Seismotectonics in the Pamir: An oblique transpressional shear and south-directed deep-subduction model

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Abstract The 3-D geometry of the seismicity in Hindu Kush–Pamir–western China region has been defined by seismic records for 1975–1999 from the National Earthquake Information Center, the U.S. Geological Survey, and over 16,000 relocated earthquakes since 1975 recorded by the Xinjiang seismic network of China. The results show that most $M_s/C2$ $\geq 5.0$ hypocenters in the area are confined to a major intracranial seismic shear zone (MSSZ). The MSSZ, which dips southwards in Pamir has a north-dipping counterpart in the Hindu Kush to the west; the two tectonic realms are separated by the sinistral Chaman transform fault of the India–Asia collisional zone. We demonstrate that the MSSZ constitutes the upper boundary of a south-dipping, actively subducting Pamir continental plate. Three seismic concentrations are recognized just above the Pamir MSSZ at depths between 45–65 km, 95–120 km, and 180–220 km, suggesting different structural relationships where each occurs. Results from focal mechanism solutions in all three seismological concentrations show orientations of the principal maximum stress to be nearly horizontal in an NNW–SSE direction. The south-dipping Pamir subduction slab is wedge-shaped with a wide upper top and a narrow deeper bottom; the slab has a gentle angle of dip in the upper part and steeper dips in the lower part below an elbow depth of ca. 80–120 km. Most of the deformation related to the earthquakes occurs within the hanging wall of the subducting Pamir slab. Published geologic data and repeated GPS measurements in the Pamir document a broad supra-subduction, upper crustal zone of evolving antithetic (i.e. north-dipping) back-thrusts that contribute to north-south crustal shortening and are responsible for exhumation of some ultrahigh-pressure rocks formed during earlier Tethyan plate convergence. An alternating occurrence in activity of Pamir and Chaman...
seismic zones indicates that there is interaction between strike-slip movement of the Chaman transform fault system and deep-subduction of the Pamir earthquake zone. Pamir subduction-related seismicity becomes shallower in depth with increasing distance east of the transform fault. Therefore, sinistral movement of the Chaman transform fault appears to be influencing continental deep-subduction in the Pamir region and may provide an explanation for the unusual south-dipping geometry of the intracontinental Pamir plate.

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1. Introduction

Intermediate- and deep-focus earthquakes occurring in the Hindu Kush–Pamir region are thought to result from the on-going deep subduction of continental lithosphere following continent–continent collision along the Tethys zone (Vinnik et al., 1977, 1978; Roecker, 1982; Katok, 1988; Hamburger et al., 1992; Burttman and Molnar, 1993; Fan et al., 1994; Pegler and Das, 1998; Zhang et al., 2002). As yet, there has been no detailed study about how and why deep-subduction occurred at such a place. Epicenters of intermediate- and deep-focus earthquakes in the area trend in a WSW-ENE direction along the Hindu Kush–Pamir–southwest Tianshan region, and have an “S”-shaped configuration when viewed on a plane of 70 km in depth (Fig. 3). Since the late 1970s, various authors have discussed the three-dimensional distribution of earthquakes in this region using seismic records from the International Seismological Summary (ISS) and the International Seismological Center (ISC), and set up models to explain the tectonics of the Hindu Kush–Pamir seismic zone. Some workers have suggested that the earthquakes are caused by stresses within materials surrounding a rigid tectosphere (the subducting slab; Vinnik et al., 1977); others, by subduction of the preexisting oceanic lithosphere (Billington et al., 1977). Over the past 20 years, controversy has existed on the geometry of the subduction slab. Nowroozi (1971) published the first detailed seismic profile of this region and considered that two seismic zones existed, one striking EW at a depth of 70–175 km below the Pamir, and the other striking NE–SW at a depth of 175–250 km beneath the Hindu Kush; he believed it likely that the two zones were one and the same. Billington et al. (1977), however, did not discount the possibility of the existence of two oppositely directed subduction zones. Nevertheless, Vinnik et al. (1977) insisted that the intermediate-depth earthquakes represented a single active zone considering possible coupling of the earthquake zones at depth, and the occurrence of Precambrian rock outcrops in the region. The presence of two subduction zones was also concluded from later studies of micro-earthquakes in the area (Chaterlain et al., 1980; Roecker et al., 1980). Subsequent geophysical studies were inclined to support the existence of oppositely directed subductions under the Hindu Kush and Pamir (Hamburger et al., 1992; Burttman and Molnar, 1993; Fan et al., 1994). Based on relocated seismic sources, Pegler and Das (1998) suggested an improved single S-shaped seismic zone model of opposite-direction subduction, and pointed out that there is a seismic gap between 90 and 110 km at depth. The debate concerning the structural relationship of intermediate- and deep-focus earthquakes, and the mechanism of the deep-subduction of continental lithosphere in this region still continues.

