will be much more important in 1994 than in 1984, but will still fall short of being the major means used by the Chinese government to achieve its planning objectives. In the meantime, we may observe oscillations in the trend toward a market-oriented economy because the Chinese leaders are in the process of experimenting with and learning about the working of a market economy.

Reform toward a more market-oriented economy will continue in China. The degree of success may be uncertain, but there is no turning back to a system of central control in agriculture or to an industry operating with closed doors. Substantial economic growth will continue even if structural reforms progress slowly. The Chinese economy was able to grow between 1952 and 1979 in spite of the adverse conditions of inefficient central planning and two very serious political disturbances. It can only be expected to grow faster under the more favorable economic and political conditions of the 1980's.

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11. The author would like to acknowledge with thanks the helpful comments of two referees on an earlier draft and the financial support of The Garfield Foundation in the preparation of this article.


# Geologic Evolution of Northern Tibet: Results of an Expedition to Ulugh Muztagh


PETER MOLNAR, B. CLARK BURCHFIEL, ZHAO ZIYUN, LIANG K'UANGYI, WANG SHUJI, HUANG MINMIN



**A reconnaissance expedition across the northern margin of the Tibetan plateau revealed evidence of a late Cenozoic northward progression of the locus of crustal shortening and, therefore, of a northward growth of the area encompassed by the plateau. Active reverse faults crop out at the foot of the Altyn Tagh, on the northern edge of the plateau, and at the bases of several ranges within the Altyn Tagh and Kunlun, where the elevations of the neighboring basins are less than 4000 meters. Farther south, where elevations are higher, there was no evidence of recent faulting, but late Cenozoic rock in the Ayak Kum Köl basin has been strongly folded. South of this basin, Ulugh Muztagh, apparently the highest mountain in the eastern Kunlun, is underlain by late Miocene, tourmaline-bearing and two-mica granite. These rocks suggest that thickening of continental crust had begun in this area by late Miocene time. Overlying quartz-sanidine welded tuffs of Pliocene age imply that uplift and erosion occurred between Miocene and Pliocene time, but with little subsequent erosion. In addition, we found an east-west trending belt of mafic and ultramafic rock that probably marks a suture of a crustal fragment with southern Asia in Triassic or more recent time.**


THE TIBETAN PLATEAU, WITH A VAST AREA ABOVE 4500 TO 5000 m, is one of the earth's most extraordinary topographic features (*1*) and one of its least accessible and least explored large areas (*2–6*). Thus, while recognition of Tibet's peculiarity and prominence has stimulated much research during the last 15 years toward understanding the mechanisms responsible for creating a plateau of such dimensions (*5–9*), a lack of geologic work in Tibet has prevented testing most hypotheses. Since seismic studies show that the crust beneath the Tibetan plateau is very thick (70 ± 5 to 10 km) (*10*), and because isostatic compensation of such thick crust causes the plateau to float high above sea level, the important


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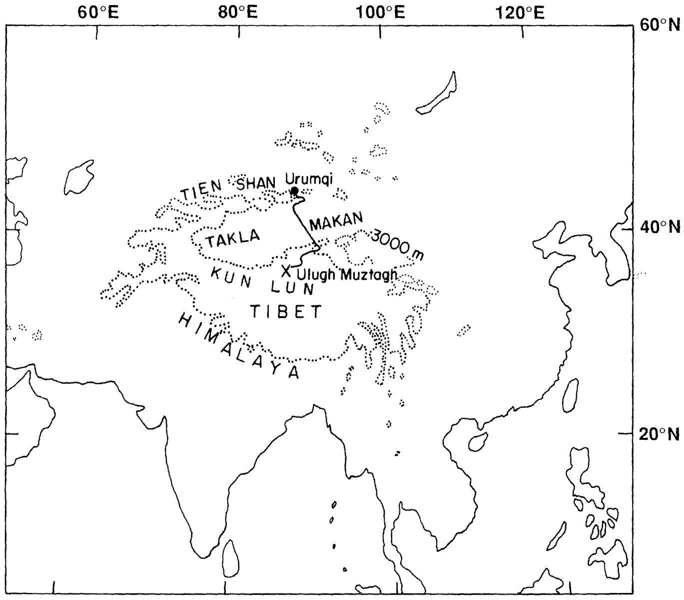


**Fig. 1.** Simplified map of Asia showing large-scale features mentioned in the text, the route taken from Urumqi to Ulugh Muztagh, and the 3000-m contour.

question is not why is the crust thick but how did it become so.

We are quite sure that this crustal thickening occurred in the last 100 million years. Geologic work carried out along the main road in eastern Tibet reveals abundant evidence for the successive collision of small fragments of continental crust with Eurasia's southern margin during early and middle Mesozoic time (*5, 6, 9*), and the collisions of these small fragments with Asia surely led to localized crustal thickening. Mountains that formed at those times, however, had eroded away when marine limestones were deposited in much of southern and western Tibet in late Cretaceous time (*4, 9*) (~80 to 100 million years ago). Therefore these areas were below sea level, and the crust beneath them would not have been thick.

