From depth to surface: how deep-earth processes and active tectonics shape the landscape in Pamir and Hindu Kush

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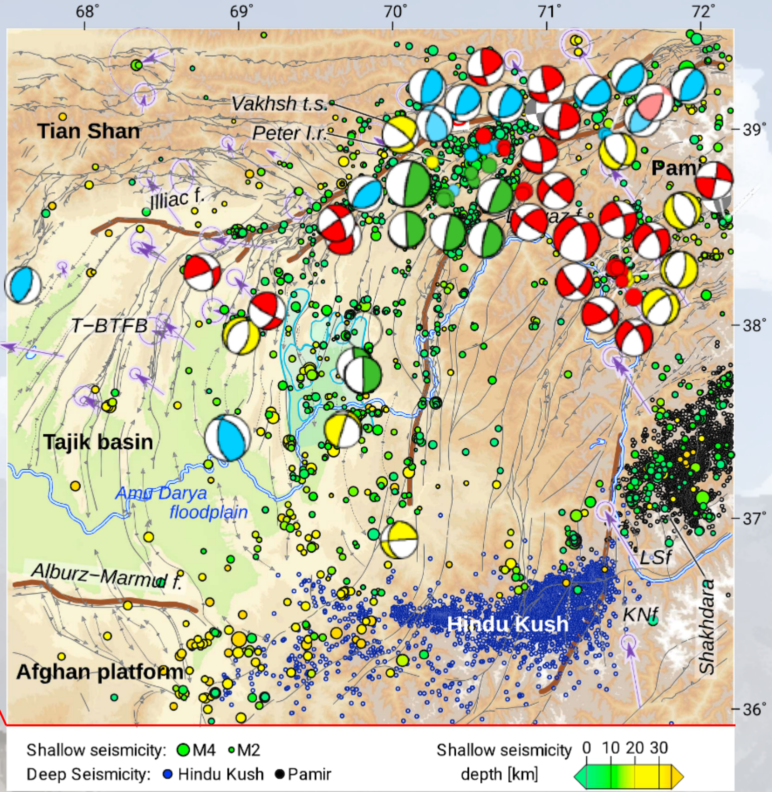
About the contribution

- Three sections:
  - Background (overview S.o.A.)
  - Paleoseismology along Darvaz fault (and plans for Vakhsh and Sarez faults)
  - Geomorphic analysis Pamir-Hindu Kush (how we plan to search for evidence of slab break-off)
- This is a work-in-progress study subject to funding opportunities; therefore, results are not presented
- Main working ideas are provided as a preliminary proposal
- **Your feedback is very welcome!**



Modern seismicity and Cenozoic structures in the NW Pamir, Hindu Kush and Tajik basin. [Kufner et al., 2018 + earthquakes moment tensors from Schurr et al., 2014]

Seismicity

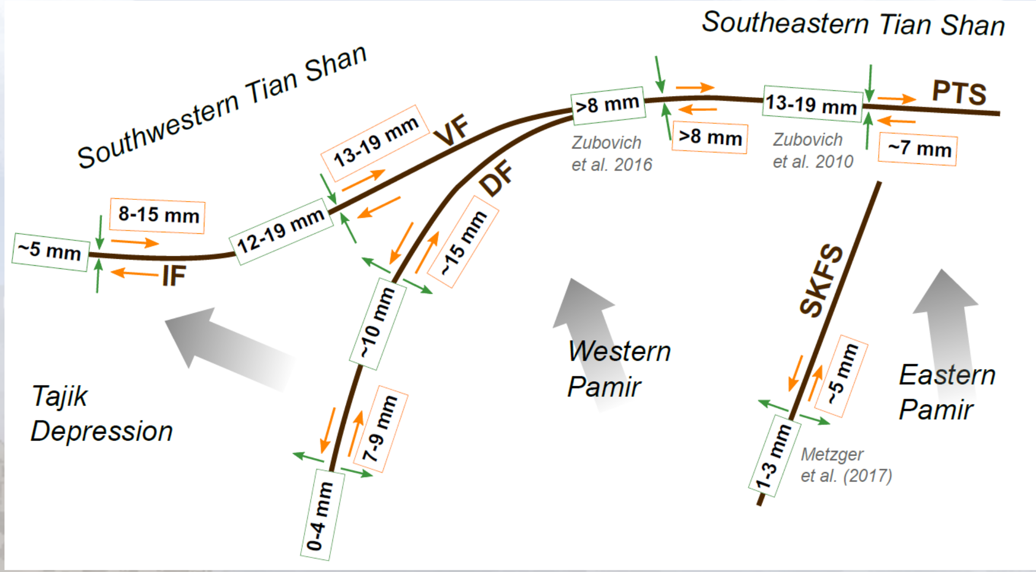
Shallow seismicity

- Active deformation N-NW Pamir
- Three main fault systems: the Pamir thrust system to the north, and the Darvaz fault and Vakhsh thrust system to the north-west.

