Surface rupture and landscape response within the core of the great Mw 8.3 1934 earthquake mesoseismal area: the case of the Khutti Khola

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- Abstract -

Great earthquakes generated along the Himalayan mega-thrust plate boundary have been shown to rupture the surface. The Mw 8.3 1934 Bihar-Nepal earthquake is one of these major seismotectonic events. Previous studies focused on sites located at the western end of the fault trace concluded that the surface rupture associated with this earthquake is still locally preserved. Here we document a new site, along the Khutti Khola rivercut, in the core of the mesoseismal area. The effects of the earthquake in that area were described as cataclysmic, generating massive damages, landslides blocking one of the local rivers at 4 sites. The Khutti river cuts the frontal range, incising a 4 m- high cumulated scarp exposed along a 19 m-long stretch of Siwaliks claystone-sandstone and alluvial deposits. A detailed study of the river cut revealed the presence of faults emplacing Siwaliks over quaternary alluvials. These units are sealed by a colluvial wedge and wash as well as by recent underformed alluvials. The C14 radiocarbon analyses of 10 detrital charcoals collected reveal that the last surface-rupturing event at that site occurred after the 17th century and prior to the post-bomb deposition of the young alluvials. The only historical earthquake known within that period is the 1934 earthquake, inferring that for this event the rupture reached the surface at that site. The rupture was followed by rapid aggradation and sealed by ~2 meters of sediments. In addition to being another rare example for the preservation of the 1934 earthquake, these observations demonstrate that, despite their magnitude and potential surface rupture, the study of the great Himalayan paleo-earthquakes are still challenging however necessary to constrain their lateral extent.

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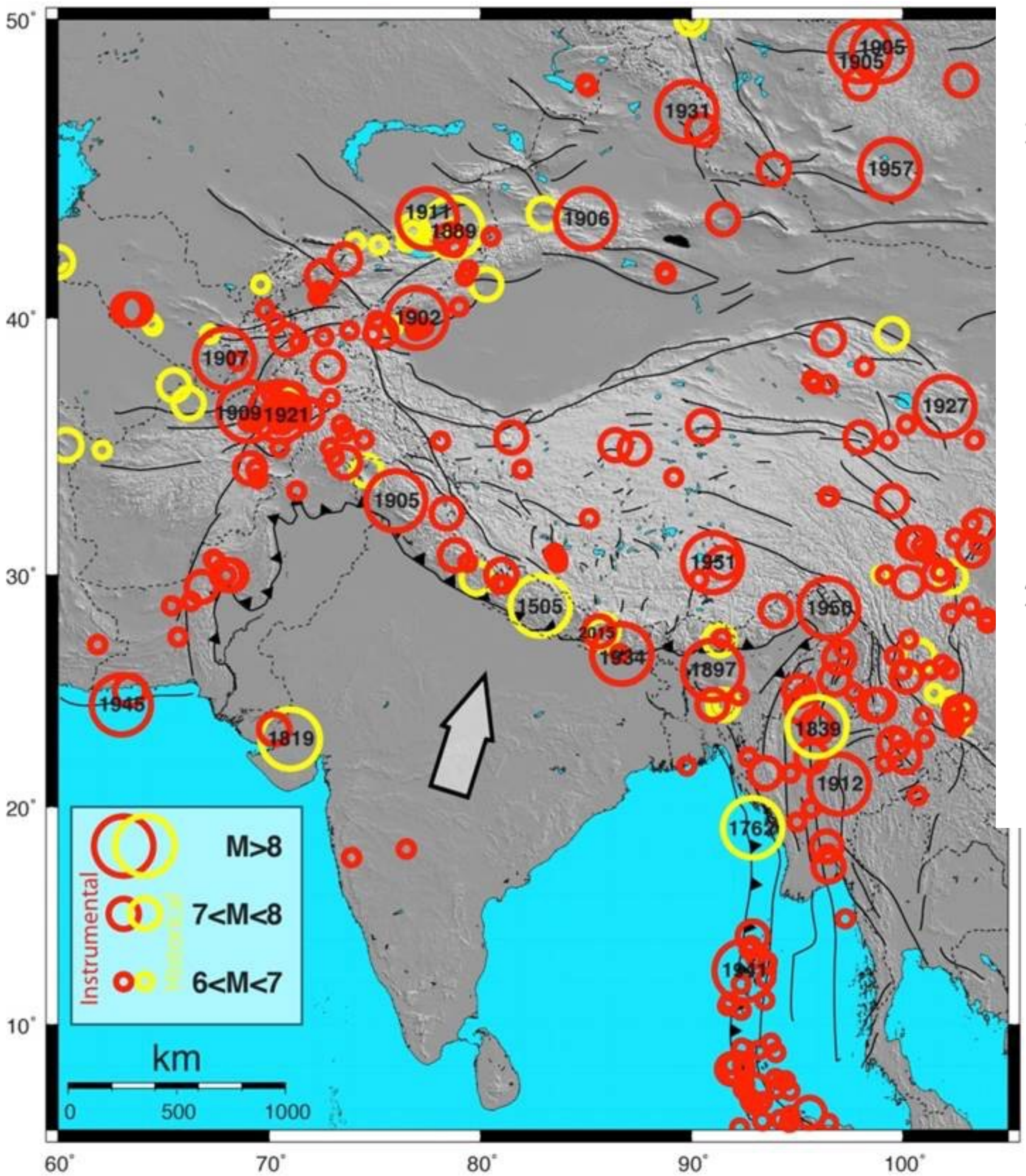
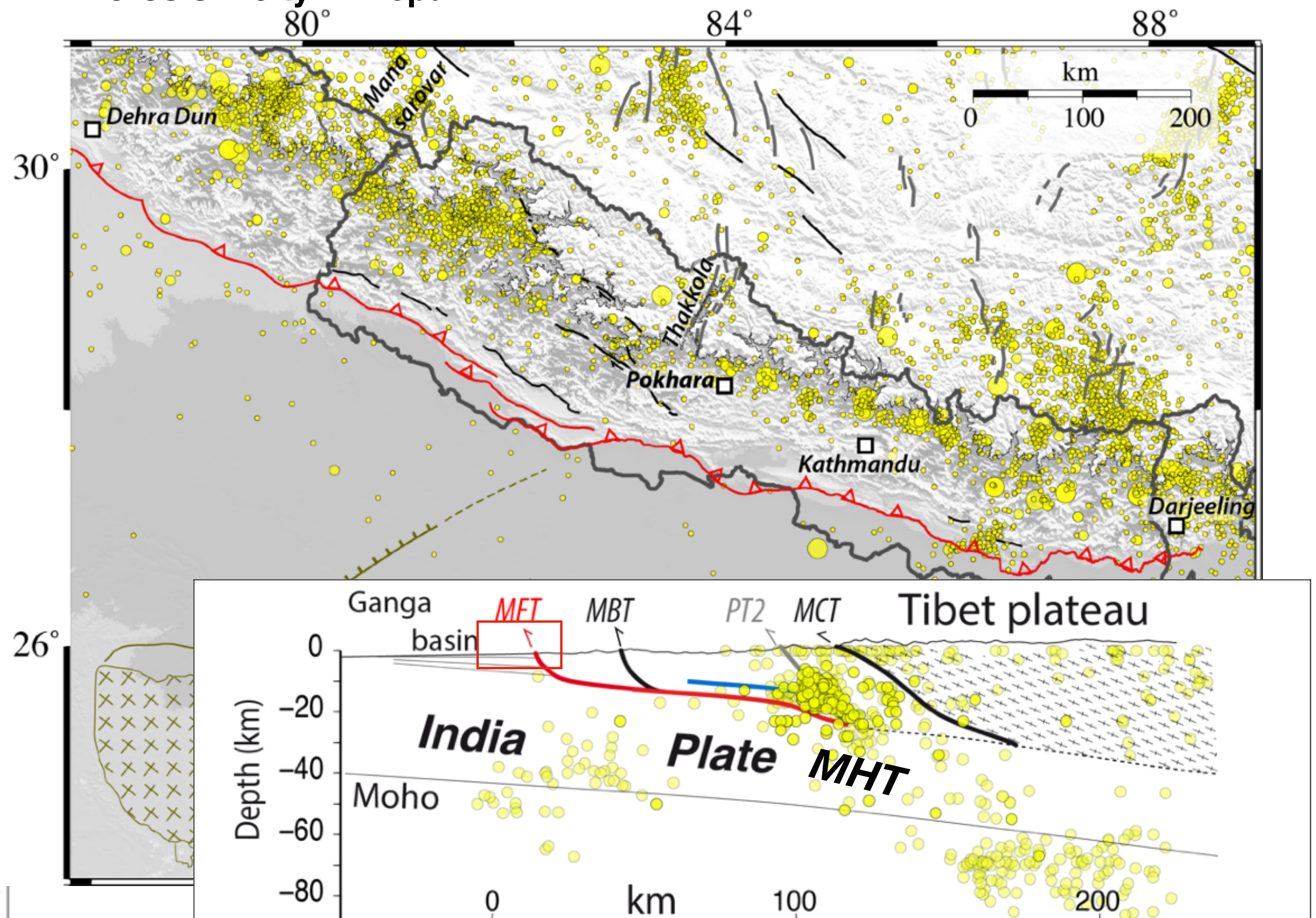
India and Tibet collision



