The Evolution of the Pamir

Oberseminar

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1. Introduction

The Pamir orogen lies NW of the Himalaya between the Hindu Kush in the SW and the Kunlun in the SE (Fig:2). Almost half of India's present convergence (44 mm/a) with Eurasia is absorbed by crustal shortening and underthrusting in this zone. In the following the geological units of the Pamir will be described. After that, the amounts of crustal shortening within the Pamir will be quantified and evidence for the subduction of continental lithosphere will be given.

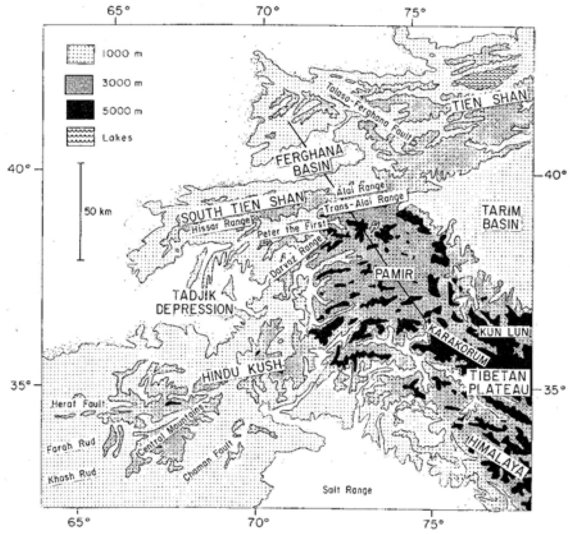

Fig.1: Geographical and topographical position of the Pamir (after Burtman & Molnar, 1993)

2. Geological Environment and History

The Pamir region can be divided into different belts: in the External zone, in the Northern, in the Central, and in the Southern Pamir. Most of these belts have continuations in the SE (Northern Afghanistan) and in the SW (Western Kunlun, Karakorum). The Pamir seems to have moved over 300 km towards north direction. Big strike slip faults – e.g Chaman fault in the W and the Pamir-Karakorum fault in the E - have isolated the Pamir arcs from their continuations (Fig.2).

