Himalayan ultrahigh pressure rocks and warped Indian subduction plane

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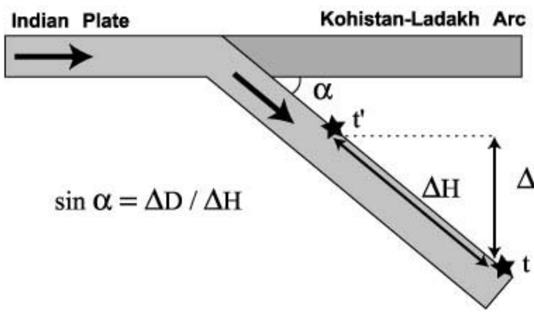
In this paper, we will use the knowledge of ultrahigh-pressure (UHP) metamorphic evolution as independent data to constraint the geometry and reconstruct the tectonic evolution of the early stage of the India-Asia collision.

The two UHP units recognized in NW Himalaya (Kaghan in Pakistan and Tso Morari in India) belong to distal parts of the continental Indian margin subducted between 55 and 45 Ma at a minimum depth of 100 km (e.g. Guillot et al. 2003 for review), evolving simultaneously during the early Himalayan evolution. They are interpreted as the signature of the early subduction of the Indian continental plate at the Paleocene-Eocene boundary. The metamorphic conditions are synthesized in Table 1 for both units. Even if similar protoliths are involved and both UHP units record the same maximum depth of about 100 km, some differences in P-T-t conditions may be emphasized. Firstly, the temperature of the metamorphism peak is significantly lower than a minimum of 100°C in the Tso Morari unit suggesting that the subduction rate is higher (Peacock 1992) in the Eastern part. Secondly, the western Kaghan unit seems to be involved in the subduction zone 4 Ma (~ 53 Ma) after the Eastern Tso Morari unit (~ 57 Ma). The later implication of the Kaghan unit in the subduction zone is related to its greater internal localization on the Indian margin, which, combined with a lower subduction rate, induce a higher temperature peak.

As the UHP units are buried and exhumed along the subduction plane (e.g. Chemenda et al. 2000), the dip angle of the subduction plane can be deduced from the geometry of the subduction and the timing of the processes. The sinus of dip angle is equal to the amount of vertical displacement (D) during an interval of time, divided by the amount of Indian plate subduction during the same time interval (H). Those two data are independently measured, D from the exhumed rocks, H from the motion of the Indian plate.



Guillot et al. (2003) demonstrated that the paleomagnetic data tracing the motion of India with respect to Eurasia can be fitted by an exponential law, allowing to numerically estimate the amount of north-south India-Asia convergence. The amount of vertical displacement (D) is simply evaluated by the combination of the barometric and geochronologic estimates on the UHP units. Combining those 2 independent data set (results in **Table 1**), it is possible to deduce that, during burial of both units, the dip angle of subduction was relatively high (30-40°), indeed much higher than previously estimated on both sides of the Western Syntaxis. During their exhumation, the dip of the subduction angle westward increased from 9°, for the Tso Morari unit, to 25-45°, for the Kaghan unit, as observed today.

As demonstrated by Klootwijk et al. (1992) and Guillot et al. (2003) the onset of India-Asia contact occurred between 57 and 55 Ma. The onset of Tso Morari subduction is closer to 57 Ma, which is the age related to the distal part of the Indian margin. The maximum depth reached by the Tso Morari unit is estimated to 100 km, and associated with a minimum age of 54 Ma. Thus the interval of time between the initiation of the burial of the unit, that could be approximated by the initiation of the subduction and the maximum depth reached, which is the maximum duration for the burial, is of 9 Ma. Considering an average subduction rate of 7 cm/yr between 55 and 50 Ma, this allows us to estimate the dip of the subduction angle between 57 and 54 Ma at a minimum of 30° (**Table 1**). Kaneko et al. (2003) proposed that the onset of subduction of the Kaghan unit is about 55 Ma with an India-Asia convergence rate of 4.5 cm/yr. This gives a time-integrated dip of the subduction angle of 14 to 19° from 55 to 46 Ma. However, as previously discussed, the average Indian subduction rate between 55 Ma and 50 was higher (7 cm/yr), and moreover, the dip of the subduction angle was probably closer to 35° rather than 14-19°. This suggests the time span necessary for the Kaghan UHP unit to reach the depth of 50 km, before 50 ± 1 Ma, is less than 2 Myr. Thus, the Kaghan UHP unit was probably involved in the subduction zone after 53 Ma rather than 55 Ma or 57 Ma as for the Tso Morari unit.

