The 25 October 2005 Surface Thrust Rupture Near Balakot: A Strip of Destruction

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Professor Asif Khan provided transportation. Ghazanfar Ali Khattak is a graduate student working on the morphotectonic problems in the Western Himalayan Syntaxis area. The team included Haniya Mir, a student from Vassar College in New York working on social aspects of the 2005 earthquake disaster. We slept in Abbottabad, about 1.5 hours by car from Balakot. Our short field trip achieved its goals: mapping and characterizing the NW terminus of the fault rupture trace and understanding the relation of the rupture to the damage distribution.

Summary

We mapped the surface trace of the fault rupture for about 5 km on the west bank of the Khunar River, through Balakot and into the Sarash Valley where it apparently ends. The surface expression of the rupture is remarkably consistent: a 10-20m wide zone of tilting to the southwest causing 2-3m of uplift of the northeast side. This tilt zone includes longitudinal (fault parallel) fractures, which may extend over the uplifted side of the fault much beyond the tilt zone. The position of the rupture, which can be sharply defined, is the critical factor controlling damage. The damage is dramatically higher along a strip on the up-thrown northeast (hangingwall) side of the fault, where the land is coseismically tilted, folded, and fractured. None of the buildings on this “strip of destruction” survived and very few avoided total collapse. In contrast, buildings on the footwall (down-thrown) side, as close as 10m or less from the fault, fared much better. Most of them avoided collapse and some showed only slight damage. This dramatic contrast between footwall and hangingwall damage does not seem to depend on foundation geology. In Balakot, for example, houses were built on the same fanglomerate on both sides of the fault, yet the difference in destruction was obvious from afar. Our observations are preliminary, of course, but the signal seems clear. Our conclusion is that geological criteria can be developed to characterize areas that are much safer from earthquake damage than others within Balakot, thus allowing for reconstruction of the town with sharply targeted restrictions. These observations also provide a model for recognizing active thrust faults in Pakistan, for targeting trenches across these faults that could expose prehistoric ruptures, and for predicting the distribution of potential damage associated with seismogenic rupture of these faults.

The strip of destruction through Sarasha Village, 3km northwest of Balakot. The cemented wall, the utility pole, and the trees were tilted 15 degrees by the fault rupture.

The Fault Rupture in the Balakot Area

A variety of data from many authors show that the October 2005 fault rupture is about 80 km long, strikes northwest and dips northeast with an intermediate angle. This rupture is shallow, probably not more than 15km deep at its deepest and breaches the surface southeast from Balakot. It may continue several tens of kilometers northwest as a blind rupture. Intense damage in Shinkiari and other towns along this hypothetical buried continuation of the rupture is consistent with this hypothesis. We mapped the surface trace of the rupture over the northwestern-most 5 km, west of the Khunar River, where the fault bends northward. This portion of the rupture comprises two segments. Along the 3-km segment between the Khunar and the Sarash Rivers (the latter is a tributary of the Khunar River), the fault is on the west side of a discontinuous ridge, which is probably the accumulated effect of thrust motion of the northeast-dipping fault. The southernmost portion of this ridge is an uplifted terrace at the heart of Balakot, and now the most severely destroyed part of the town. North of this segment the fault follows the bed of the Sarash River. Rupture was observed along the southernmost 1km of this segment, but not further north. The fault trace is along the west bank so that the 100-200 m wide floor of the valley is on the uplifted side of the fault.

Bedrock is exposed both sides of the fault only in very steep terrane, where the rupture caused landsliding. This tectonic contact separates Murree formation on the up-thrown northeast side from Salkhala formation on the down-thrown southwest side. Where the rupture traverses lower relief, the down-thrown (southwest) side of the rupture is covered by sediment, either fanglomerate or river deposits. In these areas, a zone of warping and tilting manifests the rupture.