MFT: Main Frontal Thrust
MBT: Main Boundary Thrust
MCT : Main Central Thrust

Microsismicity in Nepal



Microseismicity (yellow) and surface trace (red)

- Half of the convergence rate between India and Eurasia is accommodated along the Main Himalayan Thrust plate boundary fault.
- The up dip end of the Main Himalayan Thrust is fully locked during interseismic period and it ruptures during the largest devastating earthquakes up to the Main Frontal Thrust.
- Instrumental, historical and paleosismological archives document a more than 1000 years long history of these devastating earthquakes that remain partially undocumented.

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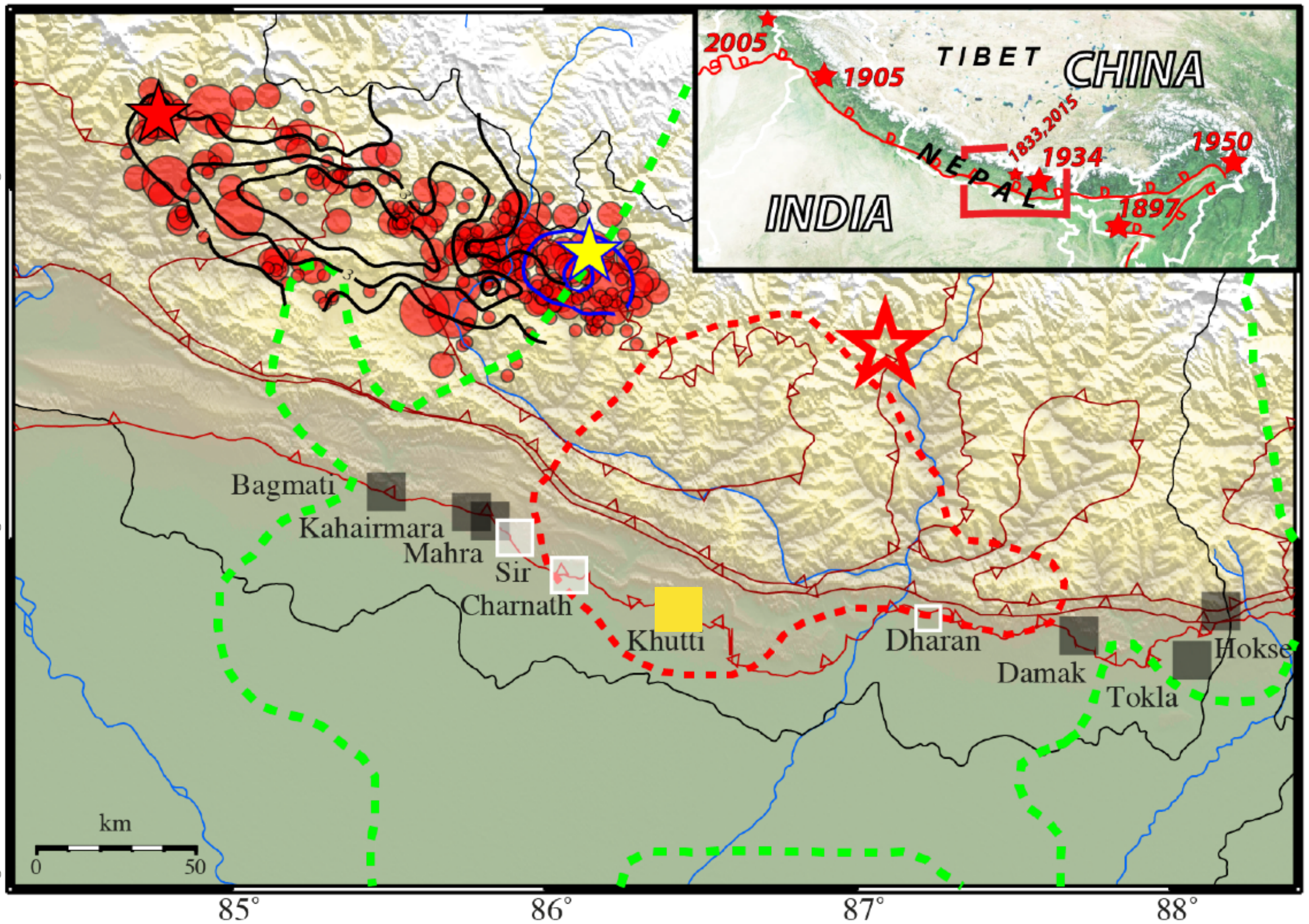
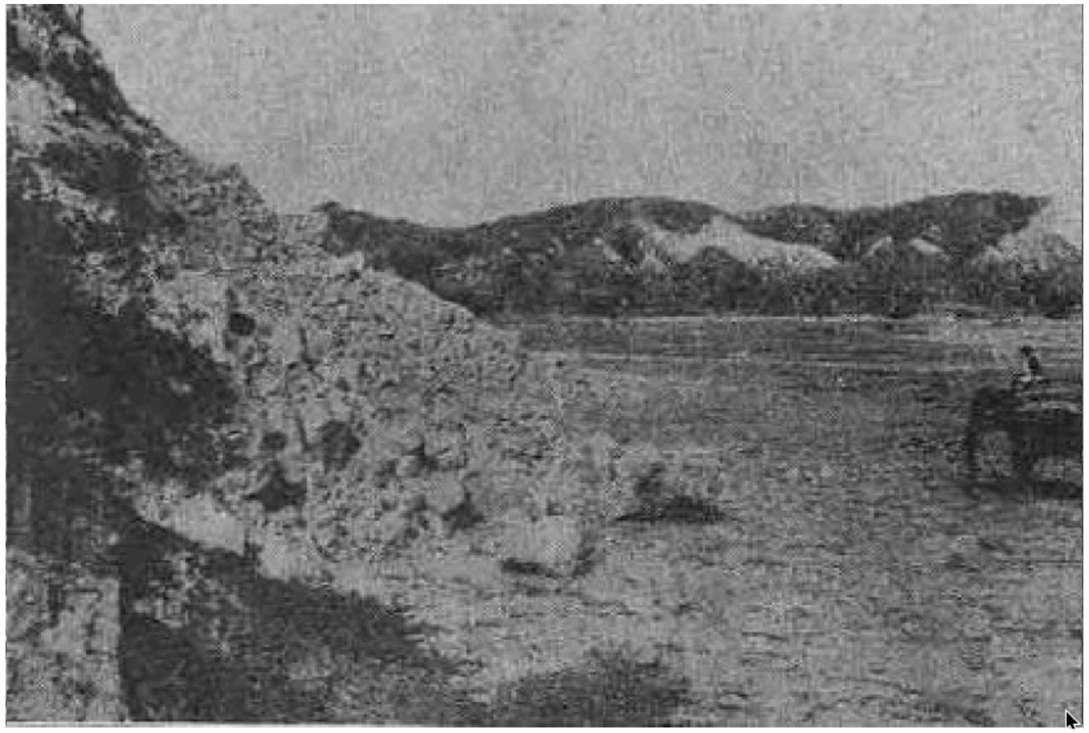
Context and location of the great Mw 8.3 1934 Bihar-Nepal earthquake



Seismotectonic map of the central-eastern Nepal. Red circles correspond resp. to the epicentres of the aftershocks of the April 25 Gorkha Nepal earthquake and the May 12th 2015 Kodari earthquake -yellow star (Adhikari et al., 2015).
The large squares locate the paleoseismic sites surveyed along strike the 1934AD rupture. Black squares for sites with no rupture demonstrated in 1934, white squares with rupture in 1934. Dashed red and green line resp. indicate the area with intensity >VIII (very important damages and devastation) and > VII. Red star corresponds to the instrumental epicentre of the earthquake (Sapkota et al., 2016).