Deep seismicity

- Hindu Kush, to the south (and central Pamir)

Main active faults of NW Pamir



Main active faults of NW Pamir and their slip sense.
Gray arrows= main direction of motion with respect to stable Eurasia observed by GPS; Orange arrows= shear; Green arrows= shortening or extension. VF: Vakhsh fault; DF: Darvaz fault; PTS: Pamir Thrust System; SKFS: Sarez-Karakul fault system. [Metzger et al., 2020]

The Darvaz fault and the Vakhsh fault splay from the main Pamir Thrust System.

Darvaz fault: sinistral-trantensive, separates the Pamir from the Tajik Depression

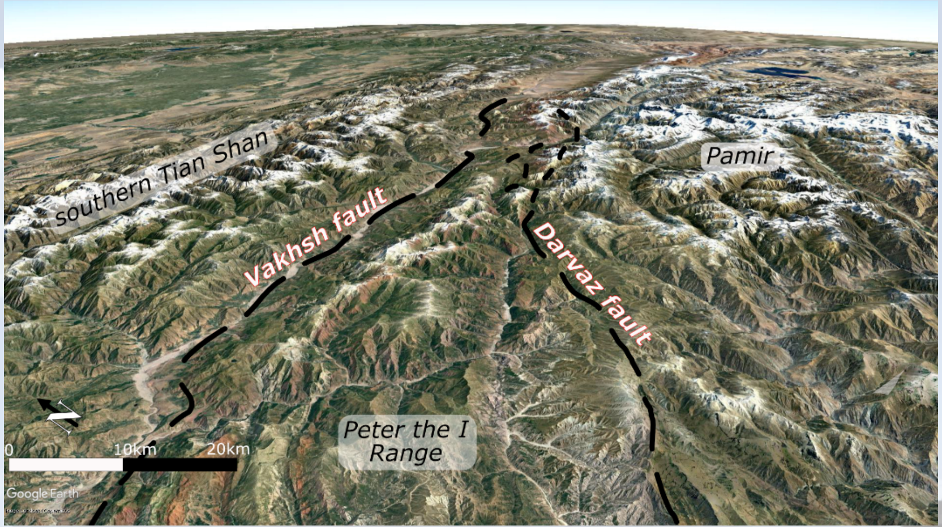
Vakhsh fault: dextral-transpressive, marks the boundary of the southwestern Tian Shan.

Together, these faults accommodate NW-SE shortening and southwestward flow of Western Pamir material into the Tajik Depression.

Darvaz fault: slip rates

Geodetic: 6-15 mm/yr (~15 mm/yr sinistral shear, ~10 mm/yr of dip-slip)

Geologic: 10-15 mm/yr



View of the Darvaz fault and Vakhsh fault parallel segments.
© Google Earth

Holocene to Late Pleistocene slip rates

<u>Southern segment</u>:
- 10-15 mm/yr sinistral slip [Trifonov, 1978]

<u>Northern segment</u>:
- 10-40 mm/yr of sinistral slip - ~21 m displacement of ~1500-2200 y.o., man-made defense structure [Kuchai & Trifonov, 1977]
- 3-4 to ~8 mm/yr sinistral-transpressive slip rates since LGM ~20 ka [Trifonov, 1983] - here, an association of the mapped fault segments with either the Vakhsh or the Darvaz fault is unclear.

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Darvaz fault: palaeoseismology

Existing slip rates are based on relative and regional terrace chronology and are probably prone to high uncertainty, as indicated by rates that vary by 300% depending on the respective authors (Burtmann & Molnar, 1993).

