THE GEOLOGICAL EVOLUTION OF TIBET

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THE GEOLOGICAL EVOLUTION OF TIBET

REPORT OF
THE 1985 ROYAL SOCIETY – ACADEMIA SINICA
GEOTRAVERSE OF
THE QINGHAI – XIZANG PLATEAU
LED BY
CHANG CHENGFA,
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[Sixteen plates and one pullout; two microfiches and map in pockets inside back cover]

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PREFACE

The Tibetan Plateau is a unique feature of the Earth's surface. Its elevation, 5 km above sea level, and a crust twice the normal thickness, have long been recognized as resulting from the collision of the Indian and Eurasian continents. The region is regarded as the prime example of collision tectonics. However, because Tibet was for long virtually inaccessible to geologists from the rest of the world, the mechanism by which the Plateau evolved and by which the crust was doubled in thickness, remained speculative.

During the past two decades, Chinese geologists have explored and systematically mapped much of this vast and largely uninhabited region; Academia Sinica mounted a series of geological expeditions. The results of this and other work were presented at an international symposium on the Qinghai–Xizang (Tibet) Plateau in Beijing in 1980 and demonstrated on a traverse through southern Tibet from Lhasa to Kathmandu.

The excitement generated by this introduction to the geology of Tibet led Professor Gansser, Professor Molnar and me to the idea of a Geotraverse, based on the newly completed road from Lhasa to Golmud across central and northern Tibet. Chinese colleagues were enthusiastic. Because the Royal Society and Academia Sinica had an agreement for scientific cooperation, I submitted our proposal to the Society and an agreement was eventually signed.

Chinese geologists chosen for the project prepared for the Geotraverse by making detailed geological strip maps of the region to be covered and locating significant outcrops. In June 1985, the geologists, ten from the Royal Society side and fifteen from Academia Sinica, assembled in Lhasa. The next two months were spent working across the Plateau.

The Chinese took complete responsibility for the logistics. A fleet of lorries and jeeps, loaded with supplies, was driven into Tibet across the mountains and gorges from Chengdu. After acclimatization in Lhasa, and work from there, we set off northwards towards Golmud. Along the road, we stayed in military posts and, off it, in tents. Access to exposures was by jeep as far as they could go (heavy rains had made much of the area a morass) then on foot. Rarely, we used horses and yaks. Most of the food had to be brought in from outside.

We worked in small specialist groups, so understanding and friendships developed quickly. The thorough preparation by the Chinese geologists meant that little time was wasted.

The large collections of rocks and fossils were divided between ourselves and our Chinese colleagues for analysis and identification. Work on all this material is not yet complete; the results so far obtained are presented in this volume. The conclusions were discussed at an exceptionally successful conference in Beijing in 1986, followed by another geological traverse from Lhasa to Kathmandu.

The 1985 Geotraverse was inevitably only a reconnaissance. Many important unsolved problems remain. We hope that this is only the start of a collaboration between ourselves and our Chinese colleagues, which has led already not only to the results presented here but also to close and lasting friendships.

We acknowledge the wise and experienced leadership of Professor Chang Chengfa of the Chinese team, the linguistic and organizational skills of Freddie Sun Yiyin and the remarkable feats of the drivers of the jeeps. We thank Dr Peigi Wallace for editing the volume. Finally, we thank the Royal Society and Academia Sinica for enabling us to carry out this project.

April 1988

ROBERT SHACKLETON

Note

In reading the papers in this volume, reference should be made to the coloured geological map (1:125000) in the pocket at the end of the volume, and to the microfiche copies of the 1:100000 maps on which all localities mentioned in the text are plotted, together with structural and other field data. Copies of these maps, as well as satellite imagery and other materials, will be housed in the British Museum of Natural History, where they are available for study. Any type specimens of fossils will be preserved in Nanjing; duplicates of many of them will be housed in the B.M.(N.H.).

Meanings of a few commonly used Chinese and Tibetan words may be useful: Co, Tso (Tibetan), Hu (Chinese) = lake; Jiang = large river; Qu, He = river; Heyan = source of river; Datan = valley; -gou = valley; -quan = spring (as in Wenquan: hot spring, Budongquan: not-quite-frozen spring); Shan = mountains; Tagh = mountains; Tsangpo = Zangbo; Jinsha = Yangtze = Yangzi.

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The Tibetan plateau: regional stratigraphic context and previous work

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[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.

