Dras Fault: a major active fault in Kashmir Himalaya

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ABSTRACT

Previous works have shown that the oblique tectonic convergence between the lithospheric plates of India and Eurasia in NW Himalaya is primarily manifested by the formation of a series of fold- and thrustbelts, and the ~NW–SE trending dextral strike-slip fault, the Karakoram Fault. However, here we demonstrate, through geomorphic, structural, seismological, and geological evidence, that there is evidence for another major ~NW-SE trending oblique fault that shows reverse faulting with a component of dextral strike-slip movement. The fault, named here as the Dras Fault, is identified in Jammu and Kashmir portions of NW Himalaya where oblique faulting was expected from the previous global positioning system (GPS) data but evidence for oblique faulting was lacking. We have mapped the fault zone for >540 km and it consists of two major strands that are separated by a prominently developed topographic ridge. The eastern portion is ~380 km long, and the western portion is ~ 165 km long. The characteristic geomorphic features were mapped on the 30 m shuttle radar topography, which includes the triangular facets, typical stream captures, displaced fluvial and alluvial fans, ruptured and displaced Holocene sedimentary and glacial deposits. The displaced markers vary from ~24 km to few meters, and the presence of ~33 km long ridge that separates the two major fault strands is hereby interpreted as a restraining fault bend structure. A series of ~NE-SW trending larger scale normal faults are also mapped on the ~NW and ~SE portions of the dextral fault zone, and it suggests that the region is actively undergoing transtension.

1 INTRODUCTION

Leh region is an intermontane valley with one major river, the Indus River, draining the basin (Figure 1). The basin is linear and follows the structural trend of the past subduction boundary between the lithospheric plates of India and Eurasia (Searle et al. 1990; Shah et al.2020). The basin is bounded by Ladakh batholith in the north and the Himalayan rocks in the south. The calc-alkaline batholith is one of the most prominent geomorphic features in the region, which has been exhumed since its formation when the collision between tectonic plates jammed the subduction process, thereby largely halting the magma manufacturing process (Weinberg and Dunlap, 2000). The batholith crystallization ages range from 70 and 50 Ma, which indicates that plate collision and batholith formation are related. The batholith marks the position of the Indus Suture zone in Leh, where Himalayan rocks are juxtaposed with it. The structural mapping of the suture zone is controversial, as some researchers have mapped it as a backthrust (e.g. Searle et al., 1999) while others as a thrust (e.g. Lacassin et al., 2004). Similarly, controversies exist regarding evidence for active tectonic deformation in the region, and in particular, the Leh basin where the Quaternary deformation is either related to tectonic (e.g. Kumar et al., 2020) or to non-tectonic causes (e.g. Sangode et al., 2011). Therefore, our motivation was to refine the earlier maps by mapping the active geomorphic features on the 30 m shuttle radar topographical images. The mapped landforms are supplemented with the seismological, and previously published geological, and geodetic data. We show evidence for active dextral strike-slip faulting in the Dras valley region where Neogene to Quaternary sediment is deformed and faulted. We report for the first time that active oblique faults exist in the Higher Himalayan region, and it raises questions on the slip distribution, deformation budget, out of sequence faulting, and the possible earthquake hazards in the interior regions of the Himalayan orogenic belt.