The crustal thickening is surely a consequence of the collision and subsequent penetration of India into the rest of Asia in Cenozoic time. Some earth scientists believe that India was once a much larger continental mass than it is now and that its ancient northern part has underthrust all of Tibet (*11, 12*). Others have inferred that the crust of Tibet has undergone widespread crustal shortening by folding and thrust faulting since the collision with India (*7–9*). Seismic data show that the structure of the upper mantle presently beneath Tibet is not that of a shield (*10*), like that underlying India or like what Ni and Barazangi (*12*) had inferred for Tibet. More importantly, paleomagnetic results from southern Tibet show that this area has moved 1900 ± 850 km closer to Siberia since Late Cretaceous times (*13*). Finally, study of Tertiary sedimentary rocks in Tibet along the main highway across Tibet reveals abundant evidence for a large amount of Tertiary crustal shortening (*9*). These results suggest that instead of being underlain by a foreign lower half, Tibet's crust is now much narrower in its north-south dimension than it was 50 million years ago and that the rocks in southern Tibet have moved several hundred kilometers or more closer to those in northern Tibet. Nevertheless, the uncertainties and the nonuniqueness of the interpretations cannot yet rule out the underthrusting of India beneath a substantial fraction of Tibet.

The ultimate test probably will require the demonstration of either large amounts or only small amounts of crustal shortening, for which numerous studies of different parts of Tibet will be necessary. The work described here is one such investigation, albeit only reconnaissance. Much of our effort was directed toward understanding how and when crustal shortening has occurred in northern Tibet, an area where very little geologic work had been done (*2, 3*). To present our observations, it is convenient to progress geographically from north to south.

## Active Faulting in the Altyn Tagh

We entered the Tibetan plateau on its north by crossing the Altyn Tagh from the Takla Makan (Figs. 1 and 2). One of the world's greatest strike-slip faults, the Altyn Tagh fault, trends approximately N65°E and passes between the Altyn Tagh and Kunlun ranges (*14*). This fault is especially prominent on the Landsat imagery, and left-lateral slip on it surely helps to accommodate India's penetration into Eurasia by allowing Tibet to be extruded eastward, with respect to Eurasia farther north, and out of India's northward path (*14*). This fault is noteworthy for its apparently low level of seismic activity. Two earthquakes with magnitudes of 7.2 occurred within 2 weeks of one another in 1924 near the western end of the fault, and one with a magnitude of 6 occurred near its eastern end in 1951 (*14*). No significant earthquakes ($M \geq 6$), however, can be associated with the segment 1000 km long and centered on the area that we examined. This lack of activity results in part from the remoteness of the area and from the short historic record (since 1900), but the lack of major earthquakes has caused some workers to doubt that this fault is active.

Along much of the 10-km section of the fault that we examined, we saw evidence for recent disruption that could be associated with a large earthquake in the last few hundred years (Fig. 3). In hilly terrain, small gullies and ridges were displaced about 10 m, and the deflected drainage around them suggests that the offsets occurred in one event (*15*). In flatter terrain, a zone approximately 20 m wide and trending N60° to 70°E across both alluvial fans and playa deposits marks the active trace of the fault. This zone is characterized by vegetation contrasts and prominent "mole tracks" (*16*), typically 0.4 m (and up to 1.5 m) high and 5 m long, that trend N90° to 100°E. The dimensions of these mole tracks are comparable with those associated with the 1920 Haiyuan earthquake (*17*) ($M = 8.7$) in Ningxia, north central China. Elsewhere a low scarp 0.5 to 1 m high is sharply defined (Fig. 3); its width is 0.6 to 1.2 m and the average slope is 30° to 35°. The freshness of the scarp implies little erosion of it, and by analogy with other areas we infer that it formed only a few hundred years ago (*18*). For these reasons we think that a very large earthquake ruptured a segment of the Altyn Tagh fault within the last few hundred years, and that slip during occasional large earthquakes is the primary mechanism by which slip occurs on much of the Altyn Tagh fault, instead of by fault creep or slip during small events.

