14).

The five suites of the Baitang Group represent five sedimentary associations; from bottom to top and south to north: (1) variegated clastic; (2) intermediate-basic volcanic (including

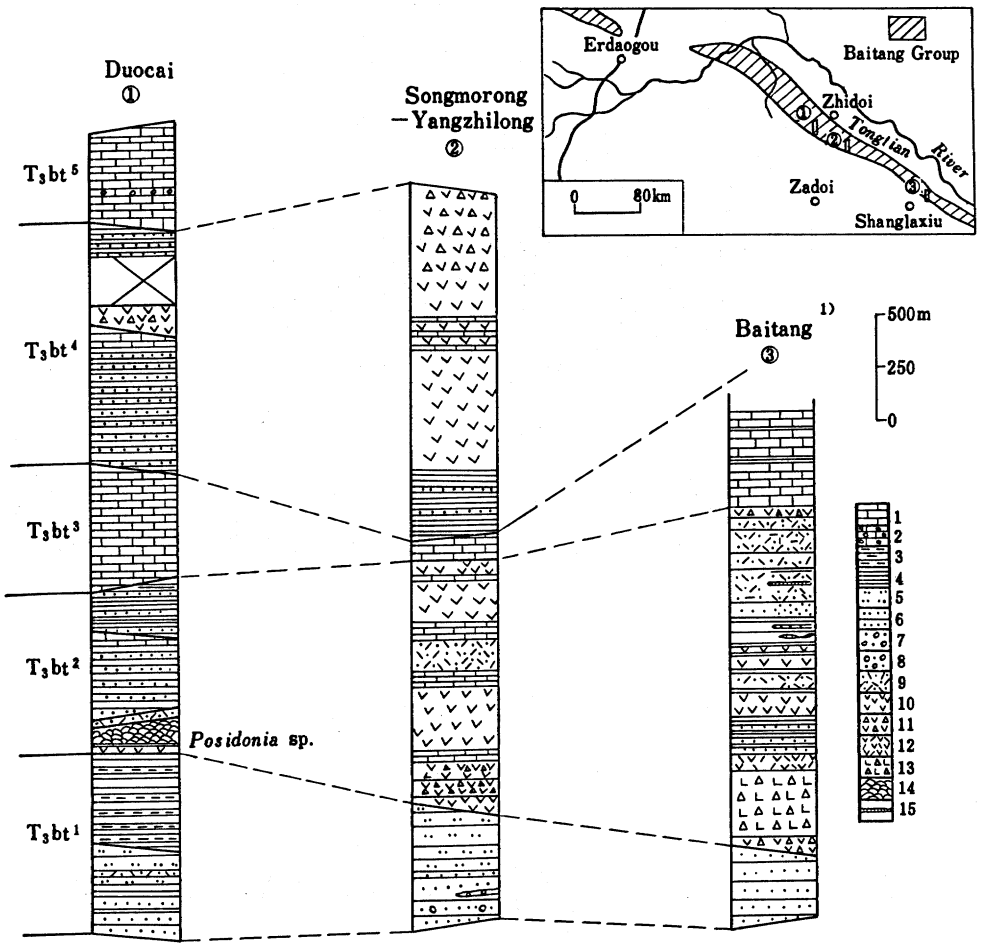

FIGURE 14. Correlation of columnar sections of the Baitang Group in the Zhidoi–Yushu subregion. 1) Ref. Shanglaxiu Sheet. 1. Crystalline limestone, limestone; 2. Oolitic limestone; 3. Calcareous mudstone; 4. Shale and slate; 5. Siltstone; 6. Sandstone; 7. Pebbly sandstone; 8. Conglomerate; 9. Tuff; 10. Andesite; 11. Intermediate-acidic volcanics; 12. Dacite; 13. Basalt; 14. Pillow lava; 15. Jasper.

pillow lavas); (3) carbonate; (4) intermediate-acidic and flysch; and (5) carbonate. 'The southern volcanic rock belt' (association 2) extends along the strike to the Baitang district south of Yushu, while the 'northern volcanic rock belt' (association 4) extends along strike to Chumda, north of Yushu, and joins with the 'Ophiolite–island arc complex belt'. Chemical analyses (85YR16a, 85YR18) indicate that the calc-alkaline pillow lavas of association 2 are comparable with island arc volcanics (Zhao Rongli 1982).

Flute casts and graded bedding are found in the greywackes of suite 4. The angular and ill-sorted lithic clasts are composed mainly of volcanics and subordinate chert indicating that they were deposited rapidly near the source region. The carbonates of suites 3 and 5 are made up mainly of micritic bioclastic limestone and a little oolitic limestone. They yield numerous bivalves and brachiopods at some horizons and display platform and platform-margin slope facies. Judging from the alternating layers of lower neritic clastics passing up into submarine basic lava, platform carbonates and sandstone and slate of flysch facies, it appears that the Baitang Group was deposited in a mobile tectonic setting. Widespread intrusions of grano-

diorite and the occurrence of a few small ultrabasic and gabbro bodies suggest that the Baitang Group represents a late Triassic mature island arc.

The outcrop of the upper part (suites 4 and 5) of the Baitang Group at Damjong widens gradually eastwards to 20–40 km around Chumda–Xiwu north of Yushu. Here the rocks have undergone low grade metamorphism. The thickness of the volcanics is over 2500 m. There are more than ten small tectonic lenses of ophiolite, mainly serpentinite, gabbro and pillow lava and basic dyke swarms, such as the ophiolites in Gala village, only 150–200 m in width. The ophiolites are commonly intruded by granodiorites, granites and quartzose diorite. This series extends southeastwards to the Garze and Litang areas of western Sichuan Province, joining the ophiolitic melange of MORB type there (Jiang Yaoming 1984). The authors interpret these ophiolitic associations as an 'Ophiolite–island arc complex belt' rather than as another stratigraphic unit as some authors have suggested.

Thus the rocks exposed in the Zhidoi–Yushu region where the 'Litian Lake–Jinsha Suture Zone' passes through vary greatly in lithology, metamorphism and tectonic deformation and form a complicated collision zone (figure 15).

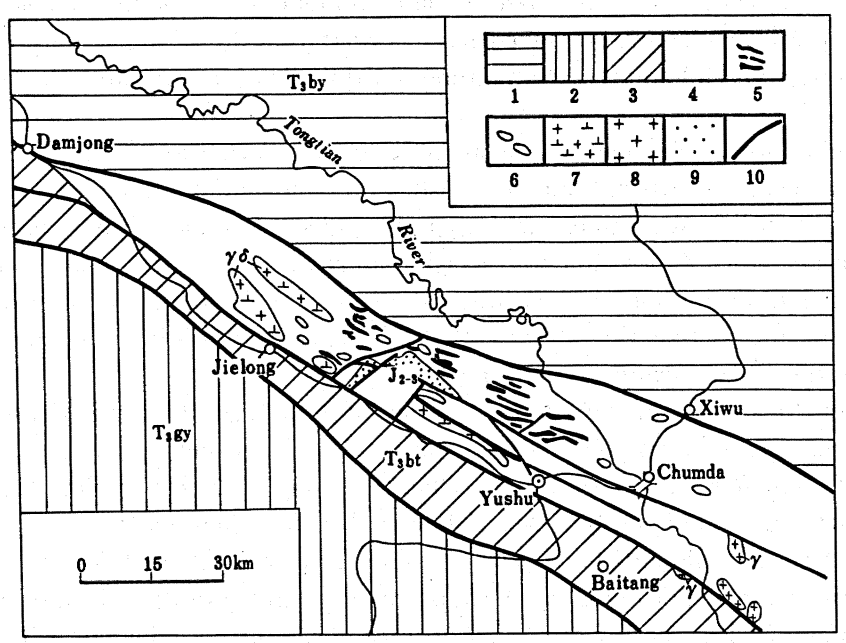

FIGURE 15. Sketch map of the ophiolite-island arc complex belt in Damjong–Yushu. 1. Bayan Har Group (T_{3by}); 2. Tuotuoheyan–Ziqu fold zone (Middle–Upper Triassic and part of the Palaeozoic sediments); 3. Southern volcanic rock belt of the Baitang Group; 4. Ophiolite-island arc complex belt; 5. Diabase dykes; 6. Ultramafic rock (or ophiolite); 7. Granodiorite; 8. Granite; 9. Yanshiping Group (J_{2-3}); 10. Fault.

(ii) *Tuotuoheyan–Ziqu Subregion*

The Gyiza Group (Middle and Upper Triassic) is intermittently exposed between Wuli and Yanshiping. At Zakongjian, 30 km southeast of Wuli, the variegated clastics of the Dongmaolong Formation and the Xiaoqiaco Formation carbonates are exposed. These are equivalent to the lower and middle parts respectively of the Gyiza Group (the stratotype) south of Yushu. The Dongmaolong Formation, 630 m thick, rests unconformably on the Lower Permian

volcanics. Its lower part consists of fluvial pebbly sandstone, coarse lithic quartzose sandstone and grey conglomerate. The clasts are of quartzite, andesite, tuff and cherts originating from the island arc to the north. The upper part consists of dark calc-alkaline to alkaline purple andesites and basalts, chemically similar to those of the Baitang Group. The conformably overlying Xiaoqiaco Formation, over 370 m thick, is covered by Tertiary red beds. This comprises grey medium- to thick-bedded limestone with chert bands in the lower part and bioclastic limestone above. Late Triassic fossils (brachipods, bivalves, foraminifers, conodonts, crinoids etc.) indicate a mid Norian age (loc. B67).

The Gyiza Group (Middle to Upper Triassic) outcrops in the Ziqu River Valley, southern Yushu, south of the Geotraverse route, where it reaches over 4000 m in thickness. The lower Dongmaolong Formation of purple clastics with inter-layers of iron-bearing deposits, carbonaceous shale, thin-bedded limestone and gypsum yields fossil plants and marine bivalves. Such Anisian ammonoids as *Balatonites gracilis* Arthaler, *Paraceratites trinodosus* (Mojs.) and Anisian to Ladinian bivalves, foraminifers and brachiopods collected from the Dongmaolong Formation (Chen Chuzhen, personal communication) indicate a complete Middle Triassic sequence. The upper Dongmaolong Formation yields early Carnian brachipods, bivalves, foraminifers, etc. (Ma Fubao *et al.* 1984). The Carnian–Norian ammonoids *Trachyceras* cf. *aon* (Munster), *Tropites* sp. and *Pseudocardioceras* sp. have been recorded from the Xiaoqiaco Formation, which is mainly composed of dolomites and limestones representing platform and platform-marginal slope facies.

The Jiagenda Formation, conformable on the Xiaoqiaco Formation, is composed of alternate terrestrial–marine coal-bearing clastics, bioclastic limestones and intermediate-acidic tuffs. The sandstone and shale are intercalated with gypsum and show shallow water ripple-marks and cross-bedding near the 'Zadoi oldland' (Ma Fubao *et al.* 1984; Zheng Yanzhong 1984).

The Tumaingela Formation on the southern slope of the Tanggula Mountains is composed of terrestrial–marine coal-bearing clastics of late Triassic age and is laterally equivalent to the upper part of the Gyiza Group (Wu Xiangwu 1982).

The Anisian–Norian marine invertebrate fauna from the Gyiza Group is Tethyan while the *Clathropteris meniscioides–Pterophyllum minutum* plant assemblage belongs to the *Dictyophyllum–Clathropteris* Norian flora of South China (Chen Guolong *et al.* 1982; Yin Hongfu & Ling Qiuxian 1986; Wu Shunqing 1983; Ma Fubao *et al.* 1984) (figure 16).

No Lower Triassic sediments have yet been discovered in southern Qinghai. The Middle–Upper Triassic sediments of the Gyiza Group are very similar to those in the Burhan Budai Mountains (Kunlun Terrane), overlapping or unconformable on older rocks. They represent back arc deposits related to tensional tectonics.

(*c*) *Lhasa District, Lhasa Terrane*

Fossiliferous Triassic sediments in the Lhasa Terrane are found at Quesangwenquan in Doilungdeqen County and at Mailonggang and Qibunong in Lhunzhub County. The East Hill section of Quesangwenquan provides the best exposures. Despite previous work on this section (Chen Guoming *et al.* 1980; Sun Dongli *et al.* 1981; Gu Qingge *et al.* 1980), the classification, age and lithological description are still confused. Based on the observations of Yin Jixiang and Sun Yiyin in 1981 and fieldwork during this Geotraverse, the following sequence has been deduced from this section (figure 17).

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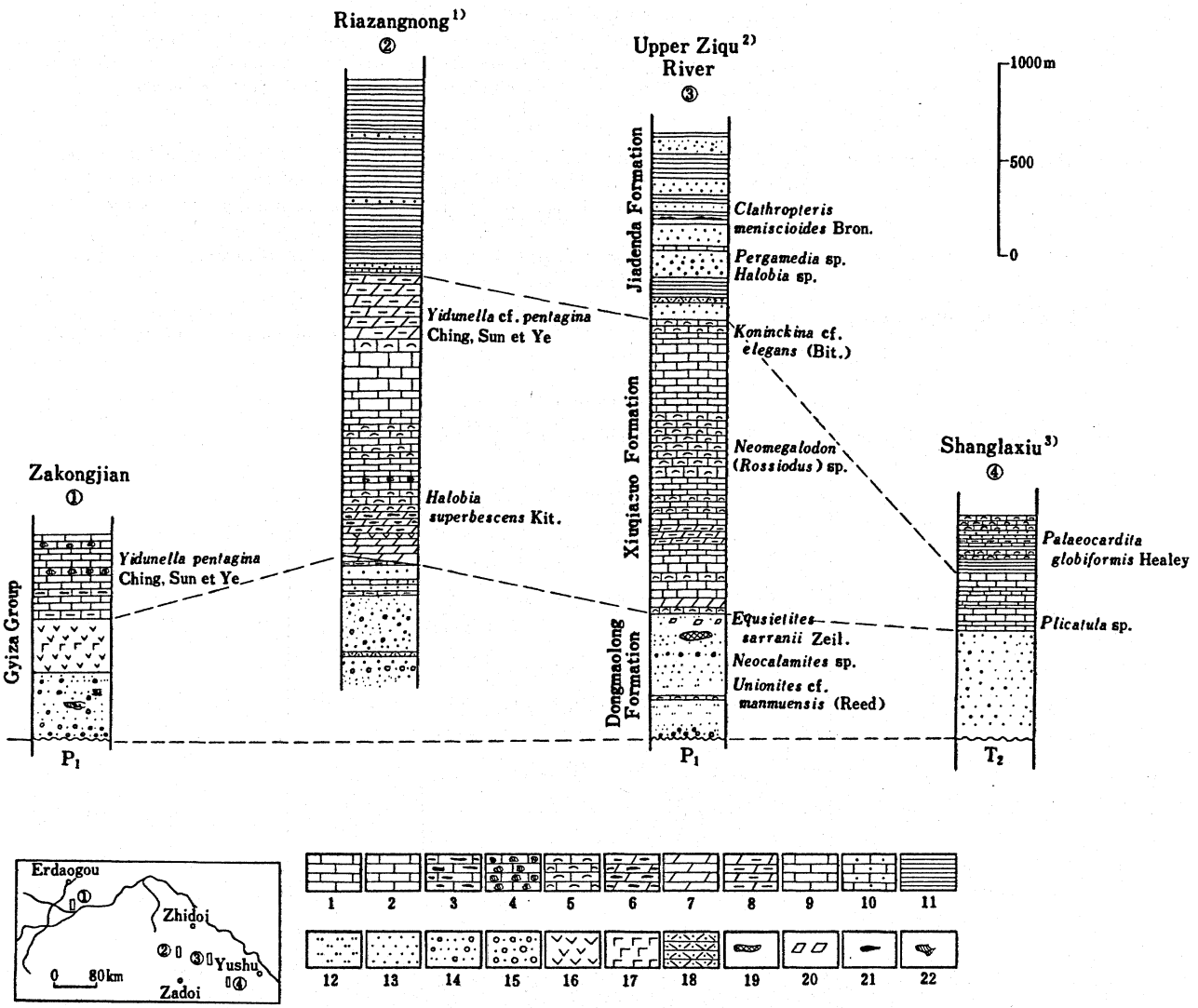

FIGURE 16. Correlation of the Gyiza Group in the Tuotuoheyan–Zadoi region. 1) After Zhidoi County Sheet; 2) After Zadoi County Sheet; 3) After Shanglaxiu Sheet. 1. Limestone; 2. Argillaceous limestone; 3. Banded chert limestone; 4. Shelly limestone: 5. Bioclastic limestone; 6. Banded chert dolomite; 7. Dolomite; 8. Dolomitic limestone; 9. Marble; 10. Arenaceous limestone; 11. Shale and slate; 12. Siltstone; 13. Sandstone; 14. Pebbly sandstone; 15. Conglomerate; 16. Intermediate volcanics; 17. Basic volcanics; 18. Tuff; 19. Iron Formation; 20. Gypsum; 21. Coal; 22. Cross-bedding.

