The Collision between India and Eurasia

For the past 40 million years the Indian subcontinent has been pushing northward against the Eurasian land mass, giving rise to the severest earthquakes and the most diverse land forms known

by Peter Molnar and Paul Tapponnier

The region of the earth that exhibits the greatest diversity of geology, topography and climate, together with a strong susceptibility to major earthquakes, is the part of Eurasia that lies east of the Ural Mountains and north of the Ganges, embracing northern India, Pakistan, Afghanistan, the Tibetan plateau, Mongolia, most of China and a large part of the eastern U.S.S.R. This profoundly disarranged region is roughly equal in area to all of North America from the Rio Grande to 60 degrees north latitude, the parallel that crosses the northern tip of Labrador on the east and Cook Inlet in Alaska on the west. The world’s highest mountains, the Himalayas, rise abruptly from the flat, densely populated Ganges Plain in northern India and shield the Tibetan plateau from the seasonally shifting monsoon winds of southern Asia. Tibet supports a population of less than 1.5 million in an area somewhat larger than Texas, Oklahoma and New Mexico combined. Tibet’s average elevation is 5,000 meters, higher than any point in the 48 contiguous states of the U.S. In contrast, eastern China has abundant rainfall and supports a population of close to a billion. (As long ago as 1556 a single earthquake near Sian, then the capital of China, is known to have killed 830,000 people.) The broad, high mountainous zone that includes the Himalayas and the Tibetan plateau presents such a barrier to travel that throughout history the populations of India and China have had remarkably little contact. North of Tibet the Gobi Desert presents another formidable barrier to migration and communication. The Tarim Basin, part of the Gobi Desert, is one of the driest and most inhospitable regions on the earth. Mountains as high as 5,000 meters surround it on three sides. Nearly constant winds blow across the basin with such force that they pile up sand dunes as much as 150 kilometers long with wavelengths of three to five kilometers. clearly visible in satellite pictures. North of the Gobi Desert, Lake Baikal, at 1,800 meters the deepest lake in the world, fills the Baikal rift zone, a huge crack in the earth’s crust similar to the one in East Africa.

Although the geology of Asia seems to present a chaotic jumble of land forms, much of the deformation of the surface, when it is viewed as a whole with the help of satellite photographs, seems to fall into a simple, coherent pattern attributable to a single cause: a geological collision between the Indian subcontinent and the rest of Eurasia. This collision is still in progress. As an example of its current effects, we believe the great earthquake that devastated the industrial city of Tang Shan last summer was the result of forces originating in the collision area 2,500 kilometers to the southwest.

The possibility of quantitatively analyzing the collision between India and Eurasia has developed only in the past 10 years. The hypothesis of sea-floor spreading was first advanced in the mid-1960’s to explain the mid-ocean ridge, the great mountain range on the ocean floor that runs for 40,000 kilometers across the world’s ocean basins. At a rift in the crest of the ridge molten rock wells up from the mantle below and fills the gap that is left as the ocean floor on each side of the rift moves outward. It was also recognized that the ocean floor is magnetized in stripes of opposite polarity, depending on the magnetic polarity of the earth itself at the time the molten rock crystalized. (For reasons still not known the earth’s magnetic polarity reverses at intervals of several hundred thousand years.) The study of magnetic reversals in the floors of the Indian and Atlantic oceans showed that India had traveled 5,000 kilometers with respect to Eurasia before the two collided. Since the beginning of the collision India has continued to move northward another 2,000 kilometers with respect to Eurasia. How can one account for the vast area of land that was displaced by the collision? We shall describe our hypothesis to account for the displacement and present the evidence supporting it.