Slip on this fault accommodates part of the convergence between India and Eurasia. The average rate of convergence at the longitude where we crossed the fault has been 58 ± 6 mm per year for the last 3 million years (*15, 19*). Of this, approximately 15 mm per year, but probably no more than 20 mm per year, have been absorbed by underthrusting of the Indian plate at the Himalaya (*20*). Some 5 mm per year, but probably less than 10 mm per year, of north-south shortening occur within the Tibetan plateau by conjugate strike-slip faulting (*21, 22*). The seismic history of the Tien Shan (Fig. 1) suggests another 11 mm per year, and possibly as much as 20 mm per year of north-south shortening (*22*). The sum of the largest of each of these values, 50 mm per year, is less than the minimum calculated convergence rate (*19*). If more representative values are combined, roughly 25 to 35 mm per year must be accounted for by deformation outside the areas mentioned. Given the strike of the Altyn Tagh fault, if 10 mm per year of north-south convergence is absorbed by left-lateral slip on it, the rate of slip must be 30 mm per year. This rate is comparable with that for the San Andreas fault (*23*) and is a high rate for continental strike-slip faults. Thus, even if the missing convergence were absorbed by slip on this fault, then all of the other rates noted above would be underestimates.

We found that part of the missing convergence appears to be absorbed by active reverse or thrust faulting in the Altyn Tagh and northern Kunlun ranges. A clear recent scarp marks the foot of every significant range that we saw on the northern edge of Tibet (Fig. 2): the north slope of the Altyn Tagh, the north and south slopes of the Akato Tagh (Fig. 4), and the north slope of the Chiman Tagh (*15*). All such faults crop out at elevations below 4000 m, but we did not see evidence of recent faulting south of the Chiman Tagh where elevations at the bases of the mountains are, in general, above 4000 m. Thus, active faulting seems to be confined to areas where elevations have not yet reached the mean value of 4500 to 5000 m of the Tibetan plateau, and the plateau is growing by the elevating of its flanking areas (*8, 24*).

We were not able to examine in detail any of these recent fault scarps, but several aspects show them to be due to thrust or reverse faulting. First, they are not straight for distances longer than 1 or 2 km, as are most strike-slip fault scarps. Second, somewhat dissected parts of alluvial fans are perched on the flanks of the ranges and therefore attest to a vertical component of displacement. Unlike those typical of normal faults, most of these scarps cross the alluvial fans in their lower parts, not at the break in slope between the eroding mountains and the aggrading fans. Finally, in some cases, it was possible to see the scalloped shape of the scarp in map-view, with the scarps convex away from the ranges. Thus the faults appear to dip beneath the ranges as would thrust or reverse faults, and not beneath the valleys, as would normal faults.

The heights of scarps are from several to more than 10 m. We have no evidence constraining their ages, but if the dissected fans underwent rapid deposition during the melting following the last glaciation, just before the Holocene epoch (10,000 years ago), then rates of vertical motion at each scarp would be of the order of 1 mm per year. Fault plane solutions (*14, 25*) of a few earthquakes around the Tsaidam basin indicate thrust and reverse faulting on planes dipping at 30° to 60°. Thus the amounts of vertical and horizontal displacement are comparable. We conclude that crustal shortening by thrust and reverse faulting on the northern edge (north of 37.5°N) of the Tibetan plateau is probably occurring at a rate of a few to several millimeters per year and that this shortening contributes to the roughly 58 mm per year convergence of India with Eurasia.