Overlying strata: Jurassic sandstone and conglomerate (Quesangwenquan Formation)

Unconformity

'Yeba Formation' (T_3):

Ferruginous, chamosite-cemented sandstone and thin-bedded sandstone with plant fragments (13 m thick) in the lower part: variegated andesite, altered andesite basalts with basic tuff, brecciated basalt and tuffaceous pebbly sandstone interlayers in the middle and upper parts.

Paraconformity

Chaqupu Group (T_{1-2}):

Upper Formation (T_2^2): Intermediate-basic welded breccia in the lower and middle parts with haematite lenses at the base, 66 m thick; medium- to thin-bedded limestone, oolitic lime-

stone interlayered with banded shelly limestone and arenaceous shale in the upper part yielding bivalves, gastropods and crinoids; bivalves:? *Leptochondria* cf. *michaeli* Assman, ? *Pseudocorbula* sp., *Myophoriopsis* aff. *lineata* (Munster), *Modiolus* sp., *Myophoria* (*Costatoria*) *curvirotris* Schlotheim emend. Seeb, *Entolium* sp.

Paraconformity

Middle Formation (T_2^1): Medium to thick-bedded grey limestone with layers of argillaceous limestone, altered tuff, with 5 m thin-bedded altered volcanics at the base, yielding crinoids, ammonoids, brachiopods and bivalves from the argillaceous limestone; Bivalves:? *Lima* sp. aff. *L. tarnowitzensis* Assmann, *Myophoria* (*Elegantinia*) sp., *M.* (*Neoschizodus*) *laevigata* (Zeithen), *Entolium subdemissum* (Munster), *Pleuromya* cf. *fassaensis* Wissm., *Plagiostoma* sp. 81 m.

Lower Formation (T_1): 1.7 to 2 m thick arenaceous limestone intercalated with epidotic marble at the base and brachiopod-bearing limestone and oolitic limestone in the middle and upper parts. 125 m.

Conformity

Underlying strata: Upper Permian Sandstone (Lielonggou Formation)

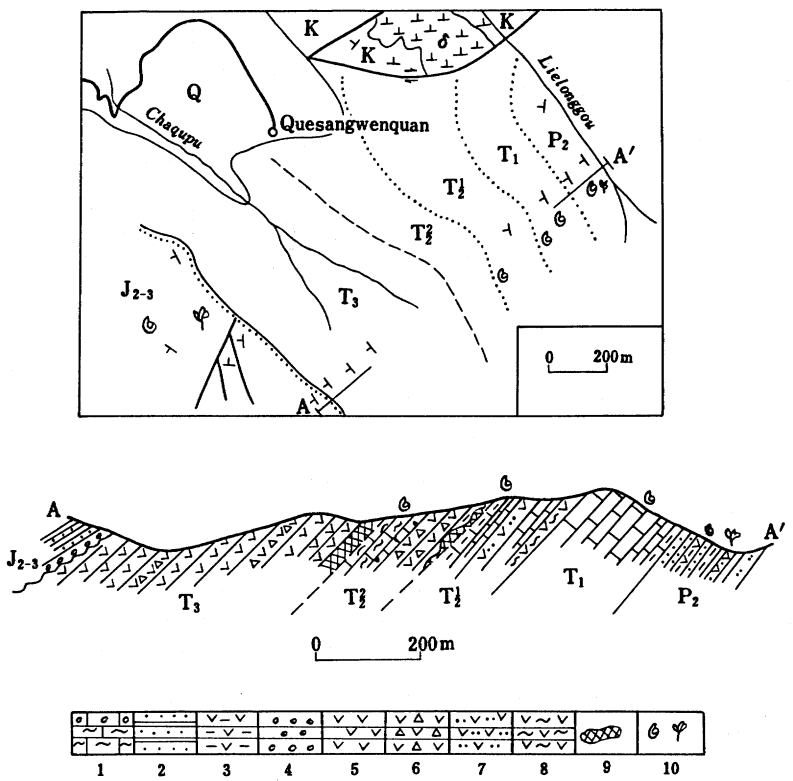

FIGURE 17. The Triassic section at Quesangwenquan in Doilungdeqen County. 1. Oolitic and shelly limestone; 2. Alternating siltstone and arenaceous shale; 3. Tuffaceous mudstone intercalated with altered andesite and andesitic basalt; 4. Conglomerate; 5. Intermediate-basic lava, tuff and volcanic breccia; 6. Intermediate-basic welded breccia; 7. Altered ignimbrite; 8. Altered volcanics – 'greenstone'; 9. Hematite lens and ferruginous sandstone; 10. Fossil localities.

Fossils previously reported from the Lower Triassic in the Himalayas and the Far East Coastal Province of the U.S.S.R. were collected from the limestones of the Chaqupu Group, such as the brachiopods *Neowellerella lielonggouensis* Sun, *Abrekia chaqupuensis* Sun, *Paranorellina duilongdeqingensis* Sun, the conodont *Neospathodus homeri* (Bender) and the gastropod *Natica* cf. *subtilistriata* Frech (Sun Dongli *et al.* 1981). Anisian brachiopods and ammonoids have been

collected from the middle Chaqupu Group; this assemblage resembles the late Anisian Palaeotethyan ammonoid fauna of northern Tibet and the Alps more closely than the Neotethyan ammonoid fauna of the same age in the Himalayas (Gu Qingge *et al.* 1980). Most fossils from the upper formation are Middle Triassic genera, only *Myophoriopsis* aff. *lineata* is similar to *M. lineata* commonly seen in the Ladinian in Europe. These bivalve-bearing strata could be Ladinian as the underlying strata are late Anisian. The volcanics of the 'Yeba Formation' are interposed between fossil-bearing Middle Jurassic sandy conglomerate and the Chaqupu Formation, so a late Triassic age is ascribed to them. Similar volcanics are found near Dagze. The Multidisciplined Survey of the Bureau of Geology and Mineral Resources of Tibet named them the 'Yeba Formation' in 1979 based on the sequence observed at Yeba. The Yeba Formation is deduced to be late Triassic since it is unconformably capped by Jurassic limestone and *Thecosmilia* was found from strata equivalent to the lower part of the Yeba Formation elsewhere in the Lhasa region. Chinese and French geologists previously took the Yeba Formation to be Upper Cretaceous because they believed it to be faulted against the overlying Upper Jurassic Duodigou Formation and to rest conformably on the Lower Cretaceous (Wang Naiwen 1983). As the relations of the volcanics are still obscure and the volcanics may be of different ages, further study is needed. However, palynomorphs indicate a late Carboniferous or Permian age.

10. Jurassic

Fossiliferous marine Jurassic strata are restricted to the Qiangtang and Lhasa Terranes. The Kunlun Terrane was mountainous during Jurassic times: a small amount of coal-bearing clastics was deposited in fault basins.

(*a*) *The Southern Mountain of Xidatan, Kunlun Terrane*

The coal-bearing strata of the abandoned coal mine near Xidatan in the Bayan Har subregion form a 65 m thick and 1 km long wedge-like slab which is bounded by faults and surrounded by the Lower Bayan Har Group. The clastics contain five or six layers of poor-quality coal seams (about 10 cm thick) containing early to mid Jurassic plant fossils, such as *Eborasia lobifolia* (Phillips) Thomas and *Ciliatopteris pectinata* Wu (see Naij Tal Sheet).

(*b*) *Yanshiping–Amdo Region, Qiangtang Terrane*

From Yanshiping south to Amdo, Jurassic strata are dominant, forming a synclinorium centred on the Tanggula Mountains. Despite previous studies of this area (Sun Dongli & Zhang Binggao 1979; The Compiling Group of Charts of Stratigraphical Units Sequence of Qinghai 1980; Li Guangcen & Lao Xiong 1982; Jiang Zhongti 1983), the classification, correlation and age of the units are still confused. Here we assign the 'Yanshiping Group' to the suite of alternating terrestrial/marine molasse on the basis of the data published in the Stratigraphical Charts of Qinghai Province.

Based on field observations at Wenquan and data from Jiang Zhongti (1983), the Yanshiping Group is divided into five suites, in which four clastic-carbonate rhythms are observed (figure 18). The total thickness attains 5021 m. For a detailed sedimentological description, see Leeder *et al.*, this volume. The sequence in ascending order is as follows.

Suite 1 (1000 m). This is truncated by a fault at the bottom. The lower and middle parts are

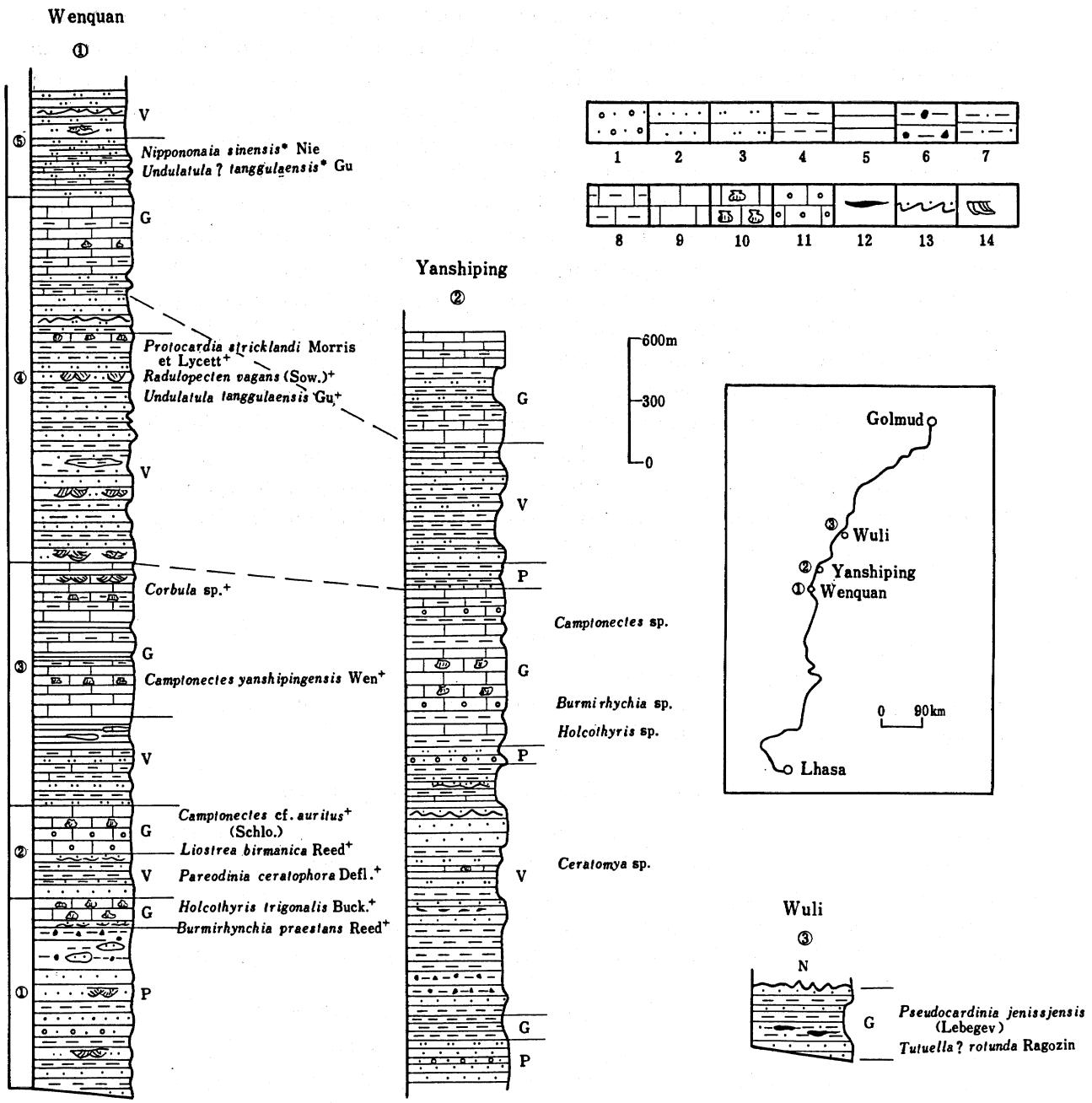

FIGURE 18. Correlation of the Jurassic on the northern slope of the Tanggula Mountains. ① and ② Modified from the 'Wenquan Section' and the 'Yanshiping Section' by Jiang Zhongti (1983, pp. 92–96). 1. Conglomerate; 2. Sandstone; 3. Siltstone; 4. Mudstone; 5. Shale; 6. Clay-boulder mudstone; 7. Arenaceous shale; 8. Muddy limestone; 9. Limestone; 10. Bioclastic and shelly limestones; 11. Oolitic limestone; 12. Coal seams; 13. Ripple marks; 14. Cross-bedding.

purplish-red mudstone, siltstone interbedded with sandstone and conglomerate lenses (888 m). Cross- and convolute-bedding are very common in the sandstone and the palaeocurrents were southwards. The upper part is composed of fossiliferous limestone, argillaceous and shelly limestones, 122 m thick (loc. B57).

Suite 2 (437 m). The lower part is composed of variegated sandstone, arenaceous mudstone

and shale with dinoflagellates (loc. B58, lower shales) (184 m) with asymmetrical current ripple marks on the sandstone surfaces. The upper part is of oolitic limestone, shelly limestone and mudstone (253 m). Both are fossiliferous (loc. B58).

Suite 3 (1191 m). The lower part, 445 m thick, is composed of interbedded variegated sandstone, arenaceous shale and mudstone with thin-layered argillaceous limestone bands. Some cross-bedding and a few plant fragments are found in the red siltstone; the upper part, 746 m thick, consists of grey bioclastic and arenaceous limestone; some cross-bedding, wave-ripple marks and storm flow rollers are found in the medium-thick bedded limestone at the top. Palaeocurrents trend NW 320°. Fossil bivalves were collected from the limestone in the upper part (loc. B58, beds 37–45).