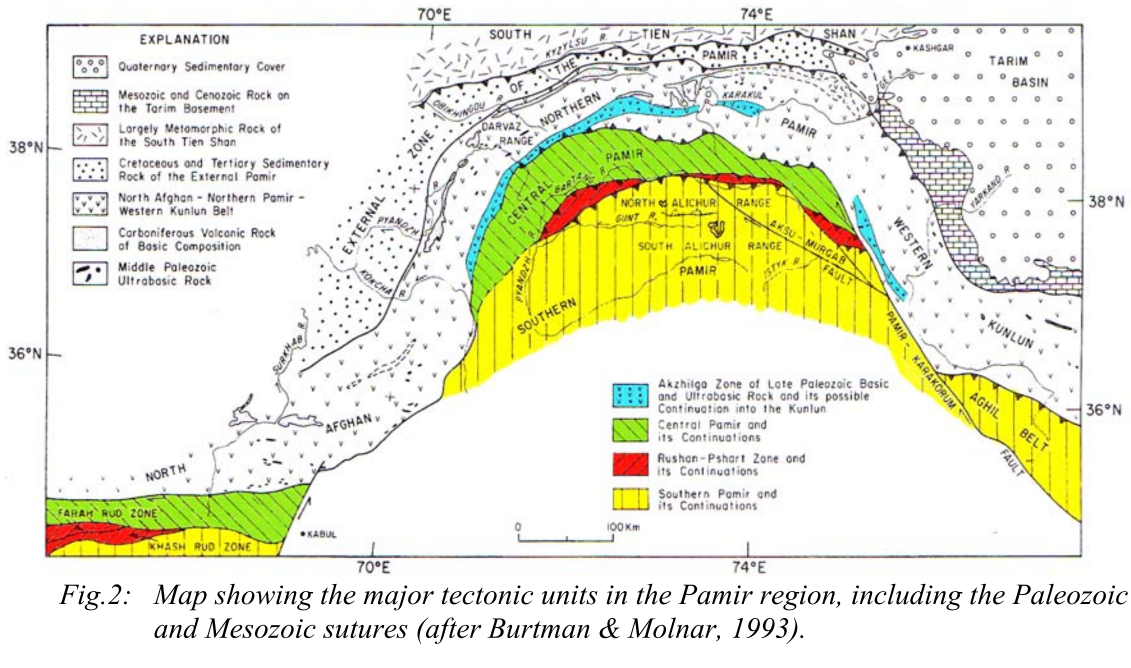

Fig.2: Map showing the major tectonic units in the Pamir region, including the Paleozoic and Mesozoic sutures (after Burtman & Molnar, 1993).

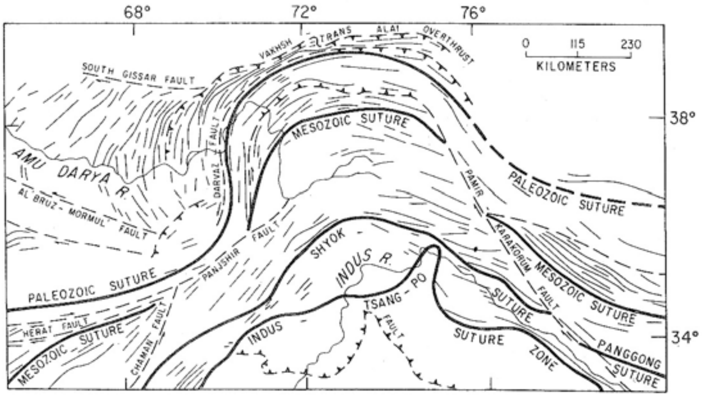

Fig. 3: Structural map of the Pamir-Punjab syntaxis, Tadjik Depression and surrounding regions (Burtman & Molnar, 1993)

2.1 Paleozoic Suturing:

The **Northern Pamir** represents the Paleozoic suture zone between the Central Pamir and the rest of Asia. This suture wraps around the Pamir, from the northern Hindu Kush in Afghanistan, through the Northern Pamir and then across the Kunlun of northern Tibet.

The Northern Pamir consists of outcrops of Carboniferous (Tournaisian to Serpukhovian) igneous and sedimentary rocks from an oceanic environment (ophiolites). In the eastern part of Northern Pamir, there is a section of tholeiitic basalt about 1 km in thickness, tectonically overlying gabbro and ultrabasic rock. Small massifs of ultramafic rocks, gabbro diorite and plagiogranite are lying within the basalt. In the upper part, basalt alternates with sand-, silt- and limestones, containing foraminifera of Visean age. All are overlain by argillites with bands of limestone, containing brachiopods and foraminifera of Serpukhovian and Moskovian age.

In the western part of Northern Pamir mélange of serpentinite is prevalent and overlain by more than 2 km of pillow basalt of tholeiitic composition. In the upper parts there are sections of basalt containing limestones with goniatites of late Visean to early Serpukhovian age. The Upper Serpukhovian and Bashkirian layers contain different sections. One shows basalt, another sections shows island-arc volcanic rocks and a third contains terrigenous sediments and olistostroms. A nappe comprising these rocks has been thrust over the Eurasian margin and later compressed into folds that were thrust back southward. This nappe is overlain by conglomerate and limestone of Moscovian age and later Carboniferous and Permian deposits.

These igneous and sedimentary rocks in the Northern Pamir record a **pre to late Carboniferous ocean basin** and its closure.

The **Akzhilga Zone** contains late Paleozoic mafic and ultramafic, metamorphosed volcanic rocks. It seems to continue southwest in the Kunlun in western China. It seems to be another indication for the existence of a Carboniferous ocean basin.

The **Central Pamir** contains deformed and metamorphosed Precambrian and Paleozoic rock, it seems to be a continental fragment that collided with Asia, probably in Permian time after the closure of the Akzhilga ocean basin.

The Geological Paleozoic history of the **Western Hindu Kush** is very similar to that of the Northern Pamir. The Suture Zone can be traced from Northern Pamir through northern Afghanistan to the northern edge of the western Hindu Kush. Observations in the **Kunlun** seem to give evidence that the suture zone continues also in the eastward direction.

