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Cenozoic uplift and deformation of the Tibetan Plateau: the geomorphological evidence

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[Plates 1 and 2]

An erosion surface, interpreted as a pediplain, is traced across the Tibetan Plateau. As a result of faulting and warping, its elevation now varies from approximately 4500–6000 m. It was cut across folded and thrust Eocene strata and mid-Miocene granites, but was dislocated by major faults before the Pliocene. Its age is thought to be mid- to late Miocene. Crustal shortening after pediplanation is small. If the crust beneath the Plateau was thickened by deformation during crustal shortening, the thickening must mainly have occurred before the pediplanation.

1. Introduction

The Tibet Plateau is a vast elevated area, about 2000 km from east to west, and up to nearly 800 km from north to south. Much of this area is over 5000 m above sea level. It is, however, by no means a plateau in the literal sense of 'an elevated tract of comparatively flat and level land'. Mountain ranges, among them the Gangdise Shan, Nyainqentanglha Shan, Tanggula Shan and Kunlun Shan, rise to 7000 m. Rivers have cut down to 3000 m.

The 1985 Geotraverse crossed the Plateau from Lhasa to Golmud, near the limit between a western region of lakes and internal drainage and an eastern region where the drainage is towards the east and southeast. Field excursions from Lhasa to Kathmandu in 1981 and 1986, arranged by Academia Sinica, extended the traverse southwestwards through southern Tibet and the Himalaya. During these traverses, it became clear that relics of a widespread former erosion surface could be recognized (figure 1) and that its present form puts constraints on interpretations of the tectonic evolution of the Plateau.

A striking feature of all the mountain ranges crossed by the Geotraverse is the evenness of the summit levels, which at once suggested the existence of a formerly planar, though now deeply eroded, erosion surface. Since many of the ranges are bounded by major fault scarps, it is clear that extensive faulting occurred after the planation; many of these faults are still active (Kidd & Molnar, this volume).

The existence of block mountains surmounted by planar erosion surfaces was recognized by many of the early explorers of Central Asia (Berkey & Morris 1927; Norin 1935; de Terra 1933). More recently, much work on the erosion surfaces in Tibet has been done by Chinese geologists and geographers (Li Jijun *et al.* 1981; Zhang Qingsong *et al.* 1981; Xu Shuying 1981). However, there is no clear agreement about the number, correlation or age of these surfaces, nor about the chronology of the uplift of the Plateau. Evidence obtained during the Geotraverse is described here, in particular that relevant to tectonic interpretation.

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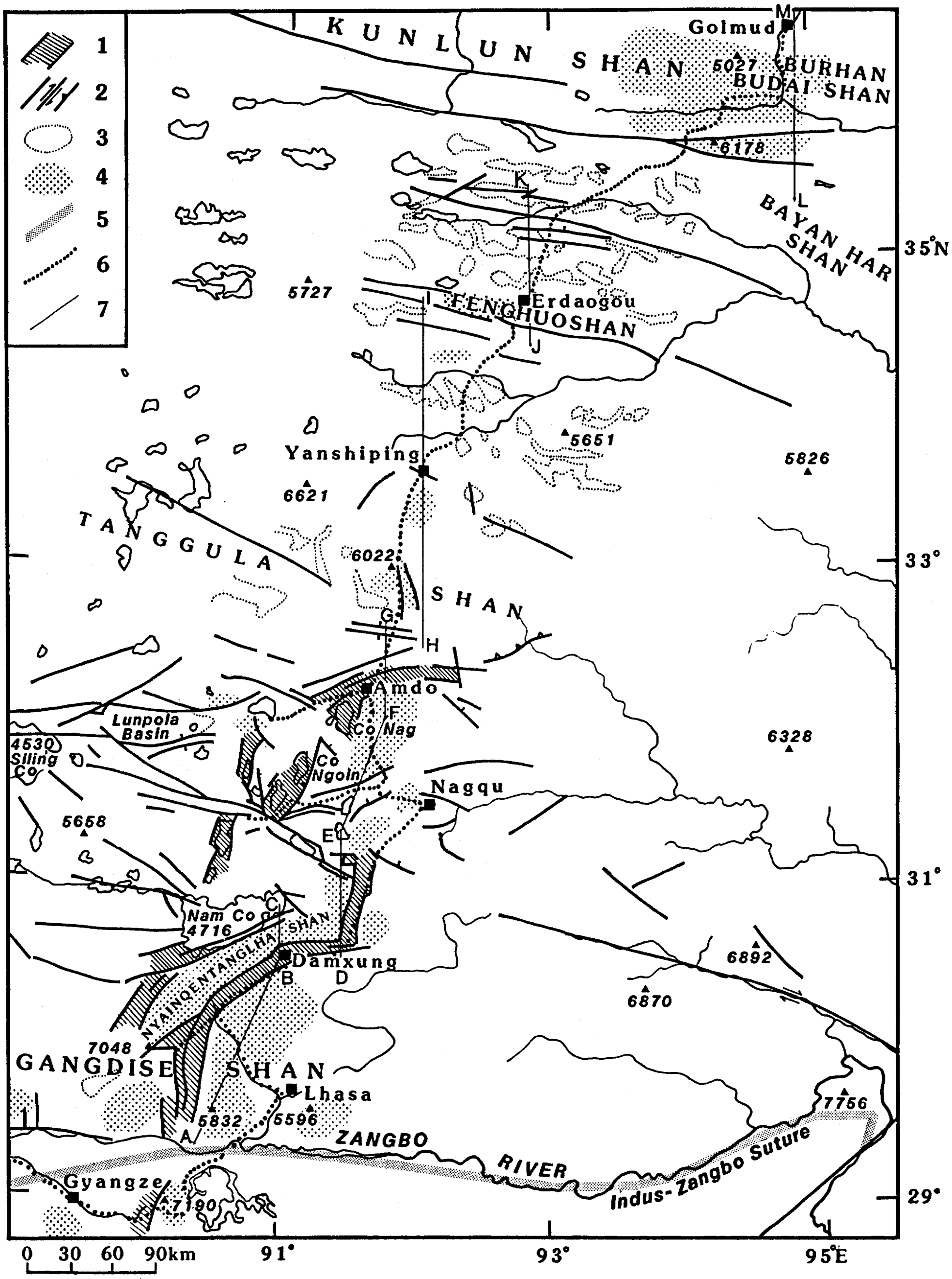

FIGURE 1. Map of Geotraverse route (6) to show observed remnants of the pediplain (4), postpediplain grabens (1) and faults (2), Neogene deposits (3), the Indus–Zangbo Suture (5) and the lines of profiles used in figure 2 (7).