Suite 4 (1135 m). The lower part (472 m) consists of interbedded variegated arenaceous shale and siltstone with intercalations of mudstone and thin-bedded bioclastic limestone. The upper part, 663 m thick, is composed of limestone, marls and bioclastic limestone with siltstone and mudstone intercalations bearing fossil bivalves (loc. B58).

Suite 5 (599 m). The lower part is dominated by grey siltstone interbedded with micrites, while the upper part is brown and grey bivalve-bearing siltstone and fine sandstone intercalated with argillaceous siltstone.

The bottom of the Yanshiping section is covered but it is assumed that the Jurassic unconformably overlies the Middle and Upper Triassic Gyiza Group. Cupreous intermediate volcanics are intercalated in the red clastics in the lower part of the Yanshiping Group south of Yanshiping.

The Yanshiping Group on the northern slope of the Tanggula Shan is composed mainly of fine-grained clastics with channel sandstones and conglomerate lenses with abundant well-preserved shallow-water structures, such as cross-bedding, mud cracks and ripple marks. The carbonates are mainly bioclastic, shelly and oolitic limestones with some cross-bedding and storm flow rollers. These structures suggest that the Yanshiping Group was rapidly deposited in terrestrial, littoral and neritic environments.

The carbonates of the Yanshiping Group on the southern slope of the Tanggula Mountains are much thinner than those on the northern slope. The rhythmic clastics and carbonates seen in the Yanshiping and Wenquan sections are less evident on the southern slope. North of 114th Highway Maintenance Squad, the strata are mainly variegated red/grey clastics whereas further south the dominant rocks are limestones interbedded with grey clastics, implying increasingly marine conditions southwards.

Li Guangcen & Lao Xiong (1982) noted that the Jurassic in the Wenquan region is more than 5375 m thick, and thins both southwards and northwards, implying that this was the area of maximum subsidence. Changes in thicknesses of carbonate units, palaeocurrents and the thickness of the Yanshiping Group support the assumption that a Jurassic elevated belt of Palaeozoic strata in the present Tanggula Mountains area (from Wenquan to Amdo) influenced the adjacent sedimentary basins. It is concluded that the Yanshiping Group represents an overlapping sequence of foreland and neritic sediments in a paralic molasse basin at the northern margin of the Neotethys.

The age of the Yanshiping Group is mid- to late Jurassic. The lower part of Suite 2 in the Wenquan section yields dinoflagellates including *Pareodinia ceratophora*, a typical widely distributed Bajocian/Bathonian species, whereas the abundant brachiopod and bivalve fossils from Suites 1, 2 and 3 exhibit noticeable endemic features, i.e. most of the genera and species

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are also elements of the Liuwan Formation in Western Yunnan and the Namyau series in North Burma, both mid-Jurassic. This represents a biogeographical subprovince at the northern margin of East Tethys during the Jurassic (Yin Jixiang & Fang Zhongjing 1973; Reed 1936; Buckman 1917). The abundant non-marine bivalves of Suite 4 are also found in the Upper Jurassic of Sichuan and Yunnan Provinces. Furthermore, *Peregrinoconcha*, reported from this formation (The Compiling Group of 'Bivalve Fossils of China' 1976; Zhang Zuoming *et al.* 1980) is typical of the 'Jingxing Fauna' of Yunnan; this fauna is generally taken as late Jurassic or late Jurassic/early Cretaceous. When discussing the age of the Yanshiping Group, Sun Dongli & Zhang Binggao (1979) noted the occurrence of the freshwater bivalves *Nippononaia sinensis* Nie and *Undulatula tanggulaensis* Gu in strata equivalent to Suite 5 of the Yanshiping Group. *Nippononaia sinensis* Nie is a key element of the Upper Jurassic fauna in western Liaoning Province. Thus the existence of the Upper Jurassic in the Yanshiping Group is certain. In the Wenquan area, Suites 4 and 5 are characterized by the *Undulatula* Fauna of late Jurassic age.

Four km west of the highway at Wuli, non-marine Jurassic bivalves were collected (loc. B64) from a coal series previously taken to be late Permian. From a section at Yanshiping, many individual bivalve fossils were also collected (loc. B56). Combined with the bivalve fossils *Lamprotula* (*Eolamprotula*) *cremeri* (Frech) and *L.* (*E.*) *subquadrata* Gu found in the Wenquan area (The Compiling Group of 'Bivalve Fossils of China' 1976, pp. 315–316), these fossils belong to the *Lamprotula* (*Eolamprotula*)–*Pseudocardinia* fauna widespread in Asia during the Jurassic.

The shales on the eastern bank of the Jiebu River, south of Tanggula Shan, yield dinoflagellates and the argillaceous limestone 80 m above this yields abundant poorly preserved ammonoids (loc. B50). The age of the dinoflagellate *Pareodinia ceratophora* from Suite 2 in the Wenquan section is early Bajocian. The ammonoid *Stephanoceras* is Upper Bajocian (i.e. the 'Middle Inferior Oolite' of Britain), hence, both fossil-bearing beds are Bajocian (but see loc. B60). The strata beneath the dinoflagellate-bearing beds are covered; ammonoid-bearing beds pass gradually up into medium- to thin-bedded limestones yielding Bathonian brachiopods and bivalves (loc. B51). In 1961, Yin Jixiang collected bivalves and gastropods of Bathonian age from the same limestone: *Astarte subcardiformis* Fan, *Protocardia lamellosa* Fan, *Grammatodon minutus* Fan, *Trigoria* sp. (Fan Jiasong 1965). These strata are however reported to yield late Jurassic ammonoids (Jiang Zhongti 1983). Bathonian brachiopod and bivalve fossils were also collected 4 km southwest of 114th Highway Maintenance Squad (loc. B49).

(*c*) *Lhasa Region, Lhasa Terrane*

The Jurassic may be divided on facies into three subregions, which are, from north to south: the Dongqiao–Nagqu Subregion, the Doilungdeqen–Lhunzhub Subregion and the Sangri Subregion.

(i) *Dongqiao–Nagqu Subregion*

The subregion is bounded to the north by the Banggong–Dongqiao–Nujiang fault zone which separates it from the Qiangtang Terrane. However, lithostratigraphical features seem to be transitional across this boundary. The southern boundary is a line from Qilingco–Duoba–Senco–Jiuzila–Sangba (i.e. the northern marginal fault of the Nyainqentanglha Shan). The Jurassic in this region is intensely deformed constituting a synclinorium with destroyed limbs. The lithofacies changes notably, both across and along strike; it is associated with

ophiolites. The stratigraphy is complicated and despite several geological surveys and the discovery of early to late Jurassic fossils, the basic stratigraphy remains uncertain (Li Pu 1955; Wang Mingzhou & Cheng Liren 1980; Jiang Zhongti 1983; Han Tonglin 1983, 1984; Wang Naiwen 1983, 1985).

The early Jurassic fossiliferous strata are restricted to a small, narrow area from the Lunpola Basin eastward to the east of Amdo in the northern part of the subregion. Early and middle Jurassic ammonoids and bivalves were collected from the grey argillaceous limestone, shale and nodular shale in the 'Zhamunaqu' (the present 'Raoqinlongbaqu') section, 19 km northeast of Amdo (loc. B45). The fossiliferous strata are 200–300 m thick and situated on the southern limb of a syncline; they grade gradually upward into shale and bioclastic limestones. *Grammoceras* is a zone indicator of the European Toarcian stage (Yeovilian of Britain), and *Soninia* (*Soninia*) a zone indicator of the Upper Bajocian ('Middle Inferior Oolite' of Britain), suggesting that the fossiliferous strata are upper Lower Jurassic to lower Middle Jurassic. The bivalve *Hippopodium ponderosum* (Gu Zhiwei 1982) and the ammonoids *Giveliceras* and *Arnioceras* (Jiang Zhongti 1983), zone fossils of the European Sinemurian stage, are an earlier fauna, from a horizon probably lower than that from which fossils were collected during the 1985 Geotraverse.

The Sinemurian ammonoids *Baucaulticeras* cf. *baucaultianum* (d'Orbigny), *Angulticeras* cf. *lacunatum* (Backman) and the fossil plant *Cladophlebis* sp. were recorded (Wen Shixuan 1984) from pelites and shales at the northern and southern margins of the Lunpola Basin, 60 km west of Dongqiao. These neritic sediments are a westward extension of the Lower Jurassic from the northeast of Amdo. The underlying strata are concealed; upwards these strata cannot be distinctly separated from the Middle Jurassic fossil-bearing strata.

The flysch series widely distributed in the lake region from Dongqiao to Jang Co has been variously named (Wang Mingzhou & Cheng Liren 1980; Wang Naiwen 1983). These names are abandoned here because there are no appropriate stratotype sections and the precise timing for these units is uncertain. Here the name 'Lake Area Flysch' is temporarily substituted for the previous names.

Some pillow lavas dipping southwestward crop out at Luobuzhong Hill 8 km southeast of Dongqiao and grade upward into a flysch sequence, both being intensely deformed. Grading in the flysch in Erong valley south of Luobuzhong Hill suggests the sequence near the lava is inverted. A detailed sedimentological description is given by Leeder *et al.*, this volume.

The transitions from volcanoclastic and argillo-calcareous to arenaceous-argillaceous flysch, and from pelitic to neritic bioclastics upwards to terrestrial clasts represent environmental changes from pelagic to continental slope. The occurrence of olistostromes implies a steep slope and unstable sedimentary environment.

The 'Lake Area Flysch' elsewhere is composed of intercalations or lenses of limestone turbidites, intermediate-basic volcanics, fine-grained conglomerates, pebbly sandstones, and neritic bioclastic limestones attaining a thickness of over 4000 m.

The argillaceous graywacke on the northern bank of Jang Co yields abundant orientated gastropods and other fossils showing a southward palaeocurrent (loc. B32). The strata, previously regarded as Triassic, yield the coral *Stylosmilia* (Middle Jurassic to early Cretaceous). The faunal assemblage indicates these strata are Upper Jurassic.

From the slate and limestone in the west hill of Murong, Jiaqiong village at the western bank of the Daru Co, previous workers have collected Middle Jurassic bivalves: *Inoceramus* cf. *kudoi*,

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Protocardia cf. *hepingxiangensis*, *P. strichlandi*, *Astarte* sp., *Camptonectes* (*Camptonectes*) sp., *Grammatodon* (*Indogrammatodon*)? sp. Late Jurassic fossils found in limestone interlayers north of the Luoertai–Regala area, southeast of Luobuzhong, include hexacorals, hydroid stromatopora: *Enallhelia*? sp., *Microsolena agariaformis*, *Epismilia*? sp., *Actinarea* sp., *Spongiomorpha* (*Heptastylopsis*) *asiatica*, *Parastromatopora delicata* (Wang Mingzhou & Cheng Liren 1980). In the limestone 3 km north of 26th Highway Maintenance Squad (E 91° 47′, N 31° 43′) north of Nagqu, the top Jurassic gastropod assemblage *Nerinea*, *Nerinella*, *Ptygmatis* and *Pseudomelania* was found (Yin Jixiang 1964). Late Jurassic ammonoids *Himalayites*, *Pseudocadoceras*, *Lilloetia*, the gastropod *Aptyriella* and some bivalves were found at Guishan (Jienu) on the northern bank of the Xiaqiong Co (Liao Weihua & Chen Tingen 1984). The above fossils found at various localities in the lake area verify that the 'Lake Area Flysch' is of mid-late Jurassic age. North of Dongqiao, there is a series of ophiolitic clastic rocks. A limestone sequence unconformably overlying the ophiolites yielded late Jurassic to early Cretaceous plant fossils, stromatopora and bivalves (Wang Mingzhou & Cheng Liren 1980; Wen Shixuan 1984). Hence, the upper age limit of the 'Lake Area Flysch' should be earlier than late late Jurassic.

The lithofacies of the 'Lake Area Flysch' changes remarkably eastward towards the upper Nujiang River. Fossiliferous Middle Jurassic with a red conglomerate at the base overlies the Amdo Schists and the Upper Triassic (Tumaingela Formation). The upper Middle Jurassic, 1130 m thick, comprises oolitic limestone, mudstone and bioclastic limestone interlayered with andesite and volcanic breccia without flysch structures. The base of the Upper Jurassic consists of red and grey conglomerates and granitoid conglomerates, also resting on Amdo schists and the Middle Jurassic northwest of Xiaqiuka. The middle and upper parts are arenaceous slate interlayered with nodular slate, fine conglomerate and pebbly sandstone of flysch facies. The late Jurassic ammonoids *Virgatosphinctes*, *Aspidoceras* and *Berriasella* are reported from the nodules. The Upper Jurassic is more than 2300 m thick (Han Tonglin 1983).

(ii) *Doilungdeqen–Lhunzhub Subregion*

This subregion is separated from the Sangri subregion to the south by a line between Doilungdeqen and Lhasa. The Jurassic here lies in three roughly E–W trending belts. The northern belt runs from the southeast of Nam Co–Deqen, east through Doilungdeqen County, passing south of Nam Co to Sangba; the middle and southern belts lie north and south of the Cretaceous red bed basin north of Lhasa. The middle and northern belts are separated by the Carboniferous–Permian and Nyainqentanglha metamorphic rocks.

The Jurassic in the northern belt is well developed near Deqen. According to Han Tonglin (1983, 1984), the unfossiliferous lower part, 1200 m thick and unconformable on Permian, consists of basal conglomerate, tuffaceous and pebbly sandstone. The middle part, 800 m thick, comprises intermediate-basic volcanics with tuffaceous sandstone, siltstone and conglomerate, yielding the ostracodes *Damonella* and *Lycopterocypris*, the foraminifers *Quinqueloculina*, *Textularia* and *Endothyranella*, the coral *Goniopora* sp., bivalves, brachipods and crinoids. The ostracodes and foraminifers from the middle and upper parts are of late Jurassic age.

The Jurassic in the middle belt, well-exposed at Quesangsi (figure 19), was studied by Yin Jixiang and Sun Yiyin in 1981 and later by the Chinese–French geologists. The lower part of the Middle Jurassic, the Quesangwenquan Formation, unconformable on Triassic volcanics, is 33 m of interbedded volcanic conglomerate. The middle part is 85 m of interbedded sandstone and shale with amygdaloidal andesite intercalations and yielded the bivalves *Protocardia* aff.

