Phil. Trans. R. Soc. Lond. A **327**, 287–305 (1988) [287]
Printed in Great Britain

Geological mapping of the 1985 Chinese–British Tibetan (Xizang–Qinghai) Plateau Geotraverse route

By W. S. F. Kidd[1], Pan Yusheng[2], Chang Chengfa[2], M. P. Coward[3], J. F. Dewey[4], F.R.S., A. Gansser[5], P. Molnar[6], R. M. Shackleton[7], F.R.S., and Sun Yiyin[2]

[1] *Department of Geological Sciences, State University of New York, Albany, New York* 12222, *U.S.A.*
[2] *Institute of Geology, Academia Sinica, Box* 634, *Beijing, People's Republic of China*
[3] *Department of Geology, Imperial College, Prince Consort Road, London SW*7 2*BP, U.K.*
[4] *Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX*1 3*PR, U.K.*
[5] *Geologisches Institut, Eidgenossische Technische Hochschule, CH*-8092, *Zürich, Switzerland*
[6] *Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, Massachusetts* 02139, *U.S.A.*
[7] *Department of Earth Sciences, The Open University, Walton Hall, Milton Keynes, MK*7 6*AA, U.K.*

[Map and microfiche in pockets]

The 1:500,000 coloured geological map of the traverse route combines observations from the Geotraverse, previous mapping, and interpretation of orbital images. The position of all localities visited by Geotraverse participants and basic geological data collected by them along the traverse route are shown on a set of maps originally drawn at 1:100,000 scale, reproduced on microfiche for this publication. More detailed mapping, beyond a single line of section, was achieved in five separate areas. The relationships between major rock units in these areas, and their significance, are outlined in this paper. Near Gyanco, (Lhasa Terrane) an ophiolite nappe, apparently connected with outcrops of ophiolites in the Banggong Suture about 100 km to the north, was underthrust by a discontinuous slice of Carboniferous–Permian clastic rocks and limestone, contrary to a previous report of the opposite sequence. At Amdo, a compressional left-lateral strike-slip fault zone has modified relationships along the Banggong Suture. Near Wuli, (northern Qiangtang Terrane) limited truncation of Triassic strata at the angular unconformity below Eocene redbeds demonstrates that most of the folding here is of Tertiary age. The map of the nearby Erdaogou region displays strong fold and thrust-shortening of the Eocene redbeds, evidence of significant crustal shortening after the India–Asia collision began. In the Xidatan–Kunlun Pass area, blocks of contrasting Permo–Triassic rocks are separated by east-trending faults. Some of these faults are ductile and of late Triassic – early Jurassic age, others are brittle and part of the Neogene–Quaternary Kunlun left-lateral strike-slip fault system. Some more significant remaining problems that geological mapping might help to solve are discussed briefly, including evidence for a possible additional ophiolitic suture within the Qiangtang Terrane.

1. Introduction

The purposes of this chapter are to document the sources used to compile the 1:500,000 scale geological map of the Geotraverse route and its surroundings (map 1, in pocket) and to discuss briefly the detailed geological maps, originally drawn on the 1:100,000 scale topographic map sheets provided by Academia Sinica, that record localities and basic data collected by all working groups during the traverse (microfiche 2).

Fifty-five days were spent on the traverse route, from June 4th to July 28th, 1985, covering a distance of about 1300 km along the main paved road from Lhasa to Golmud, with additional distances of several hundred kilometres on subsidiary traverses along less travelled dirt roads and tracks leading away from the main road. This required an average of about 30 km of section completed each day. Consequently, *detailed* geological mapping, in the strict sense of areally extensive and well-distributed observations, was not possible (nor was it originally intended) at most places along the traverse route. Where detailed observation of more than a narrow section line (i.e., mapping) was achieved, the results are discussed below. The immense scope for further investigations in many sections of the traverse route is well-illustrated by the current lack of detailed geological maps along most of its length, not to mention the vast remainder of the rest of the Qinghai–Xizang (Tibetan) Plateau. Some of the more critical geological problems remaining from the Geotraverse route whose solution would likely be provided or assisted by detailed mapping are also briefly discussed.

2. Geological map of the Geotraverse route

The coloured map (map 1, in pocket) is partly based on the field observations and subsequent laboratory results of the participants of the 1985 Academia Sinica – Royal Society Geotraverse, documented in the papers in this volume, on earlier work from various Chinese sources, and on the 1981–83 Franco-Chinese collaboration. Information from both the 1985 Geotraverse and the earlier sources has been extrapolated using interpretations of orbital imagery, which have also been used to modify previous map patterns in some places.

(*a*) *Previous work*

The principal maps used for compilation of map 1 are:

a) Geological map of the Southern Tethys of the Qinghai–Xizang Plateau [1:1 million scale]. (Yin Jixiang *et al.*, in press.)

b) Geological map of Qinghai Province [1:million scale] (Qinghai Bureau of Geology and Mineral Resources 1981).

c) Geological map of the Qinghai–Xizang (Tibet) Plateau [1:1.5 million scale]. (Ministry of Geology and Mineral Resources, Beijing, 1980).

d) Geological map of Lhasa Sheet [1:1 million scale] (Xizang Bureau of Geology and Mineral Resources 1979).

e) Geological map of Golmud Sheet, and Geological map of Naij Tal Sheet [1:200,000 scale] (Qinghai Bureau of Geology and Mineral Resources 1984).

f) Carte géologique du sud du Tibet [1:500,000 scale] (J. P. Burg 1983).

Stratigraphic units, defined by previous work, to which reference is made in this chapter or in the map legend are discussed, with citations, by Yin *et al.* (this volume).

(*b*) *Orbital imagery*

For most of the Qinghai–Xizang Plateau, the only orbital imagery at the time of the geotraverse consisted of multispectral scanner (MSS) images from the older series of LANDSAT platforms. Other imagery available to us consisted of a line of Metric Camera (colour film original) images obtained from a Shuttle–Spacelab mission that closely follows much of the line of the Geotraverse. The large-format Camera (9 × 18 inch negative, black and white) flown on another Shuttle mission provides a few spectacularly high-resolution images from two paths crossing the northern end of the Geotraverse route.

The LANDSAT imagery was obtained in false colour composite prints at a scale of 1 : 250,000. Because these images are from the older 4-spectral-band MSS instrument, they have a limited capability to discriminate bedrock lithologies (and lithologic units), especially when compared with the more recent Thematic Mapper (TM) 7-band instrument. Because of certain operating constraints on the LANDSAT 4 and 5 platforms, and a lack of a suitable data-relay satellite, TM images are not available for most of the Qinghai–Xizang (Tibetan) Plateau. Unlike the TM data, MSS images do not generally yield significant additional geologic information over the standard false colour print when various computer-generated enhancements are applied to the original digital image data. It may be possible to make certain features more obvious but, in most cases, they are easily seen on the original "unenhanced" images.

The Metric Camera images (obtained as prints at a scale of about 1:240,000), being visible light products, have an even more limited capability to discriminate lithologies. Lithologic boundaries and units can be clearly seen *locally* on these two kinds of images, especially the LANDSAT images, but it is not possible in most places to distinguish bedrock units with any confidence, or to follow contacts precisely, over more than a few kilometres. For this reason alone, it would be inappropriate to use the imagery to extrapolate from the detailed traverse observations to fill each sheet of the 1:100,000 scale maps. There are two reasons why it is difficult to distinguish most lithologic units and/or their boundaries on the images; the rocks along the traverse route are with minor exceptions not structurally simple, and the rock exposures are quite extensively veneered with *felsenmeer* or solifluction materials in the less rugged areas, it being hard to trace structurally complex units in any area of rugged relief no matter how good the exposure. However, reliably distinguishable lithologic contrasts do occur in some local areas, usually where the contrast is very striking on the ground, and these can be used to check or modify previous maps for the compilation of the 1:500,000 traverse route map. For example, the contacts between granites and darker and/or more fractured rocks can be seen in several, but not all places, near Gyanco and Dongqiao, and in the southern Kunlun Shan. Contacts of limestones with darker sedimentary rocks also stand out in some places, for instance between Ordovician carbonates and Triassic arenites in the Golmud River valley, and between volcanics and carbonates near Yaxi Co. Where topography is modest, a fairly general lithologic distinction can be seen on the LANDSAT images between redbeds (of several ages) and other rocks, for example near Gyanco, Amdo, Yanshiping, and near Erdaogou. This can be done because the redbeds have, in many places, a distinctive yellow–orange tone on the false-colour images. However, where the topography becomes rugged, and where soil or solifluction cover is developed, this feature becomes less prominent, and it is clear that it does not show reliably all areas of redbed occurrence.