Trace of the northern segment of the Darvaz fault, highlighted by the arrows. View to SE. © Google Earth

Future work

By analysing the abundant geomorphic markers, such as river terraces, moraines, alluvial fans, and streams, we aim at identifying:

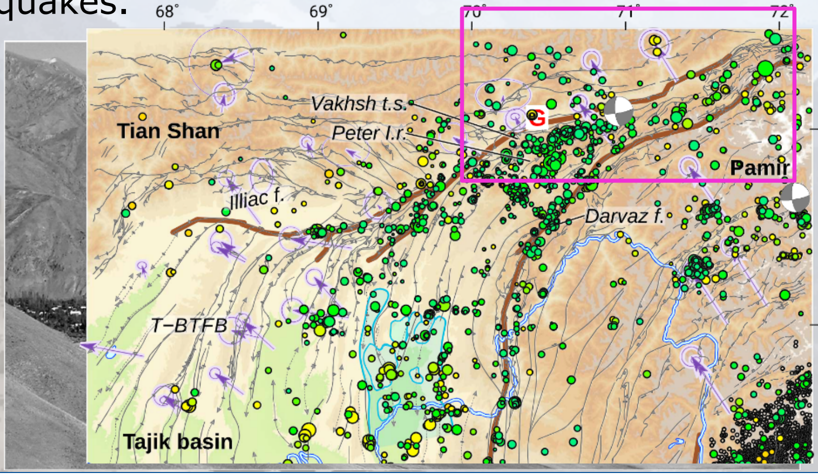
- datable offset surfaces, in order to determine in more detail slip rates
- suitable palaeoseismological trenching sites, to define the number of rupture events occurred along the fault

Vaksh and Sarez faults palaeoseismology

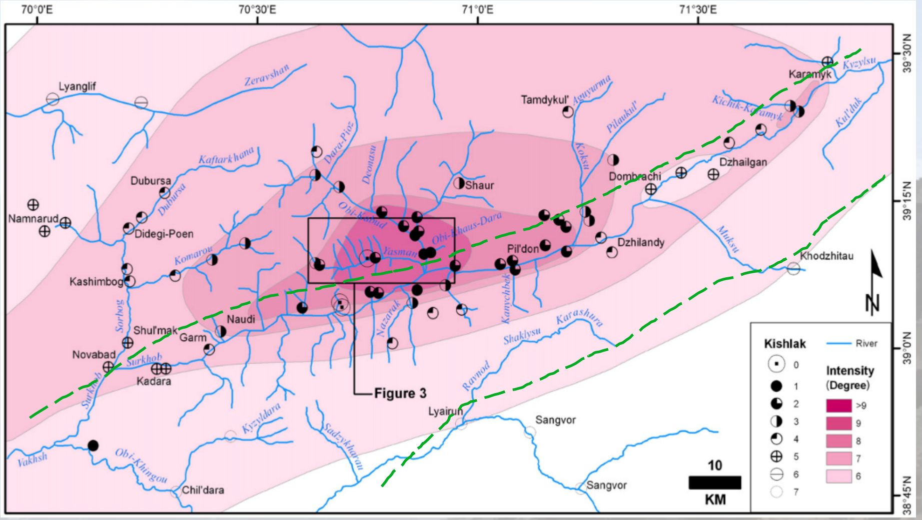
Within project '*The major earthquake ruptures of central Asia*' (COMET). Methods: seismology, geomorphology, historical record to investigate: 1907 Karatag, 1949 Khait, 1911 Sarez earthquakes.

Ben Johnson (PhD student, Univ. Oxford)

Planned trenching aims at unravelling the earthquake history and long-term slip rate of the faults by comparing observed strain rates to force balance models and paleoseimic data.



View of the Khait rockslide–loess flow triggered by the M7.4 1949 Khait earthquake (from Evans et al., 2009)



Isoseisms based on degree of damage to kishlaks in the Khait area. Kishlak degree of damage scale 1=total destruction and 7=no damage. Intensity scale MSK-64 (from Evans et al., 2009)