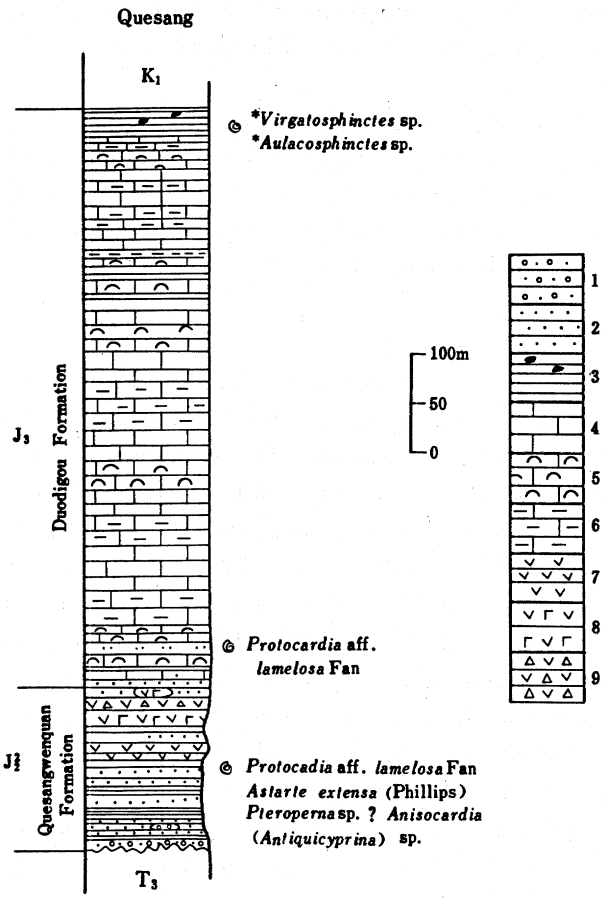

FIGURE 19. Columnar section of the Jurassic at Quesangsi. * The fossil list of ammonoids is from Wang Naiwen *et al.* (1983). 1. Conglomerate; 2. Sandstone; 3. Shale, nodular shale; 4. Limestone; 5. Shelly limestone and bioclastic limestone; 6. Argillaceous shale; 7. Andesite; 8. Andesitic basalt; 9. Volcanic breccia.

lamellosa Fan, *Astarte extensa* (Phillip), *Pleuromya* sp., *P. uniformis* (Sowerby), *Pteroperna* sp., and ? *Anisocardia* (*Antiquicyprina*) sp. The upper 40 m comprises greyish-purple and green andesite basalts and volcanic breccia. Chinese and French geologists recorded the bivalves *Astartoides dingriensis* Wen, *A. gambaensis* Wen & Lan and *Pleurotomaria spitiensis* Spitz, and also the plant fossils *Ptilophyllum* sp. and *Zamites* sp. from the Quesangwenquan Formation. The bivalves recorded commonly occur in the Upper Jurassic, e.g. *Astarte extensa* in Basu, East Xizang (Tibet), *Astartoides dingriensis* and *A. gambaensis* from the Upper Jurassic in the Mt. Qomolangma (Everest) region; *Protocardia* aff. *lamellosa* has affinity with specimens from the Bathonian at 114th Highway Maintenance Squad in the Qiangtang Terrane.

The Upper Jurassic (Duodigou Formation) is 580 m in thickness, the lower 60 m argillaceous limestone interbedded with shale, shelly limestone and fine sandstone yielding *Protocardia* sp.; the upper 468 m limestone and bioclastics with argillaceous limestone layers; the topmost beds (52 m) are nodular limestones and siltstones with minor thin-bedded limestones which gradually pass upwards into the Lower Cretaceous Linbuzong Formation. From the top shale of the Duodigou Formation, *Virgatosphinctes* sp. and *Aulocosphinctes* sp. (Wang Naiwen *et al.* 1983) indicating a Berriasian (latest Jurassic of Chinese workers, early Cretaceous of others) age, were found.

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Faulting and magmatism obscure the Jurassic in the southern belt; Duodigou Formation limestones dominate the Upper Jurassic near Lhasa. Gastropods (*Nerinea*, *Cossmannea*) and corals are recorded from them.

The primary Jurassic sequence in the subregion is basal conglomerate, interbedded sandstone shale and carbonate-shale, representing a complete transgression-regression cycle. The Jurassic thickens northwards. Flexural folds caused by sea-bottom slumping in the Duodigou limestone and volcanics in the strata equivalent to the Quesangwenquan Formation imply deposition in an unstable shallow-water environment (figure 19).

(iii) *Sangri Subregion*

This subregion is bounded by the Yarlung–Zangbo Suture Zone to the south. The fossiliferous Jurassic and the overlying inseparable Cretaceous mainly occur north of the Yarlung–Zangbo River, especially in the Oin region of Sangri and Nedong County. The Jurassic–Cretaceous beds mainly occur as caps and country rocks to the granitoids and are variably metamorphosed. A suite of andesites/quartz andesites grading into metasiltstones, hornstone skarns, marbles and calcirudites, over 650 m thick, occurs immediately north of the Yarlung–Zangbo Suture Zone east of Zetang and represents the lower part of the Sangri Group. From the marble, the Second Geological Surveying Team of Xizang Autonomous Region collected gastropods, bivalves, corals etc., among which the gastropod *Ptygmatis nodosa* Voltz is widely spread in the Kimmeridgian of Europe and *Elegantella conoidalis* Peel is also found in the Ruac Series in the Crimea, U.S.S.R. Hence, the fossiliferous strata are late Jurassic (Yang Shengqiu & Wang Huiji 1985). The Sangri Group resembles the Doudigou Formation in sequence and lithology, except that it contains enormous amounts of calc-alkali volcanics, which implies that the Sangri Group was deposited under the influence of the Gangdise island arc at the southern margin of the Lhasa Terrane.

11. Cretaceous

The marine Cretaceous in the Tibetan Plateau is restricted to the Lhasa Terrane. The Terrane is divided into three subregions.

(*a*) *Pangkog–Nam Co Subregion*

This area lies west of Nagqu in the lake region from Nam Co to Pangkog Co. Two major sedimentary facies of the early early Cretaceous are found. Firstly, terrestrial beds with marine intercalations, the Douba Formation are distributed around the southern margin of the Baingoin Basin and extend westwards to the west of Nam Co. Secondly, in the lake area north of the Bangoin Basin, the lowest Cretaceous, the Xiaqiongco Formation, is mainly composed of marine clastics and volcanics while the Langshan Formation is composed of neritic carbonates of late early to early late Cretaceous age (Ma Xiaoda 1981; Wang Naiwen 1983).

(i) *Duoba Formation*

The base of the Douba Formation on the northern slopes of Langshan Mountain in the Douba region, Baingoin County, is thrust southwestward over Tertiary pebbly sandstone. The lower part is composed of purple arenaceous conglomerate-pebbly sandstone–siltstone–mudstone rhythms. The middle part is formed of rhythms of grey or greyish-green grits–

siltstone–mudstone and the upper part of rhythms of interlayered grey or purple fine sandstone–siltstone–mudstone. The whole sequence fines upward. Individual beds of the lower sandstone and conglomerate are commonly 10–15 m in thickness and 50–80 m in length with fluvial facies cross-bedding. Pebbles in the conglomerate are well-rounded and sorted and composed of mudstone, limestone, granite and occasional mafic rock. The lower part of the Duoba Formation on the southern slope of Langshan Mountain is grey sandstone and conglomerate intercalated with nodular shale. Derived *Orbitolina* are found in the calcareous sandstone. The thickness of the Duoba Formation is over 1300 m; it is faulted against the underlying Qusongbo Formation (Han Xiangtao *et al.* 1983). The Duoba Formation passes lithologically into the Xiaqiongco Formation to the north.

(ii) *Xiaqiongco Formation*

The Xiaqiongco Formation occurs in the Guiya–Raibadange–Gushan area of Xiaqiong Lake, north of Pangkog Lake, and is composed mainly of rhythmic alternations of variegated fine-grained calcareous sandstone, mudstone and quartzose sandstone interlayered with purple and green siliceous mudstone, amygdaloidal basalt and bioclastic limestone. It passes upward into the Langshan Formation. The base is covered; only some 300 m of strata can be seen. The lower part has yielded the ammonoids, *Neocosmoceras*, *Spiticeras*, *Neocomites*, *Calliphylloceras*, *Thurmaniceras*, *Killianella*, *Sarasinella*; the corals *Acrosmilia*, *Montlivaltia*, and bivalves, gastropods, foraminifers and echinoids as well as a few plant fossils such as *Zamiophyllum*. The age of the fossil-bearing beds is Berriasian–Hauterivian (Han Xiangtao *et al.* 1983; Liang Shousheng & Xia Jinbao 1983; Wang Naiwen 1983). North of Gushan, east of Xiaqiong Lake, palaeontological collections were made from equivalent beds (locs. B29–32).

(iii) *Langshan Formation*

The Langshan Formation forms the core of a syncline in the Duoba region and is composed mainly of grey limestones and biolithites with argillaceous limestone, siltstone and mudstone intercalations, up to 700–900 m thick. The upper part is absent in the section. The biolithites consist of Orbitolina limestone, rudist bioclastic limestone and calcareous algal limestone yielding abundant fossils (Zhang Binggao *et al.* 1981; Han Xiangtao *et al.* 1983; Liang Shousheng & Xia Jinbao 1983; Yu Wen & Xia Jinbao 1985). During the Geotraverse, extensive fossil collections were made (loc. B28). The nerineid (gastropod) species are all common in the Aptian of Europe and the Middle East. Most of the foraminifers are found in the Albian. If the previous identification of *Orbitolina concava* is reliable, the age range should extend to the Cenomanian (but see Smith & Xu, this volume). The bivalves and other fossils may range from early to late Cretaceous. Equivalent strata near Xungmai, Xainza County, west of Langshan Mountain, also yield *Orbitolina* (*O.*) *birmanica* associated with an Albian–Cenomanian brachiopod assemblage (Liao Weihua & Chen Tingen 1984). Since the uppermost part of the Langshan Formation is absent in the Langshan section, the Langshan Formation may extend into the Cenomanian, although the sequence may be inverted.

The Cretaceous sections along Gushan–Hongyashan and the northern bank of Xiaqiong Lake have been worked on previously but the stratigraphy is still confused. The authors agree with Ma Xiaoda (1981) that these sequences are equivalents of the Langshan Formation, because of their lithological and palaeontological similarities. The Cretaceous on the northern bank of Xiaqiong Lake is more than 1600 m thick and is composed mainly of limestone and

biolithites in the lower and upper parts, interlayered with quartzose sandstone, siltstone and bioclastic limestone in the middle part. At Hongyashan, the upper limestone is unconformably overlain by Tertiary red beds. The Cretaceous in this region yields abundant corals, brachiopods, foraminifers and echinoids, but no *Orbitolina* (foraminifera), despite its common occurrence in the Langshan Formation, which might either suggest a difference in biofacies between the two regions during Cretaceous times, or, alternatively, a different age. The limestone of the uppermost Langshan section supposedly yields rudists similar to those from the late Cretaceous in the Mount Qomolangma (Everest) region (Wang Naiwen 1983). However, the fossils associated with the rudists, especially the brachiopods *Orbirhynchia*, *Lunpolaia*, *Trochifera* and *Yuezhuella*, are very similar to those of the Langshan Formation at Xungmai southwest of the Baingoin Basin (Ye Songling & Yang Shengqiu 1979), hence the Cretaceous sequence on the northern bank of Xiaqiong Lake seems to be no younger than Cenomanian (see also Smith & Xu and Leeder *et al.*, this volume).

Around Dongqiao, a series with ophiolitic sandstone and conglomerate at the bottom, picotite-bearing sandstone, siltstone and carbonaceous shale in the lower part and interbedded bioclastic limestone and thin-bedded sandy conglomerates in the upper part unconformably overlies the ophiolites south of Zige Tang Lake. The clastics in the lower part yield the plants *Ptilophyllum*, *Podozamites*, *Cladophlebis*, *Baiera* and *Nilssonia*: the limestone in the upper part yields the stromatopora *Milleoporella*, *Milleporidium*, *Parastromatopora*, *Cladocoropus* and *Astrorhizopora*, and the bivalves *Pterinella*, *Mytilus*, *Placunopsis* and *Protocardia*. These fossils range from latest Jurassic to earliest Cretaceous (Wen Shixuan 1984; Wang Mingzhou & Cheng Liren 1980).

(*b*) *Doilungdeqen–Lhunzhub Subregion*

The Cretaceous around Lhunzhub, Lhasa region, has been studied in detail previously; the sequence is as follows.

(i) *Linbuzong Formation*

The Linbuzong Formation, of which coal-bearing terrestrial clastics form the major part, is 300–1000 m thick and conformably overlies the Upper Jurassic Duodigou Formation. In Quesangsi, it yields plant fossils (loc. B69). From the same locality, Wang Naiwen *et al.* (1983) collected *Weichselia reticulata* (Stockes & Webb) Ward and *Onchyopsis* sp. This assemblage is similar to that of the Wealden Stage in Europe and is correlatable with the plant assemblages from the Duoni Formation, Nujiang River (Duan Shuying *et al.* 1977; Li Pu 1955). Both represent fossil plant assemblages of a swamp environment along the continental margin or the central uplift region of the Lhasa Terrane.

(ii) *Chumulong Formation*

Succeeding the Linbuzong Formation, the Chumulong Formation (700–1000 m) is composed mainly of terrestrial quartzose sandstone, conglomerate with variegated arenaceous shale and some irregularly distributed andesites and andesitic ignimbrites.

(iii) *Takena Formation*

Succeeding the Chumulong Formation and overlain unconformably by volcanics of the Linzizong Formation, the Takena Formation is divided into two members, the lower Penbo

Member and the upper Lhunzhub Member. The Penbo Member, interbedded grey marine limestone, siltstone and argillaceous limestone, is 170–300 m thick. Aptian-Albian fossils such as the foraminifers *Orbitolina* (*Mesorbitolina*) *texana* (Roemer), *O.* (*Eorbitolina*) *prisca* Zhang, *O.* (*Columnorbitolina*) *tibetica* Cotter, *O.* (*Columnorbitolina*) *pengboensis* Zhang, the ammonoids *Acanthohoplites* sp., *Uhligella* cf. *chansayensia* (Jacob), *Paracycloceras*? sp., *Parahoplites* cf. *melchioris* Anthula and echinoids, gastropods, bivalves, marine vertebrates, shrimps and crabs have been recorded from it (Wang Naiwen *et al.* 1983; Chen Chuzhen & Wang Yujing 1984).

The Lhunzhub member, 600–1000 m thick, consists mainly of interbedded marine and terrestrial variegated siltstones and mudstones intercalated with argillaceous limestone, irregularly distributed andesite and ignimbrites. The bivalve *Amphidonte* reported from the argillaceous limestone is supposed to be Cenomanian in age.

(*c*) *Sangri Subregion*

The Sangri Group is developed along the southern margin of the Lhasa Terrane, immediately neighbouring the Yarlung–Zangbo Suture Zone. It is an unsubdivided Upper Jurassic to Lower Cretaceous stratigraphical unit over 4500 m thick. The principal components of the Lower Cretaceous part of the Group are rhythmic alternations of volcanics, clastics and carbonates. The volcanics pass from intermediate-basic upward into intermediate-acidic and further into acidic rocks. Bivalves, corals and gastropods are recorded from the limestone (Xu Baowen *et al.* 1982); the nerineid gastropods are similar to those from the lower part of the Langshan Formation in the Baingoin district (Yang Shengqiu & Wang Huiji 1985).

The marine Cretaceous of the Lhasa Terrane is restricted to the lake area west of Nagqu; east of Nagqu, along the middle Nujiang River, there are only Lower Cretaceous marine bands in a non-marine sequence, and further east or southeast only terrestrial Cretaceous beds crop out. The uppermost Cretaceous marine beds in the eastern part of the lake area and the Lhasa area are similar in age, i.e. Aptian to Cenomanian. The Cretaceous east of the lake area is characterised by 'platform' neritic clastics and carbonates which overlie the Middle to Upper Jurassic flysch and indicate the beginning of the decline of the Banggong Lake–Dongqiao–Nujiang River 'back-arc basin'. The Cretaceous in the Lhasa area is dominated by terrestrial deposits indicating fluvial, lacustrine or neritic environments in the central uplifted area of the Lhasa Terrane. The thick calc-alkaline volcanics associated with sediments in the Sangri area are interpreted as deposits at the frontal margin of the Gangdise magmatic island arc (figure 20).