Although lithologies and their contacts are generally difficult to distinguish, stratification expressed by topographic features is more easily identified and followed on these images. It is not always possible to show the full amount of stratification detail available from the images on the 1:500,000 scale map, but the general trends and the major folds are included. Because of the poor expression of the stratification in most places, it is not possible to identify easily old, inactive faults subparallel with strike. The assumption must be that most of these fault structures are not detected reliably from the images.

The structures that are most prominent on the images are the active (Quaternary) faults, as has been known for some time (Molnar & Tapponnier 1978). These are distinguished from the older faults on the 1:500,000 map. The observations made during the geotraverse on these structures are discussed by Kidd & Molnar, this volume). Most concern the major east-trending left-lateral strike-slip fault system in the southern Kunlun Shan, of which two major fault strands, the Xidatan and Kunlun Pass Faults, are crossed by the traverse route. The north-trending normal faults, and related NE- and NW-trending strike-slip faults, seen in several places along the southern half of the route, have been recently described in detail by Armijo *et al.* (1986).

The orbital imagery, therefore, is extremely helpful in providing a general overview of the topography and geology, and for mapping some more detailed aspects of the geology, particularly neotectonic structures. It has limitations, however, in extrapolation of lithologic map units and older (inactive) structures. The speculative nature of most of these extrapolations means that the 1:500,000 map will probably need revision when ground investigation is done of areas not covered by our traverse or previous Chinese field work. Several of the Chinese maps, particularly the 1:1.5 million scale geological map of the Qinghai–Xizang plateau, have incorporated substantial input from interpretation of LANDSAT images. The areas in which this has been done are not readily separable from those in which there is ground-based map data. Therefore caution is needed in using particular map patterns or relations on the 1:500,000 scale traverse map for far-reaching conclusions, particularly for geology far from that known on the ground.

3. DETAILED TRAVERSE MAPS

(*a*) *Introduction*

Base maps used during the traverse were provided by the Academy of Sciences and consisted of a set of 69 topographic maps at 1:100,000 scale (figure 1) of excellent detail and quality. Most have a contour interval of 20 metres; some, in areas of rugged topography, have an interval of 40 metres. These maps proved ideal for the purposes of recording locations and basic geology throughout the traverse. In a few places, some Geotraverse groups locally went beyond the coverage of these maps; in these areas we used 1:100,000 scale black-and-white prints of the LANDSAT images as base maps, although it was clearly easier and preferable to use the topographic maps for location in the field rather than the images. A set of the topographic maps is lodged with the British Museum (Natural History).

Localities and basic geological information, such as observed lithologies, lithologic unit boundaries, faults, fold hinges, attitudes of bedding, foliation, lineation, etc., were recorded on a master set of maps during the traverse. These data were checked and supplemented from participants' field notes after the end of the traverse. The master set of geotraverse geologic maps is lodged in the collections of the British Museum (Natural History). The localities and all the geological information have been abstracted by redrafting from the 48 topographic map sheets that were used, for reproduction on microfiche (in pocket). The intention is that these maps show only data observed in the field, and modest extrapolations ("field glasses geology") made in the field at the time by those who visited the particular localities. Because all the localities visited by all participants are shown on these maps, each with its locality number, it will be clear which information is from outcrop observations and which consists of extrapolation

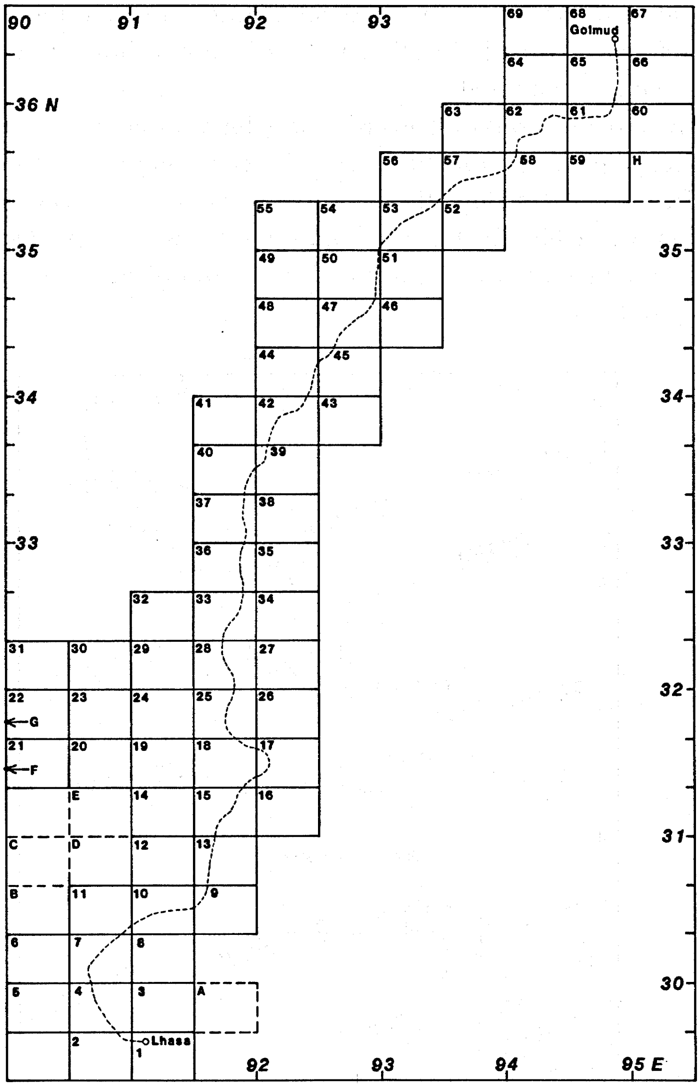


FIGURE 1. Index map to topographic map sheets (1:100,000 scale) provided for the Geotraverse. Lhasa–Golmud highway shown by dashed line. Numbers are keyed to map sheet names in the list below. Detailed geological maps drawn on this base (microfiche, in pocket) use these sheet numbers and names for identification. Not all map sheets were used and in cases where only a small proportion of a map sheet was used, it may be combined with an adjacent sheet in the microfiche geological maps. Areas labelled with letters A–H refer to geological observations made on LANDSAT image base maps; these areas are included with the other maps on microfiche.

1. Lhasa City
2. Quxu
3. Lhunzhub
4. Maqu
5. Jidaguo
6. Junmaching
7. Yangbajian
8. Pangduo
9. Baga
10. Damxung
11. Ningzhong
12. Nam Lake
13. Gulu
14. Bengcuo
15. Sangxiong
16. Dareng
17. Nagqu
18. Gajia
19. Baerda
20. Jiangcuo
21. Baingoin
22. Dongkacuo
23. Dongqiao
24. Jibuxiang
25. Erdaohe Station
26. Nyimaqu
27. Nyainrong County
28. Amdo
29. Zhashuqu
30. Cigetangcuo
31. Yatucuo
32. Chaqu
33. 112th Station
34. Maisairi
35. Dengka
36. Tanggula Pass
37. Wenquan
38. Longyala
39. Yanshiping
40. Wenquan Station
41. Jiri
42. Tongtian Bank
43. Cuojiangqin
44. Tuotuo River
45. Yaxicuo
46. Bayingzangtuoma
47. Erdaogou
48. Tangrijiapang
49. Gelushankecuo
50. Fenghuoshan
51. Lemacuo
52. Duoqun
53. Wudaoliang
54. Gongmaorima
55. Cuorendejia
56. Haidingluoer
57. Budongquan
58. 63rd Station
59. Zheseke
60. Reshui
61. Naij Tal
62. Qingbanshan
63. Diayingshan
64. Tuotuolalin
65. Dishantou
66. Duoyahe
67. Golmud East Farm
68. Comm. of Golmud
69. Dazaohuo

from them. The locality numbers can be used to relocate precisely the sampling and fossil localities to which reference is made in other papers in this volume and in any subsequent publications on the material collected.

The locations of the cross-sections of Coward *et al.* (this volume) are given on each map; in most cases, one section crosses several sheets and the continuation is indicated by subscript letters in sequence. In a few places along the Geotraverse route, some detailed mapping beyond a single line of section was achieved. Results from those areas are now discussed briefly. The location of each of the detailed maps (figures 3, 4, 6, 7, and 8) are given with respect to the traverse route on figure 2.