2 METHODOLOGY

Satellite image-based structural mapping has truly revolutionized mapping (Tapponnier and Molnar, 1977, Nakata, 1989; Malik, and Nakata, 2003; Sahoo and Malik, 2017; Shah 2013), and in particular, those regions that remain inaccessible because of multiple reasons (e.g. Shah et al., 2020). Our study area is one of the most intense political conflict borders in Asia (Shah et al., 2018a), and therefore the satellite-based mapping is the most useful and preferred method to map the regions (Figure 1). We have used the 30 m shuttle radar topography to map the active geomorphic features in regions that are included in the NW Himalaya (Figure 1). The study area includes the regions that are de facto border areas where fieldwork was difficult (Shah et al., 2020), and therefore we have only been able to conduct fieldwork in Leh regions, which we have not included here due to page limit restrictions. The mapping of geomorphic features on satellite images was done by examination topography where we manually traced the geomorphic features that show evidence for active faulting. It includes triangular facets, topographic breaks, ridge crests, water/glacial stream deflections etc. The relative age relationships are used to constrain the age of faulting where the ruptured/deformed Neogene to Quaternary sedimentary deposits (e.g. alluvial fans, fluvial terraces etc.) are used as criteria for active faulting. We have also used Rule-of-V to know the dip direction of lithological units. We have also used the earthquake centroid moment tensor solutions to map the types of faults, which were correlated with the geomorphic mapping. The earthquake centroid moment tensor data are extracted from the GeoMap App, which covers events from January 1976 to January 2020 (Figure 2b). The seismological data (Figure 2b) has 60 years of spatial coverage and includes events from 1960 until 2020.

3 RESULTS AND INTERPRETATIONS

3.1 Tectonic topography and geomorphology

The 30 m satellite image (Figure 1) shows an intermontane Leh valley, which has a prominent geomorphic expression in the middle of mountains, and it marks the position of the Indus-Tsangpo suture zone where the Kohistan-Ladakh Arc Complex meets the Tethys Himalaya. The valley is drained by one major river, the Indus River (Figure 1), which follows the ~NNW-SSE structural trend of the valley. The valley is ~40 km towards the west of the Karakoram fault zone, which is a regional dextral strike-slip fault system (Valli et al., 2007). The geomorphic expression of the valley suggests that the eastern and western limits are very narrow and mountainous, and the central portions of the valley are broader. The curvature of the Ladakh Batholith complex coincides with the longest width of the valley, which indicates that the valley has been formed by the tectonic processes that have caused the bending of the batholith, which are usually competent igneous bodies and hard to deform. The geological and tectonic map of the region shows the two major backthrusts that have placed Tethyan rocks onto the Kohistan-Ladakh arc system (DiPietro and Pogue 2004; Shah et al. 2020). However, such faults are not mapped towards the west and north of the Kashmir basin, which is in contrary to what we have mapped. Importantly, our mapping indicates active tectonic faults that have displaced glacial and fluvial sediments and show dextral strike-slip movement. Therefore, we have divided the entire study region into two main sections that lie on either side of the ridge that has a prominent geomorphic expression (Figure 2), and the detailed tectonic geomorphology and outcrop geology of the western section is presented below.

3.2 Active deformation in the Dras River valley and adjacent regions

At Kargil region, a strangely looking ridge appears on the satellite and topographic maps (Figures 1 and 2) and equally unique are the river patterns (Figure 2). The ridge region resembles a frog on the map view, and therefore we have named it a Tectonic-Frog because it is unique and nothing similar is observed in the region. The Suru River flows towards the north and is a tributary of the west-flowing Indus River. The Dras River also flows north and becomes the part of the Suru River at Kargil area, and both these rivers form the sides of the ridge (Figure 2). The Sind River drains south and into the Kashmir basin, but at the north, the same river valley forms the southern extension of the Dras River. The eastern portion of the Dras River coincides with the Kishanganga/Neelum River valley, which we think is because of active faulting. Therefore, we think the two rivers were initially connected and have been deflected by the active faulting. The clear trace of the dextral strike-slip fault is mapped on the western portion of the ridge and mostly in the Dras River valley and that is why we have named the fault as Dras fault zone (Figures 2 and 4). The river is right laterally deflected along the trace of the fault and the deflection is ~25 km. However, the ridge is located on the west of the fault zone, but it shows no sign of faulting that could be expected to cut across it. The faulting seems to have stopped at the ridge and stepped right to resurface as the Leh fault system in the east. The western portion of the fault system would be expected to have similar rupture zones, but we didn't find right laterally deflected rivers as well developed and with a clear-cut fault-related landform as in the Dras River valley. However, the ridge crests are broken, and rivers are consistently deflected along the fault zone (Figure 2a), which makes us interpret the ~NW-SE trend of the Kishanganga River valley as the trace of the fault. Several active ~NNE-SSW trending normal faults have been mapped earlier in the region (Shah et al., 2018b; Omar et al., 2020), and these normal faults could explain the absence of large scale dextral strike-slip offset along the entire length of the fault zone. The crustal extension could be compensated by the normal and strike-slip faulting (e.g. Yin, 2000), which therefore require no large-scale displacements. Since the region is mostly hard rock area, which could also mean that active deformation would not be easy to map from the satellite data where lithology is used as a tool to differentiate active from inactive faults.