2.2 Late Mesozoic Suturing:

The **Rushan-Pshart zone** between Central and Southern Pamir marks a small Mesozoic ocean basin within the Pamir. Remnants of the northern margin of the basin can be found throughout the Rushan-Pshart zone. Pillow basalt, andesite-basalt and tuff are predominant. Small bodies of ultramafic rock are associated with basalt. Jurassic and Cretaceous deep-water terrigenous material overlie the Triassic volcanic rock. The Rushan-Pshart zone marks an important zone of latest **Palaeozoic to early Mesozoic rifting** with formation of an **ocean-like basin**. This basin closed in late Jurassic or early Cretaceous.

The **Farah Rud zone** and the **Khash Rud zone** in Afghanistan seem to be comparable with the Rushan Psart zone. Large parts of the Farah Rud basin are occupied by flysch, reaching 7 to 9 km in thickness, implying the presence of a deep basin. The Khash Rud zone marks an ophiolithe complex.

The **Southern Pamir** is divided into Southeastern and Southwestern regions. The Southwestern Pamir consists of Precambrian metamorphic rock with Mesozoic and Palaeogene granite, the southeastern Pamir consists of sedimentary and volcanic rock from late Carboniferous till Cretaceous. Within the Southern Pamir there are two notable ranges, the North and the South Alichur Range. In the North Alichur range metamorphic rock of Southern Pamir underlies remnants of a nappe of basalt, picrite and tuff (ophiolites) containing limestone with corals and ammonites of Ladinian and Carnian ages (Triassic). The nappe seems to root in the Rushan Pshart zone. It was emplaced in late Triassic time. In the Southern Alichur Range there are significantly thicker ophiolithes with marine sediments in tectonic contact to the metamorphic rock of Southern Pamir.

2.3 Latest Mesozoic / early Cenozoic suture:

The Indus – Tsang-po suture zone is an ophiolitic belt that wraps around the northern margin of the Indian subcontinent. The suture follows the Indus and Tsang-po valleys in southern Tibet; it seems to continue into southern Pakistan, Afghanistan and Iran. It marks the **suturing between the Indian subcontinent with Eurasia and volcanic arcs**. The Indus – Tsang-po suture zone probably marks the precollisional shape of India´s margin better than that of southern Eurasia because the Himalaya is largely built up with rock scraped off of the northern Indian margin when India plunged beneath Eurasia. Wide expanses of oceanic crust seem to have been subducted before the collision.
The collision with India is the reason for the bending of the Pamir arcs. Not only the main zones show this bending, also fold axes of Cenozoic crustal – shortening show bending in the same manner.

Measurements of palaeomagnetic declinations of early Cretaceous and Eocene-Oligocene sedimentary rocks of the Pamir outer arc (Trans-Alai, Peter the First and Darvaz Ranges) show smooth variations from a NW orientation in the western Pamir to roughly due N in the NW Pamir, to due E at the northern edge of the range. So the declinations rotated around vertical axes- clockwise in the North and counter clockwise in the west- with respect to Eurasia (Fig. 4).

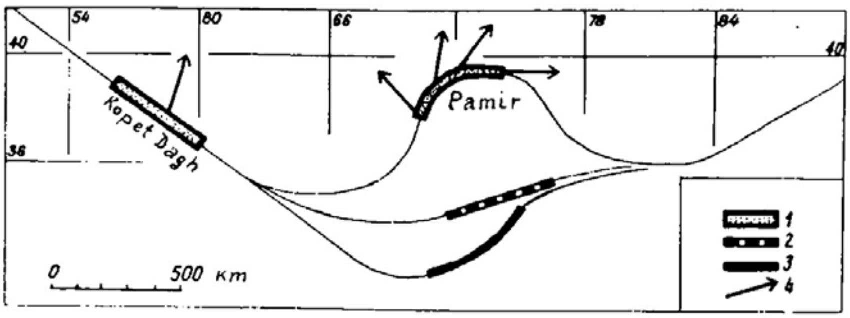

Fig. 4: Present and reconstructed positions of the outer Pamir arc from paleomagnetic data. (1) Present Position. (2) Reconstructed Position for the beginning of Neogene time. (3) Early Cretaceous time. (4) Summary of paleomagnetic declinations from early Cretaceous sites. (after Burtman & Molnar, 1993)