The width of this zone varied and was narrowest where the sediment was thinnest, suggesting that the sediment played a role in spreading the fault displacement into a zone of shear near the surface. One important effect may be "footwall collapse." The floor of the valley is covered by young unconsolidated sediment, mostly coarse fanglomerate from the steep flanks of the valley interfingered with fluvial sediment. Reverse faulting in this setting typically brings bedrock up in the hangingwall above a footwall of unconsolidated, unlithified sediment. As a result the footwall tends to collapse thereby decreasing the dip of the fault near the surface and deforming the fault into a shape concave downward. When such a fault slips, the hangingwall block buckles, causing extension fractures and weakening. This could account for both the fracturing parallel to fault strike and for diffused shear and tilting instead of the formation of a sharp scarp.

Sarasha Village: one of the few houses that did not collapse along the strip of destruction. Note fractures widening downward. It appears that this building was damaged by deformation of the foundation, not by shaking.

The Strip of Destruction

The fault rupture is the key for understanding the distribution of damage in the Balakot area. Destruction was sharply more intense on the rupture and on the northeast or hangingwall side of the rupture. This “strip of destruction” may be accounted for by a number of contributing factors:

1. Coseismic strain, fracturing, and tilting of the hangingwall side of the fault (i.e., permanent deformation in addition to shaking) contribute to foundation failure and destruction.
2. Fracturing lowers seismic velocity, thus increasing the amplitude of shaking.
3. The hangingwall side of the fault is part of the low-velocity channel along the fault and is thus subjected to seismic waves trapped along the fault zone.
4. Seismic waves are amplified along topographic ridges. The ridge at Balakot is the result of accumulated fault motion combined with river erosion on the hangingwall side.
5. Coseismic strain, fracturing and tilting of the hangingwall side of the fault (i.e., permanent deformation in addition to shaking) contribute to foundation failure and destruction.

The relative importance of the various factors is unknown. The remarkable systematics in the level of hangingwall destruction suggests that permanent deformation, rather than shaking was the main factor in the strip of destruction.