4 SEISMOLOGICAL AND EARTHQUAKE CENTROID MOMENT TENSOR (CMT) DATA

The recorded seismicity in the study area is low, which is consistent with the forward propagation and concentrated active tectonic collision-related deformation in the frontal Himalayan belt (Figure 1b). However, the small number of earthquakes that have occurred in the past have ruptured shallow crustal depths (events colour coded in Figure 1b to show details). The CMT focal mechanisms of a few events are shown (numbered events in Figure 1b) to argue for the active tectonic deformation. These events show ~NW-SE crustal extension in the north of the Kashmir basin, and a few events show ~NW-SE compression, which is consistent with our mapped Dras Fault zone that shows reverse fault slip in the western regions where it terminates (Figure 4).

5 DISCUSSION

The satellite-image based investigations of active tectonic landforms in the NW Himalaya (Figures 2-4) regions have suggested active faulting, where dextral strike-slip faults are mapped in the Dras valley and named as Dras fault zone. The evidence of active deformation within the Neogene to Quaternary sediment is unquestionable, which indicates that active tectonic deformation is not just limited to the Himalayan orogenic fronts. It answers one of the most anticipated quests in the NW Himalayan regions where tectonic shearing was expected from the geodetic data, but the evidence was lacking (for example Schiffman et al., 2013; Kundu et al., 2014, Bilham, 2019). The geodetic data show that the active plate tectonic convergence budget in the Kashmir region would expect active faults to accommodate the shearing components, and that makes oblique or strike-slip faulting a preferred choice (e.g. Schiffman et al., 2013; Kundu et al., 2014, Bilham, 2019; Shah et al., 2020). However, the lack of geomorphic and geological evidence for the occurrence of active oblique or strike-slip faults was a major hurdle to map and understand the active oblique tectonic convergence that would accommodate 12.5 ±1 mm/yr of tectonic convergence at N175° W. The only known major dextral strike-slip fault system is the active Karakorum fault (KF), which is suggested to accommodate the c. 5 ± 1 mm/yr of shear component (e.g. Kundu et al., 2014). However, Bilham (2019) argues that the long-term slip rate on the KF system is not adequate to explain the obliquity of the GPS vectors. And it is important to note that slip rate measurements on the KF vary considerably (e.g. Valli et al., 2007), and accordingly, on an average, the recorded Quaternary slip rates vary from 30 mm/yr (e.g. Avouac and Tapponnier, 1993) to 4 mm/yr (e.g. Brown et al., 2002). Lacassin et al. (2004) have suggested a slip rate of 10 ± 3 mm/yr for the entire life span of the fault. Therefore, the variation in the slip rate and the role of fault in the tectonics of the India-Asia collision is an ongoing quest that is yet to be resolved. Our data demonstrate geomorphic evidence for active strike-slip faulting in the north of the Kashmir basin, which questions the consensus that only the KF is the major structure that accommodates the dextral strike-slip. The previous understanding on the tectonics of the NW Himalaya emphases that the oblique tectonic convergence between the lithospheric plates of India and Asia primarily is mainly manifested as a series of the fold and thrust belts in the frontal portions of the Himalayan orogenic belt, and the ~NW–SE trending dextral strike-slip, the Karakorum fault, in the northeast. Our work demonstrates, through geomorphic, structural, seismological, and geological evidence, that there is evidence for another major ~NW-SE trending oblique fault that shows reverse faulting with a component of dextral strike-slip movement. The fault is identified in Jammu and Kashmir portions of NW Himalaya where oblique faulting was expected from the previous global positioning system (GPS) data but evidence for oblique faulting was lacking. We have mapped the fault zone for >540 km and it consists of two major strands that are separated by a prominently developed ridge. The eastern portion is ~380 km long fault system, and the western portion is ~ 165 km long. The characteristic geomorphic features were mapped on the 30 m shuttle radar topography, which includes the triangular facets, typical stream captures, displaced fluvial and alluvial fans, ruptured and displaced Holocene sedimentary and glacial deposits. The displaced markers vary from ~24 km to few meters, and the presence of ~33 km long ridge that separates the two major fault strands is hereby interpreted as a restraining fault bend structure (Figure 4). A series of ~NE-SW trending larger scale normal faults are also mapped on the ~NW and ~SE portions of the dextral fault zone, and it suggests that the region is undergoing transtension.