Geological and geophysical research on whether continental crust can be subducted deep within the mantle have continued since 1987, when Chopin (1987) advanced the concept of deep subduction of continental lithosphere based on ultrahigh-pressure gneiss discovered in the Western Alps. Great attention is now being paid to the on-going deep subduction of such lithosphere in the Pamirs, Taiwan, the western Alps, the eastern Mediterranean, and the southern Carpathian Mountains among other places (Chopin, 1987; Roecker et al., 1987; Pavlides, 1992). As a consequence, widely different models of dynamics have been proposed for the deep subduction of continental lithosphere (Beukel, 1992; Cloos, 1993; Wijbrans et al., 1993; Willett et al., 1993; Ryan et al., 1995; Ellis, 1996). Since the beginning of the 21st century, arguments have been raised on the origin and exhumation mechanisms of ultrahigh-pressure metamorphic rocks in the Dabie-Sulu terrane of eastern China (Zheng, 2008). There, ultrahigh-pressure eclogites of Mesozoic age are exposed at the Earth’s surface, and show evidences of being overprinted by NE-striking left-lateral shear zones before their uplift (Zhang et al., 2003, 2005; Zhao et al., 2003). According to the results of petrological, geochemical and isotopic geochemical research, these ultrahigh-pressure metamorphic rocks in the Dabie-Sulu terrane are considered to have resulted from deep-subduction and recrystallization of Mesozoic continental crust (Zheng, 2008).

Neotectonics in the Pamir are considered to be the consequence of north-directed subduction of the Indian plate. This paper illustrates a detailed 3-D geometry of continental subduction by plotting earthquakes within 42 corridors across the Hindu Kush–Pamir–Western China seismic region onto their central profiles. A new geological explanation is made for the seismo-tectonics of this region in combination with the most recent research achievements on surface-deformation and crustal velocity structures. Our results emphasize the termination of the Chaman oblique strike-slip faults in the Pamir and Hindu Kush deep-subducting zone of continental crust, and indicate a multiple-staged, back-thrusting structure in this region. In addition, the evolutionary history of slab-retreating subduction is determined, and the mechanisms for exhumation of deep-seated rock following deep subduction of continental crust are discussed.

2. Seismic data sources and processing

The study area is defined by 34°–42° N latitudes and 69°–82° E longitudes. In order to obtain a detailed 3-D geometry of the seismicity in the area, a total of 30,308 earthquakes occurring from January 1975 to June 2003, were collected from the catalogue of the National Earthquake Information Catalogue, U.S. Geological Survey (NEIC: USGS) and records of the Chinese Xinjiang Seismic Network (XJSN), including 6174 earthquakes of $M_c \geq 3.0$ occurring during 1975–1999 from the NEIC, and the earthquakes recorded by the XJSN include: 7599 earthquakes with $M \geq 3.5$ for the same time duration; a micro-earthquake catalogue of 9277 events of $M_{L} \geq 3.4$ 1990–1999; and 1st and 2nd class records of 7258 earthquakes of all
Figure 1  Flow chart showing seismic data sources and processing.