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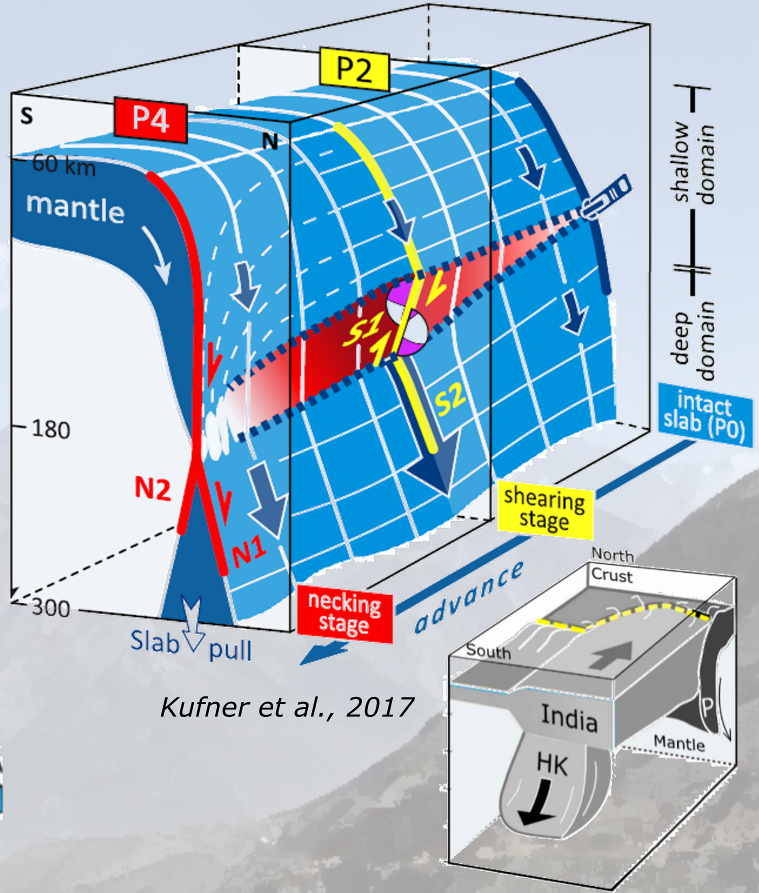
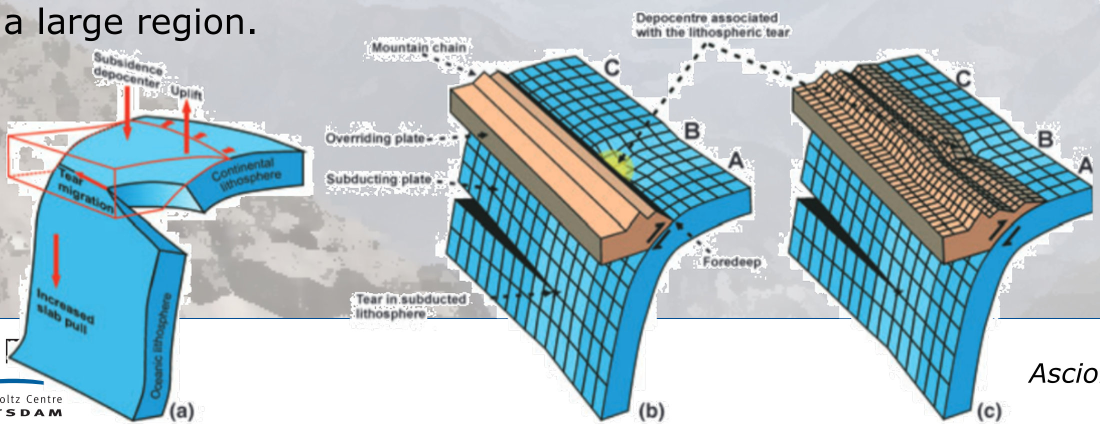
Imaging the slab break-off

Kufner et al. (2017) proposed that sub-crustal seismicity beneath the Hindu Kush, clustered in a near-vertically dipping narrow volume and displaying repeating large earthquakes at depth>200km, represents the expression of ongoing subducted slab break-off.

The loss of the gravitational slab pull force can translate to the overlying crust, which would start uplifting in a relatively uniform mode over a large region.



Kufner et al., 2017



Ascione et al., 2012

Imaging the slab break-off: numerical models

Numerical models

[**Duretz**, **Gerya**, **Buiter** *see ref. list*]:

- 2-6 km uplift using elastic models
- <2 km uplift visco-elastic models

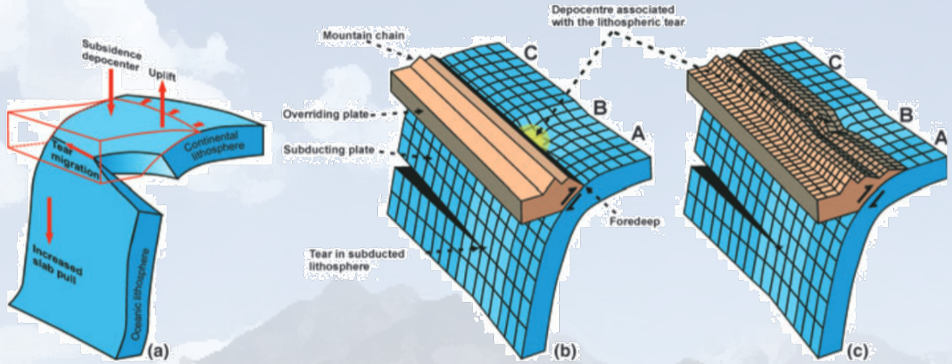


Fig. 3. Models of surface subsidence/uplift pattern associated with laterally propagating slab tear. (a) Response in the leading edge of the overriding plate (from Wortel & Spakman, 2000). (b) Response in foredeep basin (after van der Meulen *et al.*, 1998, modified). (c) Response in both foredeep and (coupled) orogenic wedge, leading to wedge-top basin development.

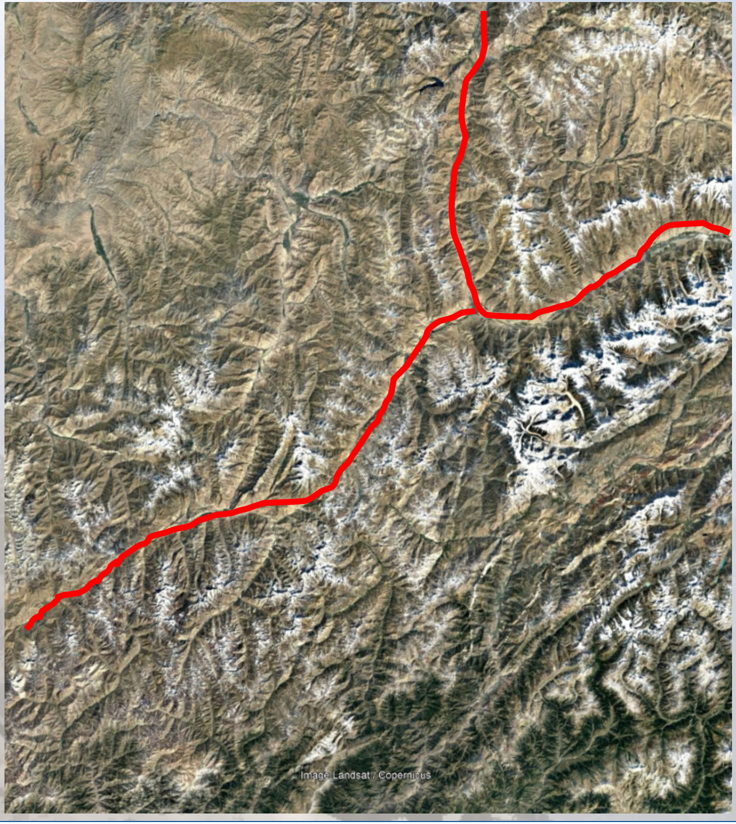
Natural examples

S Apennines Italy [Ascione 2012, *Basin Res*]
Central America [Rogers 2002, *Geology*]
Borneo [Morley&Back 2008, *Jour. Geol Soc.*]
Turkey [Cosentino 2012, *Geol. Soc. Am. Bull.*]
[Schildgen 2012, *EPSL*]
[Schildgen 2014, *Earth-Sci. Rev.*]