The Dras fault zone occupies the structural position between the Jhelum and the Karakorum fault zones (Figure 4A). We think the fault could be interpreted either as a major oblique thrust (Figure 4B) or oblique normal fault (Figure 4C). Alternatively, a major oblique backthrust would form a similar topographic expression. The presence of an active oblique fault system in the north of Kashmir basin would mean that the tectonic convergence between India and Eurasia is not just restricted to the two major fault systems, the Karakorum and the Main frontal thrust system. The oblique convergence would need thrust, normal and strike-slip faults. The fieldwork in Kargil region will illuminate such details, which could be done in collaboration with Indian officials as it is a sensitive border area between Pakistan and India and access is very restricted.

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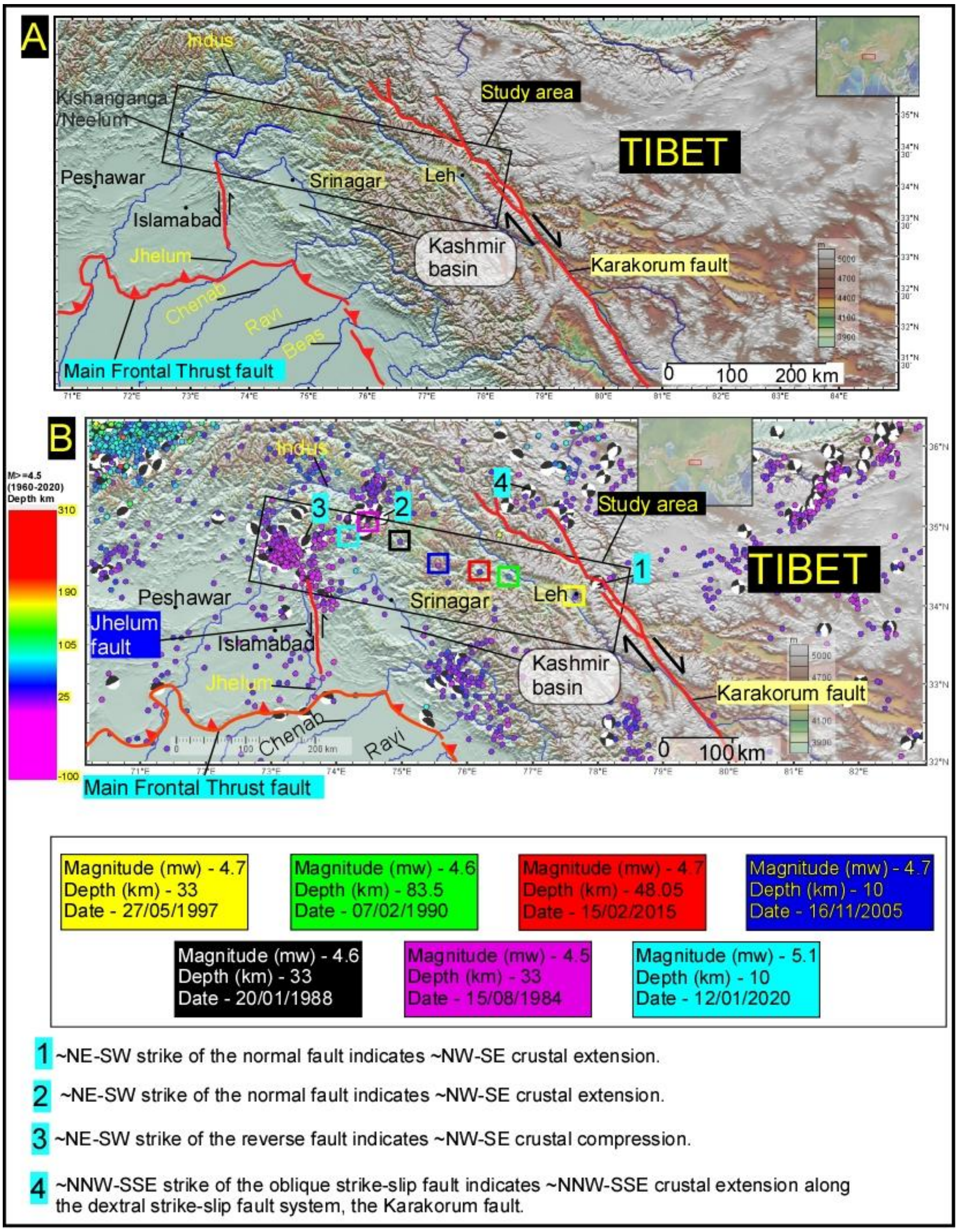

