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Structural Geology of the Higher Himalayan Shear Zone, Sutlej Section

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Throughout the Higher Himalayan Shear Zone (HHSZ), the northeasterly dipping main foliation planes that acted as the primary shear planes (the C-planes) are rarely sub-horizontal. S-C fabrics, sigmoid quartz veins and leucosomes, and asymmetric intrafolial folds denote a top-to-SW sense of ductile shearing. The angles between the S-planes of this shear sense and the C-planes in the shear zone are within 25-43^{0}which is close to the higher angular limit of 45^0. The axial planes of the intrafolial folds are at 12-22^0 to the NE direction of the C-planes. The long axes of sigmoid leucosomes and quartz veins are at very low angle 3-8^0 to the C-planes. The aspect ratios of these sigmoid elements show a wide variation between 3.6-9.5. Some of the S-fabrics are occasionally affected by secondary C$^/$-shearing synthetic to the main shearing event. The angle between the C- and the C$^/$-planes range between 15-25^0. This is well within the limit of 15-35^0 previously compiled from different shear zones. The C$^/$-planes are straight but are shorter than the C-planes. The C$^/$-planes are much less ubiquitous in the HHSZ.

Interestingly, an additional phase of a top-to-NE sense of extensional ductile shearing, deciphered from intrafolial folds of quartz rich layers, S-C fabrics, and sigmoid-shaped quartz veins and leucosomes are found to be confined within two zones in macro-scale in the HHSZ. The top-to-NE sense of ductile shearing is restricted in two zones within the northeasterly dipping C-planes parallel to hence the same as that for the top-to-SW sense. One of these zones, designated as the STDS$_L$, is delineated at the locality Karcham. The other zone of top-to-NE shearing occurs within the topmost level of the HHSZ and is equated with the STDS or the STDS$_U$. Its lower boundary is demarcated between the locations Pangi- and Kashang. The upper boundary is the same as the contact between the HHSZ and the overlying Tethyan Sedimentary Zone. In these ductile extensional shear zones, fabrics of a top-to-SW sense of shearing also occur less frequently.

In the STDS$_U$ and the STDS$_L$ in macro-scale, the angles between the S- and the C- fabrics showing a top-to-NE sense of shearing and those between the C- and the C$^/$-planes show a wide variation between 18-45^0 and 10-48^0, respectively. The former range touches the higher angular limit of 45^0 betweenthe respective fabrics as previously mentioned. However, the later range crosses the upper limit of variation of angles between the C- and the C$^/$-planes as 15-35^0 as compiled from different shear zones. The long axes of the sigmoid leucosomes and veins are at 8-20^0 with the C-plane. The aspect ratios of the sigmoid leucosomes and quartz veins show a wide range between 2.8-8.21. The axial planes dip towards SW and make 10-17^0 to the NE direction of the C-planes.

Oriented thin-sections of rocks of the STDS$_L$ and the STDS$_U$ reveal dominantly a top-to-NE sense of ductile shearing most abundantly by mineral fishes of sigmoid geometries, S-C fabrics and rarely by the sigmoidally oriented inclusion pattern inside porphyroblasts. Some of the mica fishes possess a mouth at one of their corners possibly due to their dynamic recrystallisation. The top-to-NE sheared higher grade rigid porphyroblastic index minerals indicate the extensional shearing to be quite intense. In the STDS$_L$, pronounced extension parallel to the main foliation is deciphered from crystal-plastic extension of rigid and high-grade minerals such as garnet with aspect ratios as high as 9.5. The sheared geometries of these index minerals, however, are partially destroyed by migration of quartz grains from the matrix into them. The S-fabrics are sometimes defined by a number of mutually separated mica grains. The C-shear planes are short, remarkably straight and are defined by (a) foliation minerals such as biotite; and (b) trails of minerals at the corners of mineral fishes. The long axes of the mineral fishes are at 7-15^0 to the C-planes. Their aspect ratios vary within 1.7-4.8, which is a narrower range than previously reported 2-16 from different shear zones. As in field-scales, the ductile synthetic secondary C$^/$-shear planes of both the compressional and extensional shearing are straight, less frequently developed, affect individual mineral grains but are shorter than the C-planes. For both the compressional and extensional and senses of ductile shearing in macro- and micro-scales, the S-planes are in most cases sigmoid and attain progressively lower angles as they come closer to the C-planes. The S-fabrics vary in thickness, length and curvature. The shearing secondary to top-to-SW and top-to-NE senses took place either simultaneous to or later than the respective primary shearing event.

Brittle-ductile secondary shear $C_1^{/}$-planes are rarely developed in the $STDS_L$ around 75^0 to the primary shear C-planes. In the HHSZ, including the $STDS_U$ and the $STDS_L$, a different manifestation of brittle-ductile extension parallel to the main foliation is deciphered from different varieties and sizes of boudins. Throughout the HHSZ, including the $STDS_U$ and the $STDS_L$, a late stage brittle shearing consistently in a top-to-SW sense is deciphered from duplexes of dimensions ranging from few cm to several meters. The roof- and the sole thrusts bounding these duplexes, i.e. the Y-planes, dip northeasterly usually within 30-40^0. Individual thrust slices are most commonly sigmoid-shaped. Both isolated and a number of sigmoid-shaped stacked thrust slices are noted. The P-planes of brittle shear are defined as the contact planes between individual thrust slices. The angles between the Y- and the P-planes widely vary between 30-68^0. Sometimes, the angles between the Y- and the P-planes in adjacent thrust slices vary widely. Some of these thrust slices are affected by secondary brittle shearing along discontinuous and locally developed synthetic secondary 'R' shear planes. The angles between the Y- and the R-planes vary within a wide range of 25-86^0. The range is much higher than the previously compiled average value of 15^0 from different shear zones. The Y-planes are found to be parallel to or same as the primary C-shear planes. In other words, the anisotropy created by the pre-existing ductile primary shear planes acted later as the preferential sites of brittle primary shearing.

The brittle shearing prevalent in macro-scale is also found to affect individual grains in micro-scale in terms of duplexes of stacked-up minerals in XZ oriented thin-sections that show the sense of shearing same as those in field-scale. The micro-duplexes are identified by their morphological resemblance with those well established from field-scales. The thrust-up grains are typically hat- or trapezium-shaped with their straight boundaries unaffected by migration of the adjacent grains. The longest boundaries of these trapeziums are identified as the 'P' shear planes. The 'P' planes dip northeasterly from moderate angle of $40^0$to sub-parallel to the Y-plane. Few trapezium-shaped mica grains that are surrounded by quartzo-feldspathic minerals have their longest and straight boundaries sub-parallel to the Y-planes. These grains probably represent thrust slices that were transported to relatively longer distances to the extent that they got completely detached from the underthrust counterpart grains. Such grains were exempted from determination of brittle shear sense.