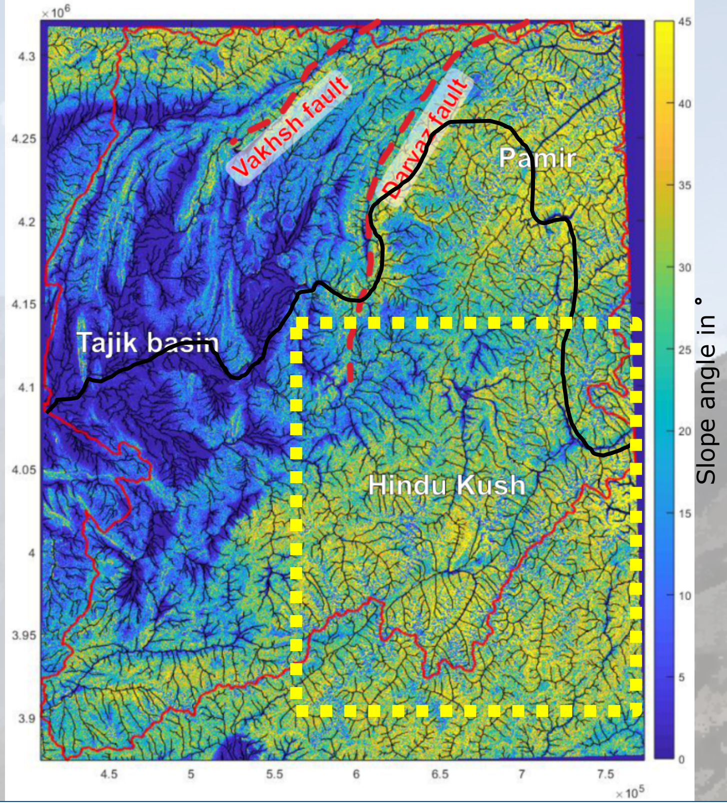
	Depth	Uplift Rate	Wavelength
Shallow	*<100 km*	*0.7-0.8 mm/yr*	*100 km*
Intermediate	*~200 km*	*0.4-0.5 mm/yr*	*300 km*
Deep	*>300 km*	*0.2 mm/yr*	*400 km*

Duretz et al., 2011

Imaging the slab break-off: geomorphic response



Can we already see its effects in the overlying topography?



TopoToolbox, *Schwanghart&Scherler, 2014*

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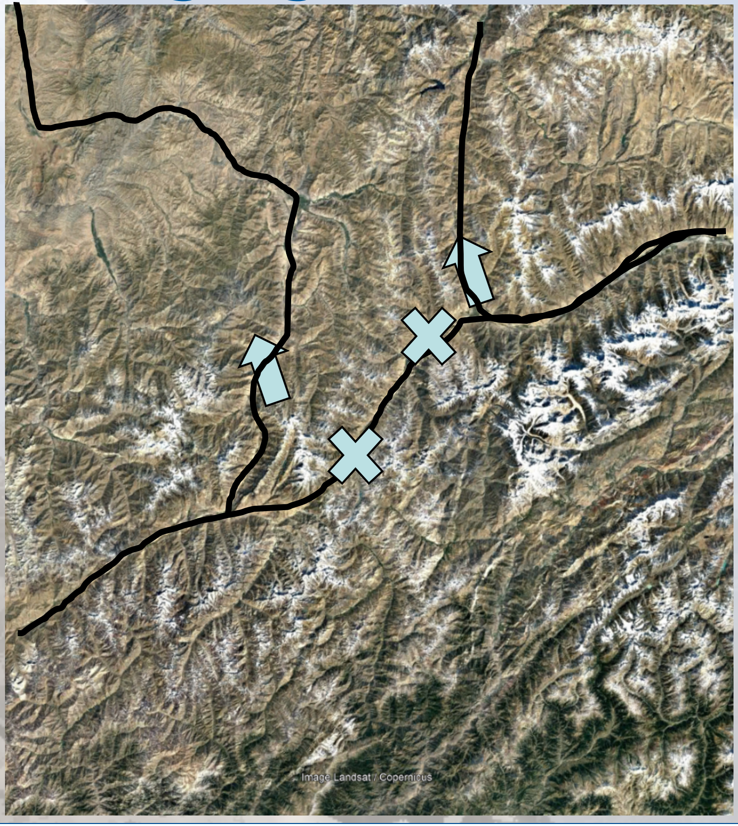
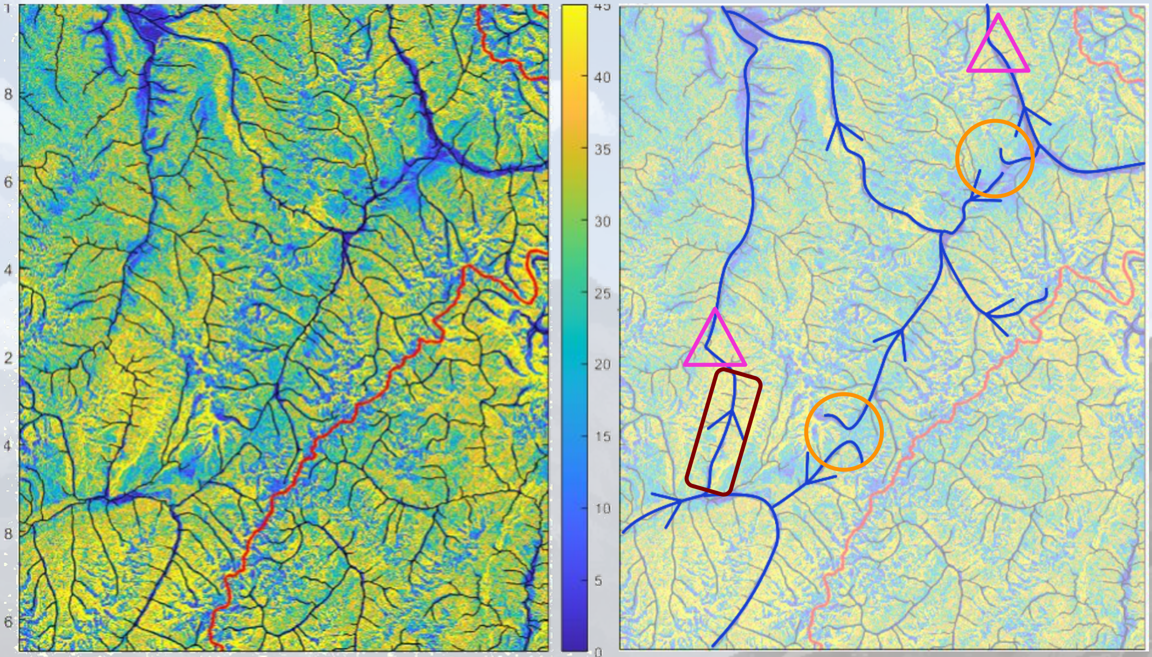
Imaging the slab break-off: geomorphic response