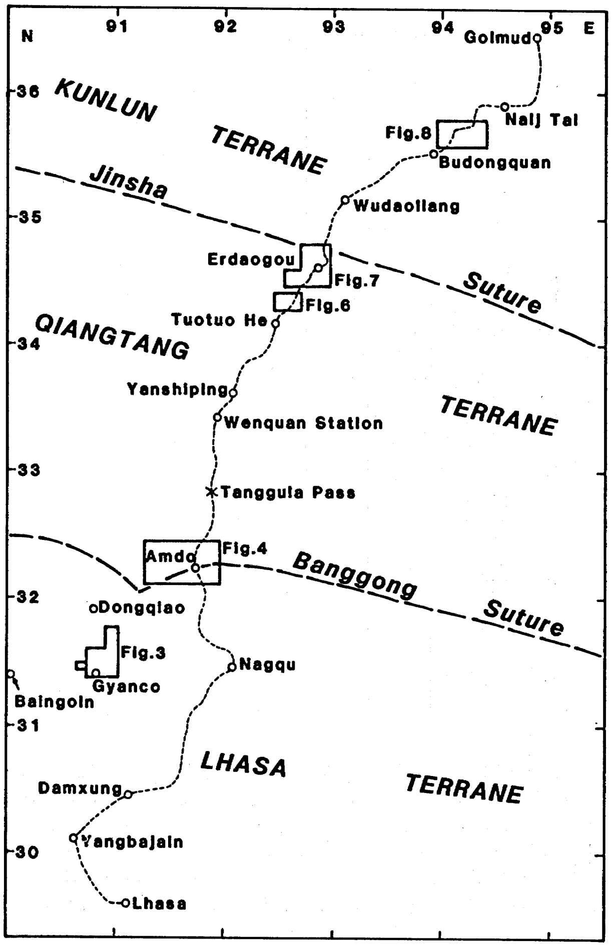


FIGURE 2. Sketch map showing location along the traverse route of detailed geological maps (figures 3, 4, 6, 7, and 8).

(*b*) *Gyanco–Pung Co*

In this area (figure 3), stratigraphic and structural relationships are exposed between the Banggong Suture-derived ophiolite nappe, Carboniferous–Permian clastics, limestones of uncertain age (?Permian or ?Jurassic), and Jurassic flysch. Mid-Cretaceous red clastics and andesite–rhyolite volcanics are also present, and mid-Cretaceous granitoid rocks and NNW-trending andesite dykes were observed to intrude all lithologies except the Cretaceous clastics

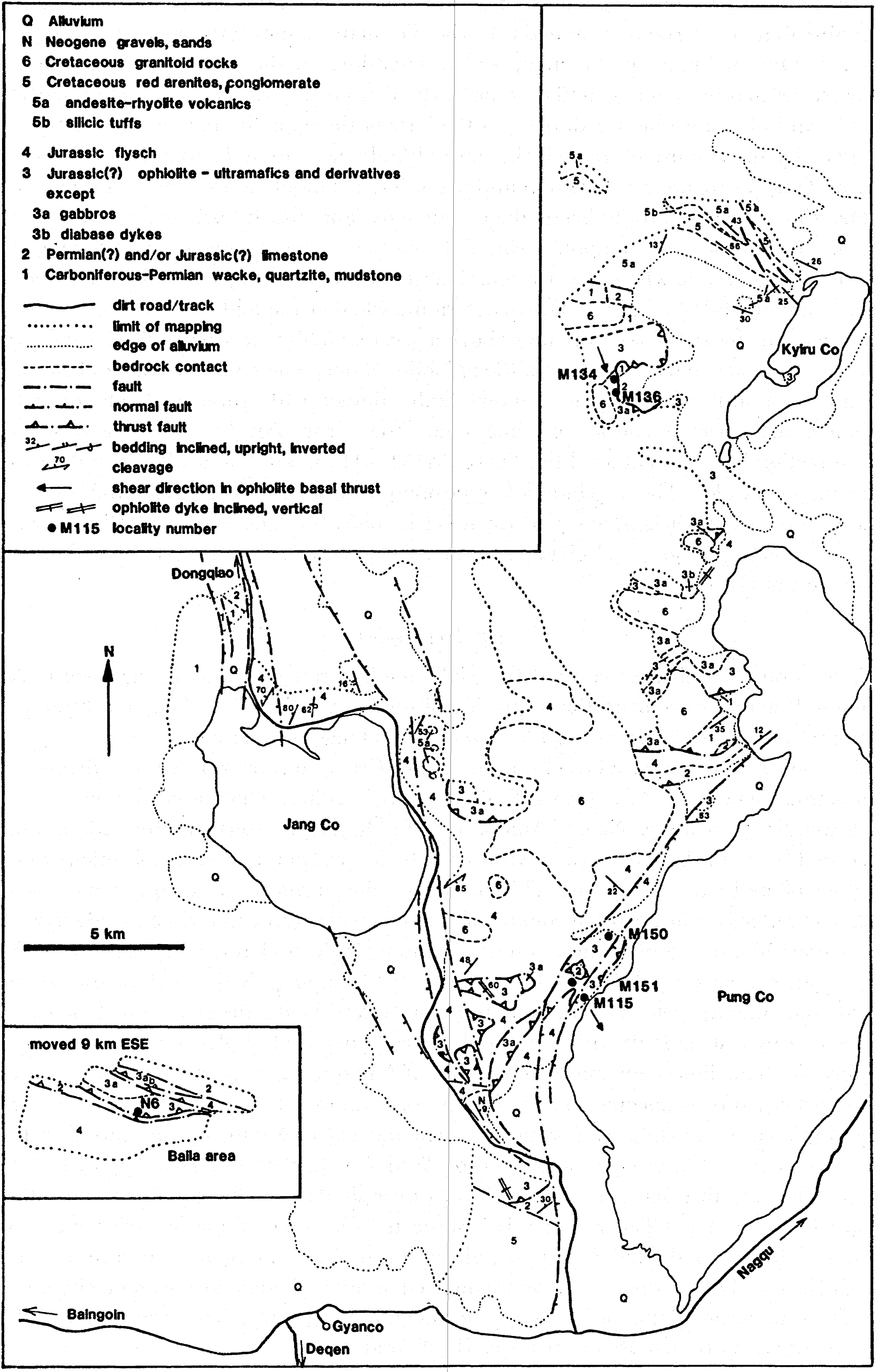


FIGURE 3. Geology in the vicinity of Gyanco and Pung Co. For location, see figure 2. This figure, and the other detailed maps, may be found easier to interpret if some or all of the units are coloured. The inset of the Baila area has been moved 9 km ESE from the true position with respect to the main area of the map.

and volcanics. A previous report on a larger area that encloses this one (Girardeau *et al.* 1984) maintains that the carbonates and the Carbo–Permian clastics form a nappe on top of the ophiolite. Our mapping in this area, and observations to the west near Baila (figure 3), demonstrates that this is not so, and that the Carboniferous–Permian clastics and the carbonates all lie in an imbricate zone (or duplex) at the base of the ophiolite nappe. The mapping also suggests why the confusion arose: if the normal faults near to and subparallel with the west shore of Pung Co are not recognised, it appears as if the ophiolite ultramafic rocks exposed near the lake shore are structurally below these sediments (and also Jurassic flysch) exposed to the west in the hillside. Our mapping was not extensive enough, given the less-than-perfect exposure, to determine whether any original large-scale relationships are preserved among the various ophiolite lithologies, nor did we determine whether the mid-Cretaceous volcanics and clastics were deposited unconformably above a severely folded or a basically flat-lying nappe pile. Structures at the basal contact of the ophiolite nappe, where serpentinite and carbonated derivatives of ultramafics are in original fault contact with Jurassic flysch, or with the Carboniferous–Permian clastics, or limestone, show clear SSE-directed sense-of-shear and shear direction indicators at localities M115, M134, M136, M150 and M151, on the west side of the Pung Co valley. These include S-C-type oblique foliations, oblique vein and fracture sets, steps in fibrous vein slickensides, and asymmetric folds. Oblique S-C-type foliation was also seen in the same position, and giving the same shear sense, at locality N6, near Baila, about 20 km west of Gyanco.

(*c*) *Amdo region*

The mapping in this area covered the ENE-trending range straddling the town of Amdo. Ophiolite lithologies occur on the south side of this range (figure 4). They mark the present location of the suture between the Lhasa and Qiangtang Terranes.

In the southwest, red clastic rocks of uncertain, Cretaceous or Tertiary age define a large asymmetrical syncline with a steeply N-dipping axial surface, which is cut by two prominent NNW-trending tear faults. Nearer Amdo, ophiolite lithologies (serpentinite and gabbro) are imbricated in south-directed thrusts with redbeds that contain andesitic volcanics, which are probably of mid-Cretaceous age. This imbricate zone projects westward above the large syncline of redbeds. The northern contact of ophiolite serpentinite in the section along the river valley about 10 km west of Amdo is a steep S-dipping fault, probably with a N-directed thrust component. Other steep faults and a moderately S-dipping, N-directed thrust cut folded redbeds and andesitic volcanics north of this point. East of Amdo, the extension of these redbeds is truncated by a steep fault with a S-side down component of displacement against mid and late Jurassic shale, limestone and arenites; west of Amdo it is not clear whether the equivalent contact is faulted or is unconformable. The Jurassic strata belong to the Qiangtang Terrane. They form a large, west-plunging anticline north and east of Amdo, and they are thrust north over redbeds of uncertain age (Cretaceous or Tertiary). In the same area (figure 4), some of these redbeds are themselves thrust northward over similar but finer-grained and softer red strata, which may be of Tertiary age. It is suspected that some of the redbeds west of Amdo unconformably cover the overthrust Jurassic strata, but a lack of good exposure prevented a firm conclusion. The northern redbeds are inferred to rest with angular unconformity on folded Jurassic strata of the Qiangtang Terrane, because a prominent erosion surface with reddening below it (figure 4) is seen about 20 km NNE of Amdo.

