# Intracontinental deformation in central Asia: Distant effects of India – Eurasia convergence revealed by apatite fission-track thermochronology

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During the Paleozoic Central Asia was the site of large-scale continental growth and accretion around the Siberian craton. By the Late Permian much of Eurasia had been assembled and formed part of the Pangean supercontinent. In Central Asia the Paleozoic basement is characterized by a complex mosaic architecture with various composing blocks mainly bound by large strike-slip faults (Sengör et al. 1993). In the Late Paleozoic and Mesozoic these faults were repeatedly reactivated (Buslov et al. 2003).

After Early Mesozoic break-up of Pangea the southern rim of Eurasia was again characterized by convergent tectonics. In eastern Asia, convergence between the amalgamated Siberian and the composite North China-Mongolian continents led to closure of the Mongol-Okhotsk Ocean. This ocean was closed in a scissors-like manner from west to east in the Jurassic to Early Cretaceous and gave rise to the Mongol-Okhotsk orogeny. To the southwest, closure of the Tethyan basin first led to accretion of several smaller units (e.g., Farah, Karakoram, Pamir, Qiangtang, Lhasa, Indochina) onto the southern, active Eurasian margin in the Late Triassic, Jurassic and Early Cretaceous. These events jointly contributed to the Cimmerian orogeny. Further closure of the Neotethys eventually culminated in the massive India-Eurasia continent-continent collision at the Meso-Cenozoic transition.

Ongoing convergence and indentation of India into Eurasia dominated the Cenozoic tectonic evolution of Asia (**Figure 1**). Strike-slip tectonics and lateral escape of crustal blocks along major shear zones (e.g. Ailao Shan-Red River system) was a key mechanism for accommodating penetration of India into Eurasia during much of the Oligocene. Thrusting, crustal thickening and uplift of the Himalayas and the Tibetan Plateau became an important factor since the Early to Mid-Miocene. A third essential effect of continued convergence between both continents is the reactivation of the inherited structural fabric in the continental interior of Central Asia, far from the active plate boundaries, since the Middle to Late Miocene.

In order to test this model of current deformation in Central Asia and to constrain the timeframe, we performed apatite fission-track (AFT) analyses on crystalline rocks from both the Kyrgyz Tien Shan Mountains and the South Siberian Altai-Sayan Mountains in Central Asia (De Grave and Van Den Haute 2002, De Grave 2003) (**Figure 1**). In the Tien Shan the main sampled area is the Paleozoic basement of the Lake Issyk-Kul region in northeastern Kyrgyzstan. Most samples were collected along elevation profiles in the Kungey and Terzkey ranges. These ranges are primarily formed by Ordovician granitoids and are thrust upon the northern and southern margins of the Cenozoic intramontane Issyk-Kul basin. In the Altai-Sayan Mountains, samples originate from four key regions. The majority of the apatites were collected in the Paleozoic basement rocks of the Plio-Pleistocene Teletskoye graben (northern Siberian Altai-Sayan). Other sample localities include the Chulyshman Plateau, and the Paleozoic basement of the Cenozoic Chuya-Kurai and Dzhulukul basins.

AFT age and length data from a total of about 75 samples were obtained (around 50 from the Altai-Sayan and 25 from the Tien Shan Mountains). Thermal history models for the studied regions were reconstructed using the AFTSolve modelling software (Ketcham et al. 2000). These models, generally reveal a three-stage cooling history throughout the investigated area, confirming and constraining the Meso-Cenozoic tectonic evolution portrayed above (**Figure 1**).

The modelled t,T-paths show a first stage of Jurassic to Late Cretaceous cooling in both the Tien Shan and Altai-Sayan regions. For the Tien Shan (Issyk-Kul area) the cooling spans much of the Jurassic, until the Early Cretaceous (~180-110 Ma). We attribute this cooling to the denudation of the Issyk-Kul basement associated with tectonic activity during the Cimmerian orogeny. At that time the active southern Eurasian margin, to the (south)west of the current Tien Shan, was the site of accretion and collision of the tectonic units building the present Tethyan belt that ranges from the Hindu Kush (west) to Indochina in the east (**Figure 1**). At the cessation of Mesozoic cooling, the studied rocks in the Issyk-Kul basement reached upper apatite-Partial Annealing Zone (APAZ) temperatures. A Late Jurassic-Mid Cretaceous cooling (~150-80 Ma) also affected all studied rocks in the Altai-Sayan region and brought them to upper APAZ temperatures as well. Considering a normal geothermal gradient of 25 to 30°C/km, the modelled AFT thermal histories indicate the rocks had been brought from below 4 km in the crust to depths of around 2 to 2.5 km after the Mesozoic denudation. In the case of the Altai-Sayan, the cooling is also interpreted as denudation associated with a phase of tectonic uplift. This uplift is thought to be a far-field effect of the major continent-continent collision of amalgamated Siberia with the composite North-China/Mongolia continent. This was a consequence of oblique closure of the Mongol-Okhotsk Ocean that existed between both landmasses. This oblique or scissors-like closure acted from west to east and initially affected the area in West Mongolia, just east of the present Altai orogen.

