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Extensional tectonics in central and eastern Asia: a brief summary

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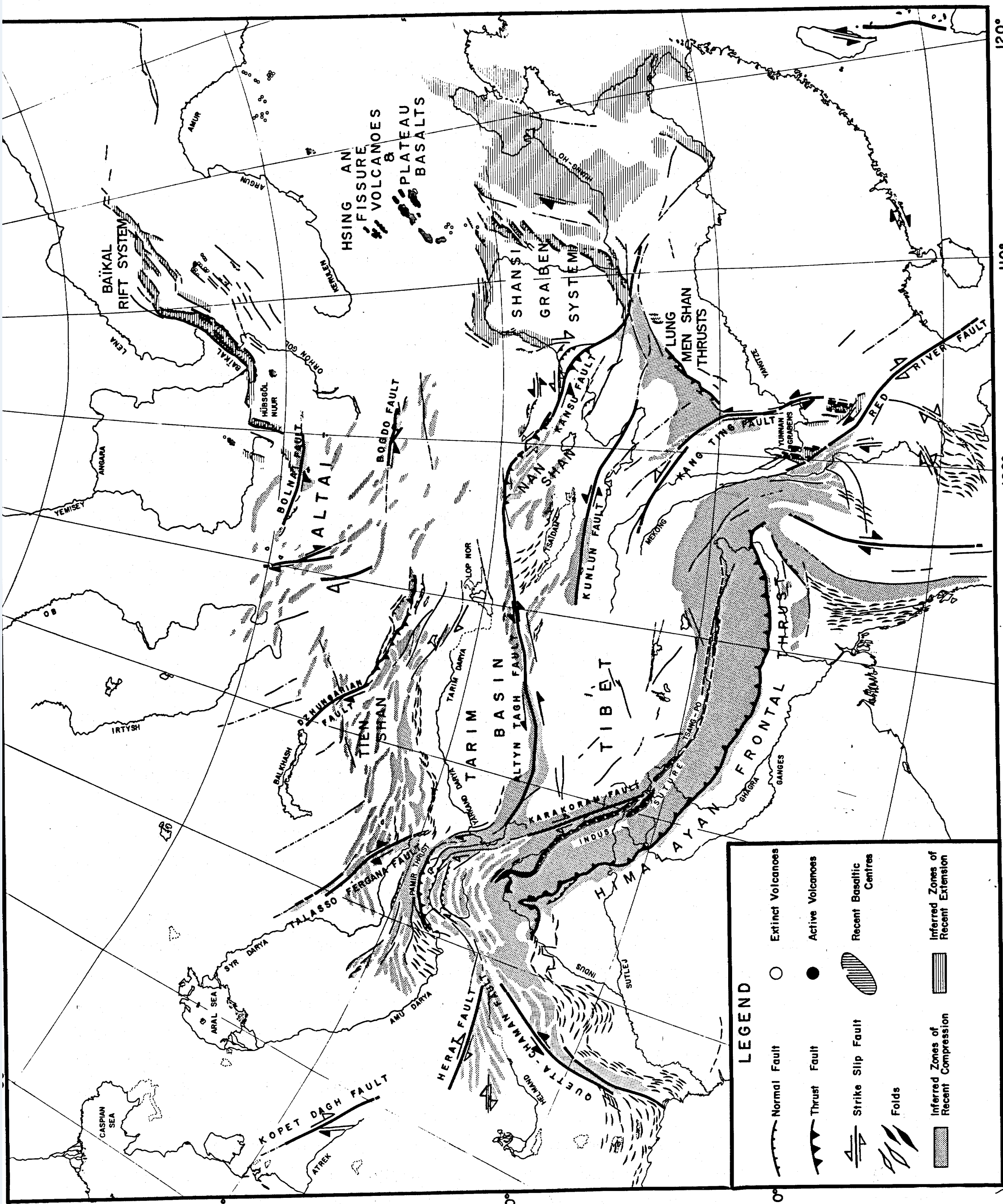
Although most of the neotectonics of eastern and central Asia seems to be due to the collision and continued convergence between India and Eurasia, extensional tectonics prevails in four portions of this region: Tibet, the Baikal rift system, the Shansi graben and Yunnan. We think that the convergence between India and Eurasia is responsible for crustal extension in all four regions, but the physical mechanisms responsible for the extension are not the same in all of these cases.

Fault plane solutions of earthquakes, and clearly defined escarpments and adjacent basins seen on the Landsat imagery, indicate widespread normal faulting in Tibet (Molnar & Tapponnier 1975, 1978; Ni & York 1978). The direction of extension appears to be east–west, but the poorly determined fault plane solutions and the lack of field studies allow some variation in the direction of extension. The normal faulting seems to be confined to the areas of highest elevation and some of the normal faults cross the Indus–Zangbu suture into the high Himalaya.

Most of the earthquakes seem to have occurred at shallow depths, but at least one event, that of 14 September 1976, occurred at 90 ± 10 km depth (Chen *et al.* 1980). The fault plane solution for it shows normal faulting with an east–west T axis. That this event occurred in the mantle beneath the thick Tibetan crust corroborates the inference that the mantle immediately beneath Tibet is not unusually hot (Chen & Molnar 1980). If the orientation of the T axis for this event is representative of the direction of the least compressive stress in the uppermost mantle beneath all or most of Tibet, then it implies that the entire outer 100 km of the Earth beneath Tibet is being stretched in an east–west direction.