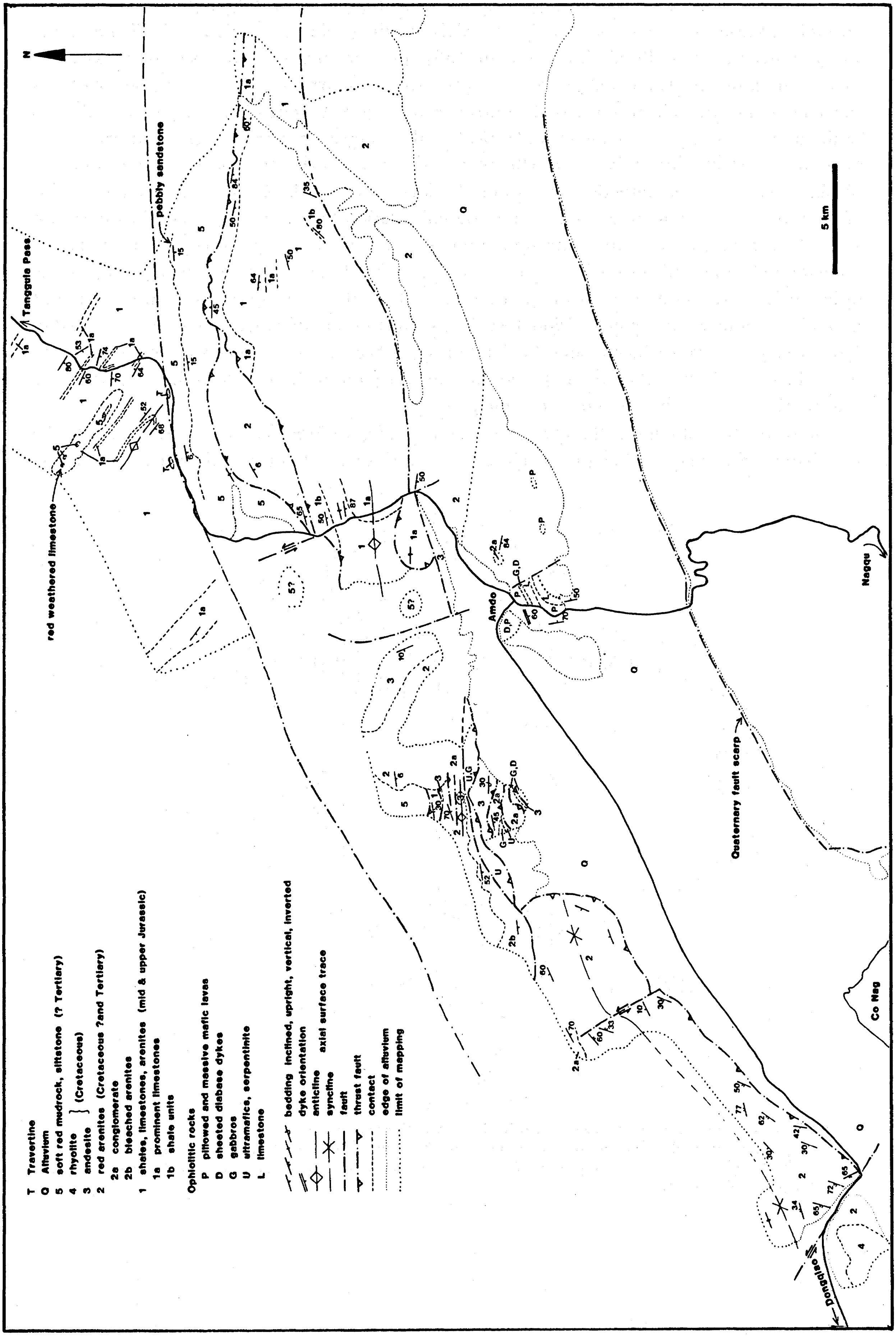


Figure 4. Geological map of the Amdo area. For location, see figure 2.

The fold trends (ESE) in these Jurassic rocks of this part of the Qiangtang Terrane are strongly oblique to and truncated by the ENE-trending fold and fault trends of the Amdo range. Furthermore, oblique slickensides and offset markers in outcrop imply that at least some of the faults in the Amdo range have a significant left-lateral strike-slip component of displacement. The overall structure of the narrow range, with outward-directed thrusts and steep faults with strike-slip components is identical to the "flower-structure" described from well-documented strike-slip fault zones with oblique compressional motion. This compressional displacement explains both the truncation of folded strata of the Qiangtang Terrane in this area, and the strong modification of the original relationships of the ophiolite in the suture zone. The structures seen in the Amdo region are thus largely the product of tectonic events younger than the initial suturing of the Qiangtang and Lhasa Terranes, even though these ophiolite occurrences now mark the position of the (modified) suture in this transect. At least a small amount of the compressional strike-slip tectonism affecting this area is probably Quaternary; several rivers crossing the Amdo range have a sharply antecedent relationship to it (see Kidd & Molnar, this volume), and the fault scarp on the south side of the Co Nag valley (figure 4) is also clearly an active tectonic feature.

The truncation of folds in the Qiangtang Terrane (figure 5) is more or less restricted to the length of the area mapped in figure 4. The trend of the Banggong Suture, inferred from ophiolite

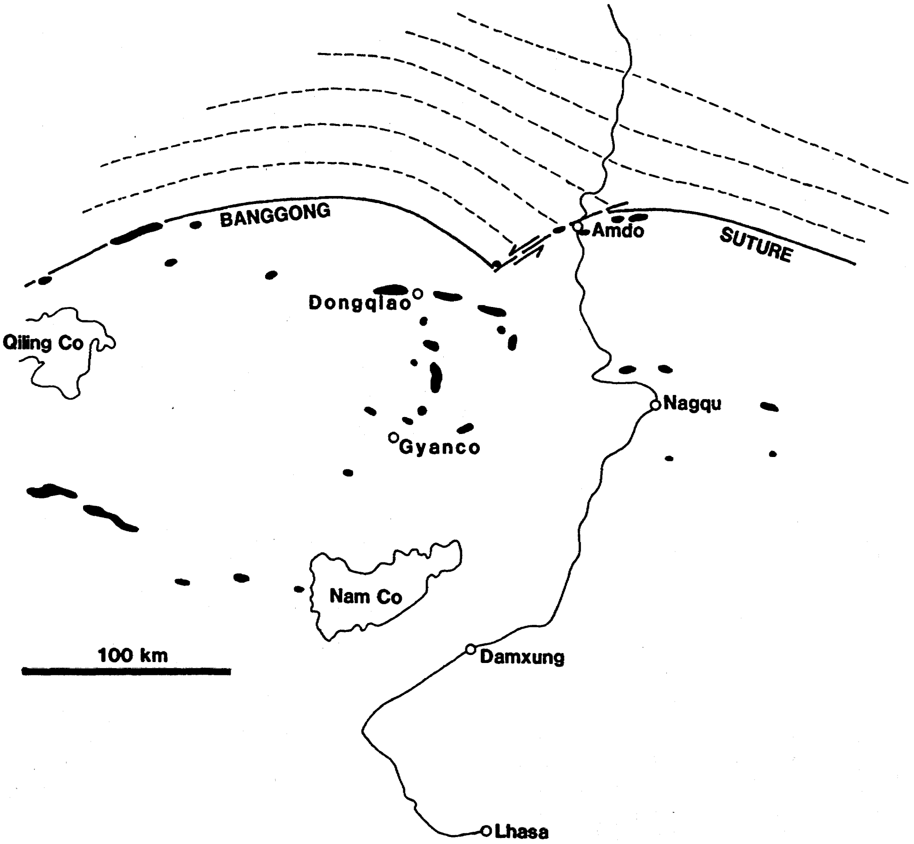


FIGURE 5. Sketch map of ophiolite occurrences in the Lhasa Terrane near the line of the geotraverse. Position of Banggong Suture and its concordance with the trend of folds in the southern Qiangtang Terrane (dashed lines) is indicated. Left-lateral strike-slip offset of the suture occurs near Amdo, coincident with truncation of the Qiangtang fold trends.

occurrences shown on the Geologic map of the Qinghai–Xizang Plateau, become parallel with these folds farther east and west (figure 5). The Amdo strike-slip zone, however, does not appear (from LANDSAT image interpretation) to extend obliquely into either the Qiangtang or Lhasa Terranes and its strike-slip displacement is therefore likely to have been accommodated by additional thrusting in the general vicinity of the suture beyond the ends of the Amdo range.