Landslide caused by the 1934 earthquake south of Udaypurgadhi, ~15 km from the Khutti Khola

- In 1934, the Mw 8.3 Bihar-Nepal earthquake devastated the region south-east of Katmandu, its effects in that area were described as cataclysmic, generating massive damages and landslides.
- 1934 earthquake observed in paleosismologic trenches at Sir Khola and Charnath Khola.
- Sites located mostly at the edge of the mesoseismal area.

➜ **Need for further exploration within the core mesoseismal area, new site in yellow.**

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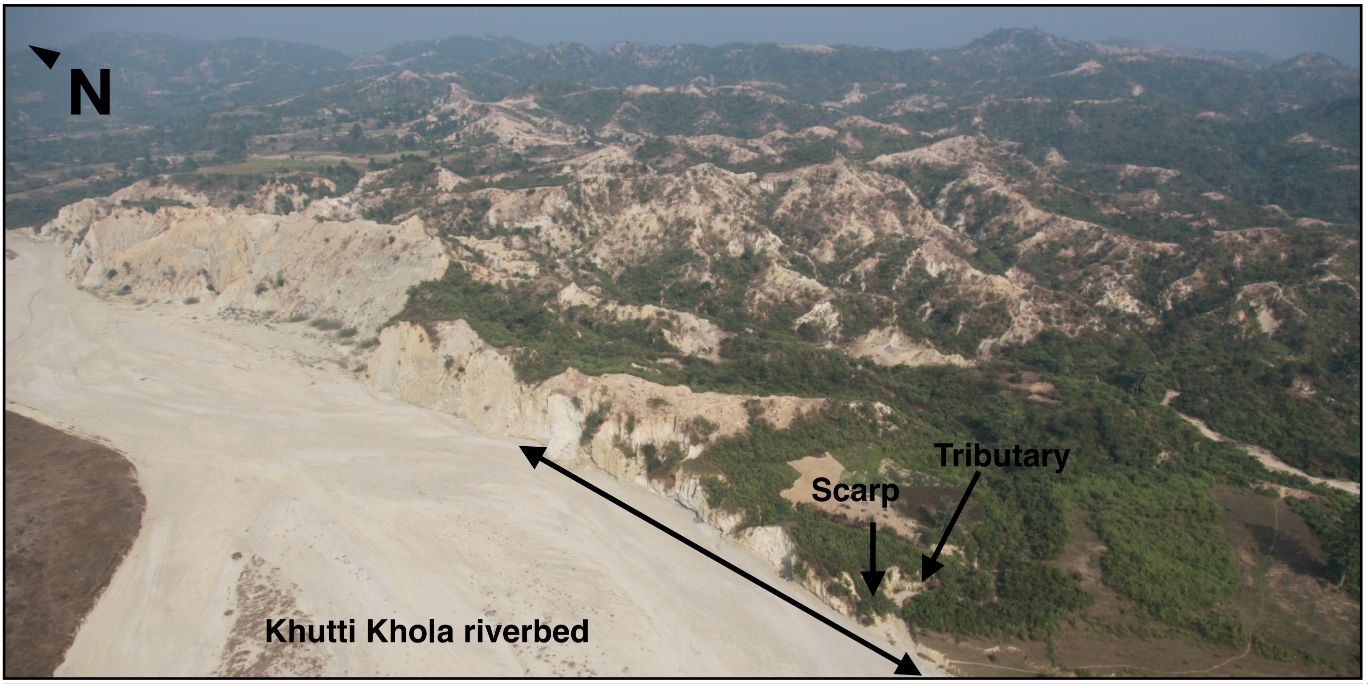
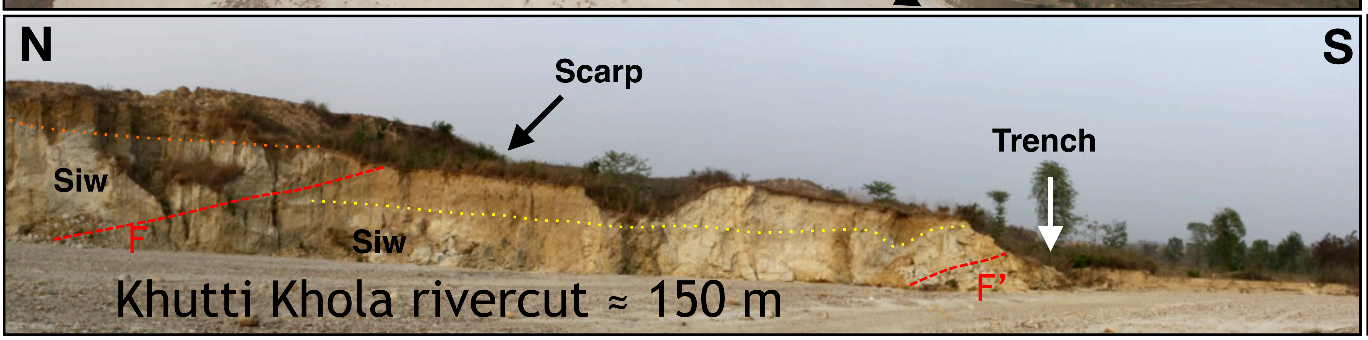
The Khutti Khola site