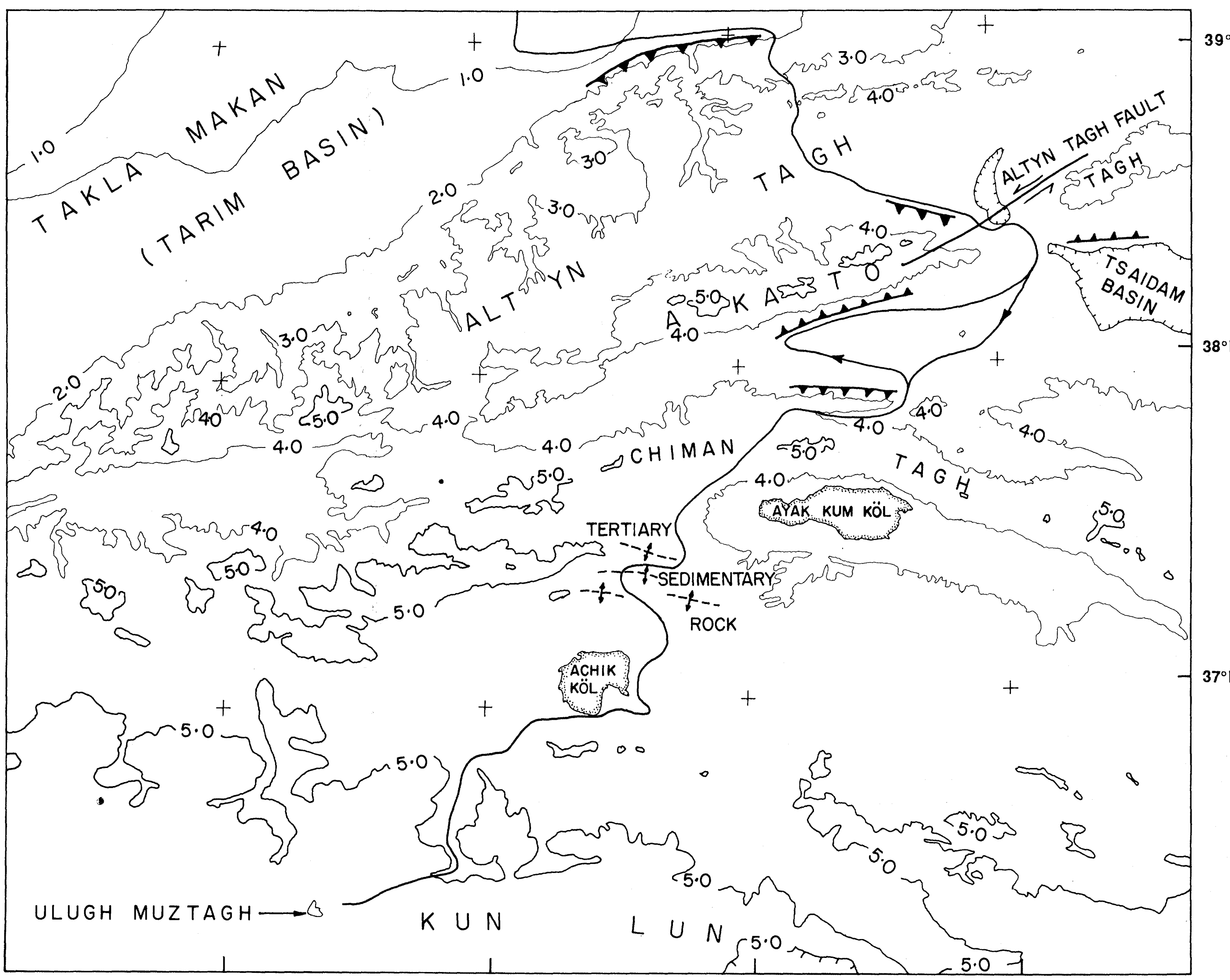


**Fig. 2.** Contour map showing our route across northern Tibet. Dark lines with teeth show the positions of young reverse fault scarps. Teeth point in the down-dip direction.

## Tertiary Deformation in the Ayak Kum Köl Basin

Whereas we saw no evidence for active crustal shortening south of the Chiman Tagh, late Cenozoic crustal shortening was significant in the Ayak Kum Köl basin (Fig. 2), which had been studied in greater detail (*3*). The Ayak Kum Köl basin, 375 km long and 125 km wide, was filled with late Cenozoic red and multicolored evaporites and clastic sedimentary rocks, which were deposited directly on folded Ordovician to early Permian rocks. The age of the oldest Cenozoic rocks (the lower Yousha Shan Formation) is not known, but this sequence is conformably overlain by finer grained material (the upper Yousha Shan Formation) that contains ostracods, sycidia, and gastropods, assigned a Pliocene age (*3*). A marked unconformity separates the Yousha Shan Formation from the overlying Hongliang Formation, which is assigned a late Neogene age on the basis of pollen and spores found within it [*Alnus, Castanea, Betalaceoipollenites, Juglans, Ulmus, Potamogeton, Mangdia, Pinus, Cedrus, Keteleeria,* and Taxodiacene species (*3*)]. The poor control on the age of the lower Yousha Shan Formation does not allow a tight constraint to be placed on the formation of the Ayak Kum Köl basin, and therefore of the relief surrounding it, but the Pliocene age of the upper part of the formation suggests that the age of the lower part also is late, not early, Cenozoic.

**Fig. 3.** Photograph of a segment of the Altyn Tagh fault (Fig. 2) showing a young south-facing scarp lying parallel to the valley. View is toward the northeast, and the position of the scarp is indicated by arrows.

**Fig. 4.** Photograph of the south slope of the Akato Tagh (Fig. 2) showing uplifted fans and a recent reverse fault scarp at the foot of the slope.