We estimate that during the burial of both units the dip angle of subduction was quite steep (30-40°), and much steeper than previously estimated (14-19° according to Kaneko et al. 2003). The steep dip angle deduced from both UHP unit for the early Indian plate subduction, close to the oceanic subduction angle, is compatible with modelling of Chemenda et al. (2000), suggesting that the Indian plate was initially attached to the already subducted Tethyan oceanic plate. This corresponds to the subduction of the thinned continental lithosphere, with the same geometry as for the oceanic subduction. In contrast, during the exhumation of the UHP units, the dip of the subduction angle seems to evolve differently for the eastern and western units. In the eastern part, we estimate from the Tso Morari unit that the subduction plane dips gently around 9°. This value is similar to the estimated dip of the present Moho and MHT between the Himalayan foreland and southern Tibet (Nelson et al. 1996). This result is also compatible with the conclusion of Chemenda et al. (2000) showing that the near frontal subduction of the buoyant Indian plate allows the subduction plane to straighten up beneath the Southern Tibet. Moreover, an early break-off of the Indian plate between 50 and 45 Ma has been probably evidenced East of the Western Syntaxis and would have actively participated to the straightening up of the subducted Indian plate (Chemenda

TABLE 1. Pressure temperature time path evolution of the UHP Kaghan and Tso Morari unit with the velocity and dip estimates

Kaghan unit					
Facies	Pressure	Temperature	Age	Velocity	**Dip angle**
HP	~ 15 Kbar	~ 350 °C	50 ± 1 Ma	⇒ 12 mm/yr	⇒ **35 ± 13°**
UHP	30 ± 2 Kbar	770 ± 50 °C	46 ± 0.7 Ma	⇒ 20 mm/yr	⇒ **45 ± 15°**
Amph	11 ± 1 Kbar	650 ± 50°C	43 ± 1 Ma	⇒ 7 mm/yr	⇒ **25 ± 9°**
Greenschist	~ 4 Kbar	~ 500 °C	~ 40 Ma		
Tso Morari unit					
Facies	Pressure	Temperature	Age	Velocity	**Dip angle**
HP	10 ± 1 Kbar	470 ± 10°C	> 55 Ma		⇒ ***>30°****
UHP	~ 28 Kbar	~ 650 °C	55-54 Ma	⇒ 8 mm/yr	⇒ **9 ± 4°**
Amph	9 ± 3 Kbar	630 ± 50°C	47 ± 2 Ma	⇒ 3 mm/yr	⇒ **9 ± 3°**
Greenschist	~ 3 Kbar	250 ± 50°C	40 ± 2 Ma		

* This dip angle estimate is explained in the abstract

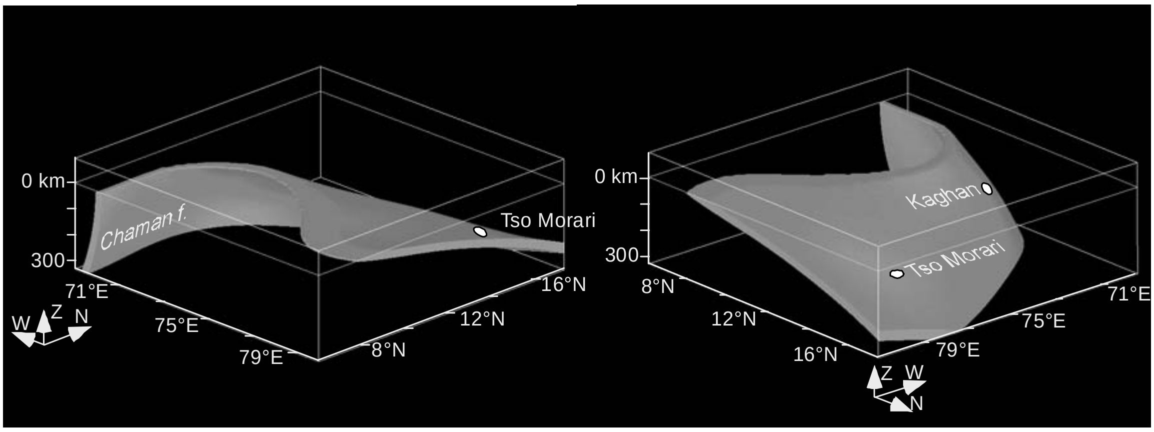


FIGURE 1. 3D models of the NW Himalaya localizing the UHP units between 55 and 50 Ma. The warped geometry of the Indian subduction plane defines, at the surface, the contour of the Western Syntaxis

et al. 2000; Kohn and Parkinson 2004). West of the Western Syntaxis, the high dip angle of subduction (30-40°) seems to persist till 40 Ma. In this area, the Indian plate is quenched towards the West by the Chaman fault. We can thus reconstruct a 3D image of the early collision slab, showing the dip change recorded by the Tso Morari unit, and the warping of the west syntaxis by the Chaman fault (**Figure 1**).

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