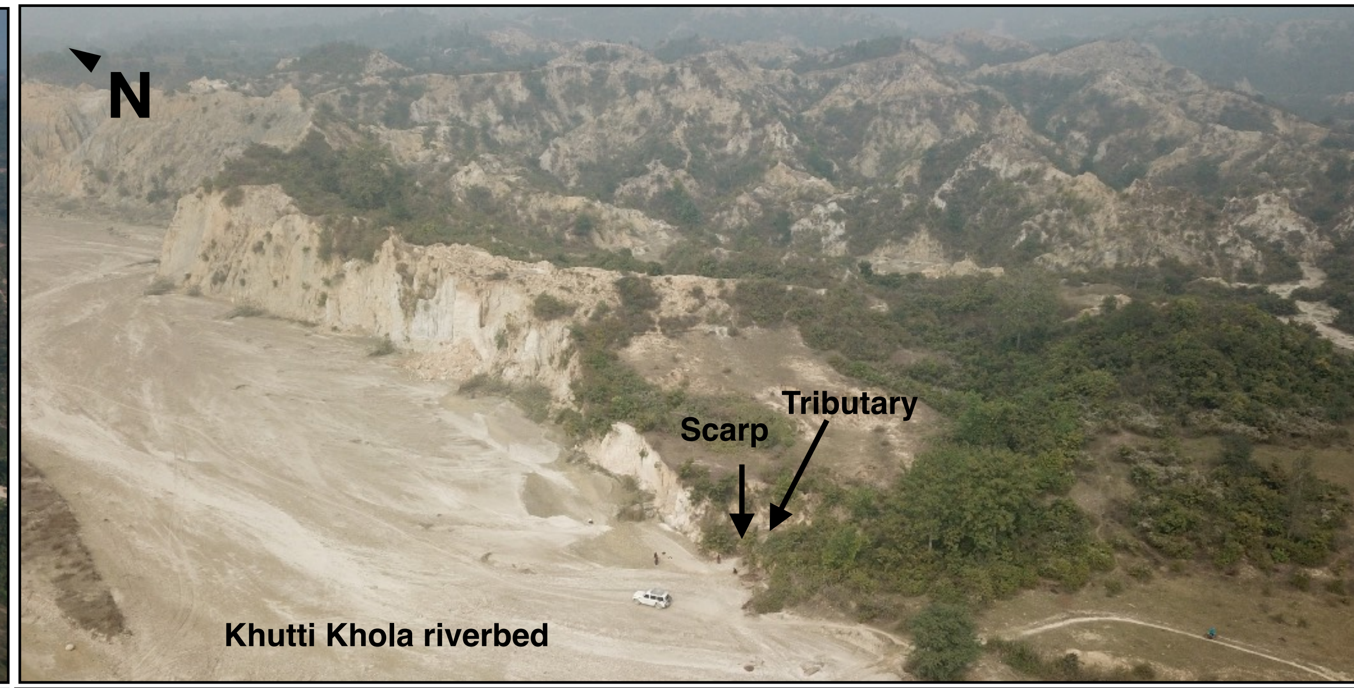
Site in 2012





- The Khutti Khola river catchment is ~20km^2 inferring important and rapid landscape evolution (erosion/aggradation) of the fault scarp erasing tectonic evidence.
- The deformation still observable today is distributed over a ~150 m-long rivercut with two major faults reaching the surface.
- At the toe of the frontal fault, tectonic evidence are still partially observable (frontal scarp eroded in most places since 1934 and rapid erosion during the last 8 years).