Figure 1: The 30-meter shuttle radar topography is at the background onto the earthquake events and are plotted (colour filled circles). The two prominent seismicity clusters are at the NW and SE side of the Kashmir basin. The relatively few events are observed at the north of the Kashmir basin. The earthquake centroid moment tensor (CMT) focal mechanisms for the north-western Himalaya (shown as black and white beach balls) show ~NW-SE directed shallow crustal extension in the NW of the study area. The earthquake events in the study area are colour coded, and 4 CMT focal mechanism events are highlighted.

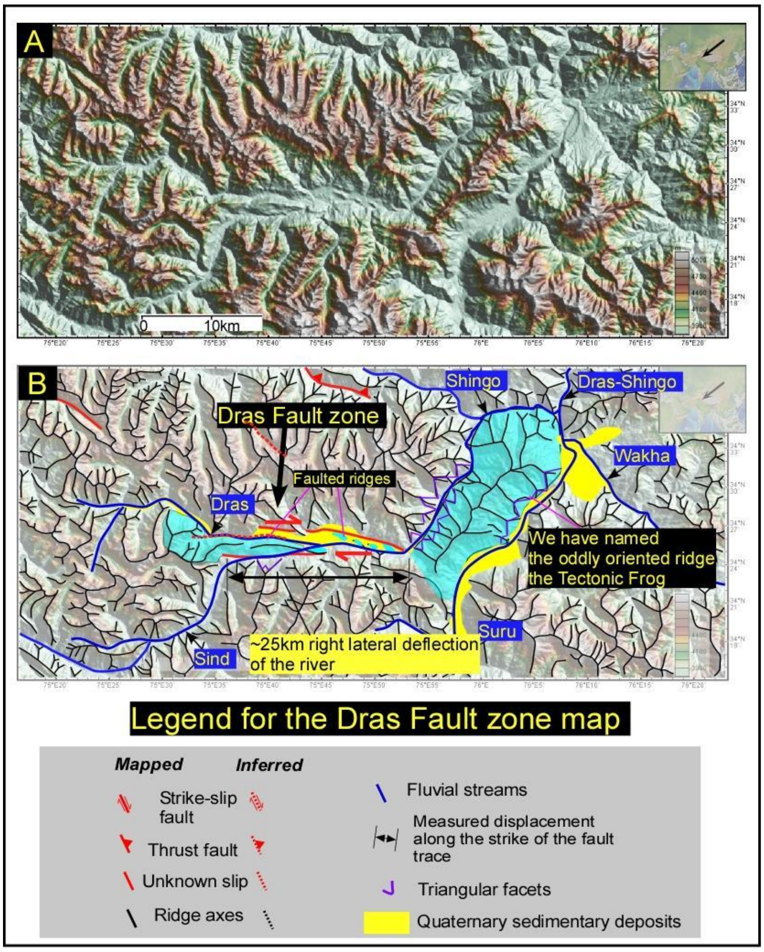