Topographic data, particularly elevations, are taken from the very high quality 1:100000 topographic maps published by the State Bureau of Surveying and Mapping, Beijing, which were made available to us through Academia Sinica. Copies of these maps are deposited in the British Museum (Natural History).

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2. The interpretation of accordant summit levels as planation remnants

When seen from a distance (usually only possible from the north or south, at right angles to the prevailing trend of the ranges) most of the ranges, from south of the Zangbo north to the Kunlun, display uniform summit levels (figures 3, 4, 6 and 8, plates 1 and 2) even though the individual summits are mostly sharp peaks separated by deeply eroded valleys. While the uniform summit level along the ranges is clear, the transverse profiles are less easily seen.

The evidence from the different sections of the Geotraverse is here discussed from south to north on the basis of a profile (figure 2) derived from plotting summit elevations from a band 10 km wide across the Plateau, on the lines shown on figure 1.

(*a*) *The southern part of the Lhasa Terrane* (*Gangdise Shan*)

The Gangdise Shan (Transhimalaya) represents an Andean volcanic and plutonic arc, trending east–west, which extends immediately north of the Indus–Zangbo Suture for some 3000 km. In the Lhasa region, and for at least 300 km westwards, the rocks forming the arc have been eroded down to a remarkably even summit surface (figure 1 and figure 3). This summit surface has been cut, by the erosion of several kilometres of rock, indiscriminately across Cretaceous and lower Tertiary volcanic and plutonic rocks and a variety of sediments, as well as across both complex late Cretaceous structures and less intense post-Eocene structures, including the late thrusts which brought Palaeozoic rocks over Tertiary volcanics 25 km north of Lhasa (Kidd *et al.*, this volume; Map in pocket; Coward *et al.*, this volume). The summit surface is itself deeply incised and dissected; its elevation is now about 5700 m in the south of the Lhasa Terrane, falling gradually to about 5000 m 100 km farther north. The Zangbo River south of Lhasa is below 3700 m.

The fact that the summit surface is cut across a variety of rocks of differing resistance to erosion and across folds, faults and thrusts clearly shows that it represents an originally planar erosion surface. It follows that at least this part of the Gangdise Shan no longer existed as a mountain range by the time planation was completed.

(*b*) *The Yangbajain graben*

The northward limit of the area around Lhasa shown in figures 1 and 3 is formed by the Yangbajain graben, probably a pull-apart basin, about 10 km wide (Armijo *et al.* 1986). Steep faults, along some of which recent gravels are displaced, bound the graben. Its floor is about 700 m below the summit surface immediately to the south and about 1000 m below the main extent of the surface farther south. It is filled with at least 300 m of Pleistocene deposits (Academia Sinica 1980).

On the north side of the graben, the even summit surface is seen again on the Nyainqentanglha Shan; it must underlie the Pleistocene deposits in the graben, having been displaced downwards by at least 1500 m relative to the block to the south.

(*c*) *The Nyainqentanglha Shan*

This range, trending WSW–ENE and varying in width from 10 to 30 km, displays (figure 4, plate 1) the same even summit surface as the block south of the Yangbajain graben, though more deeply dissected by erosion. Its northern limit, less sharply defined than the southern one,

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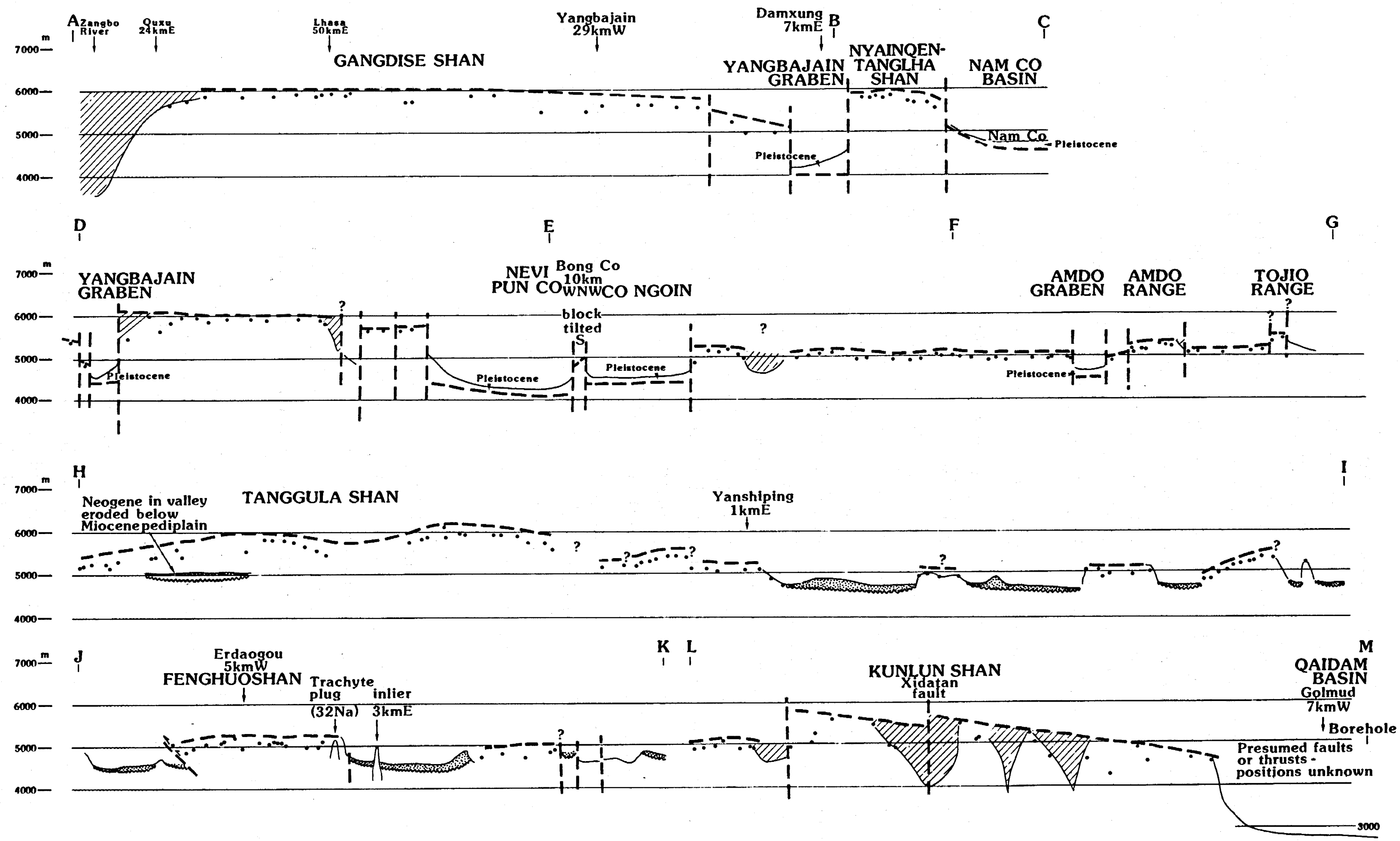

FIGURE 2. Profiles, based on elevations of peaks (dots) within 5 km of the lines shown on figure 1. Estimated position of pediplain shown by heavy broken lines. Post-pediplain faults are shown as vertical since their hade is not known. Diagonal shading indicates major post-pediplain erosion. Neogene deposits stippled. Thin lines indicate topographic surface where relevant.