3. Bounds on the present crustal thicknesses

Seismic refraction data show that the crust has a thickness of about 65 km under the Southern and Central Pamir and 75 km under the Northern Pamir. The crust under the Tadjik Depression seems to have a thickness between 32 and 49 km. Because of the very thick sedimentary rocks – between 10 and 12 km - in the Tadjik Depression, the crystalline basement seems to be only 20 to 25 km thick. Normal crust has a thickness of 35 to 40 km. That simplifies the possibility of the subduction of continental crust of the Tadjik Depression beneath the Northern Pamir.

4. Cenozoic crustal shortening within the Pamir

Crustal shortening is estimated from the displacement in nappes, thrust sheets and the shape of folds in the Southern Pamir, in the Rushan- Psart zone in the Central Pamir and in the Northern Pamir. Good markers are also strike-slip faults truncated by thrust faults.

4.1 Southern Pamir and Rushan-Psart zone:

A nappe is thrust over the Southeastern Pamir. In the west there are only remnants of this nappe in form of klippens. Prior to erosion the nappe may have covered the whole Southwestern Pamir. The exposed dimension of the thrust sheet of about 110 km gives a minimum displacement on the thrust fault. This thrusting probably began in Mesozoic era and was renewed in the Miocene. There are more thrust faults in the Southern Pamir, like the north verging Murgab fault and the south verging Gurumdi fault. Moreover, the small thrust faults have been folded after their emplacement. From these smaller faults Ruzhentsev (1990) estimated a convergence within the Southern Pamir of 50 km or more.
A system of NW-trending right-lateral strike-slip-faults, the Aksu-Murgab fault system cuts the thrust sheets within the Southeastern Pamir. A N-S-convergence of probably 50 km can be estimated in the strike-slip fault system.
The **Rushan-Pshart zone** and the Southeastern Pamir are cut by the East Pamir fault with a displacement of about 30 km.
The convergence across the **Southern Pamir** and the **Rushan-Pshart** zone – largely, if not entirely of Cenozoic age - appears to reach 240 km or more.