Figure 2: Tectonic topography related to the Dras Fault zone is shown on the 30m shutter radar topography. The interpreted image is above the interpreted version. The fault zone is clearly observable where disruption of the geology and drainage is highlighted. The location is shown in Figure 1, and the details appear in Figure 3.

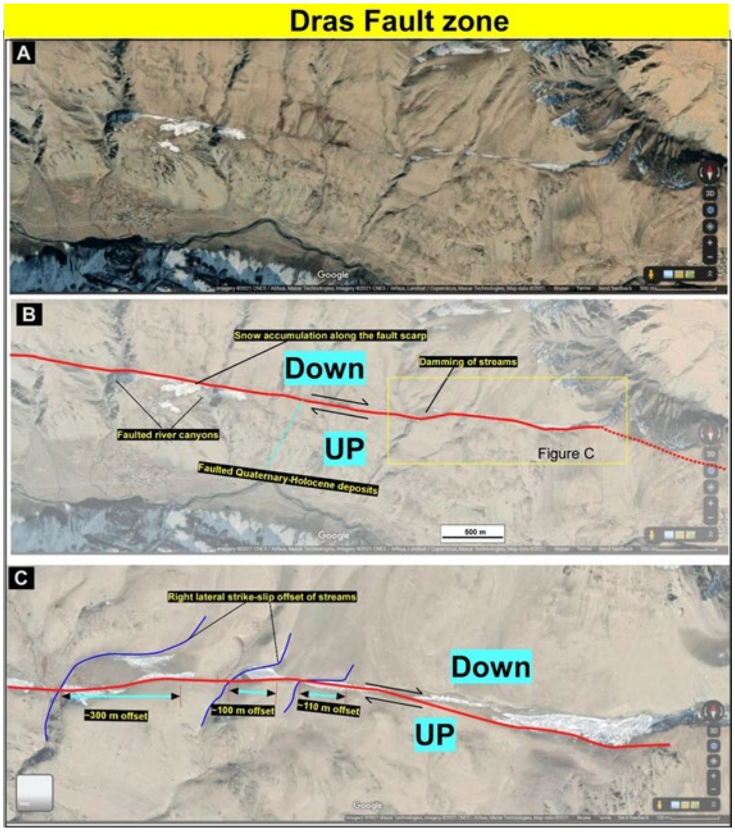

Figure 3: The Dras Fault zone is a clear-cut topographic break in the Dras river region where Quaternary sediments are faulted, and deformed. The right-lateral offset of the streams can be measured, and it varies from <100 to >300 meters along the fault. The fault zone is >25 km long and shows a prominent deformation zone with faulted and tilted ridges. The snow has accumulated along the north facing fault scarp, where streams are also dammed.