The recognition of sea-floor spreading, which confirmed earlier conjectures of continental drift, quickly led to the much broader concept of plate tectonics, a concept that has inspired the renaissance in the earth sciences. Plate tectonics provides a physically simple mechanism for large-scale horizontal motions of separate portions of the earth’s crust and makes it possible to be quantitatively precise in describing the kinematics of continental drift. One of the central concepts of plate tectonics is that a small number of large plates of the lithosphere, the high-strength outer shell of the earth, move rigidly with respect to one another at rates of one centimeter to 30 centimeters per year over the hotter, low-strength asthenosphere under them. Some 100 kilometers thick, this outer shell consists of the earth’s crust and the upper part of the mantle. Thus in plate tectonics the earth’s crust, which is both lighter than and chemically different from the mantle under it, is visualized as being carried passively as part of a lithospheric plate.

It is ironic that Alfred Wegener, who was probably the most important early proponent of continental drift, based much of his argument on the difference between the continental crust and the oceanic crust. The continental crust, which stands high above the oceanic crust, has deep roots going down about 35 kilometers, whereas under the oceans the crust is only about six kilometers thick. Wegener viewed the continents as sturdy ships sailing majestically through the much weaker crust and mantle under the oceans. In actual fact, as is recognized in plate tectonics, the oceanic crust and upper mantle—the lithosphere—are extremely strong. They seem to be deformed only at the boundaries of plates, so that the relative mo-
The continents usually act as rigid structures when they lie entirely within one plate. When a boundary between two plates passes through a continent, however, it is generally more diffuse than the boundary between two oceanic plates or the boundary between an oceanic plate and a continental one, and it is accordingly much more difficult to define. Such diffuseness is apparent throughout the Mediterranean area, and it is particularly evident in Asia, where the India and Eurasia plates are converging.

Before proceeding further we should like to emphasize the important role played in plate tectonics by the difference between continents and oceans. Oceanic crust is formed as a part of the lithosphere at spreading ocean ridges. The oceanic lithosphere cools, shrinks, and gets denser as it moves away from a consequence of the collision of India with the southern margin of Eurasia. The collision began some 40 million years ago and is continuing. About 180 kilometers of fault appears here. Entire fault can be traced for more than 2,500 kilometers if one includes Kansu fault, with which it merges at its eastern end (see map on pages 36 and 37). This ERTS photograph and those on pages 39 and 41 are reproduced with slight variation from the top, so that topographical features are illuminated from the top. Otherwise shadows would point upward and the relief would tend to reverse so that the valleys would appear to be ridges.
.motion of the India and Eurasia plates. We can exploit the fact that if we know the history of the relative motion of plate a and any two other plates, b and c, we can calculate the history of the relative motion of b and c. From geological studies in the North Atlantic by Jean Francheteau of the Centre Océanologique de Bretagne in France and by Walter C. Pitman III and Manik Talwani of the Lamont-Doherty Geological Observatory of Columbia University we know how both Eurasia and Africa moved with respect to North America, and thus we can calculate how they moved with respect to each other. Similarly, from the work of Robert L. Fisher of the Scripps Institution of Oceanography, D. P. McKenzie of the University of Cambridge and John G. Sclater of the Massachusetts Institute of Technology we know how India and Africa moved with respect to each other and therefore we can calculate where India was with respect to Eurasia at different times in the past.

We do not know where the northern margin of the original Indian continent lies with respect to India today, because that margin has been much deformed in the creation of the Himalayas. For the purposes of calculating how much the India and Eurasia plates moved with respect to each other in different intervals, however, our ignorance on this point does not matter. Moreover, although we do not know how far north of India the old margin lies, we can determine from the geology of Asia the position of the boundary between rocks of the present Indian subcontinent and those that were part of Eurasia long before the collision.

The primary evidence used to delineate a suture between two continents is the existence of the sequence of rocks known as an ophiolite suite. Ophiolites have three distinguishing characteristics. They show a particular sedimentary sequence incorporating bedded cherts, which are characteristic of deep-ocean sedimentary deposition. They contain remnants of pillow basalts: igneous rocks of lumpy form that are typical of basaltic lava extruded under water, at or spreading ocean ridges. And they incorporate dense, dark rocks low in silicon dioxide known as ultramafics, which are thought to be typical of the mantle. Ophiolites are interpreted as being a slice of the oceanic crust and upper mantle; accordingly their presence implies the former existence of an ocean basin.