After the Mesozoic, near-horizontal modelled t,T-paths prevail during the Late Cretaceous and Paleogene and reflect a period of tectonic quiescence and peneplanation throughout Central Asia. Both the thermal history models for the Tien Shan and Altai-Sayan regions exhibit this period of stability. Remnants of this vast Central Asian peneplain have been described from the Tien Shan all the way to the Baikal area. At the end of this period, before onset of rapid Late Cenozoic cooling, most of the investigated apatites remained at upper APAZ temperatures or seem to have just reached lower AFT retention temperatures. This long period of APAZ-residence is corroborated by the thermal signature in the AFT lengths and their frequency distributions. Low mean track lengths (~11 to 14 μm) and negatively skewed distributions are exhibited by all samples.

The present neotectonic reactivation of intracontinental Central Asia is shown by a new cooling stage described by the AFT thermal history models. The models obtained from the Tien Shan apatites exhibit this feature from ~15-10 Ma onwards; while for the Altai-Sayan samples this youngest stage is only seen during the last ~5 Ma. We interpret this young cooling down to ambient surface temperatures as the result of exhumation of the studied rocks to their present outcrop positions.

These observations suggest that reactivation and deformation in the interior of the Eurasian continent is gradually propagating northward through Central Asia since the Miocene as a distant effect of the ongoing indentation of India into Eurasia. Intracontinental, mainly transpressional, reactivation in Central Asia seems to follow an inherited structural pattern. The Mesozoic orogenic belts act as precursors to the Cenozoic and active mountain belts, while the ancestral Mesozoic belts in their turn were built along the inherited Paleozoic structural basement fabric. These multiphased Central Asian structures were rejuvenated in the Mesozoic as far-field effects of the orogeny and accretion acting on the distant continental margins, much in similar fashion as the ongoing India/Eurasia convergence is inducing deformation in the region today.

Our data shows that India/Eurasia convergence is partly accommodated by a northward propagation of deformation though intracontinental Central Asia via inherited large-scale structures. This deformation resulted in transpressional mountain building and roughly 2 km of denudation of the northern Kyrgyz Tien Shan Mountains since the Middle to Late Miocene. Deformation reached the Altai-Sayan area in southern Siberia significantly later. Since the earliest Pliocene this area also underwent about 2 km of denudation. Ongoing research in the vast area of the southern Tien Shan to the East Sayan, near the southwestern edges of the Baikal riftzone, is being carried out to refine and complete this image. Apart from AFT, other low-temperature thermochronometers (U-Th/He and $^{40}Ar/^{39}Ar$) will be applied in this study.

Also, our data suggests that the mechanism of far-field tectonic reactivation of discrete mobile belts cross-cutting the interior of Central Asia is not solely constrained to the Cenozoic framework of India/Eurasia collision. During the Mesozoic the area was subjected to similar reactivation in analogous tectonic regimes linked to continued accretion of the Eurasian continent.