(*d*) *Tuotuo River–Wuli area*

Mapping in this area (figure 6) was aimed at understanding the relationship between the Eocene red clastics of the Fenghuoshan Group and the underlying Triassic Batang Group carbonates, andesitic volcanics, and clastics, and Jurassic Yanshiping Group clastics. The map shows that an angular unconformity occurs at the base of the Fenghuoshan redbeds but, from measured dips, and from the limited truncation of the underlying Batang Group (figure 6) it is concluded that the latter was only gently folded, at least in this area, prior to redbed deposition. The relations of the Yanshiping Group to this unconformity were not determined conclusively. However, if the extremely pure pale quartzite seen along part of the northern outcrop of the Batang Group is at the base of the Jurassic sequence, its occurrence at two places below redbeds to the north near Erdaogou (figure 7) suggests little discordance between the redbeds and the Jurassic sequence, as long as the latter is of modest thickness in this area. Previous maps show the volcanics and carbonates below the redbeds near the main road as of Permian age, correlative with the Wuli Group, (see Yin *et al.*, this volume). The lithologic types and sequence, and the fossils of Norian age in the limestones at locality M225 (Smith & Xu, this volume) show that these strata belong to the Triassic Batang Group.

Structures observed (vein and fracture sets, slickensides) in the well-lithified redbeds of the Fenghuoshan Group on the southern edge of this range indicate southward overthrusting over adjacent poorly-lithified marls and sands (presumed Neogene in age). Unlike the Erdaogou area (see below), no strong evidence for Quaternary thrusting was seen here, but most of the folding of the strata in this area is of Tertiary age. The implications of this observation for the age of folding in the Qiangtang Terrane as a whole are discussed below.

(*e*) *Erdaogou area*

Upright folds and mostly northward-dipping thrust faults in the Eocene Fenghuoshan Group redbeds must be related to crustal shortening during the India–Asia collision. The map of this area (figure 7) and the cross-section derived from it (see Coward *et al.*, this volume) yield substantial shortening values, a minimum of about 40% by folding alone. The LANDSAT image and the topographic maps give a fairly clear idea, from well-developed stratification trends, where the major folds and thrusts are located. With the distributed ground observations, including abundant younging indicators in the redbed arenites, most of the structures shown are identified with confidence.

A prominent thrust outcrops in the southernmost range of hills placing the well-lithified Eocene red arenites over soft red marls and pale sands that are presumed from their state of lithification to be younger than the Eocene strata. A well-exposed small thrust duplex of the lithified red arenites occurs in the flank of the hill on the east bank of the river Qu Ma Liu (Moron Us; Leeder *et al.*, this volume) adjacent to the main road (locality M191), and a similar imbrication, in this case involving the young marls, is seen about 7 km west of this point. Evidence for very young (Quaternary) thrust tectonics is suggested by the presence of an

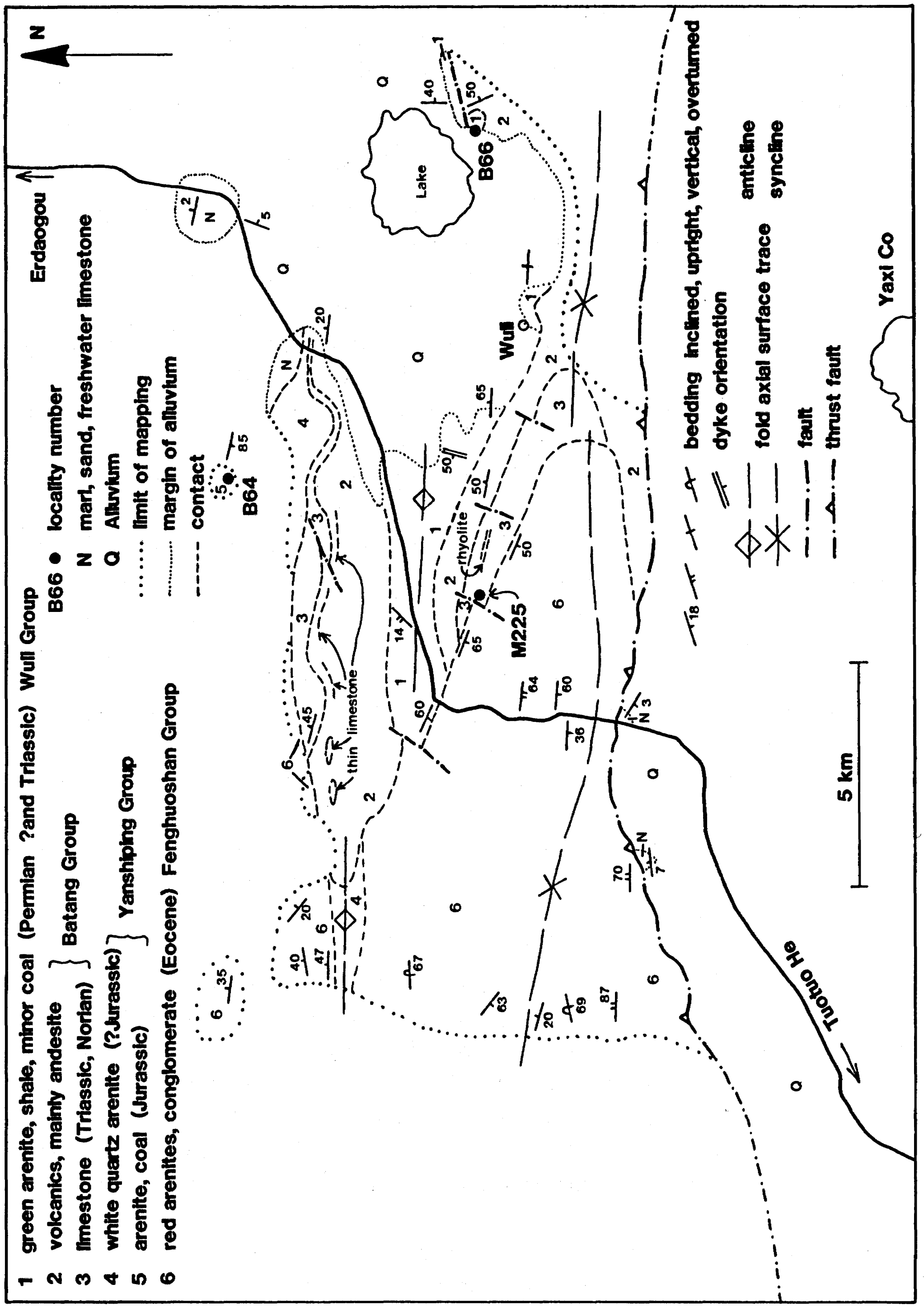


FIGURE 6. Geological map of an area near Wuli. For location, see figure 2.