A belt of ophiolites follows the Indus and Tsangpo valleys in southern Tibet north of the Himalayas; it appears to mark the boundary between the sutured continents. Somewhat farther north there are volcanic rocks typical of those found at subduction zones, as in the Andes of South America. Just as oceanic
to the east by a series of great rivers that arise in nearly parallel channels but eventually fan out into rich deltas along an arc extending from the Bay of Bengal to the Yellow Sea. To make the geography and distances more familiar one can imagine a map of North America traced on top of this one so that the Rio Grande is roughly aligned with the Ganges, which would place Brownsville, Tex., close to Calcutta. (Actually Calcutta is about four degrees farther south than Brownsville.) Los Angeles would then coincide approximately with Kandahar in Afghanistan, Miami would be near Hanoi, and Portland, Me., would be close to Peking. The Himalayas would sweep in a great arc from Nevada-Utah border to Mississippi, crossing Arizona, New Mexico, Texas and Louisiana. Tibetan plateau would include Colorado, Nebraska, Kansas, Oklahoma, Iowa and Missouri. Far to the north Lake Baikal would cut across northernmost tip of Quebec.
DURING AN EARTHQUAKE, one block of the earth’s crust slips with respect to an adjacent block along a fault plane. In a normal fault (b) the blocks act as if they were being pulled apart. The overlying block slides down the dip of the fault plane. In a thrust fault (c) the overlying block is forced up the dip of the fault plane because the maximum compressive stress is horizontal and perpendicular. In a strike-slip fault (d) the two blocks slide past each other. Lateral slippage can be combined with normal or thrust faulting. From an analysis of the seismic waves generated by an earthquake, called a fault-plane solution, one can tell what kind of fault motion has occurred.

 crust now plunges to the east under the Andes, presumably the old ocean floor between India and Eurasia plunged to the north under Tibet. In contrast the Himalayas, south of the suture, consist of slices of the old northern portion of India that have been stacked one on top of another to form the mountains. Patrick LeFort of the Centre de Recherches Pétrographiques et Géochimiques in France and Maurice Mattauer of the University of Montpellier have shown that there is a progression from north to south in the piling up of such slices, so that the oldest thrust is to the north. The next step will probably be for a new fault to form farther south on the Ganges Plain and for material to the north of it to slide up and over the plain to the south.

Although the geology of the Himalayas and Tibet is not well enough known to enable us to reconstruct the position of the northern margin of the original Indian continent, it does place important constraints on when India and Eurasia could have collided. Four observations imply a date of between 40 and 60 million years ago. First, from geological investigation of the ophiolites in the area, Augusto Gangser of the Swiss Federal Institute of Technology found “exotic blocks” of the late Cretaceous (about 70 million years ago) within the suite. Thus the ophiolites must have been part of an ocean floor until after that time.

Second, Gangser describes a sequence of sedimentary rocks on the northern edge of the Himalayas that is typical of sequences found on continental shelves and slopes and that begins in the Cambrian (about 500 million years ago) and continues until the early Eocene (about 55 million years ago). Hence there appears to have been an ocean between the converging continents until approximately that time.

Third, there is no known fossil record of mammals in India before about 50 million years ago. Ashok Sahni and Vimal Kumar of Lucknow University in India report that the oldest mammals in India date from the middle Eocene (about 45 million years ago). The first Indian mammals are similar to those found in Mongolia. Thus although mammals had evolved on other continents, it appears that they did not evolve independently in India, indicating that the continent remained isolated until about 45 million years ago. The collision enabled a horde of Mongolian mammals to sweep into India. Fourth, Gangser infers that major mountain building in the Himalayas began in the Oligocene (about 35 million years ago).