Site in 2020



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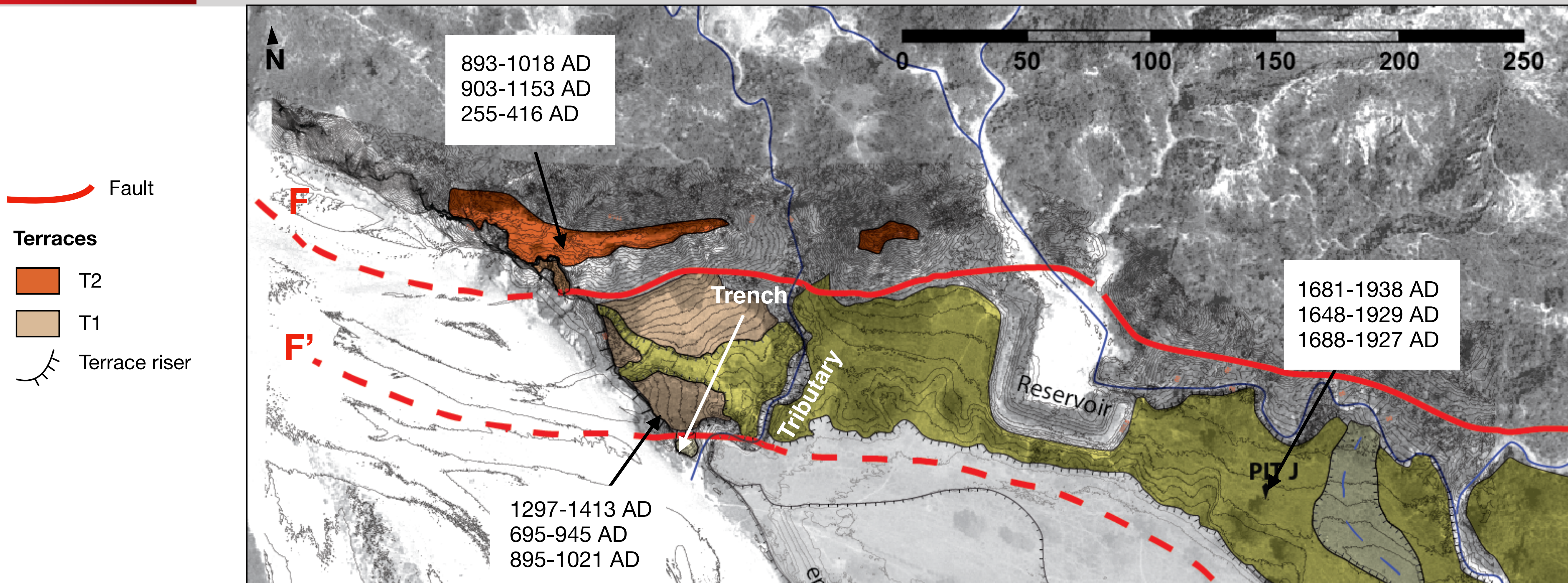
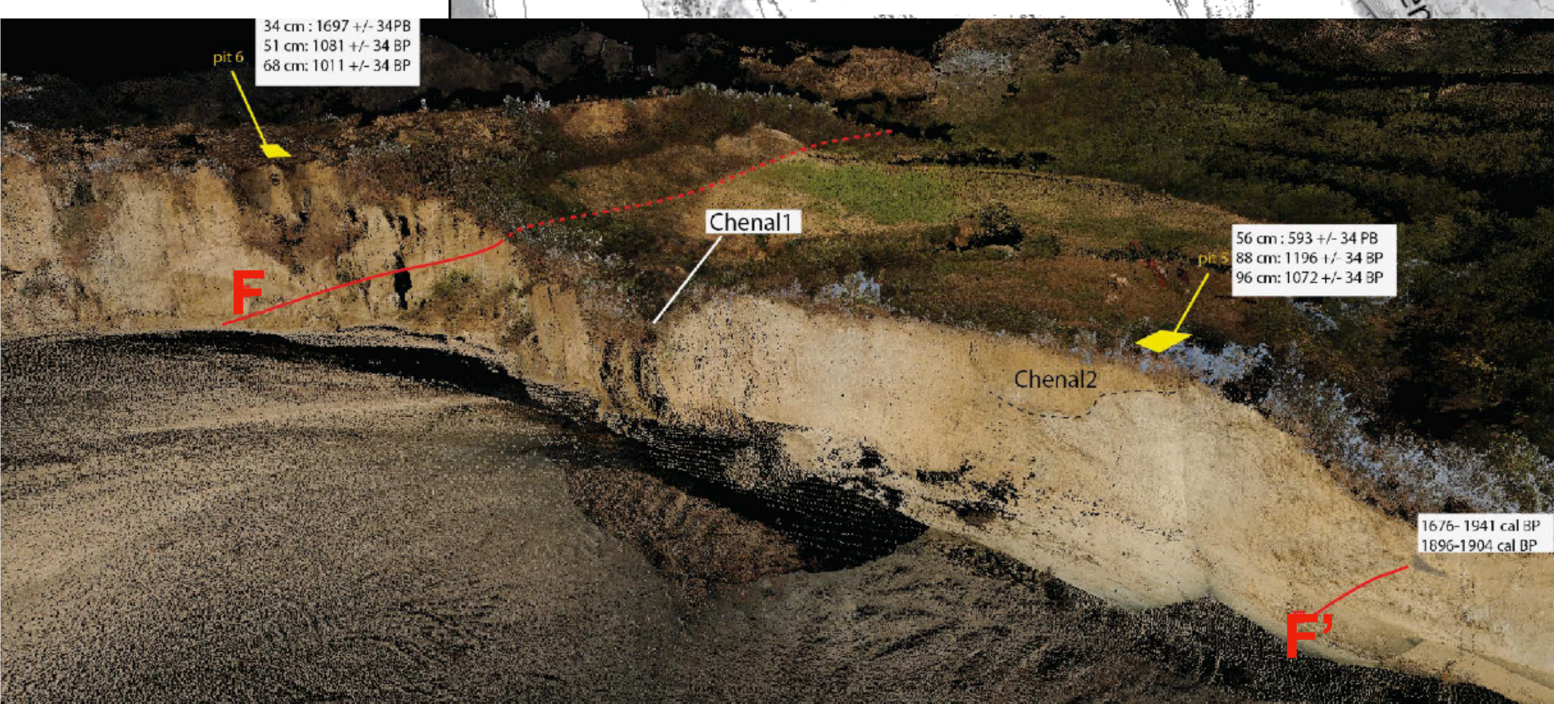
The Khutti Khola terraces