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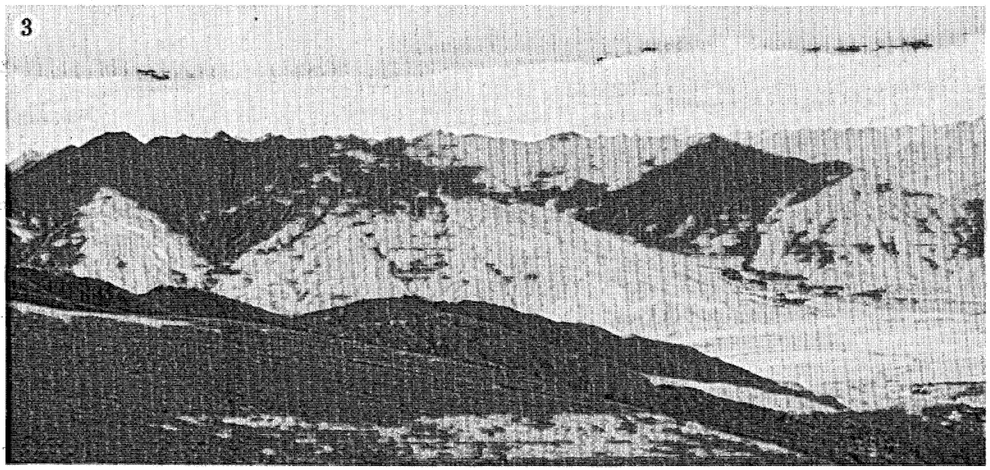

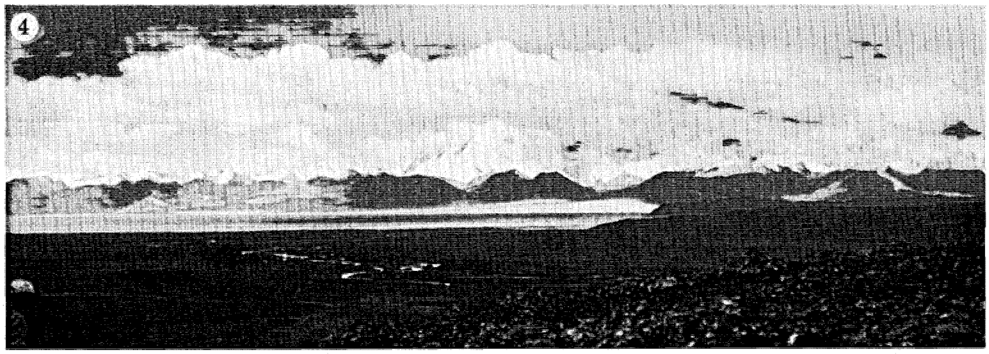

FIGURE 3. View looking 352° across the Zanbgo River from 5250 m col SW of Lhasa to show peneplain cut across southern part of Lhasa Terrane.

FIGURE 4. View looking SE across Nam Co to Nyainqentanglha Shan to show inselberg (centre, snow-covered) rising above pediplain.

FIGURE 5. Pediplain, folded into gentle syncline, cut across Jurassic and Cretaceous sediments, looking east across the southern part of the Zigetang Co from W of Gyanco.

(*Facing p.* 368)

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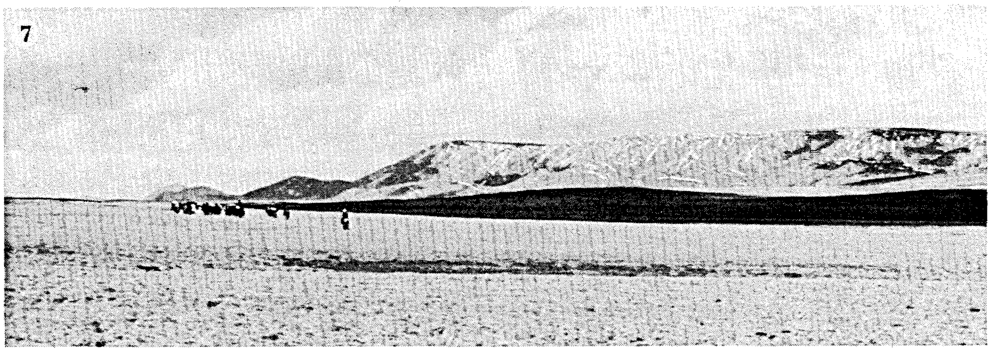

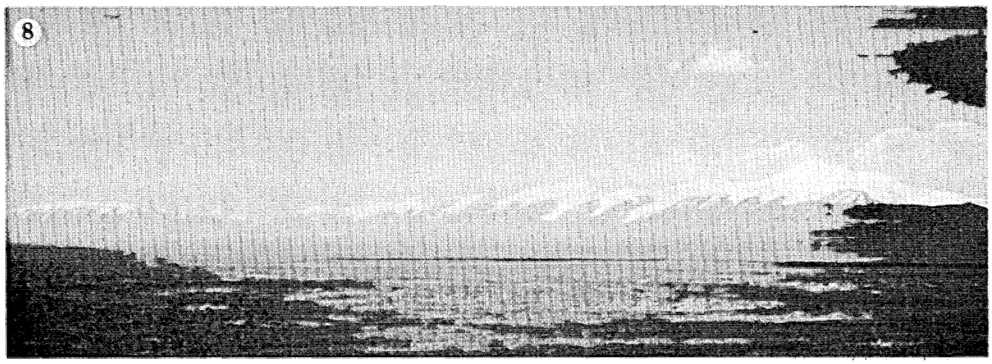

FIGURE 6. View of Tanggula Shan from south showing deeply dissected pediplan.

FIGURE 7. Pediplan cut across folded Eocene red beds. Fenghuo Shan, about 35 km NW of Erdaogou looking WSW.

FIGURE 8. View of Kunlun Shan, looking NW, with inselberg (right-hand side) rising above even summit level which represents pediplain.