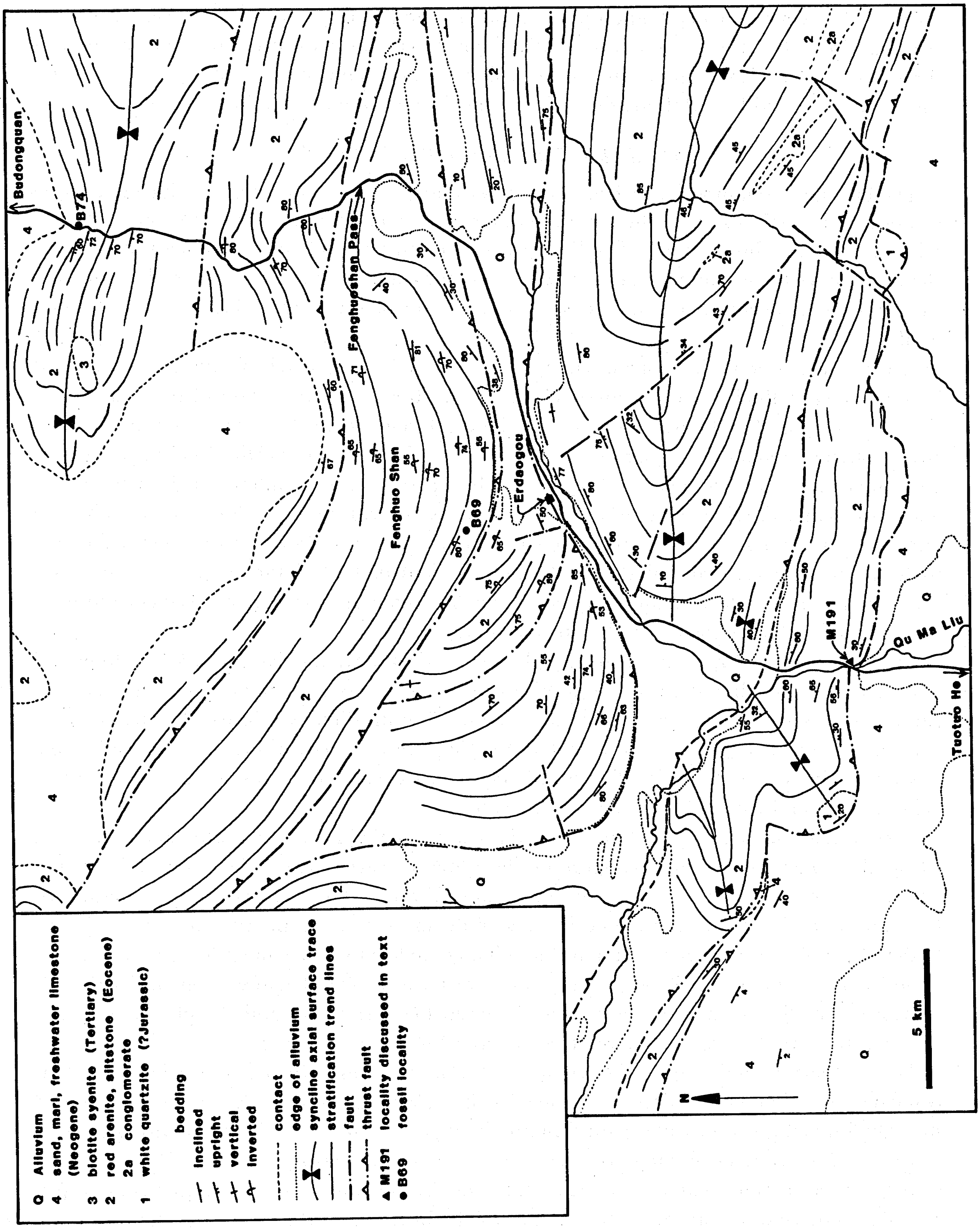


FIGURE 7. Geological map of the Erdaogou area. For location, see figure 2.

incised meander in a small side valley joining the east side of the valley of the Qu Ma Liu (Moron Us), where the thrust outcrops by the main road (locality M191). The local antecedent relationship that this river, and others like it farther east, has with this southernmost range of the Fenghuoshan also suggests late Neogene-Quaternary uplift, most likely by movement on this thrust (see Kidd & Molnar, this volume and Leeder *et al.*, this volume).

(*f*) *Xidatan Valley–Burhan Budai Mountains*

The Burhan Budai mountains form the southern side of the Xidatan valley, which marks the location of the main strand of the Kunlun Fault system, a major left-lateral strike-slip zone (see Kidd & Molnar, this volume). The bedrock on the southern side of this valley was mapped (figure 8) to try to determine the nature and age of the contacts between the several contrasting rock units that occur there, and to see whether any of the faults related to the Kunlun Fault.

A prominent ductile high strain zone in the form of a grey-black phyllonite unit several hundred metres thick occurs at lower elevations on the southern margin of the valley. The thickness suggests that it must be a zone of major displacement. The phyllonite contains a single strong phyllitic foliation dipping on average moderately to steeply north. Boudinaged quartz veins are common in this foliation. It is affected by a pervasive set of outcrop-scale open to tight folds with gently-dipping axial surfaces and gently east- or west-plunging hinge lines. Both these later folds, and a less intense to phyllitic cleavage are seen in the two major structural blocks to the south of the phyllonite; that is, all the bedrock south of the Xidatan in this map area shares the same outcrop-scale structural sequence, which is thought from regional evidence to have been formed in late Triassic – early Jurassic times.

In one locality (M306), north of the phyllonite, dark grey highly-strained limestone and pale-coloured pure limestone in variably disrupted thick beds occur in a melange-like disrupted grey slaty matrix. Evidence in outcrop of south-directed thrusting (offset layers, asymmetric folds) suggests that this material perhaps formed part of the hanging wall to the phyllonite, in which evidence of south-directed thrust-sense shear (asymmetric boudins of veins, shear-band cleavage) was also seen locally.

However, at the eastern end of the mapped area, green phyllitic rocks, partly arenaceous and feldspathic, resembling those seen structurally below the carbonates farther east in the Dongdatan area, occur to the north of the phyllonite. Either a large lateral ramp structure, or (perhaps more likely) the original occurrence of the carbonates in an imbricate slice adjacent to the phyllonite, are needed to explain this change, unless the carbonates form part of a slice bounded by a younger strike-slip fault and have been displaced many kilometres from the nearest source to the east. As the contact between the carbonates and the phyllonite is not exposed, this problem cannot be resolved without further mapping.

The southern boundary of the phyllonite is, in most places, a brittle subvertical fault that truncates the phyllonite foliation. In one locality (M244), by contrast, a short section of strongly-foliated green phyllites with thin arenite layers occur under a contact with very dark phyllonites, the contact dipping north concordant with the cleavage. Because this occurrence is so restricted, it is unclear whether this represents the footwall of the phyllonite zone or just a lens of somewhat less-strained rock within it. The brittle fault that truncates the phyllonite elsewhere was found exposed in only one locality (M284), where layering and foliation is locally folded on both sides within about 5 metres of the fault. The fault itself consists of gouge about

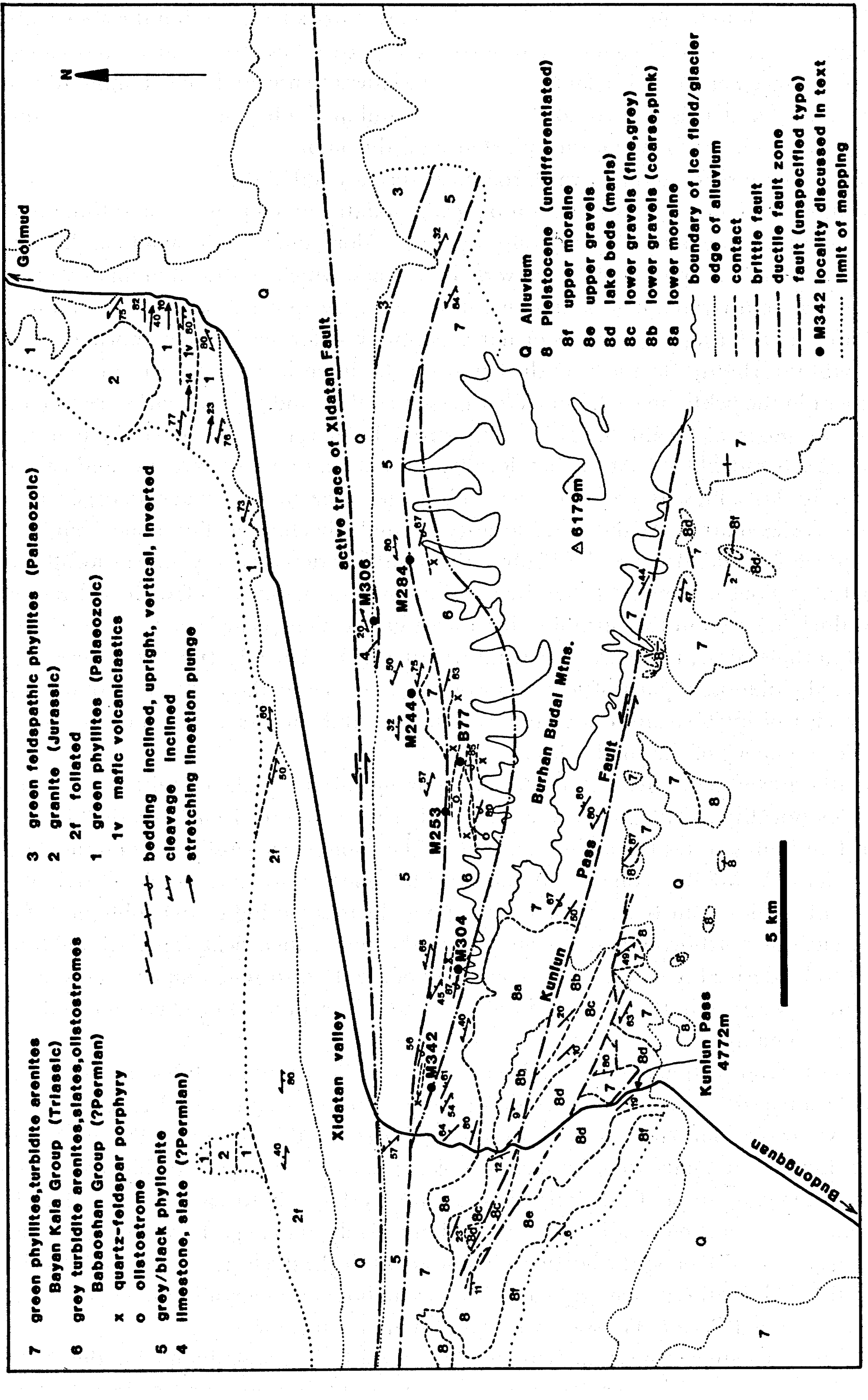


FIGURE 8. Geological map of the Xidatan–Kunlun Pass – Burhan Budai Mountains area. For location, see figure 2.
]

1 metre wide largely derived from the phyllonite. Vertically-plunging asymmetric minor folds of foliation adjacent to the gouge and in larger intact wall-rock lenses within the gouge, oblique S-C foliation in some of these lenses, and horizontal groove slickensides all suggest left-lateral strike-slip displacement on this fault. The displacement sense and the dominantly brittle character imply that it is related to the present Kunlun Fault system but there is no geomorphological evidence for Quaternary activity on this fault.