Figure 2  Sketch map showing tectonics in the study area and locations of profile lines.
Figure 3  Geographic-depth projections (a, b, c, d) of earthquakes in the study area. (a): P – Pamir; TN – North Tianshan Mountains; TS – South Tianshan Mountains; K – Karakorum; X_1, X_2-the surface trace of the Chaman fault zone.

Figure 4  Sectional projections of earthquakes in the Pamir region.
magnitudes during 2000.1–2003.7 (Fig. 1). Because the XJSN consists of 40 regional seismic stations and 11 telemetry stations, the precision of location has gradually improved since the 1970s. Some of the earthquake records in the XJSN major seismic catalogue with unclear phases and initial motion directions have been relocated using the program BLOC96 (Zhao et al., 1993). This was done by checking their phases, arrival times and amplitudes on original seismic records from the XJSN and China seismic networks (CSN), including data obtained from exchanges between China and the three adjacent mid-Asian countries (Kazakhstan, Kyrgyzstan and Tajikistan). Besides, the micro-earthquakes from the XJSN catalogue are selected to have horizontal and vertical errors less than 5 and 10 km, respectively. For this study, 3364 relocated major earthquakes and 6402 micro-earthquakes and 7258 earthquakes of 1st and 2nd class records (2000.1–2003.7) from the XJSN

Figure 5  Sectional projections of earthquakes in the Chaman and Hindu–Kush regions.
catalogues were considered acceptable. After checking overlapping records between the NEIC and the XJSN catalogues, 22,200 earthquake records were used. In addition, this seismic analysis used 46 earthquake focus mechanism solutions calculated by measuring initial motion directions of P-waves acquired from the XJSN and CSN, 243 Centroid-Moment-Tensor (CMT) data were collected from the Harvard CMT Project, and 17 earthquake focal mechanisms from the United States Geological Survey (USGS).

3. Analysis of 3-D geometry of seismicity

The earthquakes were plotted accurately on planes at different depths and projected into 42 vertical profiles with different orientations (Fig. 2). Our subsequent analysis of these plots showed not only the 3-D geometry of the seismicity, but also the specific seismotectonics defined by seismic shear zones and seismic concentrations. It has been, therefore, possible to define the shape of the deep-subducting slabs, and to discuss the seismotectonics and dynamics of deep-subduction in this region in combination with focal mechanism data, surface geology and seismic velocity structure in the study area.

Geographic-depth projections of the earthquakes in the Pamir–Hindu Kush–western China region show that shallow earthquakes above 70 km depth occur diffusely (Fig. 3, 0–70 km) and can be roughly grouped into outer and inner seismic zones. The earthquakes in the outer zone are primarily distributed along the SW-trending Tianshan Mountains range with intensity decreasing toward the NNW (Fig. 3, 0–70 km, A1). Meanwhile, the convex northwards inner zone is composed of three parts, including: an arc-shaped seismic zone (as the central part) along the northern rim of the Pamir plateau (Fig. 3, 0–70 km, P); the SE-striking seismic zone (as the SE segment) of the Karakorum (Fig. 3, 0–70 km, K); and the NE-striking seismic zone (as the SW segment) near the Hindu Kush (Fig. 3, 0–70 km, X1). According to surface investigations of the broader deformation zone in this region caused by continental—continental collision following the closure of Tethys (Windley, 1988; Fan et al., 1994; Searle, 1996), the shallow-focus earthquakes occurring in the outer zone are thought to be related to a series of active south-dipping thrust faults in the SW Tianshan Mountains orogenic belt, which disappear at depths below 70 km (Fig. 3). We suggest that the shallow-focus earthquakes in the SW and NE segments of the inner zone correspond, respectively, to left-lateral strike-slip displacement along the Chaman transform fault in the west, and
right-lateral strike-slip displacement along the Karakorum fault in the east; earthquakes in the mid-front arc are related to southward-dipping thrusting beneath the Pamir. In map view, the intermediate- to deep-focus earthquakes below 70 km depth are distributed in an S-shape zone (Fig. 3 and 71–130 and 131–200 km), consisting of a central straight NE-trending seismic zone with adjoining EW-trending seismic zones at its northeastern and southwestern ends. The middle segment of the S-shaped seismic zone corresponds to a continuation downwards of the shallow level of the SW segment of the inner zone (Fig. 3a, X1–2). It is, therefore, probably related to the Chaman strike-slip fault. The stronger E–W-trending intermediate- to deep-focus seismic
zone at the northeastern end of the mid-segment extends downwards to the shallow-focus Pamir seismic zone, and disappears below 200 km depth. Whereas the smaller Hindu Kush seismic zone at the SW end of the mid-segment extends downwards, both the Pamir and Hindu Kush seismic zones shrink towards to middle NE-trending seismic zone. The S-shaped intermediate- to deep-focus seismic zone, therefore, may indicate that the Chaman transform fault motivates E-W-trending thrusting on either side of the zone.