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is determined by several faults along the south side of Nam Co, a large lake, elevation 4716 m, in a tectonic basin. The profile (figure 2) suggests that the surface itself may be warped as well as faulted down to Nam Co.

The Nyainqentanglha Shan shows a regular longitudinal summit profile when seen from north or south, except for a single conical peak which rises abruptly to 7102 m, some seven or eight hundred metres above the general summit level (figure 4). Like a few others to be mentioned, this has the appearance of an inselberg. Transverse profiles across the section of the range south of Nam Co show that the even summit surface is only preserved, and even there in a deeply dissected state, across the central 15 km or less, beyond which erosion back from the northern fault scarp of the Yangbajain graben to the south and the series of faults to the north has left irregular slopes. The elevation of the remnants of the erosion surface varies from about 5700 m to about 6100 m, considerably higher than the block south of the Yangbajain graben. There is a distinct increase in elevation westwards but 1:100000 maps showing elevations were not available west of 90° 20′ E. Because of its elevation, the range was extensively glaciated and eroded during the Pleistocene. Snowfields and glaciers remain.

The central part of the Nyainqentanglha Shan is formed of granitoid orthogneisses, with metasediments. The orthogneiss is dated about 50 Ma and the rocks now exposed crystallized at depths of about 15 km (Harris, Xu, Lewis & Jin, this volume). Uplift and erosion of that thickness occurred before or during the planation represented by the summit surface. Further uplift raised the summit surface to its present elevation of about 6 km above sea level.

To the east the Nyainqentanglha Shan merges into a NNE-trending range immediately west of the Gulu graben, with which the Yangbajain graben connects (figure 1). In this part of the range the summit surface is tilted westwards. A profile along its eastern side (figure 2D–E) shows that the erosion surface stands at just over 6000 m; an inselberg rises to 6590 m.

(*d*) *The Nam Co Basin*

The profiles (figure 2 B–C & D–E) pass east of Nam Co. The lake forms part of the interior drainage system of the western part of the Plateau. The profiles suggest that the lake occupies a downwarp of the surface trending about 070° and pitching, east of the lake, at about 1 in 50 WSW.

(*e*) *The Bong Co fault complex*

A set of WNW-trending faults defines the Bong Co graben. The profile, passing about 10 km east of the lake, crosses a block on which the summit surface pitches at about 1 in 30 towards the WNW. A 10 km wide strip south of the fault complex cannot be interpreted without field control.

(*f*) *Area SW of Nagqu: Nevi Pun Co and Co Ngoin basins*

Immediately north of the northernmost of the Bong Co faults, there is a WNW-trending 12 km wide block with a regular summit surface at about 5000 m, rising slightly higher at the southern edge. Its northern limit is presumably a fault. North of the Nevi Pun Co the surface rises to another fault, trending nearly E–W, which defines the southern limit of the Co Ngoin trough. The northern limit of this trough is a fault trending ENE.

West of Co Ngoin, two fault strips, each a few kilometres wide, were clearly seen in the field to be tilted southwards. Southwards, the surface is warped into a shallow syncline (figure 5, plate 1).

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(g) *Area from Co Ngoin to the Amdo graben*

Less than 3 km north of the northern boundary fault of the Co Ngoin basin, the summit elevation is just over 5100 m. For about 70 km northwards to the southern boundary fault of the Amdo graben the summit surface remains at an almost constant level (figure 2) with perhaps very slight undulations and a very slight fall to the north to about 4950 m immediately south of the Amdo graben. This uniform summit surface is cut across folded Jurassic in the southern part, then across the Precambrian Amdo gneisses which are thrust south over the Jurassic. The surface shows no reflection of the change in rock types, nor of the major thrust. It extends west nearly as far as Co Nag (figure 1).

(h) *The Amdo graben*

At the profile line, the elevation of the floor of this graben is just over 4600 m. The floor under the Pleistocene fill must be below 4500 m.

(i) *The Amdo range*

The topography of this structurally complex zone, between two major WSW-trending sinistral strike-slip faults, is irregular and no clear summit surface was recognized.

(j) *From the Amdo Range to the south foot of the Tanggula Shan*

Across this zone the summit surface is regular, dropping very slightly from just over 5100 m in the south to 5000 m in the north, except for the narrow (3 km) ridge of the Tojio Range, which rises to 5364 m. The reason for this narrow range is not clear.

At the northern side of this zone, Neogene deposits have been mapped. Their elevation is about 5000 m (figure 2).

(k) *The Tanggula Shan*

The Tanggula Shan has been very intensely eroded during the Pleistocene glaciations and the pre-glacial geomorphology could not be understood during the very short time available there on the Geotraverse, nor does the profile (figure 2) based on the 1:100000 maps show any regular pattern because the strip on which the profile is based is too narrow (*ca.* 10 km) relative to the scale of the glacial erosion. To try to overcome this, a profile was based on a strip 40 km wide, the centre line passing through Tanggula Pass, with a trend N 27.5° E, normal to the trend of the range. The highest points in successive 2 km strips normal to this centre line were plotted. The result still failed to show any convincing regular summit surface. This is surprising because a number of Chinese workers agree in recognizing a peneplain on the Tanggula Shan.

One possible interpretation of the irregular profile is that this part of the Tanggula Shan is an eroded remnant of a mountain range which existed before the planar surface was eroded and which withstood planation. Alternatively, it may be that the surface was irregularly deformed there. More probably, however, the difficulty in recognizing the surface is simply that the Tanggula Shan, like other high ranges such as the Nyainqentanglha Shan and the Kunlun Shan, all strongly glaciated, has been so intensely eroded that the surface is barely recognizable. During the Geotraverse, several small areas with accordant summit levels were seen. In each case they appeared tilted, and the slopes were in different directions. Their interpretation is doubtful. However, the distant view of the Tanggula Shan from the south

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(figure 6) strongly suggests that it is carved from a block on which a planar erosion surface existed. The view is essentially similar to those of the Nyainqentanglha Shan and the Kunlun Shan. The reality of the surface on the Tanggula Shan is therefore accepted.

The northern limit of the Tanggula Shan is rather indefinite. The elevation diminishes gradually but irregularly northwards; but even as far north as 25 km east of Wenquan a subcircular plutonic intrusion rises (as an inselberg?) to 5883 m, nearly 700 m above the surrounding area with summit levels at about 5200 m.

Immediately north of Yanshiping the mountainous country ends rather suddenly.