We infer that the normal faulting results from the gravitational body forces acting on the high altitudes and the crustal root of Tibet (Molnar & Tapponnier 1975, 1978). For equilibrium, this force must be balanced by a horizontal compressive stress in the surrounding regions or horizontal extensional stress within Tibet. Tibet's elevation is then analogous to a pressure gauge (Molnar & Tapponnier 1978) and it measures the average pressure that India applies to the rest of Asia (Tapponnier & Molnar 1976). Presumably India applies sufficient pressure to prevent north–south extension within Tibet, but if eastern China is free to move eastwards relative to both India and Eurasia, extension can occur in an esat–west direction.

This current style of tectonics is probably quite young and presumably it did not occur until the high elevations and thick crust had formed. One mechanism for creating the thick Tibetan crust is very large-scale crustal shortening (Dewey & Burke 1973). Reconstructions of the relative positions of India and Eurasia since the late Cretaceous require 2000–3000 km of convergence since the collision 40–50 Ma ago (Molnar & Tapponnier 1975). Palaeomagnetic studies in southern Tibet also indicate this amount of convergence between southern Tibet and


BAÏKAL RIFT SYSTEM
HSING AN FISSURE VOLCANOES & PLATEAU BASALTS
SHANSI GRABEN SYSTEM
LUNG MEN SHAN THRUSTS
ALTAI
BOLNAI FAULT
BOGDO FAULT
NAN SHAN
KANSU FAULT
KUNLUN FAULT
KANG TING FAULT
RED RIVER FAULT
TARIM BASIN
ALTYN TAGH FAULT
TIBET
TIEN SHAN
DZHUNGARIAN FAULT
KARAKORAM FAULT
TSANG-PO SUTURE
HIMALAYAN FRONTAL THRUST
TALASSO FERGANA FAULT
PAMIR THRUST
HERAT FAULT
CHAMAN FAULT
QUETTA
KOPET DAGH FAULT
CASPIAN SEA
ARAL SEA
BALKHASH
AMUR
ARGUN
KERULEN
ORHON GOL
HÜBSGÖL NUUR
LENA
ANGARA
YENISEY
OB
IRTYSH
SYR DARYA
AMU DARYA
ATREK
HELMAND
INDUS
SUTLEJ
GANGES
GHAGRA
MEKONG
YANGTZE
HWANG HO
TARIM DARYA
YARKAND DARYA
LOP NOR
TSAIDAM
YUNNAN GRABENS
LEGEND
Normal Fault
Thrust Fault
Strike Slip Fault
Folds
Inferred Zones of Recent Compression
Extinct Volcanoes
Active Volcanoes
Recent Basaltic Centres
Inferred Zones of Recent Extension
120°
110°
100°
90°
80°
70°
40°
30°
20°

Siberia (Molnar & Chen 1978). These results militate against large-scale underthrusting of India beneath Tibet, but are consistent with large-scale shortening within Tibet. The existence of normal faulting within Tibet at present implies that shortening there has stopped, although the continuing convergence of India and Eurasia does seem to cause thrust faulting and crustal shortening on the margins of Tibet (Molnar *et al.* 1973, 1977), so that as these regions are elevated, the plateau seems to grow in area but not in altitude (Molnar & Tapponnier 1978). The convergence also seems to cause strike-slip faulting, primarily north and east of Tibet, by means of which parts of Asia are displaced eastwards with respect to the rest of Asia.

The normal faulting in the Baikal rift system, in the Shansi graben and in Yunnan, which are well studied by Soviet and Chinese geologists, is clear on the Landsat imagery and, except for the Shansi graben, is confirmed by fault plane solutions (Tapponnier & Molnar 1977, 1979). We think that there is an intimate relation between the normal faulting and some of the major strike slip faults: the Khangai fault in Mongolia (Tapponnier & Molnar 1979), the Kansu fault in eastern China (Molnar & Tapponnier 1977; Tapponnier & Molnar 1977), and (less clearly) the Red River fault in southwest China (Tapponnier & Molnar 1977), respectively. The relation of the normal and strike-slip faults is crudely analogous to that of tension cracks near the ends of shear zones. Moreover, the stress field associated with these extensional zones is approximately that which one would expect if Asia behaved like a plastic solid indented by a rigid indenter (Tapponnier & Molnar 1976).

Thus we associate the extensional tectonics in all of these areas with the convergence of India and Eurasia, but the mechanisms by which the convergence causes normal faulting seem to be different. The buoyancy forces that apparently drive the extension in Tibet are probably small in Baikal and Shansi. These grabens seem instead to open in response to a regional stress field that tends to pull the crust apart, but that nevertheless results from the convergence between India and the rest of Eurasia. The grabens in Yunnan probably result from a combination of these two causes.

This summary is not intended to be all-encompassing, but rather to give the reader an annotated bibliography of our work. The papers cited give more complete reference to the data upon which it is based and to the work of others.

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FIGURE 1. Preliminary map of recent tectonics in Asia. Bold lines represent faults of major importance, usually seismic and with very sharp morphology. Bold arrows indicate sense of motion, corroborated by fault plane solutions or surface faulting of earthquakes. Open arrows indicate sense inferred from analysis of photographs. For Tertiary folding, bold symbols indicate more prominent, more recent folds. The dotted areas indicate region of inferred recent vertical motion associated with thrust faulting and compressional tectonics. Areas shaded by dashed lines are covered by thick recent alluvial deposits and are dominated by horizontal extension and subsidence. The names of faults are not official names but purely for reference in this article.

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