Subduction-Related Metamorphism and Southwest Vergence in the Footwall Block Below Kaghan Eclogite Thrust Sheets, Swat, Pakistan, Western Himalaya

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The composite Loe Sar-Kotah dome is located at the northern edge of the Indian plate on the west flank of the Indus syntaxis in the Swat-Hazara part of the Pakistan metamorphic belt. The area is significant because it was autochthonous prior to Miocene southward displacement on the Panjal-Khairabad thrust, and because it forms part of the footwall block to eclogite-bearing thrust sheets presently exposed in the Kaghan region to the east. The rocks in the core of the dome were metamorphosed prior to the Oligocene with T-P estimates in the range of 600-700 °C and 9-14 kbar. The main focus of this report is on the Kotah dome which forms a satellite structure west of the larger Loe Sar dome.

The metamorphic core of the Kotah dome consists of Middle Permian Swat flaser granitic gneiss unconformably overlain by Late Permian Marghazar formation. The Marghazar consists of quartzo-feldspathic schist, amphibolite, and schistose marble and is roughly equivalent with the Panjal formation. In spite of penetrative deformation, the Marghazar formation shows evidence for rapid depositional facies changes and abrupt thickness variations. These characteristics, coupled with the presence of granitic pebbles and detrital zircon ages between 261 and 279 Ma (similar to the U-Pb zircon intrusive age of the Swat gneiss), suggest that rocks of the Marghazar formation filled down-dropped Late Permian extensional basins directly adjacent to up-thrown blocks of Swat gneiss. A 10 to 30 m thick amphibolite horizon forms the upper member of the Marghazar formation across the entire Loe Sar-Kotah dome directly below Triassic marble of the Kashala formation which surrounds the composite dome and forms part of the metamorphosed Tethyan shelf succession. A tourmaline granite gneiss locally intrudes the unconformity between Swat gneiss and the base of the Marghazar.

In the northern part of the dome, a layer of Swat gneiss less than 300 m thick is sandwiched below a 20-40 m thick layer of Marghazar formation composed mostly of amphibolite horizon, and above a much thicker (>500 m) section of Marghazar quartzo-feldspathic schist, amphibolite, and schistose marble. A series of intersecting cross sections combined into a fence diagram suggests that the layer of Swat gneiss forms a recumbent fold that extends about 8 km across the dome with southwest vergence. The fold does not appear to involve the amphibolite horizon, Kashala formation, or the stratigraphically overlying Saidu formation. The fold is believed to have nucleated by distributed shear across a pre-existing Late Permian normal fault that was oriented at a high angle to the shear direction and which originally separated an up-thrown block of Swat gneiss from a filled basin of Marghazar formation. Two additional west to southwest vergent folds are present in the Loe Sar dome. Field evidence suggests that the folds developed during prograde metamorphism and penetrative deformation when the Indian plate was underthrust beneath Indus ophiolitic mélange (DiPietro and Lawrence, 1991).

There are no metamorphic ages on rocks from the Kotah dome but a few 40Ar/39Ar hornblende ages from the Loe Sar dome average 38 ±5 Ma (Lawrence et al., 1985; Treloar and Rex, 1990; Baig, 1990). Peak metamorphic temperature estimates above 600 °C indicate that these are cooling ages that post-date fold development. The hornblende ages are consistent with a U-Pb LA-ICPMS zircon core age of 265 ±5.3 Ma and a rim age of 39.5 ±0.6 Ma from the tourmaline granite gneiss. The core age is identical with U-Pb zircon ages extracted from the Swat gneiss in the Loe Sar dome (DiPietro and Isachsen, 2001). The rim age likely dates crystallization of tourmaline-bearing melt. Given its age, the tourmaline gneiss is interpreted to have intruded following recumbent fold development. It is important to point out that the tourmaline granite gneiss, the amphibolite horizon, and the circa 38 Ma 40Ar/39Ar hornblende ages are restricted primarily to the region of the Loe Sar-Kotah dome. 40Ar/39Ar hornblende ages of rocks obtained to the east of the dome in the vicinity of the Indus syntaxis, and to the west of the dome in the Malakand thrust slice, are 51 ±2 Ma, 50 ±3 Ma, and 53 ±2 Ma. In addition, there are two undeformed, unmetamorphosed, intrusive rocks with U-Pb LA-ICPMS zircon ages of 48.1 ±0.8 Ma and 45.8 ±0.8 Ma.

These ages are consistent with previously published 40Ar/39Ar hornblende ages of 49 ±2 Ma, 50 ±2 Ma, and 51 ±2 Ma from the Indus syntaxis region (Treloar and Rex, 1990; Baig, 1990), and with a U-Pb zircon rim age of 47 ±3 Ma from the undeformed, unmetamorphosed, Malakand granite (Smith et al., 1994). Additionally, Treloar and Rex (1990) obtained 40Ar/39Ar hornblende ages of 67 ±2 Ma and 67 ±7 Ma.

Following W-SW-directed penetrative deformation in the Swat-Hazara metamorphic belt, the distribution of metamorphic ages implies that the Loe Sar-Kotah dome region remained buried and under metamorphic conditions until circa 38 Ma while surrounding areas were already undergoing metamorphic cooling beginning no later than 51 ±2 Ma. The circa 67 Ma hornblende ages suggest that metamorphic cooling could have begun as early as 67 Ma in at least part of the metamorphic belt. If India-Kohistan collision is considered to have occurred 52 ±3 Ma then collision did not produce metamorphism in this part of the Pakistan metamorphic belt. The Kohistan fault is a brittle, hard rock fault that separates the Kohistan arc complex from Indus mélange which is folded with the Indian plate. All three terranes truncate against the Kohistan fault (DiPietro et al., 2000; 2008). It is possible that the Indus suture zone in Pakistan is polygenetic (e.g. composed of remnants of the Late Cretaceous-Paleocene intra-oceanic subduction/obduction complex, and remnants of the Early Eocene and older accretionary prism associated with the Kohistan arc). Given available data, we currently favor the possibility that all (or most) of the exposed suture zone mélange is associated with Late Cretaceous-Paleocene intra-oceanic subduction and that this event initiated metamorphism in the Swat-Hazara metamorphic belt (DiPietro and Isachsen, 2001, DiPietro et al., 2008). Instead of causing metamorphism, the circa 52 Ma India-Kohistan collision may have instead driven exhumation and cooling in the Swat-Hazara metamorphic belt. In this scenario, the accretionary mélange to the Kohistan arc is largely or entirely buried with the northern margin of India below the obducted Kohistan arc complex. Kaghan eclogites underwent exhumation to amphibolite facies and were likely emplaced above previously deformed and metamorphosed Swat rocks circa 47 Ma (Wilke et al., 2010). Thus, the Kaghan rocks may have undergone a history similar to that of the Swat rocks and may have already been buried, possibly to eclogite facies, prior to India-Kohistan.

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