(*l*) *The region between the Tanggula Shan and the Kunlun Shan*

This is a wide region of relatively low relief, the elevation ranging from a maximum of just under 5500 m in the Fenghuo Shan down to about 4400 m. About half of the region is underlain by Neogene fluviatile and lacustrine deposits (figure 1). These areas form the lower ground, occupying irregular tracts roughly elongated sub-parallel to an array of faults, slightly curved but with a general ESE–WNW trend. The elevation of the surface of the Neogene deposits drops gradually eastwards at about 1 in 50. The pre-Neogene rocks form irregular hilly areas separating the Neogene deposits. While some contacts of the Neogene with older rocks are post-Neogene faults, at most of the contacts the Neogene is unconformable on older rocks, and many of the shapes of the Neogene areas are irregular. Their distribution and shapes are essentially the same as those of the hundreds of lakes scattered across the Tibet Plateau farther west. As could be seen in the case of the array of lakes near the Geotraverse, between the Nyainqentanglha Shan and Amdo, the lakes are in tectonic depressions, most of which are bounded by faults. Their irregular shapes are the result of the complexity of the fault patterns (figure 1).

Most of the hills formed by the older rocks between the lower areas of Neogene deposits are not, in the Geotraverse area, extensive enough to give any useful information about any erosion surface. However in the Fenghuo Shan, across a width of about 25 km, a fairly uniform summit surface, at an elevation of about 5200 m, can be seen (figure 7, plate 2) and again just south of Wudaoliang, a range, trending slightly south of east, about 10 km wide and bounded by faults, rises to a regular summit surface whose elevation is about 5000 m.

(*m*) *The Kunlun Shan*

The even summit level of this range is obvious when viewed from the south (figure 8). A single conical peak rises abruptly above the even summit level. The range is deeply eroded especially along the great faults by which it is traversed. The surface slopes down northwards, across a width of nearly 70 km, from about 5900 m to about 5000 m. North of that its elevation drops much more rapidly until, some 40 km east of Golmud in a borehole, it is at about 1580 m. Further out under the Qaidam Basin, the basement surface is much deeper still. It is not clear whether the drop from Kunlun to Qaidam is achieved by faulting, flexure or both but a remarkable planar area about 60 km 225° from Golmud, not accessible during the Geotraverse, may be a remnant of cover on the erosion surface. It appears to slope much more gently north than the general slope down to the Qaidam Basin, suggesting that the slope represents a series of fault steps rather than a flexure.

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(n) Summary of evidence from the profile of summit elevations

From just north of the Zangbo River to the southern edge of the Tanggula Shan, the continuity of a well-defined even summit surface is clearly established. Across the Tanggula Shan it is much less clear although Chinese workers who have studied it there in more detail than was possible during the Geotraverse are satisfied that it occurs there. Between the Tanggula Shan and the Kunlun Shan it can be recognized on two of the ranges rising above the mass of Pliocene and Pleistocene deposits which fill an array of tectonic depressions. On the Kunlun Shan a surface identical in its features to the surface traced across the south of the Plateau is clearly visible. The sudden changes in elevation of the surface, for example at the Yangbajain graben and at the south side of the Kunlun Shan, are clearly the result of deformations, usually faults. The remnants of the surface have not been isolated by erosion. The surface must have extended across the whole Plateau.

3. Evidence from the drainage systems

The drainage of the Tibetan Plateau can be separated into several systems: (i) northwards into the Tarim and Qaidam basins; (ii) internal drainage, into lakes in the western half of the Plateau; (iii) eastwards and southwards across the eastern half of the Plateau: the Jinsha, Lancang and Nujiang river systems; (iv) eastwards, then deviously south, along the Zangbo River (mainly following the Indus–Zangbo Suture); (v) southwards through, and from, the Himalayas. The Geotraverse was near the eastern limit of internal drainage.

The complexity of the fault pattern which produced the structural depressions containing the vast number (some 1500) of lakes on the Plateau is apparent in the area between the Nyainqentanglha Shan and Amdo. The drainage pattern is correspondingly complex. The eastward drainage becomes increasingly constricted and structurally controlled southeastwards. The western, dendritic, part of this drainage system is remarkably independent of structures, in particular the array of faults, many with substantial post-Pliocene displacements, which curve across the eastern part of the Plateau. In many places, rivers cut through uplifted blocks, in a manner which clearly shows that they are antecedent in relation to the upfaulting of the blocks. Examples are the river which flows out of the Yangbajain graben, across the Lhasa block (figure 9), and the river which flows through the Kunlun Shan from Kunlun Pass.

The simplicity of the drainage pattern has evidently been modified by capture, erosion along faults and subsidence of basins. Nevertheless, its remarkable independence of young faults and the simplicity of the dendritic pattern inescapably imply that it originated on an extensive relatively flat surface, quite unlike the present 'Plateau' with its diversity of mountain ranges, fault blocks and tectonic depressions.

It is concluded that the drainage originated on a surface of very low relief, before the major dislocations which determine the existing topography.

There are indications that the Gangdise Shan, at least westwards from Lhasa, the Tanggula Shan and the Bayan Har Shan may have been slightly elevated at the time the drainage pattern was initiated since they form watersheds. It is tempting to speculate that the Zangbo is a relic from Tethys, into which the Andean Gangdise arc must have drained, but this cannot be proved.

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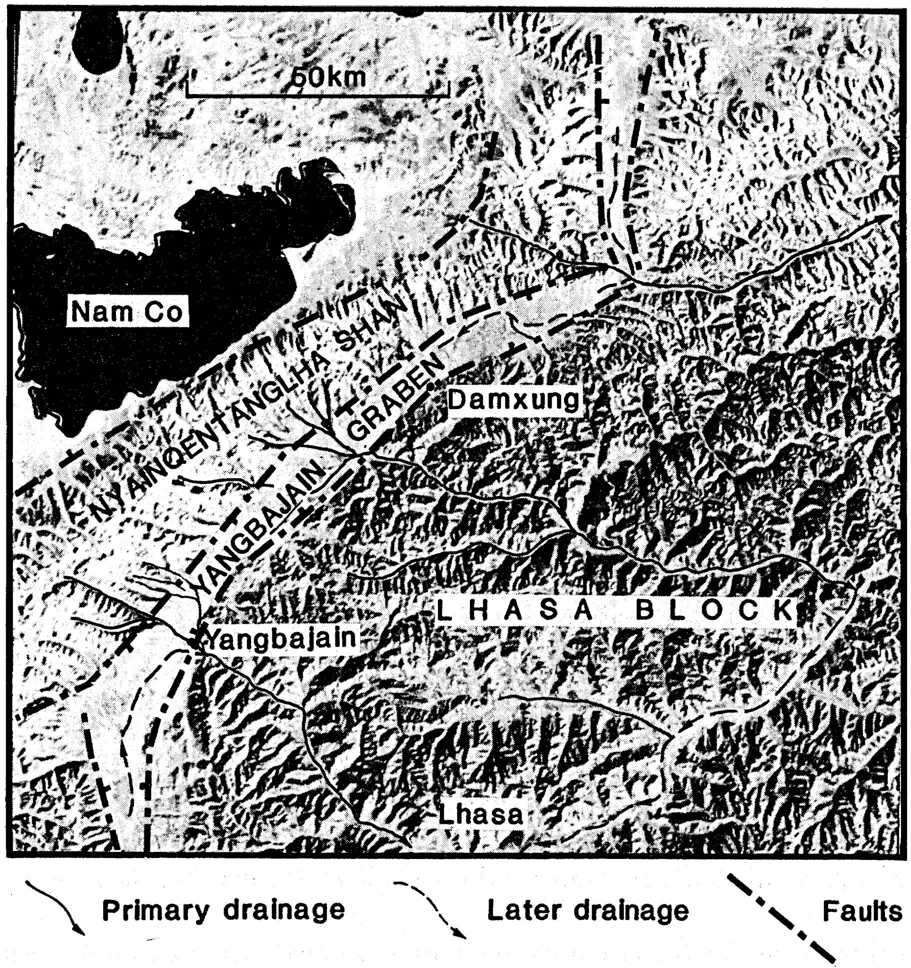