For profile plotting (Figs. 4, 5 and 7), earthquakes occurring within vertical corridors about 80 km wide, and extending 0.5° to either side of the selected section lines, were selected from the seismic database. Errors caused by the earth’s curvature along the direction of the profile were corrected using the plotting program, and longitude and latitude coordinates of the earthquake sources were transformed into distances (km) from the starting point of the profile when plotted onto the central profile, with depths in kilometers. The plotted profiles (Figs. 4, 5 and 7) are in km-scale, and are marked by reference points of longitude/latitude.

4. Three-dimensional geometry of the subducting Pamir continental plate

Earthquakes plotted on the corridor profiles at high angles to the Pamir seismic zone lie primarily within two seismic shear zones and inverted triangular areas above the zones (Fig. 4). On all profiles of Fig. 4 perpendicular to the Pamir earthquake zone, a discontinuously developed major seismic shear zone (MSSZ) separates an upper domain that is characterized by major quakes ($M_s > 5.0$) from a lower domain with a few small earthquakes. It, the MSSZ, is interpreted as defining the top of the subducting continental Pamir plate. The lower seismic shear zone (LSSZ) lies within the plate and is roughly parallel to the MSSZ; both shear zones are inclined to the south in the NE segment (Pamir) of the S-shaped intermediate-depth earthquake zone (Fig. 4). In the middle segment of the S-shaped intermediate-depth earthquake zone, the earthquake projection presents a nearly vertical strong-earthquake zone with a depth of 300 km (Fig. 5, Section 5), which is gradually substituted by a south-dipping earthquake zone (Fig. 5, Sections 6—9). In the SW segment (Hindu Kush) of the S-shaped intermediate-depth earthquake zone, earthquakes decrease and the double seismic shear zone shows an NW inclination (Fig. 5, Section 3 and 4).

The south-dipping subduction slab exhibits a downward narrowing geometry as well as a pronounced steepening below a depth of 80—120 km (Figs. 6 and 11). This slab extends continuously to the east from the Pamir, but its subduction depth decreases rapidly and it is split into two independent segments after it crosses the Karakorum right-lateral strike-slip fault. One belt is located on the north side of the southwest Tianshan Mountains and the other on the north side of the West Kunlun Mountains in China. The depths of both subduction segments are less than 120 km (Fig. 7). The Pamir deep-subducting slab stops westward at the NE-striking Chaman transform fault. There is a small NW-dipping seismic zone in the Hindu Kush, west of the Chaman fault, which probably represents a tectonic response to the left-lateral movement of that fault as discussed in more detail elsewhere.

Besides the double earthquake shear zones mentioned above, three earthquake concentrations (upper, middle and lower) can be distinguished from the sectional projections of most of the $M_s > 5$ earthquakes (Figs. 4, 5, 7 and 8). The uppermost earthquake concentration (UEC) occurs at a depth of ca. 50 km (45—65 km). It extends continuously to the east along the strike of the Pamir subduction slab, but abruptly and markedly veers to the south in the Hindu Kush after crossing the Chaman strike-slip faults. The middle earthquake concentration (MEC) lies roughly at a depth of 100 km (95—120 km), whereas the lower earthquake clustering occurs nearer to 200 km depth (180—220 km). The lower concentration (LEC) becomes shallower along strike before merging into the middle earthquake cluster and finally disappearing after crossing the Chaman fault.