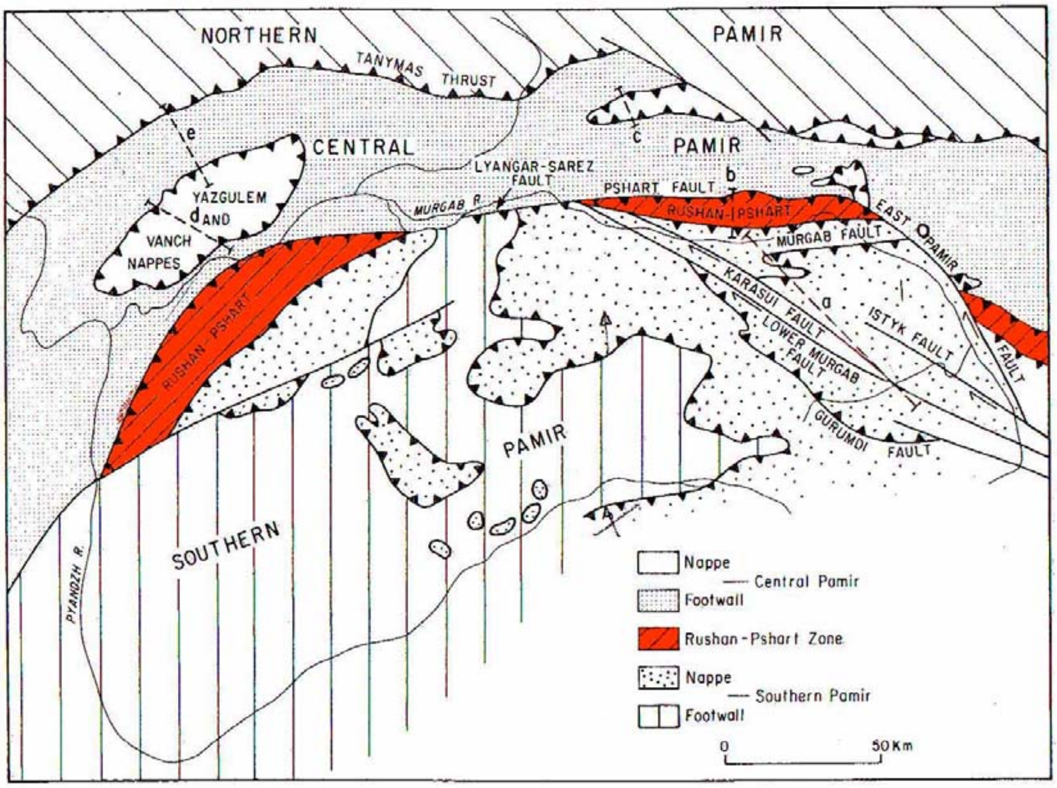

Fig. 5: Simplified tectonic map of Central and Southern Pamir (after Burtman & Molnar, 1993)

4.2 Central Pamir:

The Precambrian and early Palaeozoic rocks of the Central Pamir were folded two times. A convergence of about 20 km is estimated, but the age of the folding is not clear.

There are some klippens left from nappes that were emplaced in Cenozoic. The Akbaital, Zortashkol and the Vanch nappes consists of several tectonic slices. The root zone lies at the northern edge of the Central Pamir. After overthrusting the thrust faults have been folded. A convergence of about 100 km can be estimated in the Central Pamir.

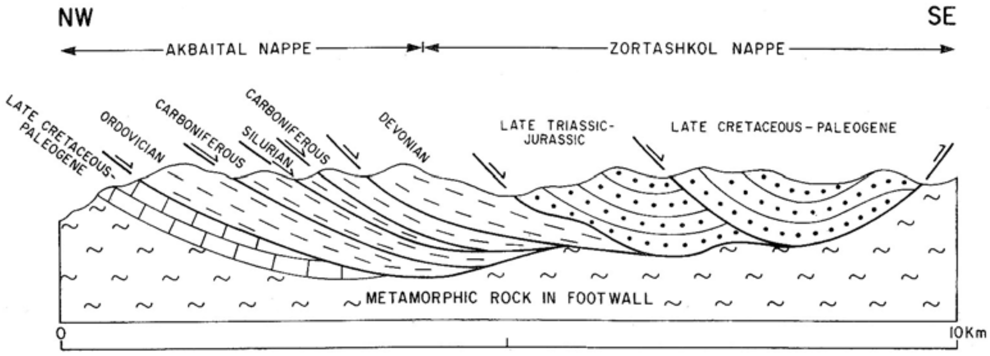

Fig. 6: Cross section across the Akbaital and Zortashkol nappes, which consists of several tectonic slices, in the Central Pamir, along c in Fig. 5. (Burtman & Molnar, 1993)

The Northern Pamir has also been subjected into crustal shortening, but quantifying the amount of convergence is too difficult in this zone of Palaeozoic rock.

A crustal shortening of more than 300 km can be estimated within the Central Pamir, the Rushan-Pshart zone and the Southern Pamir.

4.3 Convergence of the outer margin of the Pamir with the South Tien Shan

Not only the tectonic belts of the Pamir show convergence and deflection, the whole Pamir has been displaced northward with respect to the South Tien Shan. Cretaceous and Palaeogene sediments crop out widely in the Tadjik Depression. Those sediments were deposited in an E-W-trending basin bounded by highlands in the north and south. After Suvorov (1968) these E-W-trending facies zones have been displaced with respect to one another in the Tadjik depression and the Pamir Alai Range. Burtman and Molnar (1993) tried to use the shortening in these rocks to place a lower bound on the distance the Pamir has overthrusted Eurasia. The E-W-trending facies zones of the western and central Tadjik Depression are truncated by those in the outer arc of the Pamir. This corroborates the interference of large-scale overthrusting of the Pamir arc onto the South Tien Shan domain. A definite estimate of the northward displacement can not be given because the southwesternmost facies zone in the western and central parts of the Tadjik depression are not represented in the outer Pamir Domain. Burtman and Molnar (1993) estimate an amount of at least 200 km.