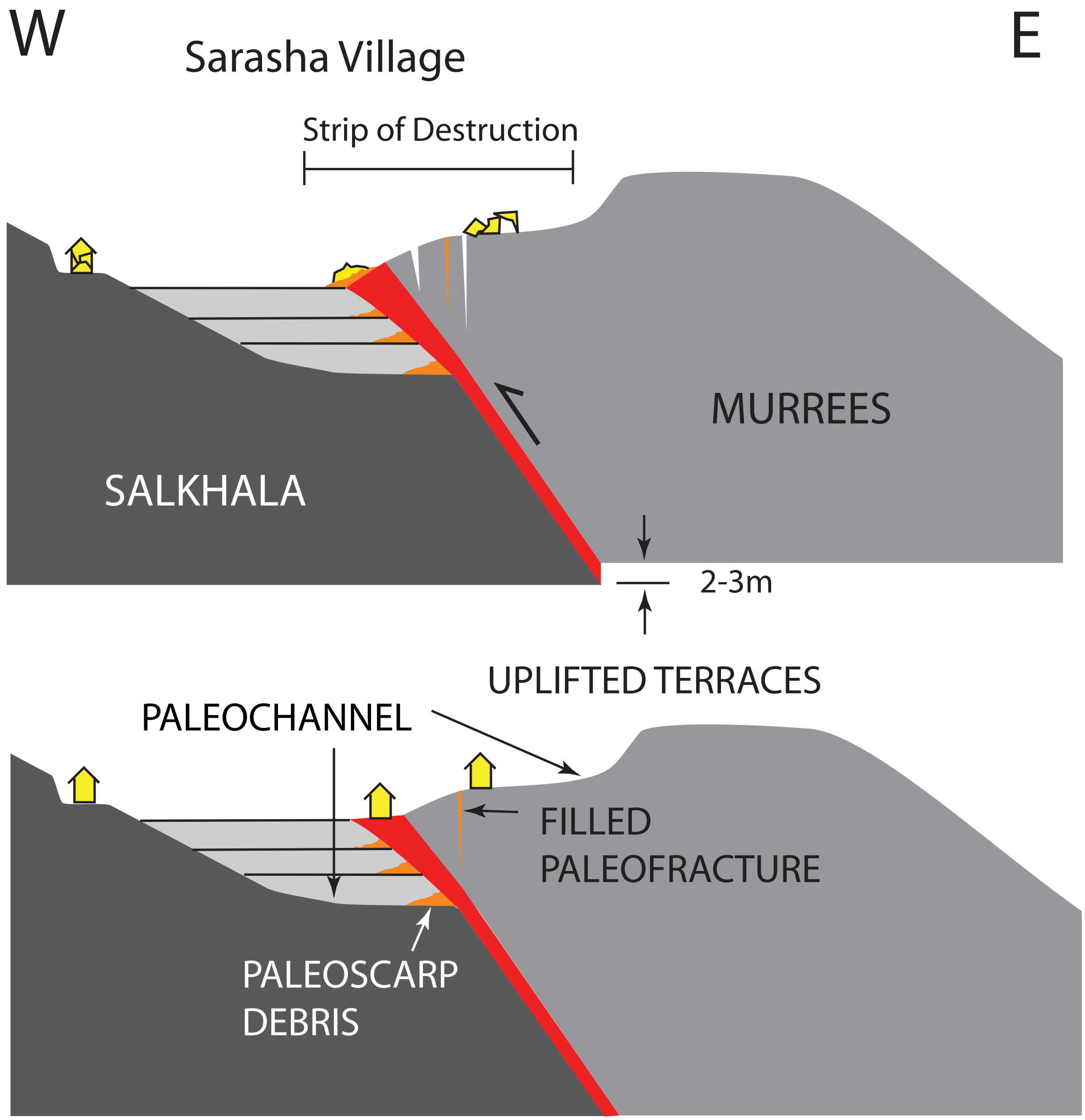
Most of the intense destruction occurred along the “strip of destruction” was associated with the fault rupture, but was not limited to it. Destruction was very intense in some other areas of Balakot, such as the hotel area on the east bank of the Khunar River near the bridge on the main road. These hotels were built on an active fan whose base was weakened by river erosion. That is a textbook case of a poor construction site in any environment, but certainly in an area hazardous for earthquakes. Coseismic and post-seismic landsliding could be recognized on many steep slopes on both sides of the Kagan Valley as well as in tributary valleys. Many of the houses built on these slopes had been affected or were likely to be affected soon.

Reconstruction of Balakot

The strong correlation between destruction and fault rupture provides a solid basis for distinguishing areas where rebuilding should not happen, from areas within Balakot where improved construction could provide safe housing and public buildings. The solution for Balakot is not a drastic and unrealistic “moving of the town” but a rearrangement of the town that excludes any buildings from the strip of destruction and from unstable slopes. Other hazards, such as flash-flooding and rock falls need also be considered. The area should be carefully zoned. Tectonic and geomorphic processes associated with thrust faulting, geologic conditions, and a detailed map of the destruction in 2005 are the essential elements to be considered in this zoning. This zoning is important for Balakot and could also serve as a guide for other population centers in similar thrust-fault settings in Pakistan and other regions of active mountain building.

Reconstructed house on top of hill about 2km northwest of Balakot. The remains of a previous house are on the left. The foundation of the house is bedrock (Murrees formation), but it is on the "strip of destruction" along the hangingwall side of the thrust rupture. No significant modifications from what may be a traditional design were observed, except possibly the large windows covered by temporary planks. No attempt to tie the top of the 2m-tall walls was seen.

Light-construction (possibly pre-fabricated) school building in Sarasha village, 3 km northwest of Balakot.



Hypothetical section through the October 2005 rupture in Sarasha Village based on surface observations of the landform changes caused by the 2004 thrust-fault rupture. Current geomorphic setting of the location is a saddle.