These observations do not enable us to determine precisely when India and Eurasia collided, but we think the event probably occurred 45 million years ago, give or take a few million years. It is highly improbable, however, that the old margins of India and Eurasia met flush along their full length. It is more likely that they first made contact when peninsulas met and that with the passage of time the zone of contact grew until the ocean basin between the continents was swallowed up. Thus we consider it likely that the initial contact may have been a few million years earlier than intimate contact.

From the history of sea-floor spreading in the Indian Ocean one can calculate the relative positions of India and Eurasia over some tens of millions of years. One can see immediately that between 70 and 40 million years ago India moved about twice as far with respect to Eurasia as it has since then. A plot of the distance of the northeast and northwest corners of India at different times in the past from their present positions shows that the rate of convergence between them changed by a factor of two about 40 million years ago. Given the uncertainties in the data the change in rate
could have come a few million years later or as much as 10 million years earlier. In any event we interpret the change in the rate at which India approached its present position as an indication that the first stages of collision came at about the same time as the change in rate, and that the buoyant continental crust of India, instead of being subducted, put a brake on the northward motion of the India plate.

Although the reconstructions provide support for the view that continental crust cannot be subducted, they leave us with what may be a more difficult problem. If we conclude that India and Eurasia collided 40 million years ago, we must also conclude that since then India has traveled northward about 2,000 kilometers with respect to Eurasia. If the continents collided earlier, the distance covered is even greater. Bearing in mind that continental crust cannot be subducted, we are faced with the problem of accounting for the displacement of a piece of crust that has an area the width of India and is 2,000 kilometers long.

The continuing northward motion of India at a rate of about five centimeters per year is probably responsible for the widespread tectonic activity in Asia. For example, seismic activity is detected over an area extending some 3,000 kilometers north and east of the Himalayas. Among the 22 greatest earthquakes listed by Beno Gutenberg and Charles F. Richter of the California Institute of Technology for the period 1897-1955, seven occurred in central and eastern Asia, four of them north of the Himalayas. The deformation of the surface of the earth that accompanied some of these earthquakes was huge. The 1957 Gobi-Altai earthquake in Mongolia, which came after the Gutenberg-Richter study and would probably have been too small to have been included, caused displacements of as much as 10 meters along the main fault associated with the earthquake. Such large displacements along faults seem to have been characteristic of several of the great earthquakes in Asia. In any case it is clear that the region as a whole does not act as a rigid plate.

Asia is known for high mountains not only in the Himalayas and Tibet but also farther north and east, where in the Tien Shan and Nan Shan ranges there are peaks of up to 6,000 meters. Ordinarily high mountains are rapidly worn down by erosion, so that their existence implies large crustal movements in recent geologic times. Studies conducted by Russian geologists (V. N. Krestnikov, A. V. Goryachev, S. A. Zakharov and others) show that the area of the Tien Shan range was nearly flat from 200 million years ago to 30 or 40 million years ago, and that it has been elevated since then. Although other reports we have seen are less definitive, they do suggest that the relief in Mongolia and China.

INDIA'S NORTHWARD DRIFT has been reconstructed from magnetic reversals in the floors of the Indian and Atlantic oceans. As molten rock welled up into the rift in the ocean floor and hardened it became magnetized according to the prevailing polarity of the earth's magnetic field. At infrequent and irregular intervals the earth's polarity changes, leaving a record that can be dated. This "time lapse" reconstruction shows that India traveled some 5,000 kilometers northward with respect to Eurasia in the 20 to 30 million years before its collision with Eurasia. Over the past 70 million years the northeastern tip has actually traveled some 7,000 kilometers. Velocity for continent as a whole was about 10 centimeters per year for the first 30 million years and about five centimeters per year for the next 40 million. In this reconstruction it is arbitrarily assumed that the boundary of Eurasia is fixed in its present location.
today is comparatively new. Hence the de-
formation of a large part of the crust of
Asia appears to have begun after the col-
losion with India. We infer that the
penetration of India into Eurasia caused the
deformation.