All three of the earthquake concentrations occur along the MSSZ and in rocks of its hanging wall near the boundary. Their distribution is related to the nature of crustal structures at these
positions. Among them, the upper earthquake concentration may respond to the brittle—ductile transition and changing of rock frictional behavior of the felsic crust, where the generation of earthquakes obeys the two-phase deformation mechanism (Sibson, 1980, 1992; Zhang, 1987). The middle earthquake concentration lies within a depth range similar to that where the dip angle of the Pamir deep-subduction slab changes from gentle to steep; the lower earthquake concentration occurs approximately at the front of the deeply subducted slab. The occurrence of the earthquakes in the middle and lower concentrations may not be related solely to the mechanics of different sections of the deep-subduction slab, but may also be affected by the interaction between cold (the

Figure 9  Focal mechanisms of earthquakes in (a) the upper and (b) the lower seismic concentrations, and a statistical analysis of seismotectonic elements.
subducted slab) and hot in situ upper mantle rocks (Vinnik et al., 1977), as well as by rheological instabilities induced by this interaction (Hobbs, 1986; Aki, 1992; Clarke and Norman, 1993).

5. Relationship between left-lateral strike-slip movement of the Chaman fault and the Pamir earthquake zone

Seismicity associated with the Chaman transform fault is represented by two separate, nearly vertical seismic zones at a depth of ca. 150 km (Fig. 5, Section 5). Previous study of focal mechanisms indicates that earthquake sources in the Chaman fault zone are predominantly strike-slip faults (Pegler and Das, 1998). However, according to the present limited results of focal mechanism solutions, earthquake sources in the upper and lower earthquake concentrations in Pamir, next to the Chaman fault, are predominantly thrusts. The analysis of focal mechanisms for the upper and lower earthquake concentrations (Fig. 9a,b) indicates that almost all of the principal compressive stress axes are nearly horizontal and oriented NNW—SSE. One of the conjugate shear fractures (F2 in Fig. 9a,b), parallel to the MSSZ, is thought to have formed in response to movement in the south-dipping subduction slab. Pole projections show that dip-directions of F2 differ slightly in both of the upper and lower earthquake concentrations, but dip-angles of F2 in lower seismic concentration (155/60) are evidently larger than in the upper (165/33). The produced dip-angles have been used to define a steeper downwards shape of the subduction slab (Fig. 10). Focal mechanisms from the Chaman transform fault and the subducting slab in the Pamir, as mentioned above, show different synchronous kinematics.

Time-space relationships of earthquakes during 1975—2003, indicate that $M_s > 5$ earthquakes with a focal depth over 200 km are predominant in the southern segment of the Chaman earthquake zone (Figs. 3 and 5). However, in addition to the Chaman seismic zone, intermediate-deep source earthquakes with depths less than 200 km are mostly related to the Pamir earthquake zone. An alternating occurrence in time of these two earthquakes zones indicates that there is interaction between strike-slip movement of the Chaman transform fault system and deep-subduction of the Pamir earthquake zone (Fig. 11). Although a ‘chicken-and-egg’ controversy exists, a reasonable hypothesis can be drawn from the fact that subduction becomes shallower with increasing distance away from the transform fault. Therefore, the sinistral movement

![Figure 10](image_url) Orientation of the conjugate shear fractures and stress fields derived from focal mechanisms of earthquakes in the upper and lower seismic concentrations and along the Chaman fault.

![Figure 11](image_url) Spatial-temporal migration of the earthquakes which occurred in the study area during 1975—2000.
of the Chaman transform fault appears to be influencing continental deep-subduction in the Pamir region.