12. Tertiary

The Tertiary in the Geotraverse region is represented by fluviatile, lacustrine and piedmont sediments. Due to the scarcity of fossils and strong deformation, it is difficult to reconstruct the morphology or recognise lateral facies changes in the Tertiary basins or correlate them. Hence the Tertiary period is the most poorly understood stratigraphically in the Tibetan Plateau. From the northern slope of the Tanggula Mountains to the Bayan Har Mountains, the Tertiary is represented by the Fenghuoshan Group and in the Nyainqentanglha Mountains southward to the Yarlung–Zangbo Suture zone by the Linzizong Formation.

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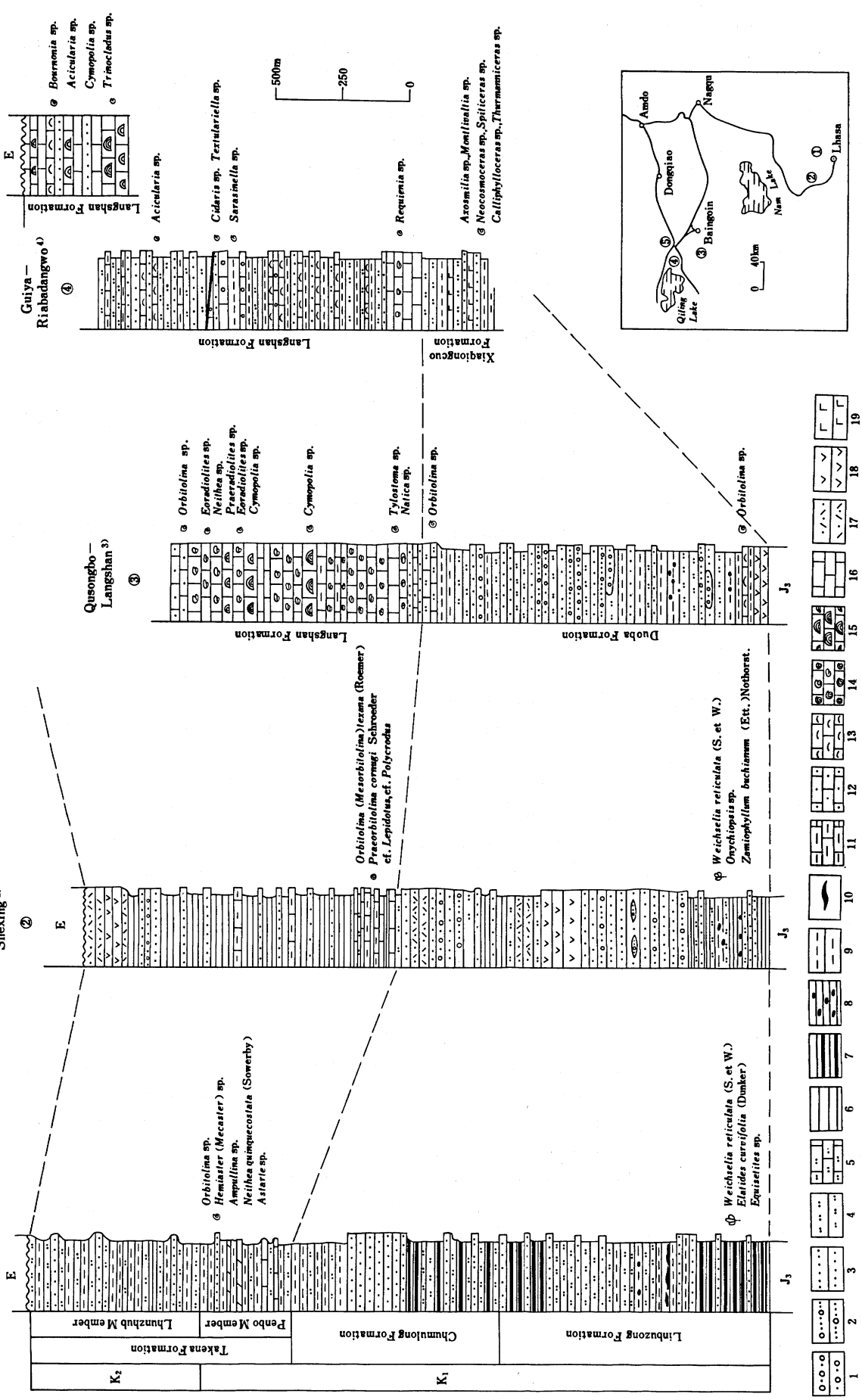

FIGURE 20. Columnar sections of the Cretaceous in the central part of the Lhasa Terrane. 1) Modified from Chen Chuzhen & Wang Yujing (1984). 2) Modified from Wang Naiwen *et al.* (1983). 3) Modified from Han Xiangtao *et al.* (1983). 4) Modified from Liang Shousheng & Xia Jinbao (1983). 5) Modified from Wang Naiwen (1983). 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4. Siltstone; 5. Calcareous sandstone; 6. Shale; 7. Slate; 8. Nodular shale; 9. Argillaceous rock; 10. Coal; 11. Argillaceous limestone; 12. Arenaceous limestone; 13. Bioclastic limestone; 14. Orbitolina limestone; 15. Calcareous algal limestone; 16. Limestone; 17. Tuff; 18. Andesite; 19. Basalt.

(*a*) *Fenghuoshan Basin*

From Tongtianheyan northward to Budongquan (about 220 km), the Tertiary was deposited in a single basin in two suites of red beds, separated by an unconformable contact. The lower red beds, the Fenghuoshan Group, are widely distributed around the Tuotuo River, Erdaogou and Fenghuoshan, dipping steeply with many folds. They form high mountains, and are more than 3000 m thick. The lower part, composed of interbedded purple-red mudstones with quartzose sandstones, unconformably overlies older rocks with a basal conglomerate; the middle part is composed of dark purple quartzose sandstone and siltstone with mudstone intercalations; the upper part is purple sandstone. A cupreous sandstone layer occurs at the boundary of the lower and middle parts. Some irregularly distributed gypsum and shallow water sedimentary structures such as cross-bedding, ripple and rill marks are frequently found in the sandstones. From the argillaceous limestone of the lower part on the northern slope of the Fenghuoshan west of Erdaogou, a fossil assemblage was collected (loc. B69), which indicates an early Palaeogene, i.e. Palaeocene and/or early Eocene age.

The upper red beds, unconformable on the Fenghuoshan Group, are called the Chabaoma Group. The Chabaoma Group, in contrast to the complexly deformed Fenghuoshan Group, dips very gently and is more than 300 m thick. The base is a soil-coloured sandy conglomerate; the lower part consists of interbedded yellowish-brown or grey mudstone and fine-grained sandstone; the upper part is grey mudstone and shale with argillaceous limestone intercalations. Palynomorphs (loc. M216) indicate a Neogene age.

(*b*) *Lunpola Basin*

The Lunpola Basin is roughly 200 km long and 15–20 km wide, elongated east–west. The Tertiary Lunpola Group in the basin is up to 3800 m thick. The lower Niubao Formation and the upper Dengqen Formation are conformable.

The Niubao Formation, 450 to 2700 m thick, rests unconformably on the Cretaceous. The lower part is mainly composed of purple-red conglomerates and sandstones intercalated with purple-red mudstone; the middle part has interbedded grey mudstone and shale with arenaceous conglomerates and crystal tuffaceous intercalations; the upper part is interbedded mudstone, argillaceous limestone, siltstone and fine-grained sandstone. Abundant Palaeogene ostracods, spores and pollen, charophyta and gastropods are found.

The Dengqen Formation is 300–1100 m thick; the lower part is composed mainly of mudstone, shale and fine-grained sandstone with oolitic sandstone and argillaceous limestone interlayers; the middle part is grey shale and mudstone with oil shale, siltstone and tuffaceous intercalations; the upper part is mudstone, shale, argillaceous limestone and siltstone alternating with brown mudstone and tuff yielding abundant Neogene ostracods, spores and pollen and some gastropods, fishes and insects (Wang Kaifa *et al.* 1975; Xia Jinbao 1983; Wu Yimin 1983).

(*c*) *Linzizong Basin*

The Linzizong Basin extends from Pengbo Farm to Doilungdeqen and westward to the north of Lhasa City. The Tertiary in the Basin comprises calc-alkaline volcanics interbedded with purple-red sandstones, conglomerates and siltstones unconformably overlying the Cretaceous. The volcanics, dated at 40–70 Ma, formed in the eastern part of the Gangdise magmatic arc (Wang Songchan 1984; Yin Jixiang *et al.* 1980).

13. Discussion and summary

It is quite probable that the Jitang Group of the Hengduan Mountains, the Jiayuqiao Group of the Lhorong–Dengqen district (southeastern part of the Qiangtang Terrane) and the Amugang Group in the west of that terrane may all be correlated with the 'Amdo Schists' and the Nyainqentanglha Group of Cambro–Sinian age (but see Harris, Xu, Lewis, Hawkesworth & Zhang, this volume) in the Lhasa Terrane. All the rocks mentioned above may be part of the basement formed by the 'Pan-African Event' of Gondwanaland during late Precambrian times. The late Precambrian metamorphic rocks in the Burhan Budai Mountains in the Kunlun Terrane, long referred to the basement series of Laurasia, differ markedly from the rocks mentioned above.

The lithological and palaeontological characteristics of the Ordovician in the Lhasa Terrane are similar to the Ordovician in the Himalayas (Lin Baoyu 1983*a*) but slightly different from those in the Qiangtang Terrane. The Lower Ordovician in the Qiangtang Terrane is disconformably or unconformably overlain by Middle Devonian (Dong Deyuan & Mu Xinan 1984). The Ordovician sequences of both the Qiangtang and the Lhasa Terranes are lithologically and faunally diverse compared with that of the Kunlun Terrane.

It is interesting that no fossil-bearing Silurian sequence is found in the Kunlun Terrane or the central and western parts of the Qiangtang Terrane. The Silurian of the Lhasa Terrane has a similar fauna to that of the Himalayas but contrasting lithology.

Complete Devonian sequences, conformable or paraconformable on Silurian, have been reported from the Lhasa and Himalayan Terranes. No Lower Devonian occurs in the Qiangtang Terrane except in the eastern Yidun–Zhongdian region, where a complex sequence through the Devonian has long been known. It consists of carbonate rocks closely resembling those of South China or the Yangtze region. The Middle and Upper Devonian of the Qiangtang Terrane are characterised by a regressive sequence with subordinate intermediate volcanic rocks. The basal, coarse, clastic rocks of molasse facies lie unconformably on the Lower Ordovician sequence or low grade Cambro–Sinian metamorphics. In the Kunlun Terrane, only terrestrial Upper Devonian deposits occur, molasse facies in the lower part and an enormous amount of basic to acidic volcanics in the upper part. They rest unconformably on Precambrian metamorphics. The Upper Devonian in the Qimantage Range northwest of the Burhan Budai Mountains, mainly composed of alternations of terrestrial and marine deposits, also unconformably overlies Lower Ordovician. Thus the Devonian strata of the Qiangtang and Kunlun Terranes shows common characters in their sedimentary history as the first sediments of the tectono-stratigraphic phase which stretched from mid- or late-Devonian to late Triassic.

The widespread Carboniferous succession of the Lhasa and western Qiangtang Terranes is characterised by flyschoid sediments (especially in the Upper Carboniferous), intermediate-basic volcanics, diamictites and a 'cold water fauna', while the Carboniferous in the Kunlun Terrane and the central and eastern parts of the Qiangtang Terrane is characterized by enormous amounts of basic to acidic volcanics intercalated with coal-bearing clastic rocks and yielding a fauna like that of South China or the Yangtze Province. In both the Qiangtang and Kunlun Terranes, the Lower Carboniferous is far thicker than the Upper Carboniferous.

The Permian sequences in the Qiangtang and Kunlun Terranes have common characteristics.

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(1) The Permian sequence is well-developed in both Terranes.

(2) The preserved thickness of the Lower Permian is far greater than that of the Upper Permian and the total thickness of the Permian and Carboniferous strata in each terrane reaches 8000 m and more.

(3) Voluminous basic and intermediate-acid volcanics occur at different levels, associated with shallow-sea flyschoid clastics and carbonates. No typical deep-water flysch deposits are found.

(4) The Permian is generally overlain unconformably or paraconformably by Mesozoic strata except in the western part of the Qiangtang Terrane, where Upper Permian coal-bearing clastics grade conformably into Lower Triassic strata.

(5) The Qiangtang Terrane, with its *Gigantopteris* flora in the Upper Permian coal-bearing series, and the Kunlun Terrane are referred to one biogeographical province with a Cathysian flora.

In the Lhasa Terrane, Lower Permian strata are unconformably overlain by Mesozoic deposits. In a small outcrop northwest of Lhasa the Upper Permian grades upwards into the Lower Triassic. The early Permian faunas from the Lhasa Terrane are similar to those of the Tethyan Himalayas, so-called 'cold water faunas'. At the beginning of the late early Permian, the sedimentary environments in these regions changed rapidly and the Tethyan fauna appeared, replacing the 'cold water fauna'. From late early Permian times, the Lhasa Terrane began to share sedimentary features with synchronous sediments in the Qiangtang, Kunlun and South China Terranes (Ching Yukan *et al.* 1977; Lin Baoyu 1983*b*). A so-called 'mixed flora' in the Lower Permian was reported from the western part of the Lhasa Terrane (Li Xingxue *et al.* 1985) but typical elements of the Gondwanan or the Cathaysian flora were not discovered in it. Some elements of the so-called 'cold water fauna' were also reported from the western part of the Qiangtang Terrane in early Permian strata resembling those of the Tethyan Himalayas.

Along the Geotraverse route, Triassic deposits, widespread in the Kunlun and Qiangtang Terranes, have been identified as representing a trench-island arc system at the continental margins of the northern and southern parts of Palaeotethys respectively. The Jielong Group (T_2) and the Baitang Group (T_3) are characterised by enormous amounts of calc-alkaline volcanics, tentatively attributed to an island arc environment at the northern margin of the Qiangtang Terrane, whereas the Gyiza (T_{2-3}) and Tumaingela (T_3) Groups outcropping to the south of the Baitang Group are platform-type sediments. These are succeeded by variegated clastics, carbonates and coal-bearing clastics, with subordinate calc-alkaline volcanics and are preliminarily interpreted as back-arc basin deposits behind the Baitang island arc. The Bayan Har Mountains are mainly formed of the Bayan Har Group, referred to the fore-arc basin at the southern margin of the Kunlun Terrane. The Lower and Middle Triassic marine strata in the Burhan Budai Mountains, of platform-type, are succeeded by coarse clastics, carbonates and flyschoid clastics with calc-alkaline volcanics, whereas the terrestrial Upper Triassic strata in the eastern part of the Burhan Budai Mountains, east of the Geotraverse route, are mainly coal-bearing clastics and an enormous amount of calc-alkaline volcanics, tentatively interpreted as back-arc basin deposits. However, the nature and location of the island arc there needs further exploration. The Triassic strata widespread in the Kunlun and Qiangtang Terranes commonly overlap or unconformably overlie Palaeozoic or late Precambrian strata. We believe that this unconformity is related to tensional tectonics resulting in the emergence and development of

the Palaeotethyan rift system or embryo ocean. Triassic strata in the Lhasa Terrane may represent deposits along the passive continental margin of the northern Neotethyan ocean.