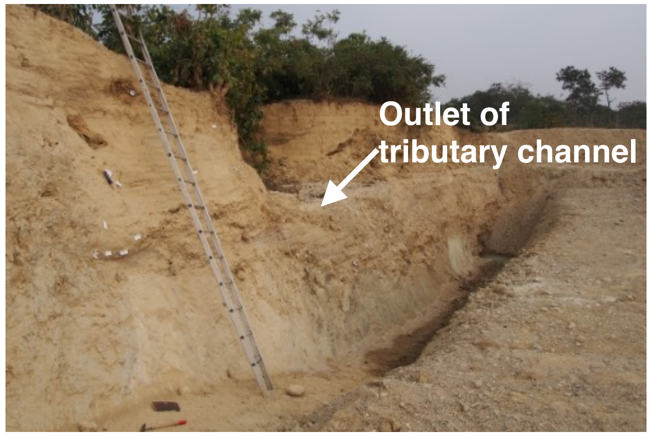


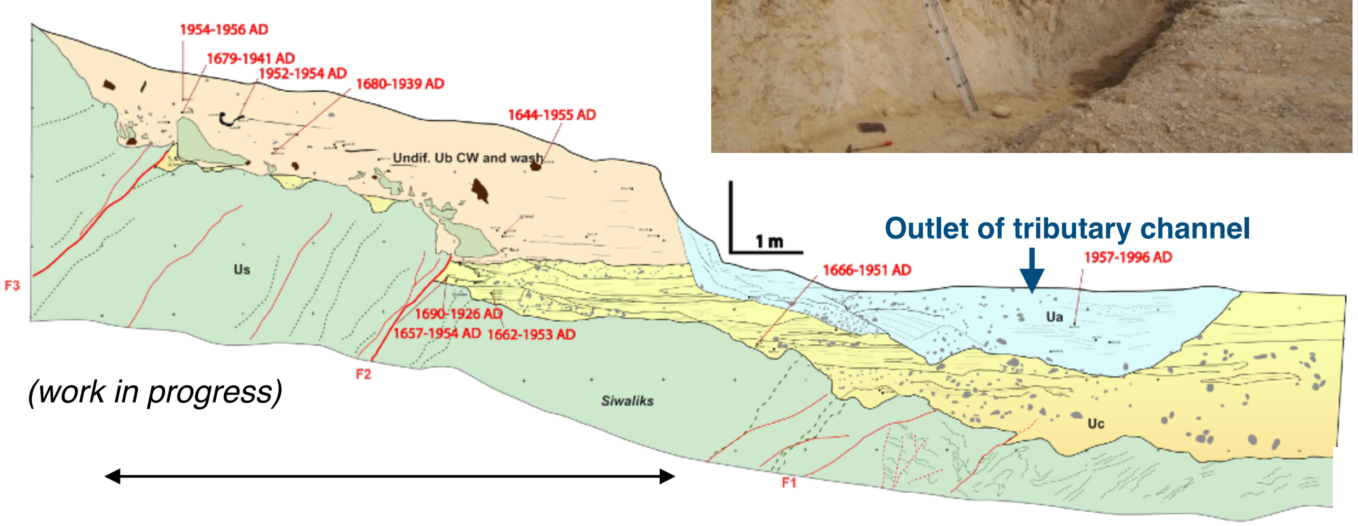
- North of the most frontal observed fault, 2 terraces treads stand at ~9 m (T1) and ~21m (T2) above the present-day river level.
- Radiocarbon dating of charcoals collected in pits on top of those terraces indicate ~9 m of incision since the 15th century and ~21 m since the 11th century.
- Aerial photographs from the 60s compared with 2019 Pleiades satellite images indicate an important erosion/aggradation along the most frontal scarp implying that the most frontal deformation can no longer be observed.

The Khutti Khola rivercut

Trench in 2012

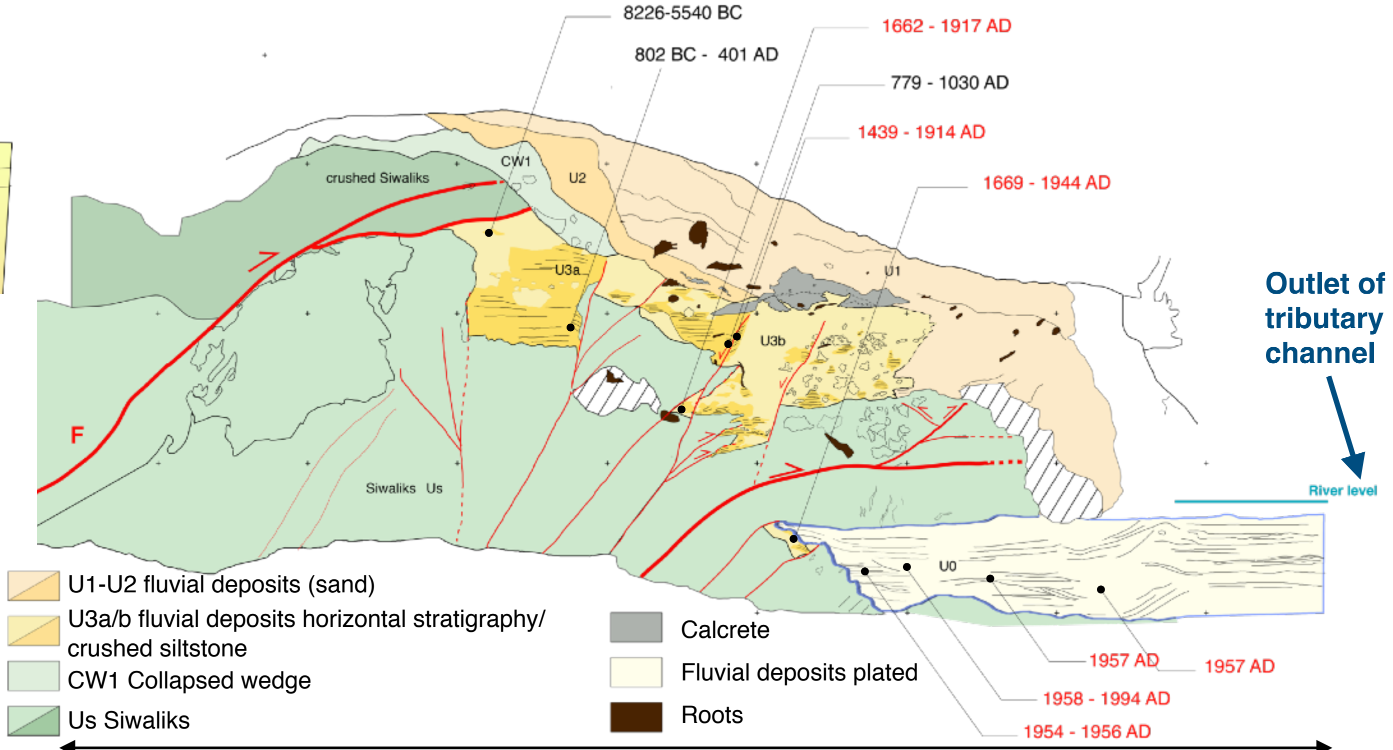
19m-long and 7m-high rivercut





(work in progress)