## References


Buslov MM, T Watanabe, LV Smirnova, I Fujiwara, K Iwata, J De Grave, NN Semakov, AV Travin, AP Kiryanova and DA Kokh. 2003. Role of strike-slip faults in Late Paleozoic-Early Mesozoic tectonics and geodynamics of the Altai-Sayan and East Kazakhstan folded zone. *Russian Geology and Geophysics* **44**(1-2): 49-75

De Grave J. 2003. *Apatite fission-track thermochronology of the Altai Mountains (South Siberia, Russia) and the Tien Shan Mountains (Kyrgyzstan): relevance to Mesozoic tectonics and denudation in Central Asia* [PhD dissertation]. University of Gent, 289 p

De Grave J and P Van Den Haute. Denudation and cooling of the Lake Teletskoye region in the Altai Mountains (South Siberia) as revealed byapatite fission-track thermochronology. *Tectonophysics*, **349**: 145-159

Ketcham RA, RA Donelick, MB Donelick. 2000. AFTSolve: A program for multi-kinetic modeling of apatite fission-track data. *Geological Materials Research* **2**(1): 1-32

Sengör AMC, BA Natalin and VS Burtman. 1993. Evolution of the Altaid tectonic collage and Palaeozoic crustal growth in Eurasia. *Nature* **364**: 299-307


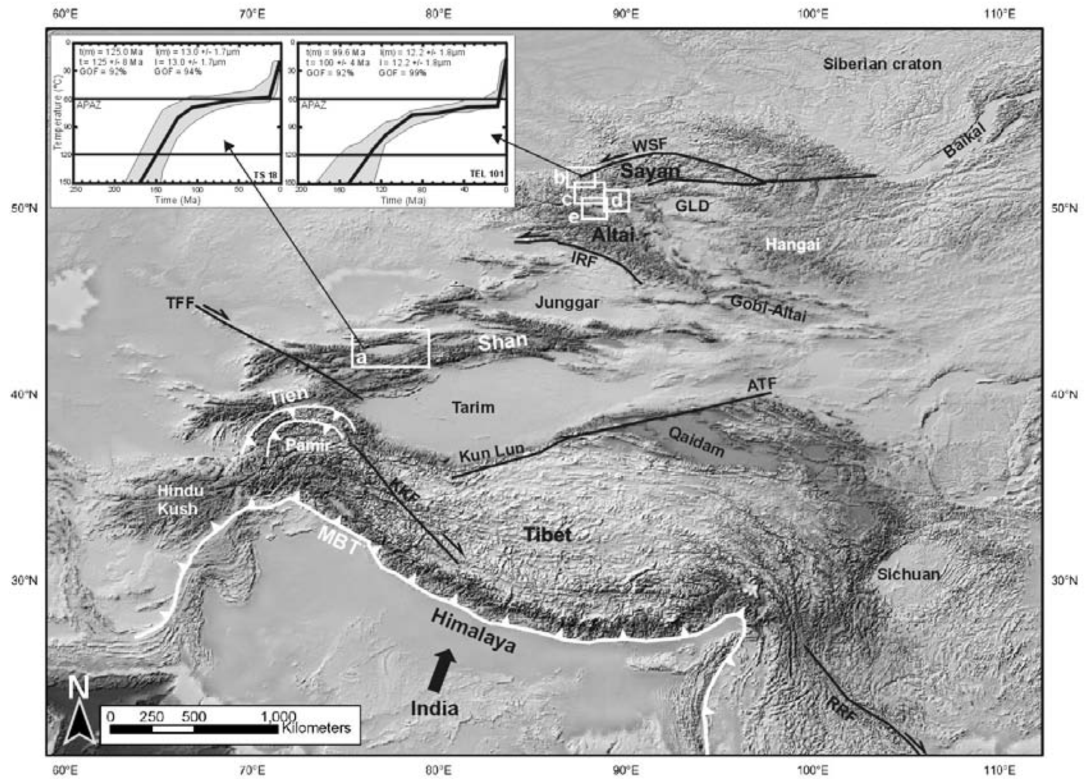


FIGURE 1. DTM of Central Asia indicating major tectonic and structural features: ATF = Altyn Tagh Fault, GLD = (Mongolian) Great Lakes Depression, IRF = Irtysh Fault, KKF = Karakoram Fault, MBT = Main Boundary Thrust, RRF = Red River Fault, TFF = Talas-Fergana Fault, WSF = West Sayan Fault. Sample areas for our AFT research are delineated by the boxes. Tien Shan Mountains: (a) Issyk-Kul basin, Altai-Sayan Mountains: (b) Teletskoye graben, (c) Chulyshman plateau, (d) Dzhulukul basin, (e) Chuya-Kurai basin. The inset in the upper left shows an AFT thermal history model of a representative sample for the Tien Shan (TS18) and the Altai-Sayan region (TEL101). Modelled (m) and measured AFT ages (t) and mean lengths (l) are indicated.