Along the Geotraverse route, marine Jurassic deposits are restricted to the Lhasa and Qiangtang Terranes. In the Qiangtang Terrane, the Middle and Upper Jurassic lies unconformably on Triassic or Palaeozoic and comprises alternating terrestrial and marine sediments. They may be regarded as a result of repeated deposition of molasse in a foreland basin in the southern part of the Bayan Har fold belt or Palaeotethyan orogenic belt and marine transgression of the Tethyan ocean. It is suggested that the Sangri Group (J_3–K_1) in the south, the Quesangwenquan Formation (J_2) and Duodigou Formation (J_3) in the central area, and the 'Lake Area flysch' (J_{2-3}) in the north may represent the deposits of the Gangdise island arc, inter-arc basin or transitional belt, and back-arc basin of the northern Neotethys respectively.

Marine Cretaceous is restricted to the Lhasa Terrane. The highest marine horizon in the northern part of the Lhasa Terrane is the Langshan Formation, late Aptian to Cenomanian in age. The Cretaceous in the central and northern parts of the terrane represents post-flysch deposits in the back-arc basin. These are succeeded by coarse clastic and carbonate associations of platform-type. The lower Cretaceous exposed in the southern part of the terrane contains voluminous calc-alkaline volcanics and represents deposits of the Gangdise island arc belt. No fossiliferous Cretaceous strata have been found along the Geotraverse route in the Qiangtang Terrane, but early Cretaceous terrestrial sediments may occur beyond the Geotraverse route.

The Tertiary continental red beds are mainly developed in the central and northern parts of the Lhasa, Qiangtang and Kunlun Terranes. Marine Palaeogene sediments are found only in the 'Xigaze fore-arc basin' south of the Gangdise island arc of the Lhasa Terrane. The foraminifer-bearing early Eocene of the Zhongba district, 450 km WNW of Xigaze City, may represent the highest marine beds in the Lhasa Terrane.

Based on the foregoing, the evolution of the Palaeotethys and Banggong Lake–Dongqiao–Nujiang River back-arc basin has been deduced as follows.

Three stages can be recognized in the pre-Jurassic evolution of the Palaeotethyan domain in the Kunlun and Qiangtang Terranes: pre-Ordovician, Ordovician and Devonian-Triassic (figure 21). The late Palaeozoic evolution of the Palaeotethyan Ocean in the Tibetan Plateau may itself be divided into stages.

I. Middle and late Devonian to early Permian (D_{2-3}–P^1_1).
The Pangaean basement was broken up, producing the 'Kunlun rift system'; further splitting led to the emergence of new oceanic crust and sedimentation in symmetric rim basins.

II. Late early Permian to late Permian (P^2_1–P_2); the sea-floor spreading stage.
Palaeotethys expanded rapidly.

III. Early Triassic to Middle Triassic (T_1–T_2); the sea-floor consumption stage.
The Palaeotethyan oceanic crust was subducted along two subduction zones towards both the southern margin of the northern continent and the northern margin of the Xizang (Tibet) microcontinent (Qiangtang–Lhasa Terrane) respectively, resulting in the emergence of two mobile continental margins facing each other.

IV. Early late Triassic to middle late Triassic (T^1_3–T^2_3); the shrinking stage.
The Palaeotethyan ocean narrowed rapidly and was completely consumed by subduction until only a narrow relict shallow sea was left.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

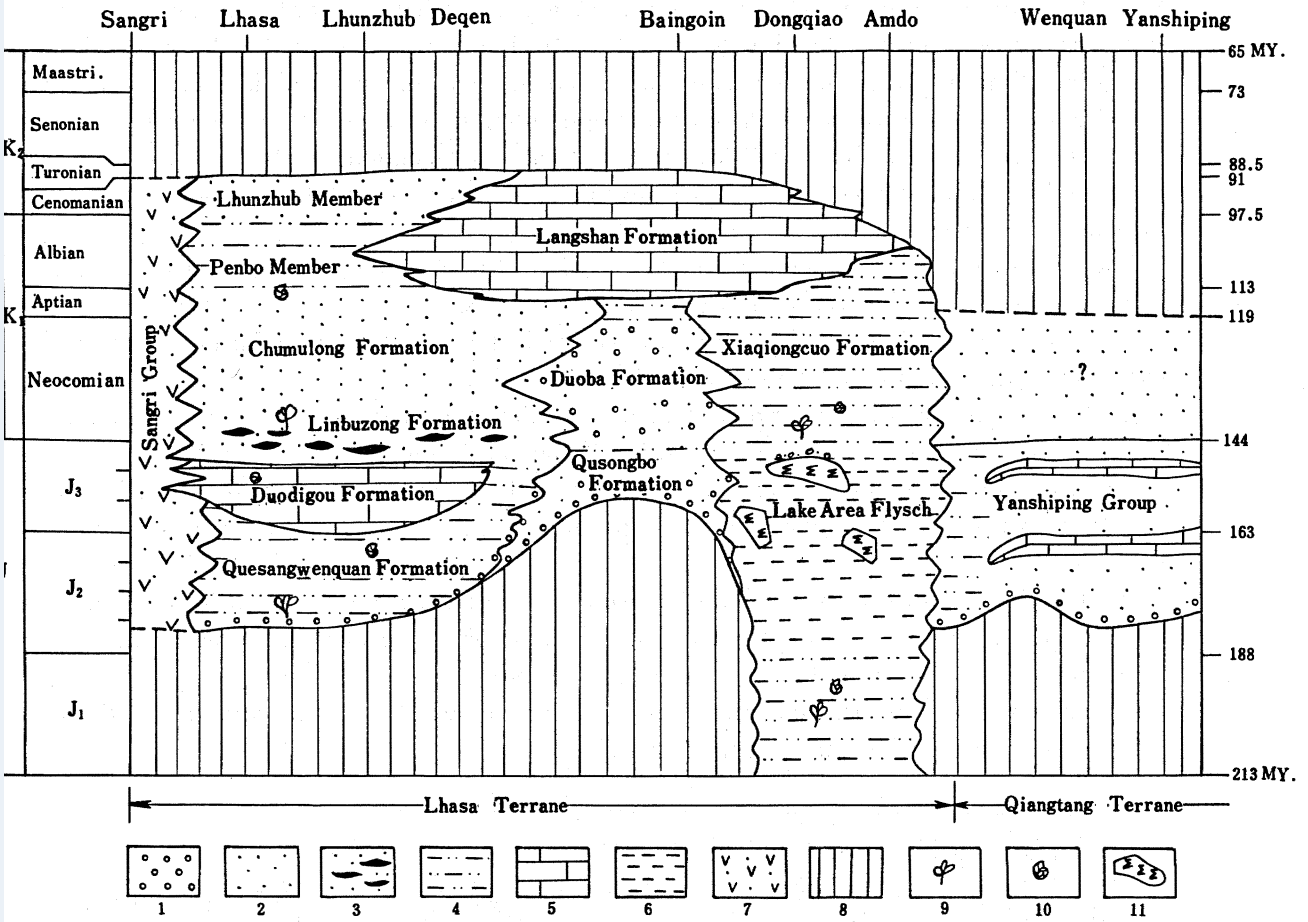


FIGURE 21. Map of the Jurassic and the Cretaceous in the Lhasa and the Qiangtang Terrane. 1. Terrestrial sandstone and conglomerate; 2. Terrestrial fine-grained clastics; 3. Terrestrial coal-bearing clastics; 4. Marine fine-grained clastics; 5. Carbonate; 6. Flysch-series; 7. Flyschoid clastics and calc-alkaline volcanics; 8. No deposition; 9. Plant fossils; 10. Animal fossils; 11. Ophiolite.

V. Late Triassic to early Jurassic (T^3_3–J_1); the initial collision stage.
The relict sea eventually vanished and the Xizang (Tibet) microcontinent collided with the northern continent and accreted into a united ancient Asian continent. The junction of these two continents is called 'Litian Lake–Jinsha River Suture Zone'.

VI. Middle and late Jurassic (J_{2-3}); the strong collision and deformation stage.
The collision and accretion of the Xizang (Tibet) microcontinent with the northern continent persisted into the late Jurassic, resulting in intense folding, thrusting and magmatic activity and the gradual uplift of the present Kunluns including the Bayan Har Mountains and the Tanggula Mountains. This created the Palaeotethyan or Indosinian orogenic belt. Foreland-type molasse basins were developed in the southern part of the orogenic belt and overlapped the marginal basins of the northern continent.

As a result of the disappearance of the Palaeotethyan ocean in the Qinghai–Xizang (Tibet) Plateau in the latest Triassic, the western part of the present Qiangtang Terrane rotated clockwise and separated in an opposite direction from the present Lhasa Terrane. This led, in the early Jurassic, to the formation of a wedged rift system, widening westward and closing eastward. Because of spreading behind the Gangdise arc, caused by early subduction of the

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Neotethyan ocean in the mid-Jurassic, the rift system extended eastwards and southeastwards as far as western Burma, leading to a mature back-arc basin along the Banggong Lake–Dongqiao–Nujiang River line. The continuous marine environments from late Triassic to early late Cretaceous, and Jurassic emplacement of ophiolites, are restricted to the central belt of the back-arc basin west of Dengqen. East and southeast of Dengqen, in the middle and lower reaches of the Nujiang River and western Burma, no marine early or late Jurassic or Cretaceous sequences have been found.

The evidence that the Banggong Lake–Dongqiao–Nujiang River back-arc basin developed from a rift system at the continental margin is as follows.

(1) Basic and acidic volcanics are best developed along the central axial line of the back-arc basin in the Middle and Upper Jurassic.

(2) The transition from continental to marine deposits in the Middle Jurassic has been found in the lake region of northern Xizang (Tibet) and along the Nujiang River.

(3) A distinct regional unconformity between Middle or Upper Jurassic strata and the underlying strata occurs at both the northern and southern continental margins of the back-arc basin.

(4) Jurassic evaporites (gypsum) and continental red beds are widespread in the Tanggula and Hengduan Mountains in the northeast, while contemporaneous coal-series occur only in the Gangdise–Nyainqentanglha Mountains in the south.

(5) After the disappearance of the back-arc basin in early late Cretaceous times, Tertiary red molasse developed in these basins (figure 22).

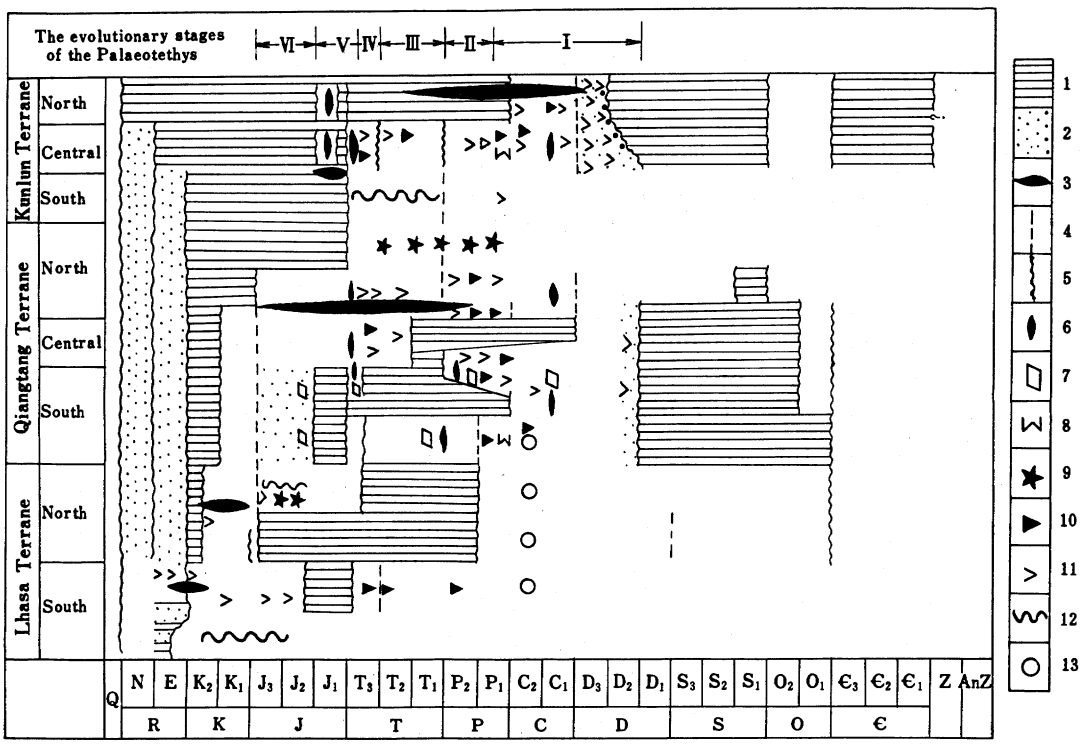
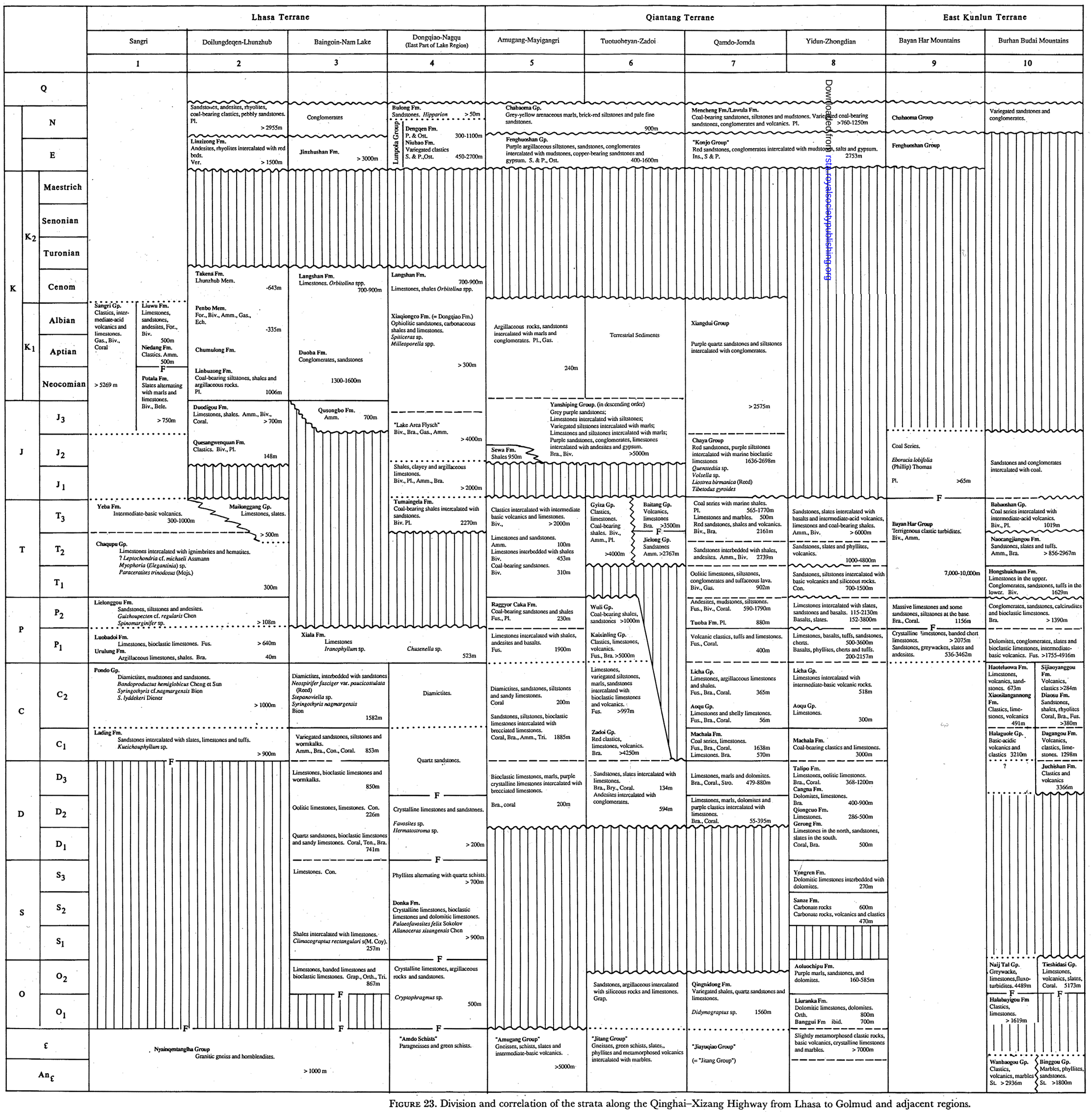