West of the main road, and eastward from near the east end of the Xidatan valley, this fault places phyllonite against steeply north-dipping well-foliated green phyllites and thin quartzose turbidite arenites of the Bayan Kala Group (figure 8). Along much of the length of the Xidatan valley, however, a lens up to about 2 km wide intervenes, which consists dominantly of steeply north-dipping, south-younging (and upward-facing) grey quartzose turbidite arenites and slates (Babaoshan Group). These seem not as strongly deformed or metamorphosed as the green phyllitic turbidites to their south, based on the intensity and appearance of foliation development in the pelites in each unit. Well-preserved flute and groove marks are seen on bed bases in a number of localities. Thick olistostromal deposits are exposed in two sections (localities M253 and M304). At the first locality, limestone, quartzose arenite, and calcareous quartz arenite clasts, most 10 cm or less across, but with a few up to 5 m across, occur in a dark grey shaly (slaty) matrix. At the other locality, a single fossiliferous limestone boulder 10 m long is exposed in shale. Because these submarine mudflow deposits only appear locally within the turbidite sections it is inferred that they are confined to channels. A few silicic tuff beds up to 10 cm thick are seen in the turbidites in at least one section (near M284). In every section examined in these rocks, there are somewhat irregular sills, typically 100–300 metres thick, of badly-altered, epidotised quartz-feldspar porphyry that occupy about 20–30 % of the section. These are clearly intrusive into both the olistostrome and the turbidites and were intruded prior to development of the single cleavage.

The southern contact of the tectonic lens containing this assemblage of lithologies was seen in one valley (locality M342); elsewhere it is mostly covered by the icefield on the higher parts of the Burhan Budai, or (at the main road) cut by the younger strike-slip fault on the northern side of the lens. At M342 a zone about 150 m wide appeared to be a syn-cleavage fault with mixing of lithologies from both sides. Rather poor shear sense indicators (oblique S-C type cleavage) suggest north-over-south thrusting on the now subvertical zone. Abundant float presumed to be derived from this zone, consisting of highly transposed quartz veins in a dark pelitic matrix, was seen in the valley of locality M284; the source, somewhere above the snout of the glacier, could not be reached.

One other narrow section of rocks has been reported to be within the Babaoshan Group. This occurs at locality B77 where a small section (about 25 m) of arenites, shales, tuff, and a coal bed with Mesozoic plant fragments is exposed (Yin *et al.*, this volume). The coal and the associated fluvial sediments seem unlikely lithological associates of the turbidites and olistostromes that make up most of the Babaoshan Group. Perhaps this occurrence is a block in the olistostrome that occurs in the adjacent valley. Alternatively, it may perhaps occur in a separate tectonic lens ("horse") along the northern boundary fault. In the latter case it could be related to the clastics with local red beds and coaly beds seen about 50 km east in the Dongdatan, and which overlie folded Permo-Triassic rocks with angular unconformity.

The Pleistocene sequence near the Kunlun Pass (figure 8) is regionally tilted to the SSW, and locally dips as much as 23°. This deformation is connected, but not in a precisely understood way, with the interaction of the Kunlun Pass Fault and the Xidatan Fault, because the area of maximum tilting is in the zone where the faults approach one another. The apparently irregular distribution of outcrop of the Triassic Bayan Kala Group south of the Kunlun Pass Fault (figure 8) is largely due to palaeotopography. South- to southwest-trending valleys filled by the Pleistocene sequence alternate with ridges of the Triassic arenites and phyllites; the ridges terminate to the south because of the southerly tilting.

4. PROBLEMS NEEDING FURTHER MAPPING

Some geological problems can be solved by examining a single good exposure or section, but others require well-distributed information (in other words, mapping) for their solution. It is, in many cases, only by looking systematically and in detail through an area that some of the key localities and sections are found, and the variability assessed in stratigraphic and structural sequences and other features. We contest vigorously the idea that all, or everything of significance, is solved by one geotraverse. This is particularly true where outcrop is discontinuous and the structure complex, as along most of the traverse route. In the interest of brevity, only a few questions are raised here; in other words, the discussion below is not comprehensive.

The timing of the beginning of the collision between the Lhasa and Qiangtang Terranes is poorly known, and it is not known whether the late Jurassic uplift of the Dongqiao ophiolite is indicative of thrusting of ophiolite onto continental lithosphere of the Lhasa block ("obduction") or reflects some other intra-oceanic event. This is so because the relations between the Triassic platform carbonates of the Lhasa Terrane and the Jurassic flysch are ill-defined. Was the flysch deposited over carbonates and continental basement and, if so, when did it start? Conversely, was it tectonically transported from an oceanic environment significantly later than its depositional age? The significance of the isolated occurrences of Triassic carbonate turbidites could be related; do they represent a response to platform rifting or are they an early response to thrust loading of the Lhasa Terrane? The basic relationships and ages of these strata will have to be established by mapping to answer these questions.

Also in the Lhasa Terrane, only extensive accurate mapping of the mid Cretaceous and younger rocks will yield useful estimates of the crustal shortening that there has been prior to and subsequent to mid-Cretaceous times, essential information for testing crustal thickening models for the India–Asia collision. Similar comments are applicable to Tertiary rocks elsewhere on the plateau, although our mapping near Erdaogou (see above) illustrates that modest efforts can quickly improve understanding.

There is still a large question to be answered about the age of folding in the Qiangtang Terrane. In the north, around Wuli, most of the shortening is younger than Eocene (see paragraph 3*d* above). In the southernmost part, just north of Amdo, the folding of the mid and late Jurassic strata predates some of the redbeds (paragraph 3*c* above). The problem rests on the age of those redbeds; are they Cretaceous, or are they Tertiary, and could the folding be Tertiary as it is in the north? If the folding in the south is Cretaceous, where in the Qiangtang Terrane does the change occur to the younger deformation seen in the north?

Besides the obvious need to define what lies below the Jurassic covering the southern two-thirds of the Qiangtang Terrane along the traverse line, the relationship of the Triassic Batang Group arc volcanics to Permian rocks is ill-defined. Could the arc volcanics be allochthonous, overthrust from the Jinsha Suture?

For the Kunlun Terrane, systematic mapping will reveal the large-scale structural relations of the Permo-Triassic sections north of the Xidatan Fault to older rocks (cf. Coward *et al.*, this volume) – essential information in understanding the tectonic significance of these Permo-Triassic rocks (were they deposited in extensional basins?). Although isotopic ages may help to solve the problem of whether there are one or two sequences of volcanics in the northern Kunlun, and whether they are Devonian, Carboniferous, or Permo–Triassic, mapping would contribute greatly to the confidence placed in the ages, if it revealed the original relationship(s) of the volcanics to the Carboniferous strata, for example.

As a final and more general problem, the location of sutures and the occurrence of ophiolites are critical to the interpretation of the assembly of the crust of the Qinghai–Xizang Plateau.

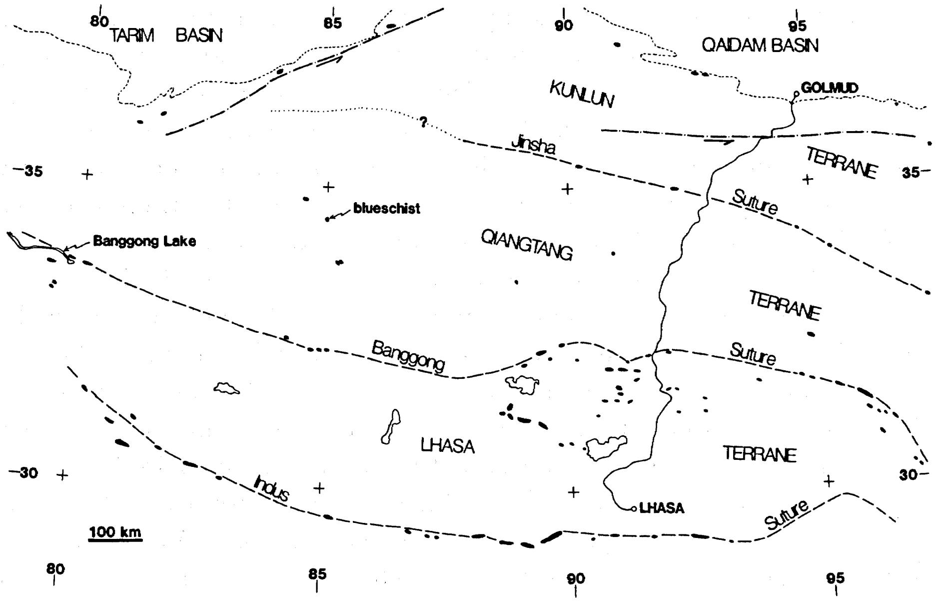


FIGURE 9. Sketch map of ophiolite occurrences in the central and western parts of the Qinghai–Xizang Plateau, with the known sutures indicated. Ophiolite and blueschist occurrences within the Qiangtang Terrane may indicate the presence of one (or perhaps more) additional sutures.)