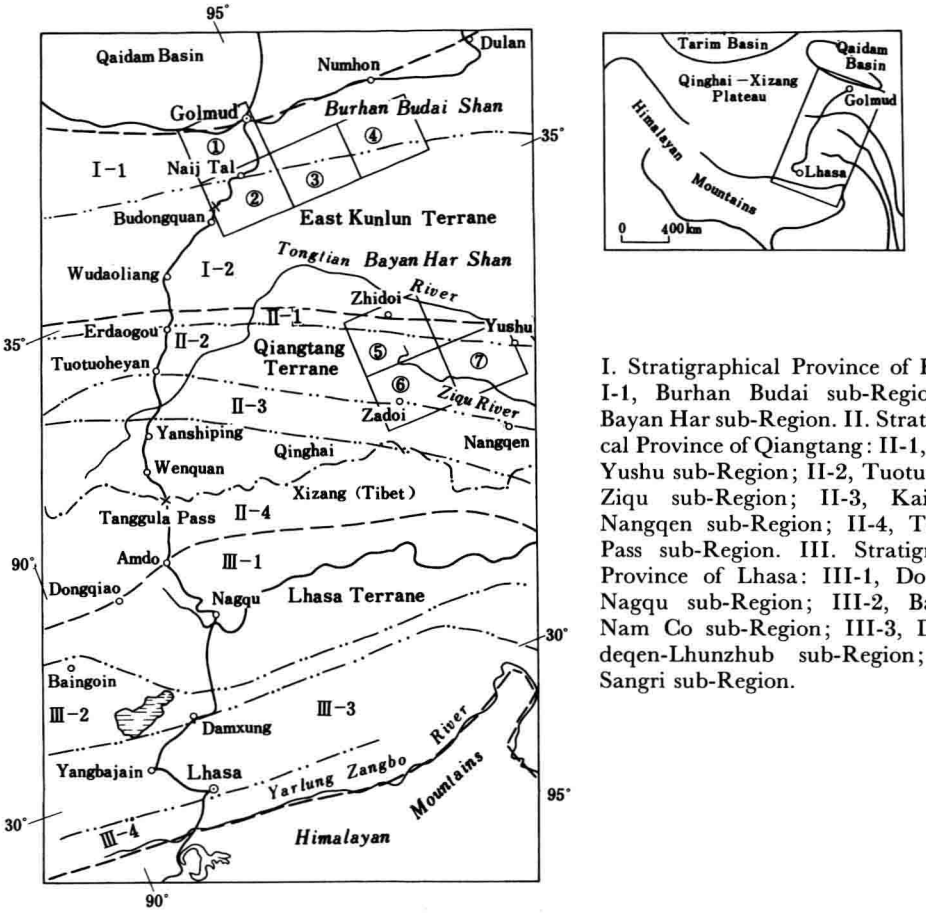
(1) The Bureau of Geology and Mineral Resources of Qinghai Province, 1981; Report on the Survey of Regional Geology, attached to the Geological Map of Qinghai Province (scale 1:200,000), People's Republic of China: Golmud City Sheet, J-46-(35); Naij Tal Sheet, I-46-(5); Zhidoi Sheet, I-46-(24); *ibid.* 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