6. Tectonic system of roll-back deep-subduction and progressive back-thrust development

Except for the seismic structures represented by the three earthquake concentrations described above, a series of linear structural belts dipping northwards, opposite to the major subduction zone (the MSSZ), are defined by seismicity less than 70 km on the profile across the Pamir earthquake zone (Fig. 4). Research of active structures on the surface (Nowroozi, 1971; Hamburger et al., 1992; Fan et al., 1994; Reigber et al., 2001) and the analysis of remote-sensing image data (Li et al., 2002) indicate that these linear structures are related to an evolving group of back-thrusts. These hanging wall back-thrusts lie above the deep-subducting slab and represent the absorption of upper crustal...
compression by shortening and thickening of the hanging wall and the uplifting of the Pamir region (Fig. 14) in concert with the expression of convergence at deeper crustal levels by the active south-dipping subduction zone. Some of the Precambrian metamorphic basement, Hercynian fold-belt and oceanic crust relics following Tethyan closure in the hanging wall were uplifted and exposed at the surface (Vinnik et al., 1977). Investigation of the surface geological structures in the Pamir region shows that the groups of back-thrust faults developed in time from south to north (Fig. 12). The earliest back-thrust assemblage, including two north-dipping thrusts in the south and their associated south-dipping back-thrusts in the central Pamir region, are the remnants of the western segment of the Himalayan convergent belt after northward-movement and reconstruction. They were truncated by the Karakorum right-lateral strike-slip faults in the east and by the Chaman left-lateral strike-slip fault in the west, and is rebuilt by the two sets of strike-slip faults mentioned above to form northward-projecting curve. The youngest back-thrust assemblage, as mentioned above, is little affected by strike-slip faulting at both east and west ends. The results of repeated GPS measurements in mid-Asia indicate that the hanging wall of the MSSZ is moving northward (Reigber et al., 2001). The movement rates decrease from 22 mm/yr to several mm/yr from south to north suggesting that the movement is being gradually absorbed by the underlying subducting slab (Fig. 13), as well as being transferred to crustal thickening and plateau uplifting. The back-thrusts continue eastwardly to the north and south margins of the Tarim Basin (Fig. 7), where they are the major structures responsible for overthrusting across the basins of the Tianshan and Himalayan Mountains. The evolving history of multiple-stage, back-thrusting structures mentioned above indicates that that part of the Himalayan main subduction zone between the Chaman transform fault and the Karakorum fault is being driven northwards during progressive continental—continental collision. During this process, the main subduction direction has been reversed in the region between Pamir and the southwestern Tianshan Mountains. At the same time, the upper plate of the subduction zone has become increasingly thicker and its once deep-seated rocks are being returned to the surface by sequential back-thrusting (Fig. 14).

**Figure 15**  Velocity structure in the crust and upper mantle beneath the Pamir—western China area. G, C, C1 and M lines in AB are velocity discontinuities where velocity contour lines merge. C is interpreted as the Conrad discontinuity between granitic crust and underlying basaltic crust; the nature of C1 is unknown. The closed 6.4 and 6.7 contour circles above and below C are thought to represent crustal domains of lower velocity. The red dashed line in AB and CD separates domains of variable crustal thickness and velocity contour lines that we think has relation to Pamir deep-subduction.
7. Continental deep-subduction

The pronounced difference between the densities of sialic and simatic lithosphere might suggest that the deep subduction of continental lithosphere during continent—continent collision is impossible. However, in some specific cases where a collision zone is being cross-cut by a strike-slip fault that continues deep into the lithosphere, the torn continental crust could be displaced to a deeper level in which local continental deep-subduction could occur. Starting from the Indian Ocean lithosphere, the Chaman transform fault extends northwards into the Eurasian continent with a cutting depth of more than 300 km in the western part of Pamir (Fig. 5, Section 5) and accompanying intensive seismic activity. We believe that Chaman fault movement is the key element that drives the Pamir deep-subduction. Wide-angle seismic reflection and refraction surveys (Zhang et al., 2002) and seismic tomography of three-dimensional velocity structure from natural seismic P-waves in the Pamir region (Lei et al., 2002) indicate the existence of SW-dipping (eastern) and SE-dipping (central) thrust faults rooted deeply into the lithospheric mantle of the Pamir region (Fig. 15). Lower crustal rocks with velocities greater than 6.6 km/s and upper mantle rocks (velocities more than 8.0 km/s) are subducting together to greater depths in AB, whereas the middle and upper crust with average velocities of 6.4–6.5 km/s exhibit significant thickening.