4.4 Cenozoic crustal shortening within the outer zone of the Pamir

The outer zone of the Pamir is marked by Mesozoic and Cenozoic sediments in the Pamir-Alai region that are thrust over the South Tien Shan along the Vakhsh and Trans-Alai overthrusts. Those sediments had been deposited in the Tadjik-Yarkand basin that embraced the whole region before the collision of India with Eurasia. Several layers in the stratigraphic sequence have very different rheological properties. The Cretaceous and Palaeogene marine sediments are separated from the underlying sediments because of Jurassic layers of gypsum and salt with a thickness of several hundred meters. Because of the complicated and disharmonic folding it is not possible to give reliable amounts of crustal shortening within the Pamir-Alai region. There is a decrease in the dimension of the outer Pamir zone from about 100 km in the west to only 15 to 25 km in the Peter the First Range. The shortening within the Vakhsh overthrust is roughly 35 km. So the initial width of the outer zone was almost 135 km. This suggests that the northern margin has been shortened about 115 km. Burtman and Molnar (1993) infer that the northern margin of the Pamir has advanced over the Tadjik sedimentary basin about 300 km or more since Palaeogene time.

4.5 Summary of Cenozoic crustal shortening

After Burtman and Molnar (1993) the Cenozoic convergence in the Pamir-Punjab syntaxis included 340 km of internal crustal shortening within the Pamir and 315 km of overthrusting of the Pamir onto the area farther north. The sum exceeds at least 600 km.

A hypothetical restoration of the terrain between the Indus suture zone and to south of the main boundary fault of the Himalaya by Coward et al. (1987) implies an estimate of 470 km of north-south shortening in this region farther south than Pamir. So the measured total convergence approaches 1100 km. After Molnar and Tapponnier (1975) India and Eurasia have moved toward one another 1800 +- 400 km since 40 Ma and roughly 3000 km since 50 Ma. Not all of this convergence can be located only in crustal shortening. Some material may have been extruded laterally eastward and westward out of India’s path, and some material may have been subducted into the asthenosphere.

5. Geophysical Evidence of subducted lithosphere

Beneath the Pamir and beneath the northern edge of the Hindu Kush there are two zones of intermediate-depth seismicity (Fig. 7). Indicated by earthquakes, a dip of about 45° and a downdip length of nearly 300km beneath the Pamir can be constructed. The seismic zone seems to be very similar to an island arc situation. Both the Pamir and the Hindu Kush seismic zones are associated with very low attenuation of seismic waves. This indicates the subduction of a cold slab within the hot asthenosphere where attenuation is high. The dipping direction is SSE in the Pamir and NNW in the Hindu Kush (Fig. 8).