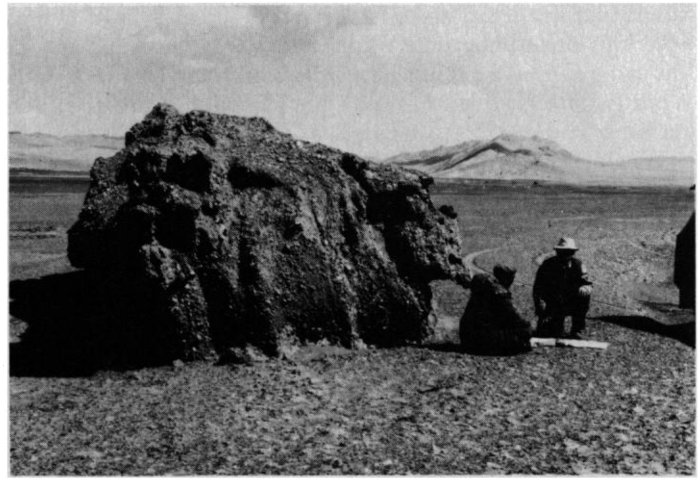

**Fig. 5.** Photograph of vertically dipping late Cenozoic conglomerate north of Achik Köl. View is to the east.

These formations are exposed in a series of folds that trend approximately east-west. The prevalence of steeply dipping beds (Fig. 5) suggests that even if there were no thrust faults within Cenozoic rocks, crustal shortening of several tens of percent has occurred since late Miocene or early Pliocene time. Thus, crustal shortening in the northern part of the plateau seems to have begun in late Cenozoic time, tens of millions of years after the collision between India and Eurasia. The locus of this crustal shortening, however, later shifted northward, for deformation now occurs north of the Ayak Kum Köl basin.

In other areas, such as just south of the Altyn Tagh fault and near Ulugh Muztagh, Jurassic and Triassic rocks contain folds similar to folds present within the Cenozoic rocks, and we suspect that Cenozoic shortening also occurred within pre-Cenozoic rocks as well. Proof of such shortening, however, will require more detailed work than we could do.

## Triassic Suture in Northern Tibet

Exposures of Paleozoic and Triassic rocks south of Achik Köl and north of Ulugh Muztagh trend east-west (Fig. 6). Parallel to and just south of the main east-west range north of Ulugh Muztagh is a narrow belt of ultramafic and mafic rock, including serpentinized peridotite and layered gabbro. Peaks of this range are capped by blocks of light-colored, massive limestone. The contact of the limestone with the mafic rock is poorly exposed but clearly is not depositional. Farther east, the limestone blocks could be seen within formations of dark shale. We could not examine contacts carefully, but our general impression was that of a mélange, and we conclude that the ultramafic and mafic rock represents dismembered parts of an ophiolite suite.

The southern edge of the ultramafic belt dips steeply in contact with a steeply dipping sequence of red to dark brown, apparently unfossiliferous, sandstone and conglomerate. The redbeds contain clasts of ultramafic rock and limestone. Thus this sequence was deposited on and derived from the ophiolitic mélange.

Farther south, the redbeds dip north and overlie unconformably a folded and thrusted sequence of sandstone and shale containing some thin coal-bearing layers near the top (Fig. 6). This sequence has been assigned a late Triassic age on the basis of fossils found farther east (*3*), and both sequences resemble another in the Kunlun 500 km to the east (*9*).

A fragment of crust, on which the late Triassic coal-bearing sandstone and shale were deposited, apparently collided with Eurasia in Triassic or more recent times. From our rapid examination, sandstone layers in the Triassic sequence did not contain grains of mafic or ultramafic material. Since we did not see the contact of the Triassic sandstone and shale with the ultramafic rock, however, we cannot eliminate the possibility of an earlier suture followed by later deposition of the Triassic sequence. The geologic map of Tibet shows granite cutting Carboniferous and Permian rocks 100 km north of this area (*26*), which may reflect a northward direction of subduction. Later, after the redbeds were deposited, and possibly in Cenozoic time, the entire sequence of Triassic sedimentary rock, mélange, and redbeds was folded.

A late Triassic or slightly younger collision was inferred for the eastern Kunlun (*9*). In that area, Triassic rocks lie conformably, or only slightly disconformably, on Permo-Carboniferous and older rocks. The entire succession was folded and faulted after the Triassic sequence was deposited, but no clear suture was found within the segment of the eastern Kunlun transected (*9*). Thus, in central northern Tibet, as in northeastern Tibet, the Kunlun appears to have been the site of Mesozoic orogenesis.

## Igneous Rocks of the Ulugh Muztagh Area

Ulugh Muztagh and its local environs form an isolated snow-capped massif, including apparently the highest mountain (*27*), in the Kunlun range of northern Tibet. Although our geological reconnaissance was restricted to isolated outcrops of rocks exposed in an area extensively covered by snow and glacial ice on and northeast of Ulugh Muztagh, this area yielded perhaps the most important result of our work on this expedition: the discovery of a suite of igneous rocks that includes tourmaline-bearing granite, two-mica granite, and sanidine-bearing welded tuff.