As discussed above, causative relations between the variety of deep and shallow seismic structures are important hints for understanding the process and evolution of continental deep-subduction. From our seismological studies, explanations can be drawn for many tectonic events including: the evolutionary history of the roll-back history of deep-subduction; the evolving ramp structure system related to continuous left-lateral movement of the Chaman fault; the mechanisms for the shortening of crust and uplifting of the plateau; the tectonic style of wide deformation zones on the surface of the continental—continental collision belt; the ultrahigh-pressure metamorphism of crustal rocks and the return to the surface of such deep-seated, subduction-related rocks; and, finally, the formation of the western Himalayan syntaxis.

8. Discussion and conclusions

Records of earthquakes occurring from 1975 to 2003, surface geological structures and velocity structure data of the crust in the Hindu Kush–Pamir–western China region prove that continental deep-subduction is taking place in this portion of the Tethys collisional belt. Although the remarkable difference in density between sialic crust and simatic crust might lead to the conclusion that continental deep-subduction caused by continental—continental collision is impossible, in some specific cases where a collision zone is being cross-cut by a strike-slip fault that is deeply rooted into the lithosphere, the torn continental crust can apparently be transported to a deeper level. In this special scenario of coupled continent—continent collision and Chaman transform faulting local continental deep-subduction has and is occurring in the Pamir region. Here, the lower crust-mantle lithosphere has been subducted to a depth greater than 200 km, whereas the middle and upper crust has peeled off at shallower depths. Seismic activities in the Pamir region are mainly related to the sinistral displacement of the deep lithosphere-rooted Chaman fault, and southward continental deep-subduction between it and the Karakorum right-lateral strike-slip fault to the east (Fig. 16). The lesser, nearly E–W-trending Hindu Kush earthquake zone with a depth of 200 km seems to have no direct relationship to Pamir continental deep-subduction. It is more likely a residual process of previous Himalayan subduction at its western end, but one strengthened during the sinistral strike-slip
movement of Chaman fault. The fundamental cause for Pamir continental deep-subduction is considered to be the Chaman transform, which obliquely cuts the continental—continental collision belt, tears apart the continental lithosphere, and drags its eastern, Pamir lithospheric wall downwards.

The Pamir deep-subduction slab is wedge-shaped with a wide top and a narrow bottom, with a gentle angle of dip in the upper part and steeper dips in the lower part changing at an elbow depth of ca. 80–120 km. The depth of the wedge is more than 200 km, whereas its strike width is only 500–600 km. We can determine five seismic domains related to Pamir deep-subduction — the major seismic shear zone (MSSZ), the lower seismic shear zone (LSSZ, between lower crust and upper mantle), an upper earthquake concentration (peeled off region, 45–65 km), a middle earthquake concentration (broken subduction region, 95–120 km), and a lower earthquake concentration (subduction front, 180–220 km).

The combined action of the main subduction zone and its related back-thrusts determines the tectonic style of the upper crust in this continental collision zone. The back-thrusts in the hanging wall of the deep-subduction slab absorb high level compression and shortening within the continent—continent collisional zone and cause both crustal thickening and plateau uplifting. Reasonable explanations can, thus, be given for the evolutionary history of roll-back deep-subduction and progressive back-thrust structure systems, the mechanisms for crustal shortening and plateau uplifting, the ultrahigh-pressure metamorphism of crustal rocks caused by deep-subduction, the exhumation of such deep-seated rocks, and the still evolving formation of the western Himalayan syntaxis. We hope that our seismological studies and the tectonic models derived from them may help resolve current controversies regarding the evolution of the older Dabie-Sulu convergent terrane in eastern China.

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