Figure 9 shows the occurrence of ophiolites from the 1 : 1.5 million scale Geological Map of the Plateau, with the addition of two localities from the samples and detailed topographic maps of Hedin (Hennig 1915). The ophiolites scattered across the Lhasa Terrane south of the Banggong Suture are thought, from mapping, to be remnants of a large nappe (Girardeau *et al.* 1984, 1985, Chang Chengfa *et al.* 1986). However, the nature of the ophiolite and blueschist occurrences within what is currently identified as the Qiangtang Terrane are unknown. This possible suture within the Qiangtang Terrane is as well if not better defined, at least by ophiolites, than much of the length of the Jinsha Suture. Whether this is an additional suture, and whether it might help explain the odd distribution of Gondwana-type Carboniferous–Permian at the western end versus Cathaysian-type at the eastern end of the Qiangtang Terrane, are questions that could be answered by detailed mapping of these purported ophiolites and their surroundings. Similar comments apply to the possible occurrence of small arc-type terranes and an additional suture within the southern Kunlun and Songpan–Ganzi area east and southeast of the northern part of the geotraverse route.

We thank David Rothery for his work in selecting and producing the LANDSAT imagery used for the geotraverse. Kevin Burke and the Lunar and Planetary Institute are thanked for access to image processing facilities and for loan of enlargements of Large Format Camera images.

We also thank Susan L. Anderson for design and much of the drafting of the 82 detailed geological data maps reproduced here on microfiche, the Department of Geological Sciences, State University of New York at Albany, for providing essential equipment and material supplies for the drafting of these maps, and Diane Paton for typing the microfiche-reproduced tables. Pan Yun and Wang Ping are thanked for translating Chinese geographic names from the topographic maps.

REFERENCES

Armijo, R., Tapponnier, P., Mercier, J. L. & Han Tonglin 1986 Quaternary extension in southern Tibet: field observations and tectonic implications. *J. geophy. Res.* **91**, 13803–13872.

Burg, J. P. (compiler) 1983 *Carte géologique du sud du Tibet (1:500,000 scale)*. C.N.R.S., Paris, and Ministry of Geology, Beijing.

Chang Chengfa & 26 others 1986 Preliminary conclusions of the Royal Society and Academia Sinica 1985 geotraverse of Tibet. *Nature, Lond.* **323**, 501–507.

Girardeau, J., Marcoux, J., Allègre, C. J., Bassoullet, J. P., Tang Youking, Xiao Xuchang, Zao Yougong & Wang Xibin. 1984 Tectonic environment and geodynamic significance of the Neo-Cimmerian Donqiao ophiolite, Bangong-Nujiang suture zone, Tibet. *Nature, Lond.* **307**, 27–31.

Girardeau, J., Marcoux, J., Fourcade, E., Bassoullet, J. P. & Tang Youking 1985 Xainxa ultramafic rocks, central Tibet, China: tectonic environment and geodynamic significance. *Geology* **13**, 330–333.

Hennig, A. 1915 Zur petrographie und geologie von sudwest-Tibet. Vol. 5 *in Southern Tibet* (ed. S. Hedin), 220 pp., Norstedt, Stockholm.

Ministry of Geology and Natural Resources 1980 *Geological map of the Qinghai-Xizang (Tibet) Plateau (1:1.5 million scale)*. Ministry of Geology and Natural Resources, Beijing.

Molnar, P. & Tapponnier, P. 1978 Active tectonics of Tibet. *J. geophys Res.* **83**, 5361–5375.

Qinghai Bureau of Geology and Mineral Resources 1981 *Geological map of Qinghai Province (1:1 million scale)*. Qinghai Bureau of Geology and Mineral Resources, Xining.

Qinghai Bureau of Geology and Mineral Resources 1984 *Geological maps of Golmud and Naij Tal sheets (1:200,000 scale)*. Qinghai Bureau of Geology and Mineral Resources, Xining.

Xizang Bureau of Geology and Mineral Resources 1979 *Geological map of Lhasa sheet (1:1 million scale)*. Xizang Bureau of Geology and Mineral Resources, Lhasa.

Yin Jixiang, *et al.* (in press) *Geological map of the southern Tethys of the Qinghai-Xizang Plateau (1:1 million scale)*. Institute of Geology, Academy of Sciences, Beijing.

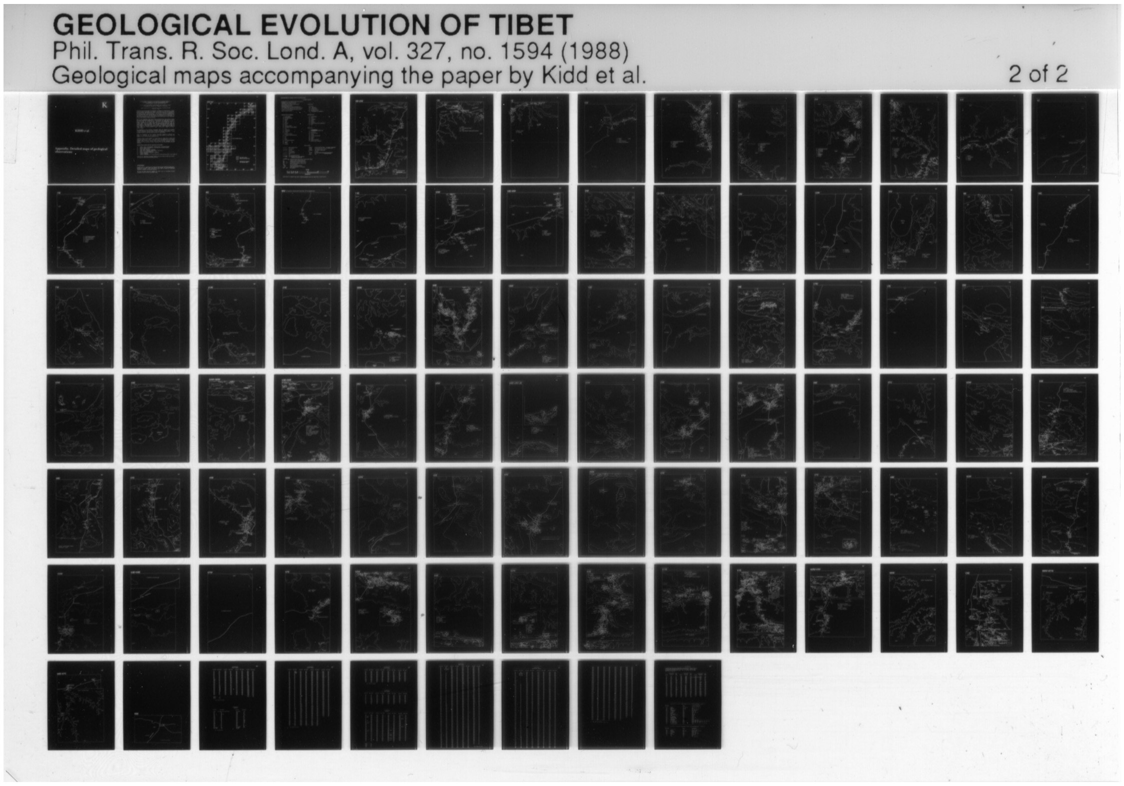
(face of envelope at back of volume containing folded coloured geological map)

GEOLOGICAL MAP OF THE GEOTRAVERSE ROUTE

Relating to the paper by W.S.F. Kidd,
Pan Yusheng, Chang Chengfa, M.P. Coward, J.F. Dewey, F.R.S.,
A. Gansser, P. Molnar, R.M. Shackleton, F.R.S., and Sun Yiyin

Phil. Trans. R. Soc. Lond., volume 327

(microfiche of geological outline maps included in pocket at back of volume)



GEOLOGICAL EVOLUTION OF TIBET
Phil. Trans. R. Soc. Lond. A, vol. 327, no. 1594 (1988)
Geological maps accompanying the paper by Kidd et al.
2 of 2