The plutonic rocks crop out in the lower part of the cirque wall on the northeast slope of Ulugh Muztagh and in a small nunatak 2 km farther northeast (Fig. 6). From about 3 km east of Ulugh Muztagh and extending for 6 km north-northeast are dikes, 100 to 200 m in thickness, of quartz-feldspar porphyry that are locally tourmaline-bearing. These plutonic rocks intruded Triassic terrigenous sedimentary rocks and locally metamorphosed the sandstone and siltstone to quartzite and the shale to fine-grained andalusite schist and phyllite. This low-grade metamorphism extends 5 to 6 km from Ulugh Muztagh, suggesting that the plutonic rocks are more widespread at depth than their limited surface expression. Recrystallization of the Triassic sedimentary rocks has made them more resistant to erosion than their unmetamorphosed equivalents. The unmetamorphosed Triassic rocks form rounded hills, but as metamorphism increases toward Ulugh Muztagh, the elevation increases and the hills become more rugged with bolder outcrops. Thus the isolated snow-capped massif of Ulugh Muztagh, "Great Ice Mountain," probably results from a localized intrusion of granitic rock and the associated metamorphism of the Triassic country rock.

The intrusive rock consists of four different, particularly unusual rock types: tourmaline-bearing quartz-biotite-potassium feldspar-plagioclase granite, potassium feldspar-biotite porphyry with zoned feldspar crystals up to 4 cm in diameter, quartz-muscovite-biotite granite, and both tourmaline- and nontourmaline-bearing quartz-feldspar porphyry. The tourmaline crystals in the tourmaline-bearing porphyry are more than 1 cm in length and a couple of millimeters in diameter. To the best of our knowledge these are the first reported occurrences of tourmaline-bearing and of two-mica granites from northern Tibet. Such rocks have been reported from the Himalaya, where they have been interpreted as melts derived from thickened continental crust, intruded at depths of 10 to 20 km, and later exposed by uplift and deep erosion (*28*). Following correlations made in other areas (*29*), we infer that the Ulugh Muztagh plutonic rocks also result from the melting of crustal rock,