FIGURE 9. Satellite view of Nam Co, Nyainqentanglha Shan, Yangbajain graben and southern part of Lhasa Terrane, showing antecedent primary drainage cutting through fault scarp along SE side of Yangbajain graben.

4. THE PROCESS BY WHICH THE EROSION SURFACE WAS FORMED

The summit erosion surface might be attributed to peneplanation, pediplanation (King 1962) or 'equilibrium' (Selby 1985). The last is rejected because it seems impossible that such a variety of rock types could be so evenly lowered many kilometres by erosion without the control of a base level, yet still leave isolated peaks standing high above the general surface. The reason that pediplanation seems more plausible than peneplanation is that there are, as on the Nyainqentanglha Shan and on the Kunlun Shan, rare but conspicuous isolated peaks which rise abruptly up to 700 m above the general summit surface. Their form suggests that they are inselbergs formed by scarp retreat although without visiting them it remains uncertain why they stand so high. Since, however, it is persuasively argued (Twidale 1976) that peneplanation and pediplanation are not sharply distinct processes characteristic of different climatic regimes (temperate and arid) but can occur together, the distinction may be unimportant. As envisaged by King (1962), however, a pediplain is necessarily diachronous, younger inland

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than at the base level (not necessarily the sea) whence it started, and so the distinction may be chronologically, even though not climatically, significant. Because of the form of the inselbergs, it is concluded that the summit surface represents a pediplain.

5. The age of the erosion surface

The surface transects the folded and thrust Fenghuoshan Group of red beds, which range up to Middle Eocene. This relationship is best seen in the Fenghuo Shan. The surface also transects the folded and thrust Linzizong, dated as 60–50 Ma and deformed (as a result of collision) later than 45 Ma. It cannot therefore be older than late Eocene. The upper limit is less certain because no Oligocene beds were seen in the Geotraverse area and the Neogene beds are not well dated. Published data indicate that west of the Geotraverse area, in the Lunpola Basin (about 89° 30′ E, 32° N), there is over 3 km of Tertiary sediments, ranging from mid- and late Eocene and Oligocene clastics to Pliocene lake beds (Song & Liu 1981), or from possible late Eocene to Oligocene (Xia 1983). The latter author indicates an unconformity between the Miocene and the Oligocene within the Deqen (Dengqen) Formation but it is not clear whether it is structurally significant. It seems likely that deposition in the Lunpola Basin was essentially continuous from late Eocene or early Oligocene times to the Miocene. In the Qaidam Basin also deposition was apparently continuous from the Eocene onwards; the Eocene is unconformable on Cretaceous or older rocks. However, since such basins could have existed during the planation, they do not date it. In the Tanggula Shan, 100 and more km west of the Geotraverse, basalts and andesites of Miocene age are said to overlie the (Tanggula) erosion surface, there standing at about 5900 m (Li *et al.* 1981).

Similar, possibly coeval volcanics near Maquiang, at and beyond the western end of the Yangbajain graben, are dated at about 10 Ma (Coulon *et al.* 1986) but the relationship to the surface is not known.

Westwards from the Geotraverse area, the erosion surface was recognized, during a rapid traverse in 1986 from Lhasa to Kathmandu, as far as the northern slopes of the Himalaya. It appears to extend across the area in which strongly folded marine Eocene rocks occur, and across the Lhagoi Kangri granites dated at *ca.* 10 Ma (Maluski 1984). The same conclusion was reached by Armijo *et al.* (1986).

The combination of evidence indicates that the age of the pediplanation is mid- to late Miocene, *ca.* 10 Ma. The erosion which produced the surface must have continued for a long time. The 'age' represents the termination of the process, probably when erosion could no longer keep pace with faulting.

6. A Pliocene peneplain not confirmed

It is thought by some workers that a second, lower and younger (Pliocene) surface can be recognized (Li *et al.* 1981; Zhang *et al.* 1981; Xu Shuying 1981). The older surface 'manifested by peaks and platforms of similar altitudes' is regarded as Oligo-Miocene; the younger 'part of the present Plateau' is thought to be Pliocene (Zhang *et al.* 1981). They seem to imply that the remnants of the higher, older surface are at a uniform elevation and were isolated not by faulting but by erosion, but as can be seen from the profile (figure 2), the remnants are not at a uniform level and it is clear that the straight scarps which bound many of the high ranges are fault scarps. The high ranges cannot have been simply separated by erosion.

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Since the high erosion surface seen on the Kunlun Shan must be faulted down by the south Kunlun faults (as well as being displaced laterally), and since it is at least older than late Miocene, it probably underlies many of the Plio-Pleistocene fluviatile and lacustrine deposits which occupy much of the region between the Kunlun and Tanggula ranges. These deposits occupy areas where the Miocene erosion surface was faulted or warped down relative to the Kunlun and Tanggula ranges. The faulted surface was substantially eroded before the Plio-Pleistocene deposits were formed; on the northern flank of the Tanggula Shan they were deposited in a deep valley (figure 2) and immediately north of the Fenghuo Shan, itself truncated by the Miocene surface, there are isolated hills rising through the Plio-Pleistocene deposits (figure 2). These inliers are too irregular to be interpreted as separated by faulting from the main Fenghuo Shan block. The original northern limit of the Fenghuo Shan block may have been a fault, now buried under the Plio-Pleistocene.