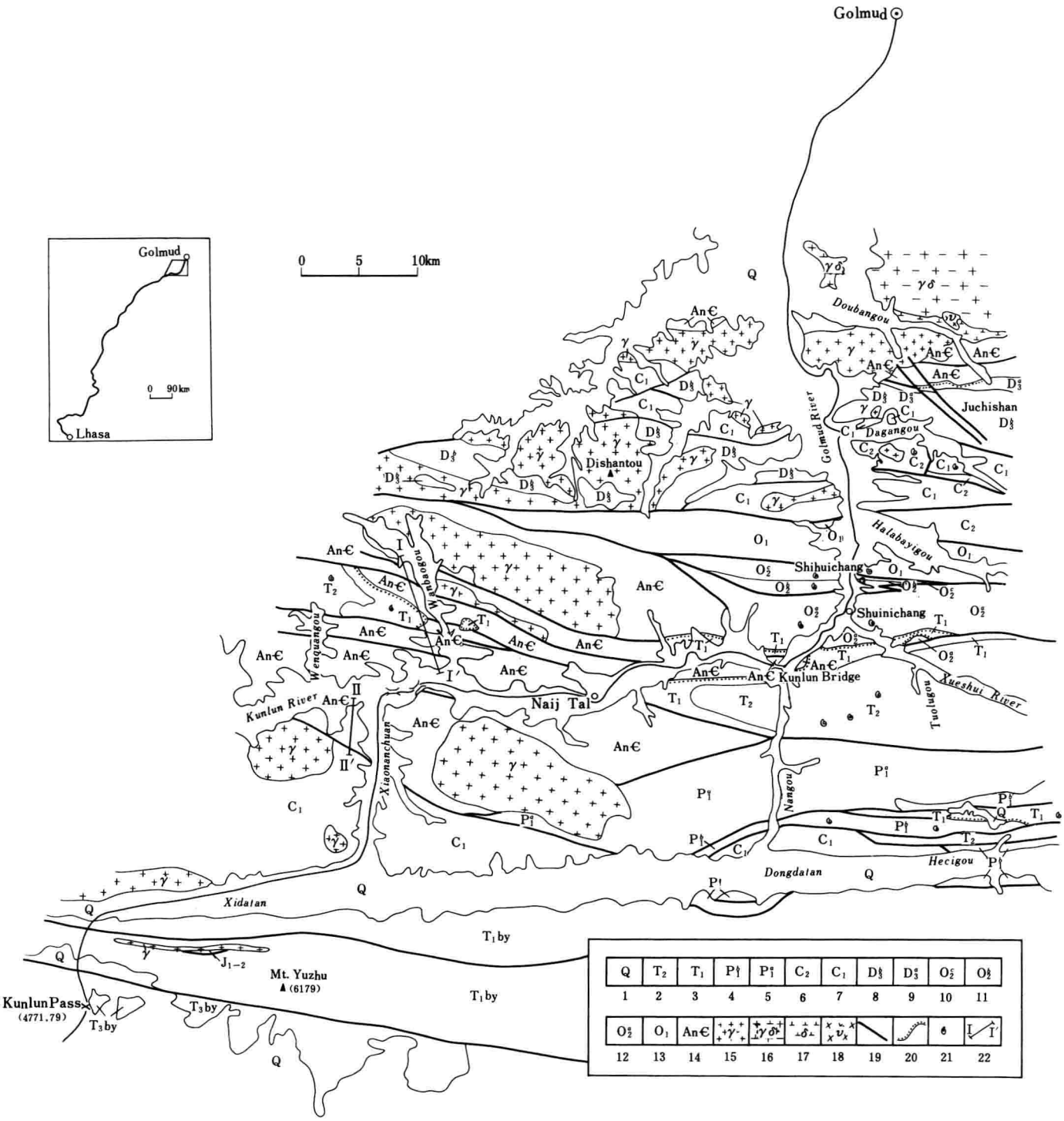


FIGURE 2. A sketch map of the geology of the Golmud–Naij Tal district showing the stratigraphy (modified from Golmud City Sheet and Naij Tal Sheet). 1. Quaternary (Q); 2. Naocangjianggou Formation (T_2); 3. Hongshuichuan Formation (T_1); 4. Carbonate Formation (P_1^b); 5. Clastic Formation (P_1^a); 6. 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.

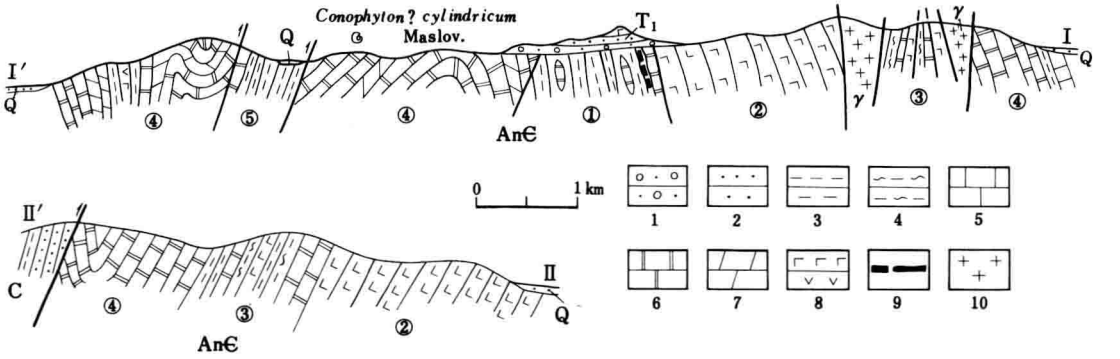


FIGURE 3. A section of the Wanbaogou Group in Wanbaogou, Xiaonanchuan, Naij Tal District and Golmud County (I–I′ Wanbaogou section, II–II′ Xiaonchuan section as shown in figure 2). 1. Conglomerate; 2. Sandstone; 3. Slate; 4. Green Schist; 5. Limestone; 6. Marble; 7. Dolomite; 8. Upper Basic volcanic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

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):