FIGURE 22. Diagram of the major geological events along the Qinghai-Xizang (Tibet) Highway from Lhasa to Golmud and its adjacent area. 1. No available geological record; 2. Molasse; 3. Plutonic rocks; 4. Paraconformity; 5. Unconformity; 6. Coal; 7. Gypsum; 8. Ultramafic rocks; 9. Ophiolites; 10. Basic volcanics; 11. Intermediate-acidic volcanics; 12. Flysch; 13. Diamictites.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

DIVISION AND CORRELATION OF THE STRATA ALONG QINGHAI-XIZANG HIGHWAY FROM LHASA TO GOLMUD AND ADJACENT REGIONS



Notes

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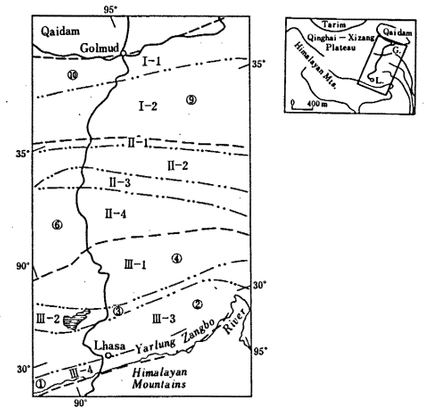
Gp. = Group Fm. = Formation Mem. = Member

Amm. = Ammonoids Fus. = Fusulinaceans Pl. = Plant
Bele. = Belemnites Gas. = Gastropoda Ra. = Radiolaria
Biv. = Bivalve Grap. = Graptolites St. = Stromatolit
Bra. = Brachiopoda Ins. = Insect Stro. = Stromatopora
Ch. = Charophyta Orth. = Orthoceras Ten. = Tentaculites
Con. = Conodonts Ost. = Ostracoda Tri. = Trilobites
Ech. = Echinoderm S&P = Spores and Pollen Ver. = Vertebrates
For. = Foraminifera

Unconformity
Disconformity
Unknown
F Fault

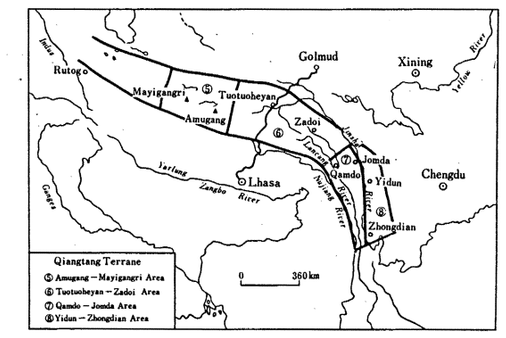


The Stratigraphical Provinces along the Qinghai-Xizang (Tibet) Highway from Lhasa to Golmud and the Adjacent Regions.

I. Stratigraphical Province of East Kunluns
- I-1 Burhan Budai Subregion;
- I-2 Bayan Har Subregion.

II. Stratigraphical Province of Qiangtang
- II-1 Zhidoi-Yushu Subregion;
- II-2 Tuotuoheyan-Ziqu Subregion;
- II-3 Kaixinling-Nanggen Subregion;
- II-4 Tanggula Pass Subregion.

III. Stratigraphical Province of Lhasa
- III-1 Dongqiao-Nagqu Subregion;
- III-2 Baingoin-Nam Lake Subregion;
- III-3 Doilungdeqen-Lhunzhub Subregion;
- III-4 Sangri Subregion.



The Subdivision of the Qiangtang Stratigraphical Province

FIGURE 23. Division and correlation of the strata along the Qinghai–Xizang Highway from Lhasa to Golmud and adjacent regions.

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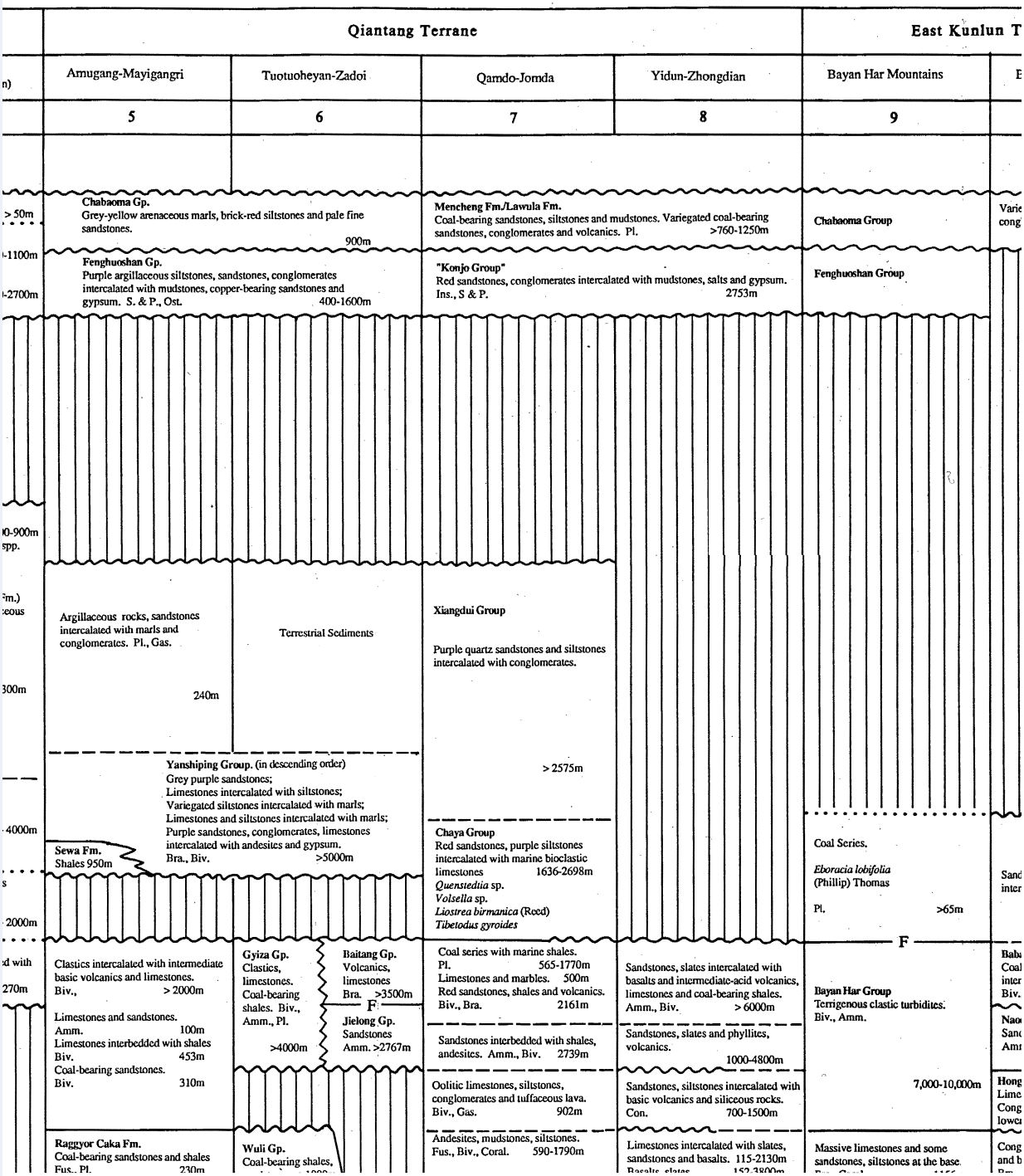
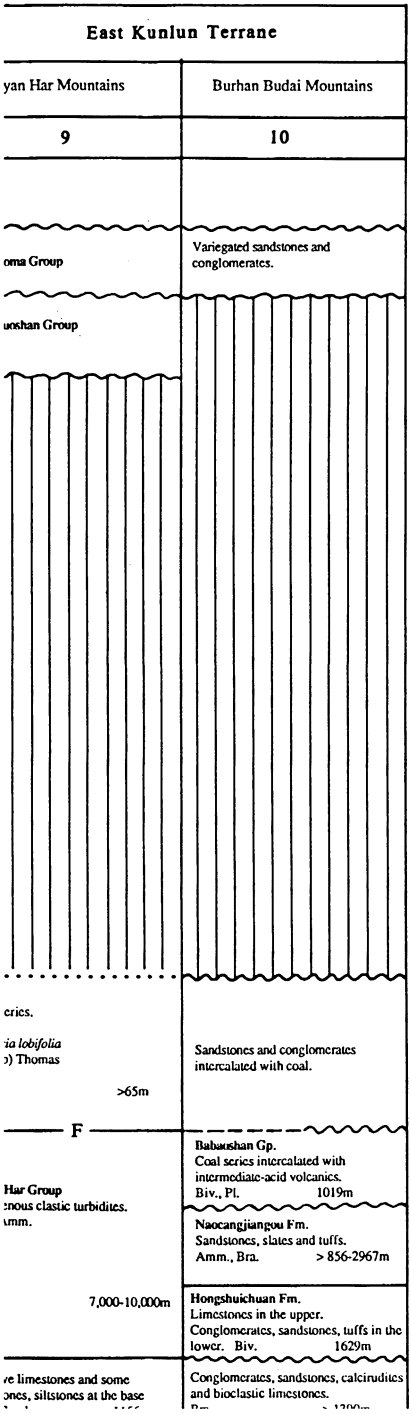
DIVISION AND CORRELATION OF THE STRATA ALONG QINGI

Lhasa Terrane

			Sangri	Doilungdeqen-Lhunzhub	Baingoin-Nam Lake	Dongqiao-Nagqu (East Part of Lake Region)	Amugang-May
			1	2	3	4	5
Q							
	N			Sandstones, andesites, rhyolites, coal-bearing clastics, pebbly sandstones. Pl. > 2955m	Conglomerates	**Bulong Fm.** Sandstones. *Hipparion* > 50m Lunpola Group: **Dengqen Fm.** P. & Ost. 300-1100m; **Niubao Fm.** Variegated clastics S. & P.,Ost. 450-2700m	**Chabaoma G** Grey-yellow sandstones.
	E			**Linzizong Fm.** Andesites, rhyolites intercalated with red beds. Ver. > 1500m	**Jinzhushan Fm.** > 3000m		**Fenghuoshan** Purple argilla intercalated w gypsum. S. &
K	K_2	Maestrich					
		Senonian					
		Turonian					
		Cenom		**Takena Fm.** Lhunzhub Mem. -643m **Penbo Mem.** For., Biv., Amm., Gas., Ech. -335m **Chumulong Fm.**	**Langshan Fm.** Limestones. *Orbitolina* spp. 700-900m	**Langshan Fm.** 700-900m Limestones, shales *Orbitolina* spp.	
	K_1	Albian	**Sangri Gp.** Clastics, intermediate-acid volcanics and limestones. Gas., Biv., Coral > 5269 m	**Linbuzong Fm.** Coal-bearing siltstones, shales and argillaceous rocks. Pl. 1006m	**Duoba Fm.** Conglomerates, sandstones 1300-1600m	Xiaqiongco Fm. (= Dongqiao Fm.) Ophiolitic sandstones, carbonaceous shales and limestones. *Spiticeras* sp. *Milleoporella* spp. > 300m	Argillaceous rock intercalated with m conglomerates. Pl
		Aptian	**Liuwu Fm.** Limestones, sandstones, andesites, For., Biv. 500m **Niedang Fm.** Clastics. Amm. 500m				
		Neocomian	**Potala Fm.** Slates alternating with marls and limestones. Biv., Bele. > 750m				
J	J_3			**Duodigou Fm.** Limestones, shales. Amm., Biv., Coral. > 700m	**Qusongbo Fm.** Amm. 700m	"Lake Area Flysch" Biv., Bra., Gas., Amm. > 4000m	
	J_2			**Quesangwenquan Fm.** Clastics. Biv., Pl. 148m		Shales, clayey and argillaceous limestones. Biv., Pl., Amm., Bra. > 2000m	**Sewa Fm.** Shales 950m
	J_1						
T	T_3		**Yeba Fm.** Intermediate-basic volcanics. 300-1000m	**Mailonggang Gp.** Limestones, slates. > 500m		**Tumaingela Fm.** Coal-bearing shales intercalated with sandstones. Biv. Pl. 2270m	Clastics intercalated basic volcanics and Biv.,
	T_2		**Chaqupu Gp.** Limestones intercalated with ignimbrites and hematites. ? *Leptochondria* cf. *michaeli* Assmann *Myophoria* (*Elegantinia*) sp. *Paraceratites trinodosus* (Mojs.)				Limestones and san Amm. Limestones interbed Biv. Coal-bearing sandst Biv.
	T_1		300m				
	P_2		**Lielonggou Fm.** Sandstones, siltstones and andesites. *Guizhoupecten* cf. *regularis* Chen				**Raggyor Caka Fm.** Coal-bearing sandst Fus., Pl.