The present surfaces of the Plio-Pleistocene deposits are not flat but gently undulating. Their elevation varies greatly from one to another (figure 2). These variations are not systematic in a manner which could be attributed to the deformation of a formerly planar erosion surface. On the contrary, their elevations are simply related to their positions in the antecedent drainage system. Farther west, in the region of interior drainage, many of the existing lakes are within areas of Plio-Pleistocene deposits and are evidently remnants in pre-existing basins. The existing subdued topography of the Plio-Pleistocene deposits cannot be interpreted as a single Plateau-wide Pliocene peneplain. That topography has evolved by erosion adjusted to the elevation of rivers which in the west drain into isolated basins while those to the east form a pattern developed on the Miocene surface before the formation of the Plio-Pleistocene basins.

It is concluded that there is no Pliocene peneplain across the Tibet Plateau. The topography of the Plio-Pleistocene deposits is essentially the result of aggradation and then stream erosion. The varying elevations imply separate areas of deposition in structural and erosional depressions within an antecedent drainage system, not a single unified erosion surface.

7. The uplift history of the plateau

The last remnants of the Tethyan ocean south of the Lhasa Terrane are represented by Lower Eocene limestones near Tingri (87° E, 24° 40′ N). Palaeogene fluviatile red beds deposited in foreland-type and ramp valley basins (Leeder *et al.*, this volume) demonstrate considerable relief at that time. All these were strongly deformed as a result of the India–Asia collision. During Oligocene and early Miocene times, erosion was dominant over the Plateau; deposition was confined to a few mostly E–W trending basins including Lunpola (90° E, 32° N). The thick (*ca.* 2000 m) Oligocene clastic deposits in the Lunpola basin, overlying a basal conglomerate which may be Eocene (Xia 1983), contain a tropical flora; the Plateau was at a low altitude (*ca.* 500 m) (Xu Ren 1981; Li *et al.* 1981; Song & Liu 1981). The floras from the Lower Miocene beds of the Lunpola Basin suggest a complex topography with some parts over 2000 m elevation and valleys below 1000 m (Xu Ren 1981).

A mid- to late Miocene flora from the Wulong Formation in the Namling area, on the southern slopes of the Gangdise Shan, about 150 km west of Lhasa, is thought to imply an elevation of over 1500 m and a humid warm climate (Guo 1981).

The relation of these and other Miocene deposits to the pediplain is not clear. It seems that by mid-Miocene times pediplanation had reduced a vast region to an even surface from which

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only a few inselbergs projected. The elevation of the Plateau, even some 1000 km from the ocean, was probably only a few hundred metres. The pediplain extended to the northern flanks of the present Himalaya and, if correctly correlated, to the present Qilian mountains (Li *et al.* 1981), so it is unlikely that it was adjusted to an intracontinental base level (cf. Armijo *et al.* 1986).

By late Miocene times, differential uplift was occurring. On the southern slopes of the Gangdise Range, at Moincer (50° 30′ E, 31° 12′ N), the elevation was more than 1500 m and deciduous broad-leaved forests flourished (Xu Ren 1981; Guo 1981).

By the Pliocene, the Miocene pediplain had been severely dislocated by faults and deeply eroded (Xu Shuying 1981). The Gangdise, Tanggula and Kunlun ranges were relatively uplifted to elevations of 2000 m or more (Zhang *et al.* 1981; Kong & Du 1981). Fluviatile and lacustrine deposits, mainly silts and clays, and also, in the north, evaporites, were laid down in shallow tectonic depressions similar to those which now contain lakes in the western half of the Plateau. Other fluvial deposits accumulated in deep (*ca.* 1000 m) valleys in the Tanggula Shan. The floras varied from tropical forest to subtropical steppe; the *Hipparion* fauna was widespread.

If the Plio-Pleistocene sediments were deposited in many separate tectonic depressions and erosional valleys, related to an antecedent drainage system initiated on a Miocene pediplain, they need not imply a low elevation, as they would if they were related to a Pliocene peneplain.

The geomorphological evidence thus shows that until about 10 Ma ago, erosion across the Plateau and beyond kept pace with uplift, which was slow. Unpublished $^{39}Ar/^{40}Ar$ ages on micas and feldspars from the Nyainqentanglha granite indicate rapid uplift over the last 10 Ma (W. Kidd, pers. comm., 1987). No new evidence was obtained during the present work to confirm or modify the view (e.g. Zhang *et al.* 1981) that the major uplift occurred in the Pleistocene. This view is based partly on the evidence, from floras and faunas, of progressively changing climate, partly from fission track data from the Himalayas which indicates very rapid recent uplift, and partly on the sudden deposition in the Pleistocene, of coarse conglomerates, on top of earlier finer-grained deposits, both in the Siwalik trough to the south and in the Qaidam basin to the north of the Plateau. Pliocene molassic deposits have recently been found along the eastern margins of the Plateau in Darji, Qionglai and Emei (Sichuan province) (Zheng 1986). Episodic post-Pliocene uplift is inferred from three knickpoints recognized on the major rivers – at 4500 m, 3500 m and 2800 m on the Zangbo River (Zhang *et al.* 1981; Yang *et al.* 1983).

The amount of crustal shortening by internal deformation across the Tibet Plateau since the pediplanation cycle was ended some 10 Ma ago cannot be more than a few per cent. Wide stretches of the pediplain are almost flat (figure 3), although Pliocene strata are locally overthrust and folded and dips of 5° are common. Crustal shortening during this period was mainly south of the Main Central Thrust in the Himalayas. However, the geomorphological evidence does not exclude shortening by lateral extrusion of crustal blocks limited by strike-slip faults (Tapponnier *et al.* 1986).

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Figure 3. View looking 352° across the Zanbgo River from 5250 m col SW of Lhasa to show peneplain cut across southern part of Lhasa Terrane.

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IGURE 4. View looking SE across Nam Co to Nyainqentanglha Shan to show inselberg (centre, snow-covered) rising above pediplain.

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IGURE 5. Pediplain, folded into gentle syncline, cut across Jurassic and Cretaceous sediments, looking east across the southern part of the Zigetang Co from W of Gyanco.