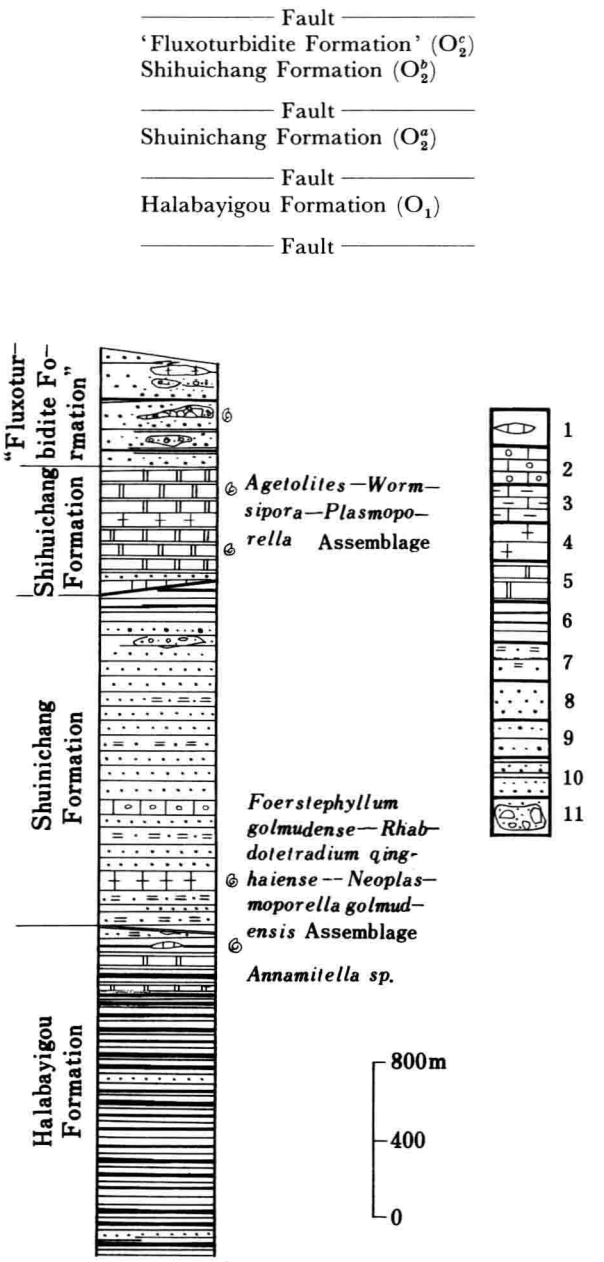


Figure 4. Generalized columns of the Ordovician in the Naij Tal district, Golmud County. 1. Lenticular limestone; 2. Oolitic limestone; 3. Argillaceous limestone; 4. Crystalline limestone; 5. Marble; 6. Slate; 7. Phyllite; 8. Graywacke, sandstone; 9. Pebbly sandstone; 10. Sandy turbidite; 11. Fluxoturbidite.

(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).

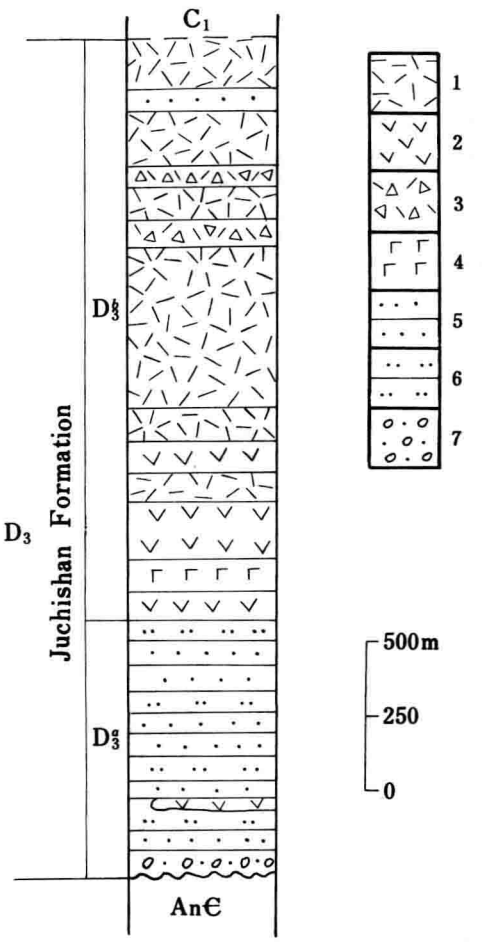


FIGURE 5. Columnar section of the Juchishan Formation at Juchi Mountain, south of Daobangou, Golmud County. 1. Rhyolite, perlitic rhyolite; 2. Andesite, dacite; 3. Volcanic breccia; 4. Basalt; 5. Sandstone; 6. Siltstone; 7. Conglomerate.