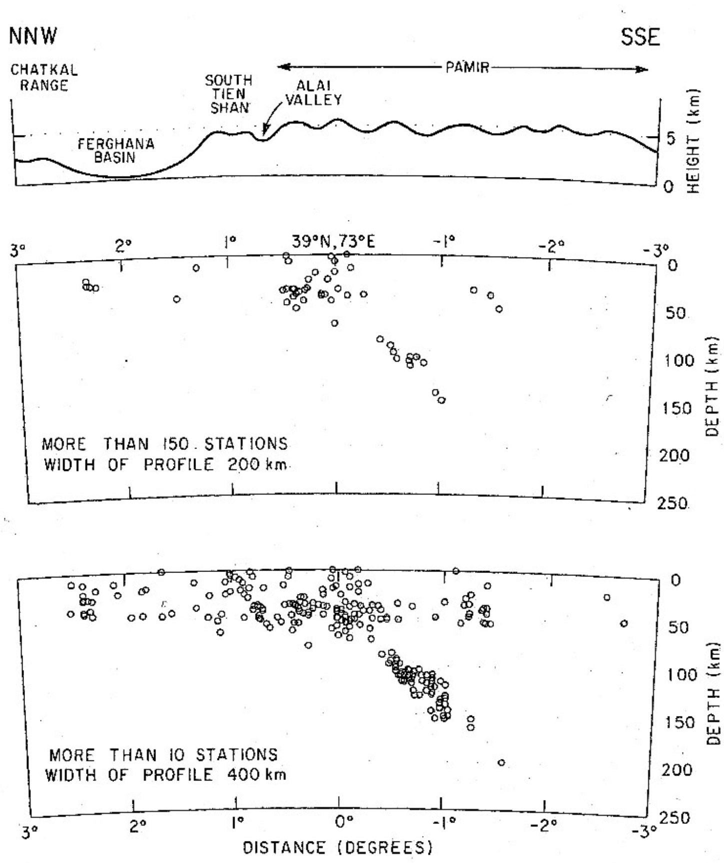

Fig. 7: Cross section of seismicity and topography through the Pamir showing a zone of intermediate-depth earthquakes dipping SE. (Burtman & Molnar, 1993)

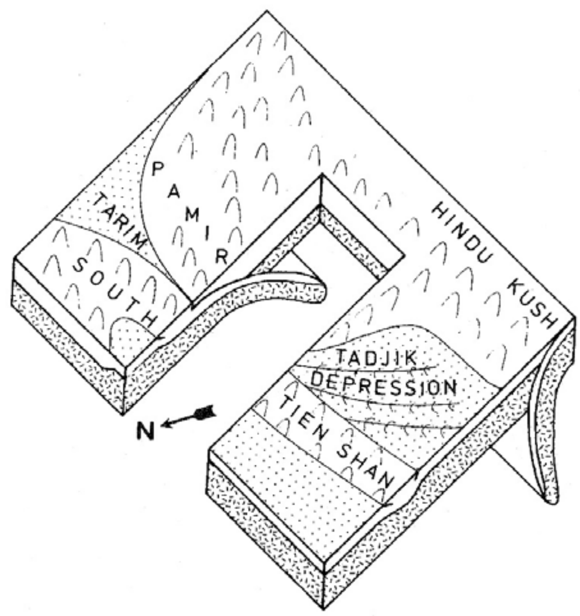

Fig.8 Block diagram illustrating lithospheric structure of the Pamir-Hindu Kush region. A slab of lithosphere has been underthrust SSE beneath the Pamir. A different slab has been underthrust NNW beneath the Hindukush. Crust is shaded and mantle lithosphere is denoted by irregular hatching. Dots show areas with thick Cenozoic sediment surrounding mountainous terrain. (Burtman & Molnar, 1993)

6. Summary and Synthesis

Although the Pamir crust has been thickened for approximately 2 times, not all convergence between India and Eurasia in the Pamir region can be measured in crustal shortening. The seismic data almost give evidence for the subduction of a cold slab beneath the Pamir. So it seems to be the simplest interpretation to subduct 300 km of a relatively thin continental crust beneath the Pamir.