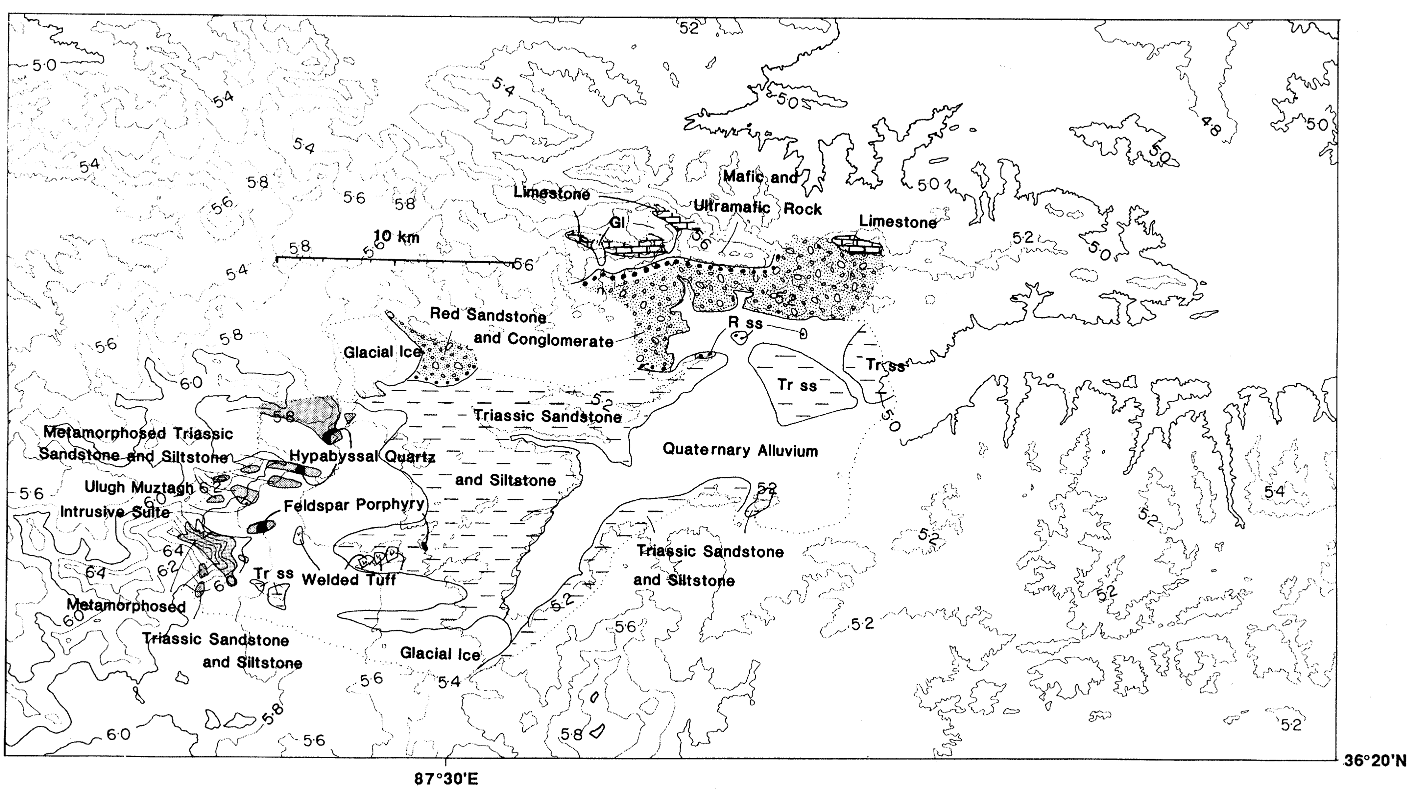


**Fig. 6.** Geologic map of the area around Ulugh Muztagh. Tr ss and R ss, Triassic sandstone, siltstone, and shale and red sandstone and conglomerate, respectively; Gl, glacial ice. Elevation contours are in 1000 m.

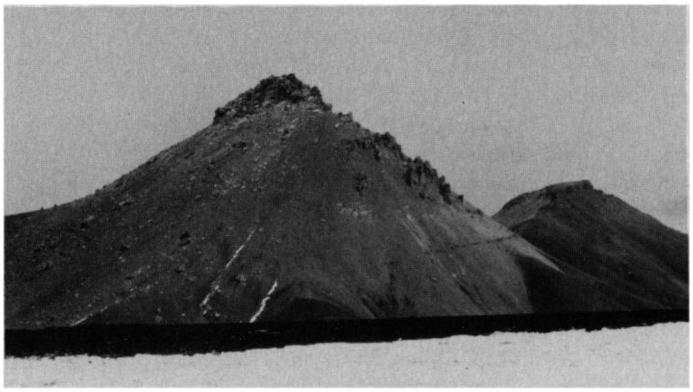

**Fig. 7.** Photograph of quartz-sanidine welded tuff unconformably overlying Triassic sandstone and shale on the ridge northeast of Ulugh Muztagh. View is northeast from the glacier east of Ulugh Muztagh.

which almost surely occurred at depth in a thickened crust (*30*).

At Ulugh Muztagh the tourmaline-bearing and two-mica granites are associated with the, often tourmaline-bearing, quartz-feldspar porphyries that appear to be the result of shallow crustal hypabyssal intrusions. Limited time did not permit us to establish the field relationships among the different intrusions, but the low-grade metamorphism of the country rock also suggests that the igneous rocks were intruded at depths considerably shallower than 10 to 20 km.

Volcanic rocks cap several hills east of Ulugh Muztagh (Figs. 6 and 7). They conformably overlie a basal conglomerate, 5 m thick, composed of cobbles with diameters up to 50 cm and that consist of rocks of the Ulugh Muztagh intrusive suite. The conglomerate is gently dipping and rests unconformably on the folded Triassic sedimentary rock. The volcanic rock, weathered tan, consists of 30 to 40 m of quartz-sanidine welded tuff with rare biotite. Quartz and sanidine are present both as euhedral and fragmental particles set in a matrix of glass shards and pumice with flattened vesicles. The basal 5 to 10 m of the sequence is a gray, densely welded tuff that crops out as a resistant ledge.

Preliminary $^{40}Ar/^{39}Ar$ ages of a biotite from a sample of tourmaline-bearing biotite granite and of two sanidine crystals from the welded tuff yielded values of 10.5 and 4.6 million years, respectively (*31*). The former age suggests that crustal thickening in this part of Tibet had occurred by 10 million years ago. The younger cap of volcanic rock on surrounding hills suggests that uplift and erosion had occurred by 4.6 million years ago. Because these volcanic rocks stand only a couple of hundred meters above the neighboring valleys, erosion since that time could not have been great.

## Conclusions

Active deformation on the northern margin of the Tibetan plateau includes not only slip on the left-lateral, east-northeast trending Altyn Tagh strike-slip fault but also uplift and convergence on several easterly trending reverse or thrust faults. Thus, it appears that some of the convergence of India with Siberia is presently being absorbed by crustal shortening and crustal thickening on the northern margin of the plateau.

Steeply dipping late Cenozoic sedimentary rocks deposited in the Ayak Kum Köl basin (Fig. 2) reveal evidence for late Cenozoic folding and north-south crustal shortening (*3*). During the last few million years, however, the locus of shortening apparently has migrated 50 to 200 km northward.

An east-west trending belt of mafic and ultramafic rock within the Kunlun lies parallel to a sequence of folded and faulted Triassic sandstone and shale and probably marks a Triassic or slightly younger suture of a continental fragment with the rest of Asia to its north.

Late Miocene two-mica and tourmaline-bearing granites crop out at the foot of the peak, Ulugh Muztagh. By analogy with other areas (*28, 29*), these rocks represent melting of continental crust, and as such the Ulugh Muztagh sequence probably is due to late Tertiary crustal shortening. Uplift and erosion occurred between their intrusion about 10.5 million years ago and the extrusion of welded tuffs 4.6 million years ago, but probably not much erosion has taken place since the welded tuffs were deposited.