Zoom in the upper part in 2020



- The rivercut was excavated twice in 2012 and 2020. It is 4 m-high with a 4 m-high cumulative scarp.
- It exposes Siwaliks on top of recent fluvial sediments. The 2 excavations reveal tectonic deformation post 17th century. The displacement is hardly measurable at that site. We observe ~1 m displacement within 5 m-long outcrop which is small compared to the > 10 m of coseismic slip probably associated to that earthquake.
- The rivercuts reveal that an important part of the deformation is accommodated by bedding slip.
- We observed important erosion/aggradation in the last 8 years quickly erasing evidences of tectonic deformation making the correlation between the two rivercuts complex.

Modern U0 series plated against the Siwaliks wall post-earthquake (work in progress)

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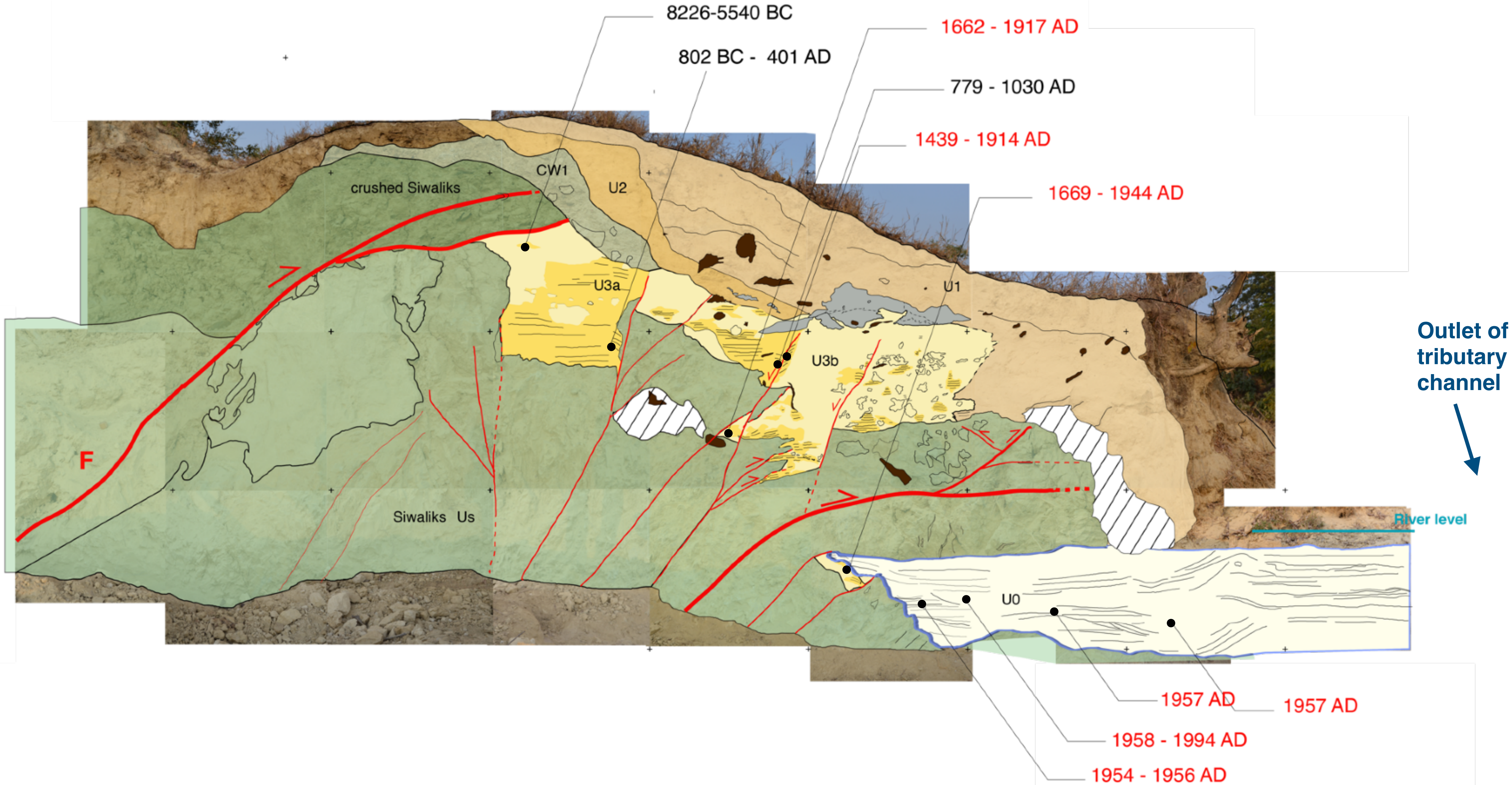
Take-home message



- At the Khutti Khola site, the latest deformation postdate the 17th century. These observations are consistent with the 1934 Bihar-Nepal earthquake rupturing the surface at this site.
- The deformation is distributed over more than a 150 m width area with major surface-rupturing faults. However quantifying this deformation is challenging. The erosion/aggradation processes observed here indicate that trace of paleoearthquakes are fading quickly at the front. And to the north, a detailed study of the deformation can be difficult due to the absence of young markers of the deformation.
- The small outcrop studied is the last relic of this past event for this valley with a high erosive capability.

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