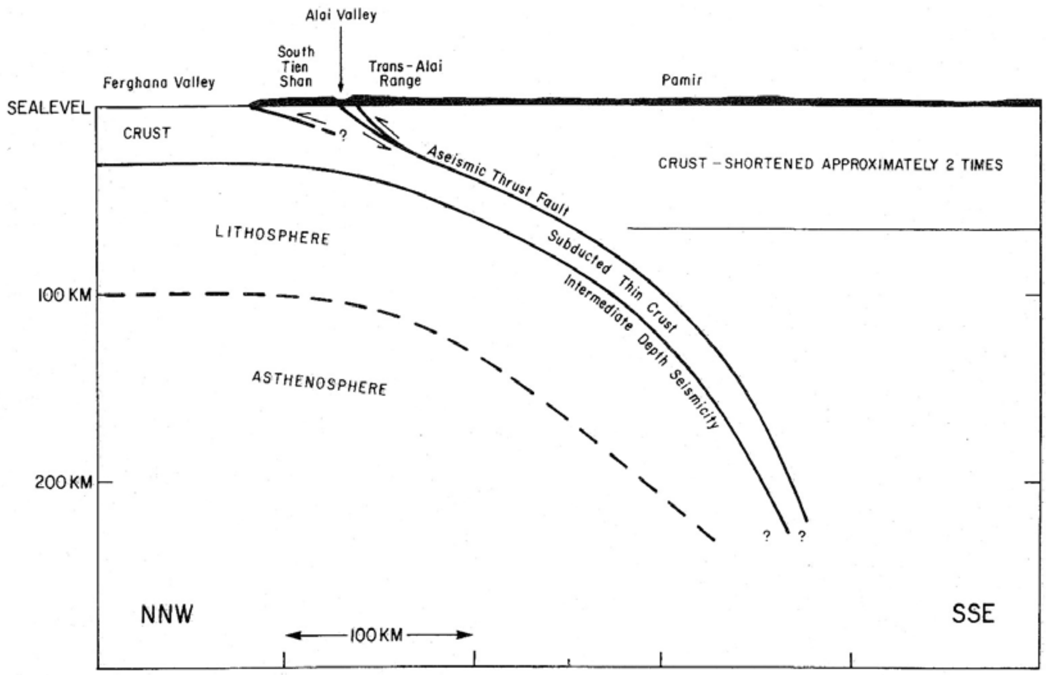

Fig. 9: Schematic profile showing the subduction of thin crust of the Tadjik Depression under the Northern Pamir

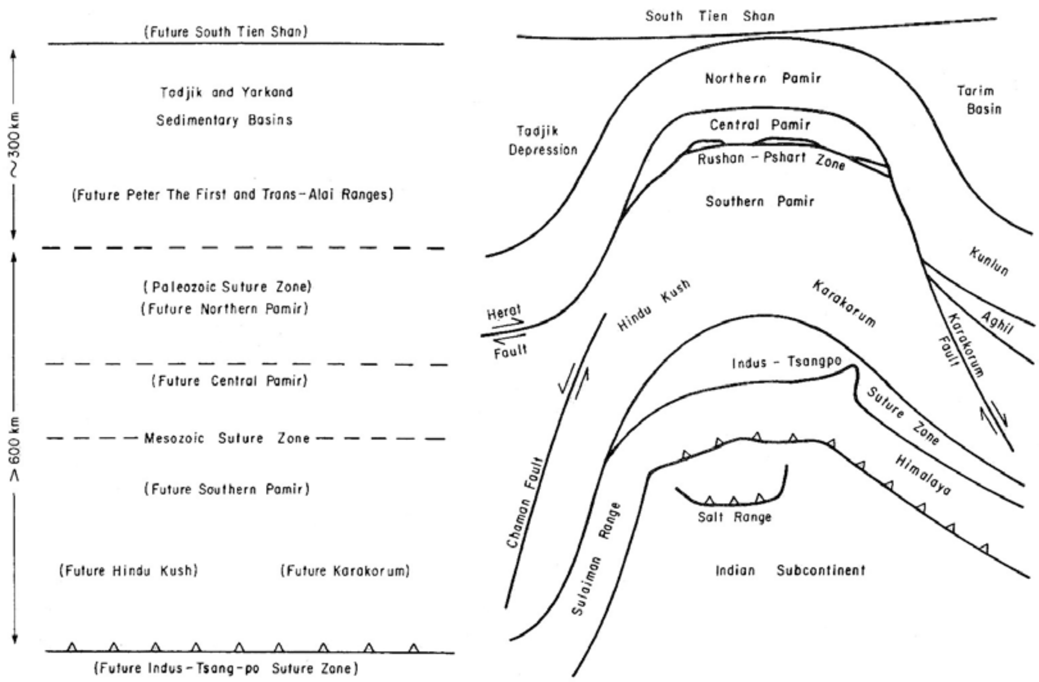

Fig. 10: Simplified maps showing the Pamir region before the collision of India and Eurasia (left side) and after the collision (right side). The Northern Pamir seems to have been displaced northward 300 km or more.

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