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.

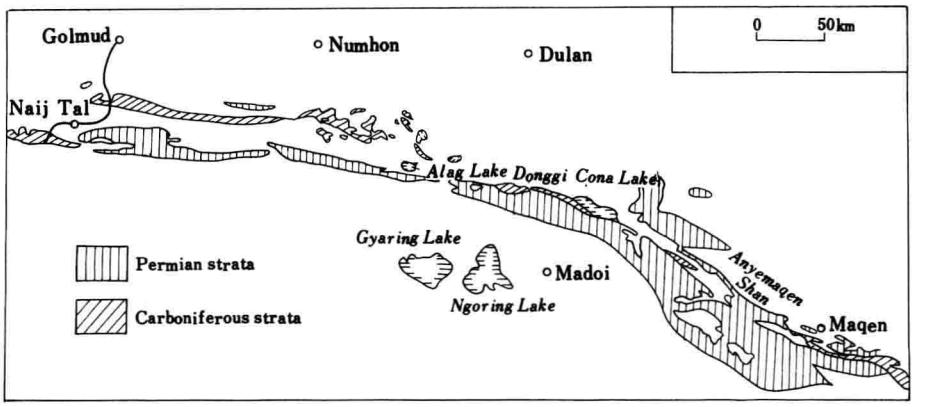


FIGURE 6. Sketch map of the distribution of the Carboniferous and the Permian in the Burhan Budai Mountains.

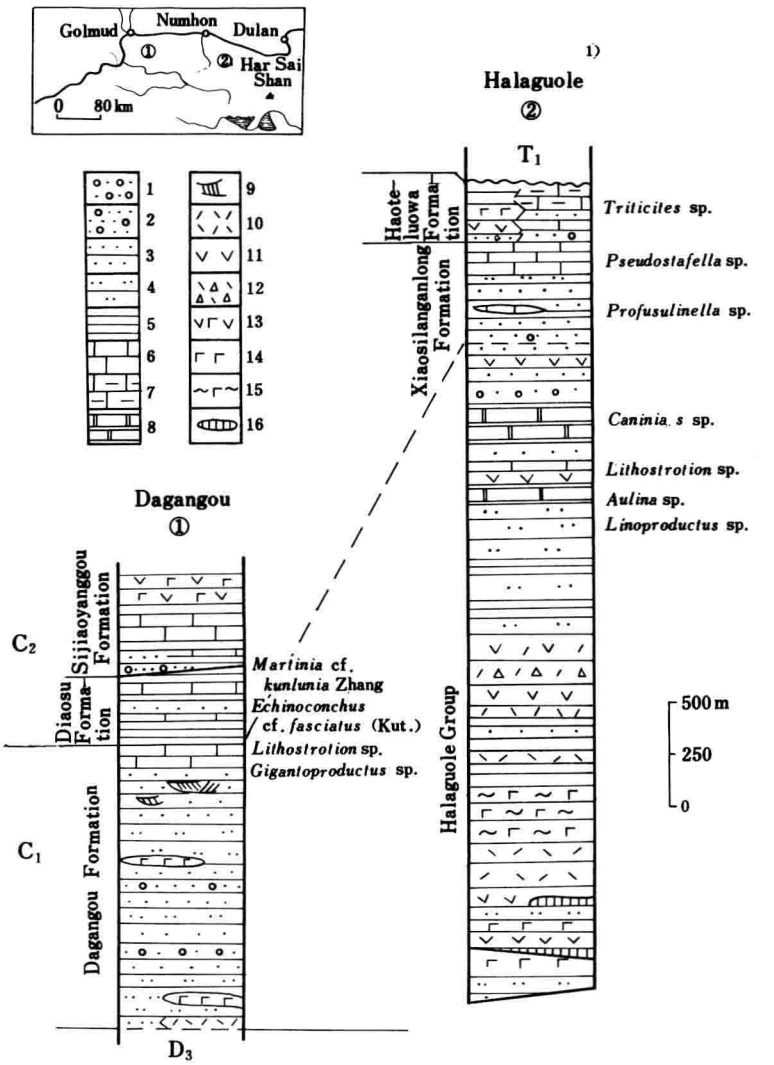


FIGURE 7. Correlation of columnar sections of the Carboniferous in the Burhan Budai Mountains. 1) Modified from Aikengdeleisite Sheet. 1. Conglomerate; 2. Pebbly sandstone; 3. Sandstone; 4. Siltstone; 5. Shale; 6. Limestone; 7. Argillaceous limestone; 8. Marble; 9. Cross-bedding; 10. Rhyolite; 11. Andesite;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