In trying to explain how India could
have traveled 2,000 kilometers after it
began to collide with Eurasia we obvi-
ously have greater freedom in account-
ing for the material displaced if we
imagine its being absorbed over several
million square kilometers rather than in a
narrow zone. The for-
mati
on
1 of the Himalayas can account
for only a fraction of the material dis-
placed, so that it remains necessary to
explain where the rest of it has gone.
One method that has proved to be par-
ticularly useful for deciding how mate-
rial is displaced in oceanic regions at
present is the determination of “fault-
plane solutions” of earthquakes. Such
solutions reveal the direction of relative
movement along the fault. From the
study of the waves radiated by an earth-
quake one can determine both the type
of faulting that took place during the
earthquake and the direction of motion
of one side of the fault with respect to
the other.

Geologists classify faults in three
main categories. A normal fault results
when stresses directed horizontally
cause one side of the fault to sink with
respect to the other. A thrust fault is
produced when compressive stresses
drive one side of a fault over the other
side. In a strike-slip fault the two sides of
a fault slide horizontally past each oth-
er. If the opposite side of the fault moves
to the left, as viewed from either side,
the movement is termed left-lateral dis-
placement. Movement in the opposite
direction is right-lateral displacement.

Working with Thomas J. Fitch, who is
now at the Lincoln Laboratory of the
M.I.T., and Francis T. Wu of the State
University of New York at Binghamton,
we have compiled fault-plane solutions
for some 75 earthquakes in Asia.

Studies of earthquakes in the Himala-
as corroborate geological observations
and show that India is continuing to
thrust under the Himalayas in a norther-
lly to northeasterly direction. Over the
past 50 years several investigators have
suggested that the northern margin of
India was also thrust under the Tibetan
plateau and that Tibet is at a higher alti-
itude because of it. We and many other
geologists now find this very unlikely.
We see no evidence of such under-thrust-
ing going on now, and mechanically
such a phenomenon seems highly con-
trived.

More recently John F. Dewey and
Kevin Burke of the State University of
New York at Albany have suggested that
the Tibetan plateau is a result of a
shortening of the crust in the entire Ti-

betan-Himalayan region, with the Ti-

betan crust behaving like an accordion,
contracting horizontally and expanding
vertically. Although we are not con-
vinced that this concept is inapplicable
to Tibet, we see no persuasive evidence
for accepting it. For one thing, studies
of earthquakes show that Tibet is not
shortening but is stretching in an east-
west direction. Moreover, from a com-
parison of satellite photographs of Tibet
with those of other mountainous areas
in Asia where shortening is currently
taking place, the surface deformation of
the Tibetan plateau appears to be much
less, and if folding of the crust has
occurred, it is less recent. Nevertheless,
even if the thickness of the crust has
doubled in Tibet as a result of pressure
from the south, only 600 or 700 of the
2,000 kilometers can be explained in this
way.

In the Tien Shan area the pattern of
deformation is again dominated by
thrust faulting, with shortening in a nor-
therly direction. The Russian seismo-
ologist V. I. Ulomov estimates that the
amount of shortening in the western
part of the area is about 300 kilometers.
A figure arrived at by imagining what
would happen if the thickened crust
there was flattened out (in his words
“with a rolling pin”) to normal thick-
ness. For most of the rest of Asia fault-
plane solutions of earthquakes indicate
the overall predominance of strike-slip
faulting. Thrust faulting is characteris-
tic in only limited areas; normal faulting
is fairly uncommon. For example, in
Mongolia most earthquakes are associ-
ated with strike-slip faulting. In any case
earthquakes in Mongolia exhibit a fairly
consistent northeast-southwest orient-
ation of the maximum compressive
stress. Although the pattern east of Ti-
bet is more complex, it is similar to the
pattern in Mongolia.