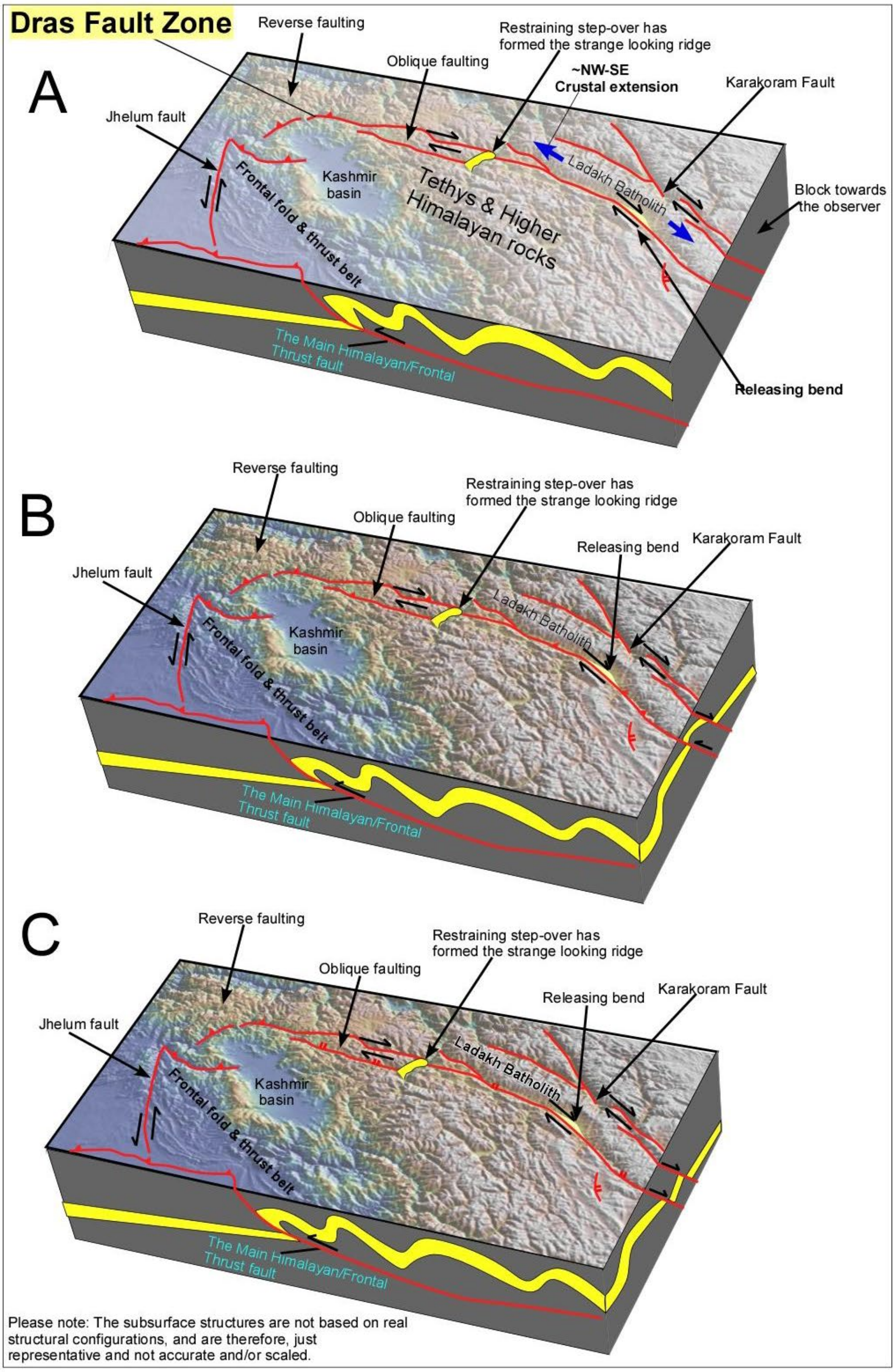

Figure 4: Newly discovered Dras fault zone is shown with yellow polygon showing the location of the ridge that fits the restraining bend geometry of an oblique fault with a strike-slip component. The fault zone region occupies the structural position between the Jhelum and the Karakoram fault zones (A). The fault could be either be a major oblique thrust (B) or a major oblique normal fault (C). Alternatively, a major oblique backthrust will form a similar topographic expression. The fieldwork in Kargil region will illuminate such details, which could be done in collaboration with Indian official as it is a sensitive border area between Pakistan and India and access is very restricted.