'A ALONG QINGHAI-XIZANG HIGHWAY FROM LHASA TO GOLMUD AND ADJACENT REGIONS





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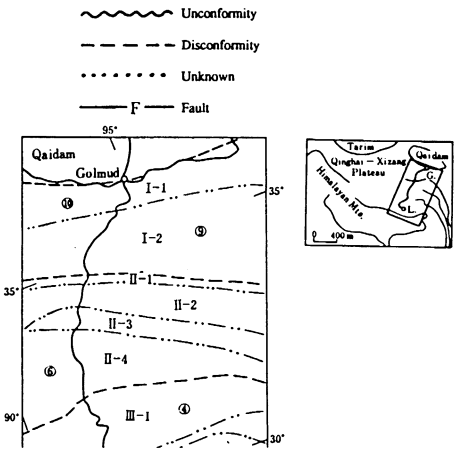

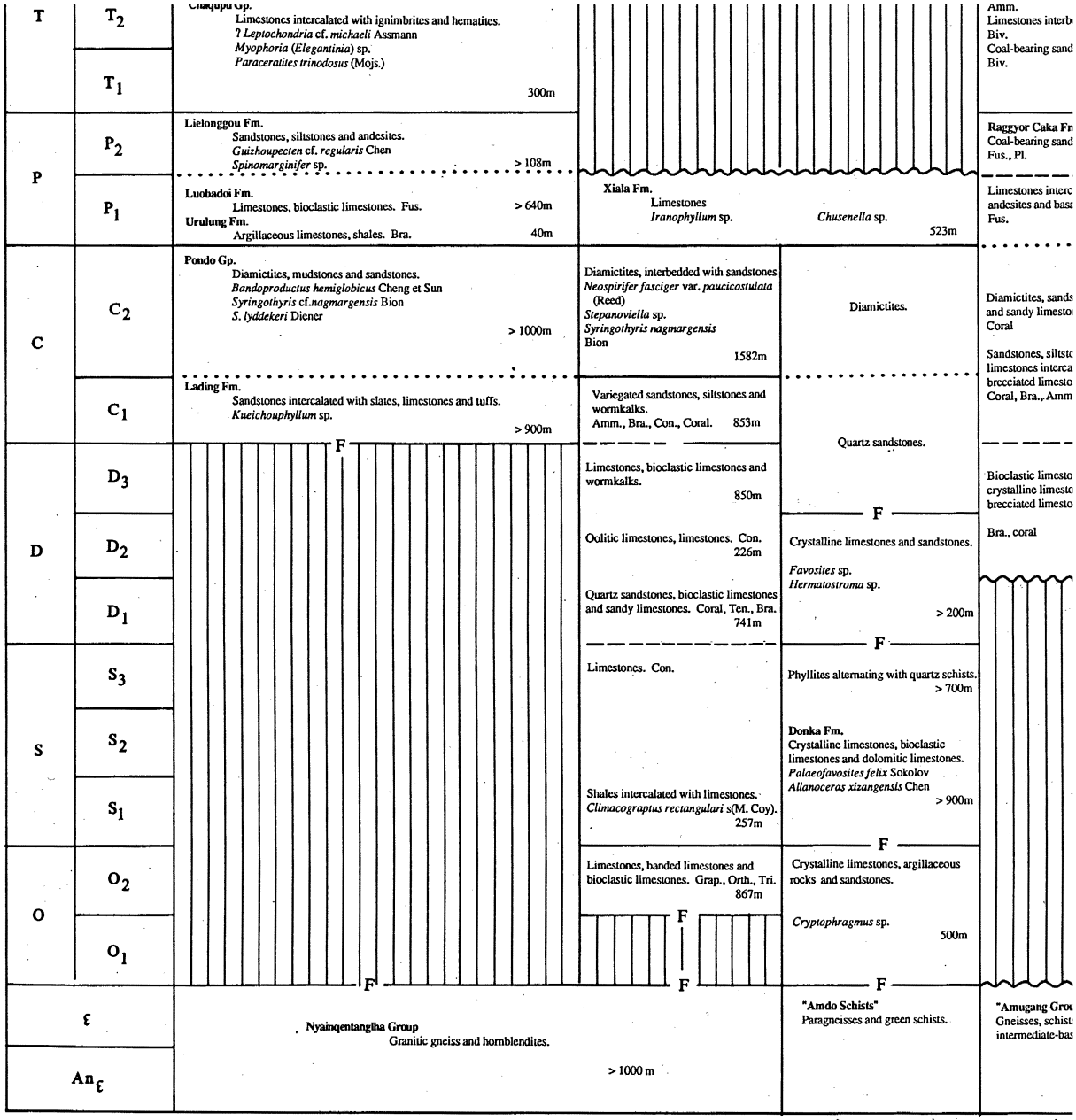

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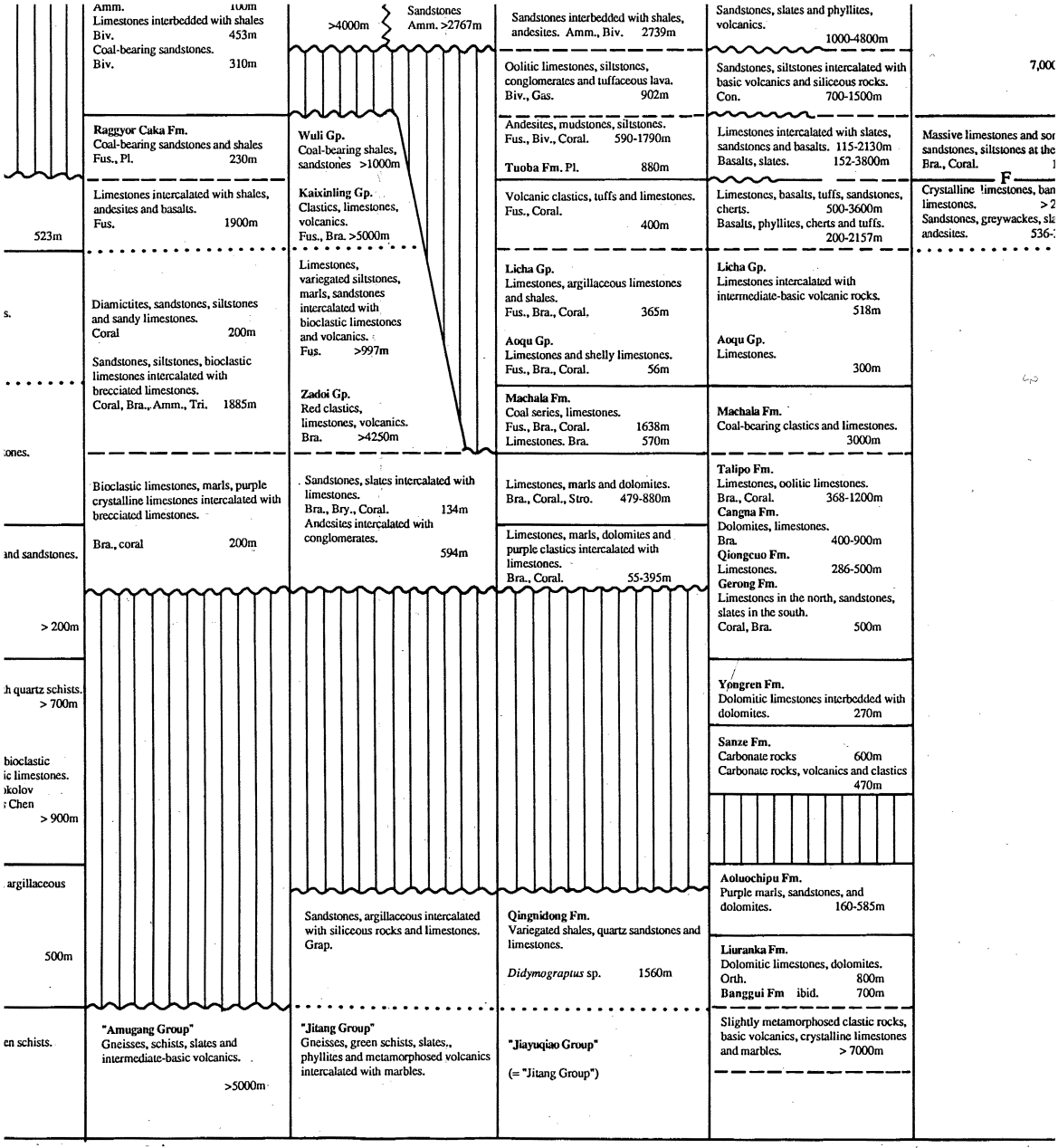

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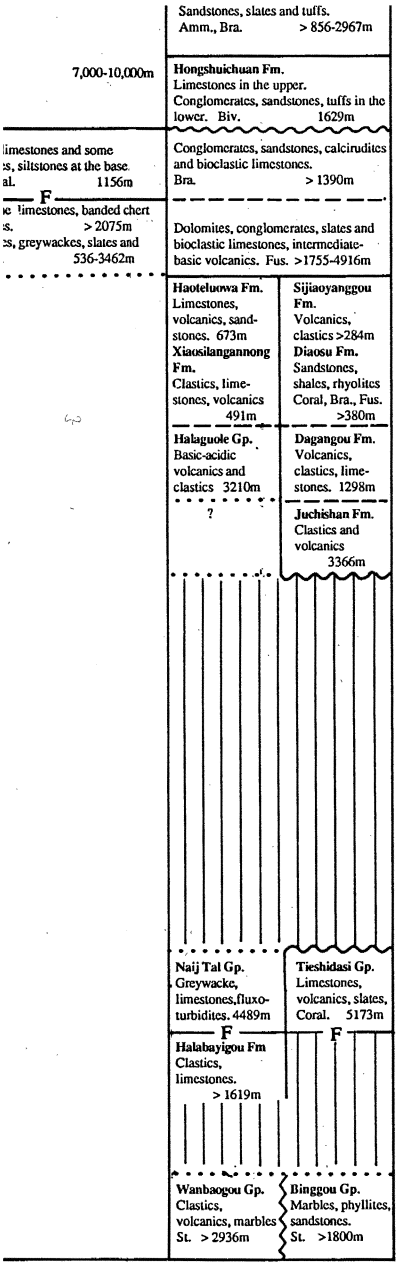
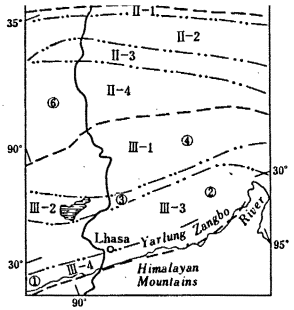


.cent regions.



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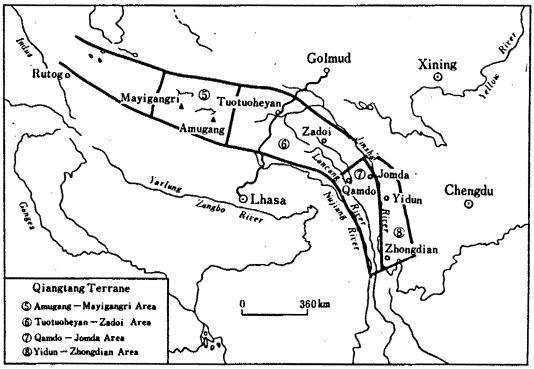

The Subdivision of the Qiangtang Stratigraphical Province

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Thus the tectono-stratigraphical evolution of the Banggong Lake–Dongqiao–Nujiang River back-arc basin may be suggested.

1. Late Triassic to early Jurassic (T_3–J_1); Early evolutionary stage.
   A change from continental rifting to initial expanding, resulting in the emergence of a narrow gulf closing towards the east.

II. Middle Jurassic to mid Late Jurassic (J_2–J^2_3); Sea-floor spreading–shrinking stage.
Deposition of flysch and new oceanic crust in the central belt of the back-arc basin and contemporaneous subduction and obduction of oceanic crust were in progress; ophiolites were dismembered and sandwiched into the flysch sequences.

III. Late Jurassic to early late Cretaceous (J^3_3–K^1_2); initial collision stage.
As a result of the collision of the Gangdise arc with the northern continent, flysch and oceanic deposition ended to be replaced by shallow sea sedimentation in the relict sea.

IV. Late Cretaceous to Palaeogene (K^2_2–E); the collision and deformation stage.
After the disappearance of the marine facies, continental sedimentation of red molasse soon occurred. The welded line of the northern continent and the Gangdise arc is called the Banggong Lake–Dongqiao–Dengqen Suture Zone.

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DIVISION AND CORRELATION OF THE STRATA ALONG QINGHAI-XIZANG HIGHWAY FROM LHASA TO GOLMUD AND ADJACENT REGIONS

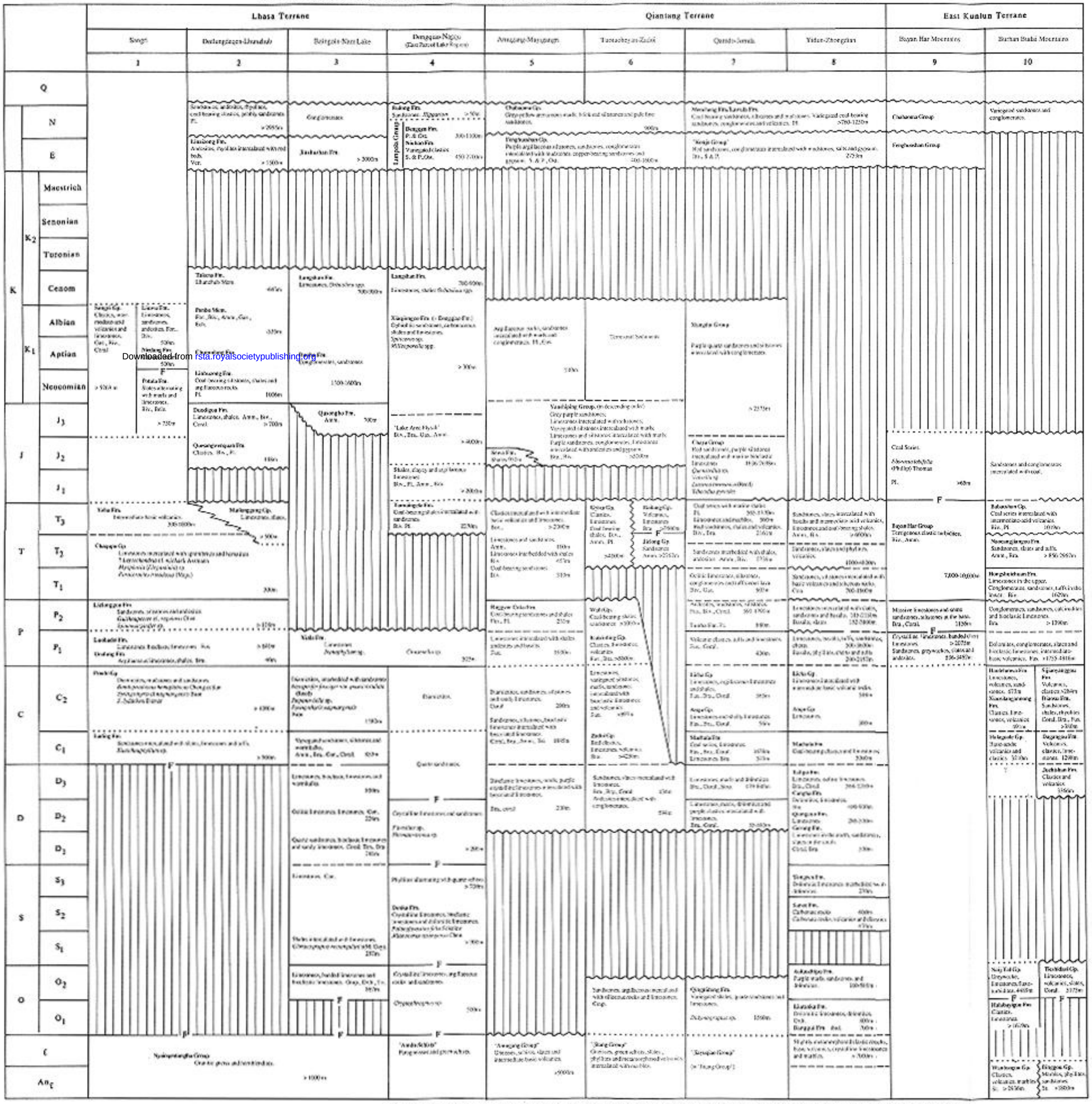

FIGURE 23. Division and correlation of the strata along the Qinghai–Xizang Highway from Lhasa to Golmud and adjacent regions.

(*Facing p. 48*)