Thus the faulting associated with
earthquakes indicates that much of Asia
is being squeezed in a direction lying
between north-south and northeast-
southwest, a pattern that is compatible
with India’s northward motion. The
squeezing causes the crust in parts of
Asia to shorten and thicken. Here again,
however, even if one adds a possible 700
kilometers of crustal shortening in Tibet
to 300 kilometers in the Tien Shan area,
one can still account for only 1,000 kil-
ometers of shortening, or half of India’s
total travel toward Eurasia since the be-
inning of the collision. Another expla-
nation must be sought for the remaining
1,000 kilometers of displacement even
if we are wrong in doubting the “accor-
dion” shortening in Tibet.

The satellite pictures of Asia play a
central role in leading us to an alter-
native explanation for the 2,000 kilome-
ters of convergence between India and
Eurasia. Perhaps the most striking fea-
PRINCIPAL TECTONIC FEATURES that are thought to be associated with continuing northward push of the India plate against the Eurasia plate have been plotted by the authors, partly on the basis of the analysis of ERTS photographs and partly on the basis of studies of major earthquakes (colored dots), which reveal how the crust has moved along faults. The straight lines without arrowheads through dots indicate thrust faults. The double-headed arrows indicate normal faults. The pairs of antiparallel arrows indicate movement along strike-slip faults. The areas in color appear to be zones of recent uplift resulting from crustal shortening. The overall impression is that the large Eurasian land mass that lies to the west of 70 degrees east longitude has remained more or less undeformed as China has been pushed to east.
CROSS SECTION OF THE COLLISION between India and Eurasia plates is shown schematically. The upper diagram shows a cross section through the lithosphere and the asthenosphere about two million years before actual contact, when the land masses were still separated by about 200 kilometers of ocean. At that time the lithospheric plate carrying India was plunging under the Eurasia plate as today the Pacific plate is plunging under the South America plate, creating the Andes along the west coast of South America. The black dots show how earthquakes tend to cluster along the boundary between plates and within the descending plate. The lower diagram depicts the situation today. The suture line, the Indus suture, is marked by the presence of ophiolites: sequences of rocks containing ocean sediments and showing other characteristics of having been formed in a suboceanic environment. Earthquakes are more diffusely distributed and shallower than they were before the collision. The Himalayas are slices of old Indian crust that have overthrust rest of India to the south, creating new faults that migrate southward. Active faulting seems to occur on main boundary fault. Crust under Tibet appears to be unusually hot; lithosphere there may be so thin that bottom may lie within crust.

GEOMETRY OF SLIP LINES observed when an indenting tool made of a hard material such as steel is pressed into a softer material such as brass bears a striking resemblance to the distribution and directional sense of strike-slip faults in Asia. The slip lines are probably less symmetrical in Asia than they are in idealized case because of asymmetry of boundary conditions.
to push against thousands of kilometers of the Eurasian land mass. The motion of China to the east is easily accommodated by its thrusting over the oceanic plates along the margins of the Pacific. Anyone who squeezes a tube of toothpaste experiences a homely analogy to this type of displacement. The thumb and fingers correspond to India and the rest of Eurasia. The closed end of the tube is analogous to the vast continental region of Eurasia that essentially blocks large-scale movement toward the west. The open end of the tube is analogous to the subduction zones of the western Pacific, with China and Mongolia acting as the toothpaste.

The existence of major strike-slip faults also helps to account for some other apparent peculiarities in the geology of Asia. Although most of Asia appears to be experiencing horizontal compression in a direction between north and northeast, there are two notable exceptions. Lake Baikal occupies a part of the Baikal rift system that is an expression of a northwest-southeast extension. Similarly, Deng Qidong and his colleagues at the Geological Institute in Peking describe the Shansi graben in eastern China as a rift system created by another extension with the same orientation. We interpret both of these systems as being partly the result of their proximity to strike-slip faults and as being comparable to the tension cracks that develop at the ends of shear cracks.