Lastly, Ulugh Muztagh, a prominent peak looming over the otherwise relatively flat Tibetan plateau, probably owes its existence to the intrusion of granitic rock into the widespread Triassic sedimentary rock in this part of the Kunlun range metamorphosing it to more resistant, low-grade schist and quartzite.

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32. The expedition to Ulugh Muztagh would not have been possible without the efforts of many kinds of R. H. Bates and N. B. Clinch, and we are particularly grateful to them. Without the help of Lu Ming it would have been impossible to carry out scientific research. B.C.B. and P.M. thank P. Schoening for taking them safely to high altitude and across the glaciers to study the immediate vicinity of Ulugh Muztagh. P. LeFort read an early draft of the manuscript, and W. S. F. Kidd critically reviewed it. Finally, we thank J. Sutter for allowing us to quote his $^{40}Ar/^{39}Ar$ dates in advance of publication.


# The Molecular Genetics of Cancer


J. Michael Bishop



**The search for genetic damage in neoplastic cells now occupies a central place in cancer research. Diverse examples of such damage are in hand, and they in turn hint at biochemical explanations for neoplastic growth. The way may be open to solve the riddles of how normal cells govern their replication and why cancer cells do not.**


Cancer may be a malady of genes, arising from genetic damage of diverse sorts—recessive and dominant mutations, large rearrangements of DNA and point mutations, all leading to distortions of either the expression or biochemical function of genes. Is this suspicion correct, and, if so, what is the nature of the ailing genes and how do their ailments sustain neoplastic growth? These are the issues that now prevail in the fundamental research on cancer.

The belief that genetic damage might be responsible for cancer grew from diverse roots: the recognition of hereditary predispositions to cancer (*1, 2*), the detection of damaged chromosomes in cancer cells (*3*), the apparent connection between susceptibility to cancer and impaired ability of cells to repair damaged DNA (*4*), and evidence that relates the mutagenic potential of substances to their carcinogenicity (*5*). Now these roots have been joined by the discovery of cellular genes (proto-oncogenes) that in another form (oncogenes) can cause neoplastic growth.

Here I review the means by which proto-oncogenes have been identified and the evidence that damage to these genes may be involved in the genesis of cancer. I will not argue that the genetic ailments already found in cancer cells offer a full explanation for the malignant phenotype, only that these ailments are not merely adventitious and thus are likely to be part of the engine that drives neoplastic growth. The search for genetic damage and the explication of how that damage affects biochemical function represent seminal lines of inquiry into the mysteries of cancer.


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Dedicated to the memory of Richard C. Parker.

## Retroviruses and Cancer Genes

The life cycle of retroviruses has provided the first clues for identifying cellular genes that might participate in tumorigenesis (*6–8*). The single-stranded RNA of the diploid viral genome is transcribed into DNA by reverse transcriptase. Viral DNA is then integrated into chromosomal DNA, and the host cell uses its own machinery to express viral genes. The scenario presents two possibilities for unveiling cancer genes.

First, integration of viral DNA is potentially mutagenic: it can damage cellular genes directly (*7–9*), and it can influence their expression by bringing them under the control of powerful regulatory elements in the viral genome (*10*). These events (called "insertional mutagenesis") have been implicated in tumorigenesis by a variety of retroviruses. Second, recombination between retroviral and cellular genomes can implant cellular genes into the viral genome, and in this new setting the cellular genes may become oncogenic (*6–8*). The genesis of retroviral oncogenes from cellular proto-oncogenes has been called "transduction" (although strictly used, the term applies only after a gene has been transmitted from one cell to another by viral infection). Not all cellular genes are potential oncogenes, of course, but those that are have often come to the attention of investigators as a result of transduction by retroviruses.

In some instances, transduction follows insertional mutagenesis in close conjunction, and it then becomes difficult to say how each has contributed to tumorigenesis. The conjunction occurs at exceptionally high frequency during the induction of erythroleukemia by avian leukosis virus (*11, 12*) and of T-cell lymphoid tumors by feline leukemia virus (*13*), perhaps because the RNA transcribed from the mutant genes is well adapted for incorporation into retroviral particles.

## Retroviral Oncogenes

Twenty retroviral oncogenes are now known that together offer experimental models for most major forms of neoplasia (*14–17*). Each of these genes encodes a protein whose biochemical action adds to our understanding of the mechanisms of neoplastic growth. Moreover, at least nine retroviral oncogenes (v-*abl*, v-*erb*B, v-*ets*, v-*mos*, v-*myb*, v-*myc*, v-H-*ras*, v-K-*ras*, and v-*sis*) have added signifi-