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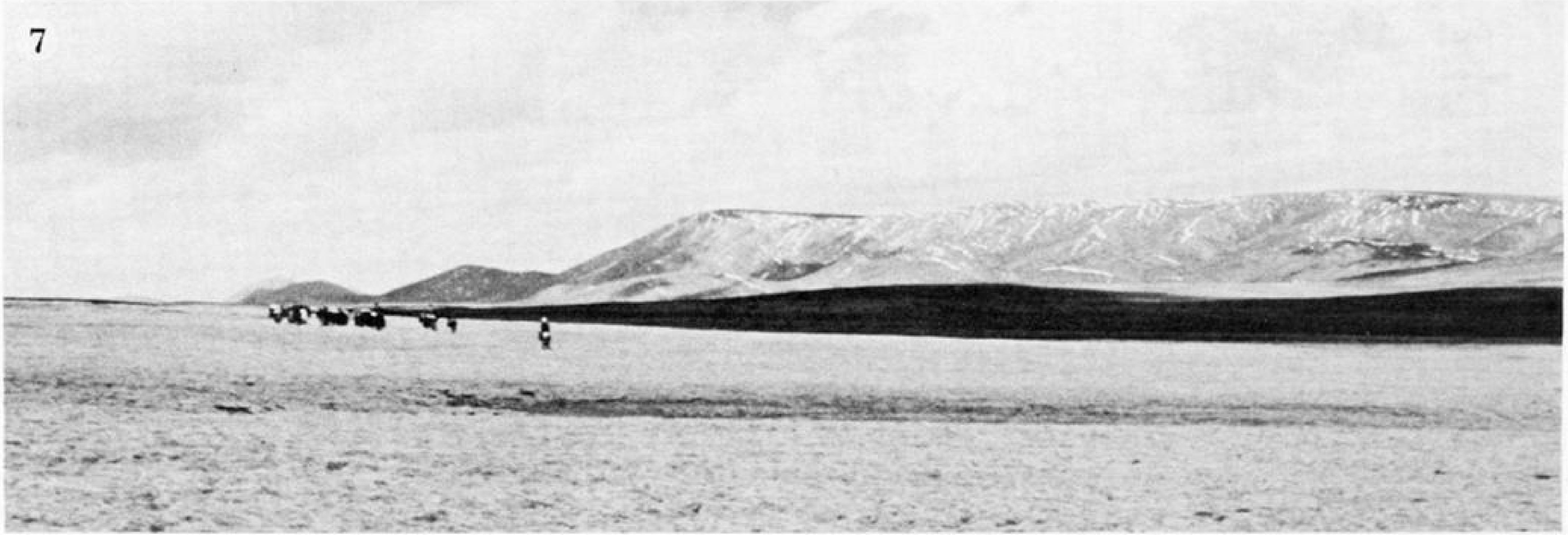
FIGURE 6. View of Tanggula Shan from south showing deeply dissected pediplan.



[F]IGURE 7. Pediplan cut across folded Eocene red beds. Fenghuo Shan, about 35 km NW of Erdaogou looking WSW.

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IGURE 8. View of Kunlun Shan, looking NW, with inselberg (right-hand side) rising above even summit level which represents pediplain.

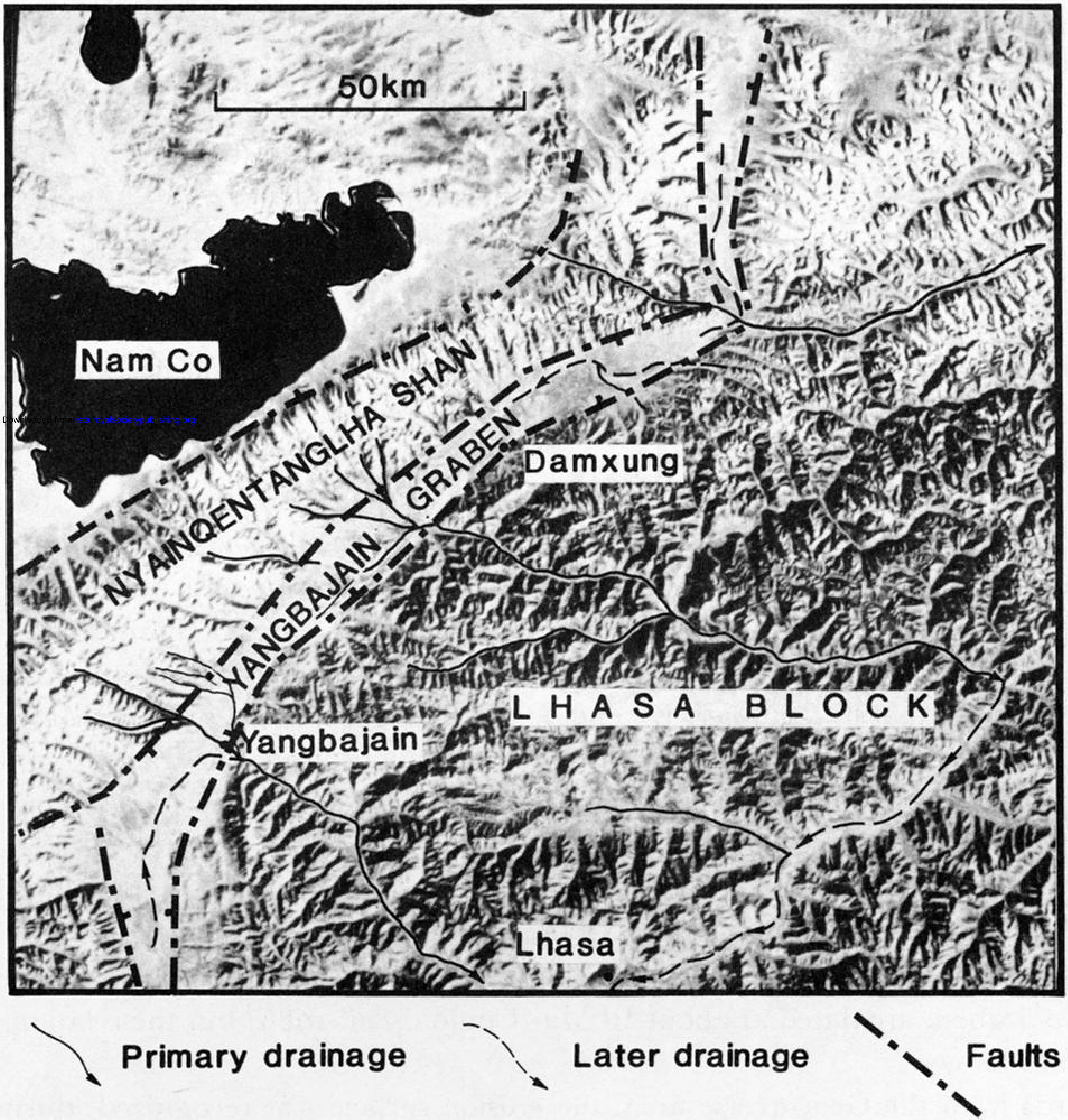

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FIGURE 9. Satellite view of Nam Co, Nyainqentanglha Shan, Yangbajain graben and southern part of Lhasa Terrane, showing antecedent primary drainage cutting through fault scarp along SE side of Yangbajain graben.

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