On this interpretation, after India collided with Eurasia the relative velocity of motion decreased, but India continued to drive into Eurasia at a rate of five centimeters per year. In so doing it

CRUSTAL THICKENING AND SHORTENING appear to have taken place in the region of the Tien Shan range southeast of Lake Baikal, as is indicated in this ERTS photograph centered on 40.5 degrees north latitude and 78.5 degrees east longitude. The picture shows folded sedimentary formations on the south side of the Tien Shan resulting from thrust faults in the crust under the sediments and dipping to the north under the Tien Shan. Seismic studies show that the crust is 20 to 30 kilometers thicker to the north of the Tien Shan than it is in stable adjacent areas. This fact suggests that the earth's crust in the eastern portion of the Tien Shan has been shortened, or compressed, by as much as 300 kilometers, presumably because of the northward thrust of India, more than 1,000 kilometers away.
The basic unproved assumption in the scheme we have been describing is that large horizontal displacements have actually occurred on the strike-slip faults of Asia. To the best of our knowledge the most thoroughly studied of these faults is the Talasso Fergana fault in the U.S.S.R. There is controversy among Russian geologists over how much displacement has taken place on the fault, but V. S. Burtman suggests that it may amount to 200 to 250 kilometers of right-lateral motion. He suggests, however, that much of the displacement occurred before India collided with Eurasia. He is unable to estimate how much has taken place since then. As for the other faults, we can only say that most of them are as prominent on the satellite photographs as the San Andreas fault in California is, which has undergone 300 kilometers of right-lateral displacement in the past 23 million years. If the displacements along the highly visible Asian faults are comparable to the displacement along the San Andreas fault, as we suspect, one can conclude that most of the 2,000 kilometers of convergence between India and Eurasia can be attributed to the lateral displacement of China. On the other hand, our hypothesis would be fatally wounded if it could be shown that the displacement along the major faults has amounted to only a few kilometers or at most a few tens of kilometers over the past 40 million years.

In any case it is virtually certain that strike-slip faulting plays a key role in the process of suturing continents together. McKenzie noted some years ago that in the Middle East, the other important region where continents are actively colliding, the motion of the Arabian subcontinent toward Eurasia is forcing part of Turkey to move to the west in a direction perpendicular to that of the converging continental blocks. Moreover, it is clear from detailed studies by Mattauer and his colleagues of portions of some old mountain belts such as those in France and Spain and in Morocco that strike-slip motion was important long after the continents had collided. It seems quite likely that as other ancient mountain belts are studied, evidence for large-scale horizontal movement along strike-slip faults will be found. Such analyses of continental tectonics are clearly not a direct application of plate tectonics to continents. To apply plate tectonics to the deformation of Asia would call for so many plates that the concept's utility would be lost. We suspect that the same will be found to be true for older continental collisions.

At the same time we view the tectonics of Asia as being a direct consequence of plate motions. The earthquakes and great faults of India, China, Mongolia and the U.S.S.R. may be attributed to a simple phenomenon: the northward motion of the Indian subcontinent riding on the India plate toward the Eurasia plate. What is perhaps most interesting about this interpretation is that it indicates that the movement of India caused the deformation of a region more than 3,000 kilometers away. Since the mountains were created by movement along the faults, and since the climate of the region is in turn profoundly influenced by the topography, environmental conditions throughout much of Asia, including the harsh climate of the Himalayas, the Tibetan plateau, the Gobi Desert, Mongolia and parts of China, can also be attributed to a collision that has been in progress for 40 million years.
PORTION OF SHANSI GRABEN SYSTEM separates the eastern end of the forbidding Ordos plateau, part of the Gobi Desert, from the fertile, heavily populated valley of the Huang Ho. A graben is a sunken region where crustal blocks are being pulled apart. This mosaic of six ERTS photographs shows the surface features in an area 260 kilometers by 345 kilometers near Taiyuan, about 500 kilometers southwest of Peking. The pictures in the mosaic were made at different times of the year, so that in some of them snow and ice appear on ground and rivers. Shansi graben and the Baikal rift system resemble tension cracks that appear at oblique angles near strike-slip faults.