Zoomed-in view of a portion of Panj river drainage basin (left) with simplified scheme of the main flow directions (right).

Imaging the slab break-off: geomorphic response

Observed evidence of uplifted landscape:

- **Low divides**

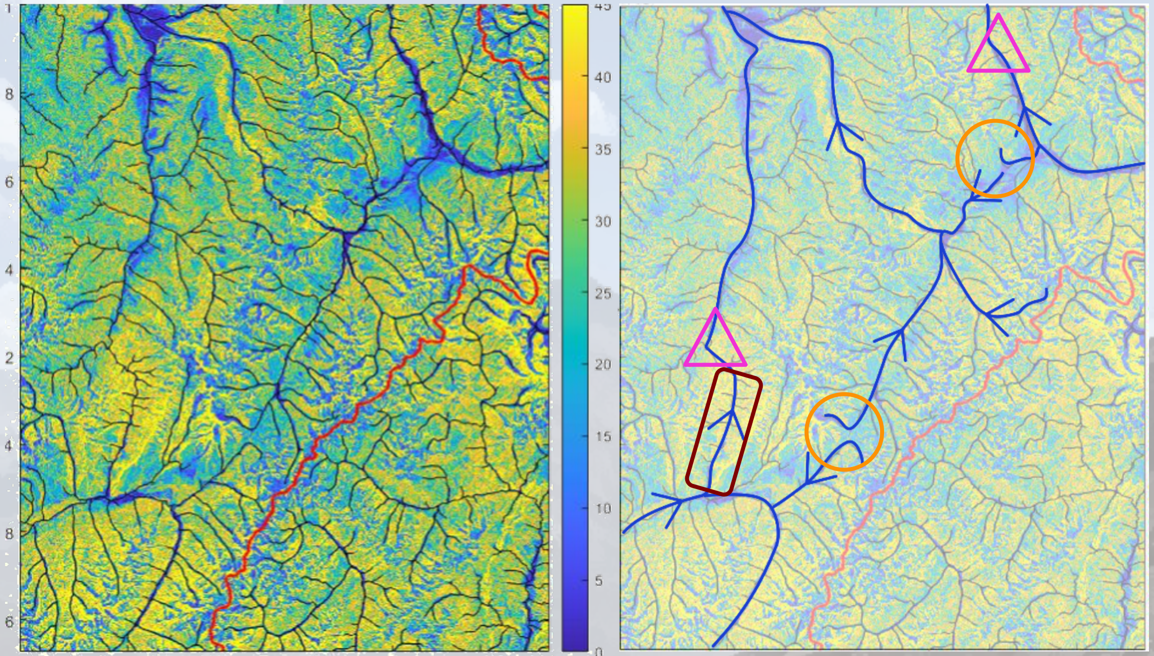
  Many examples of low divides indicate relatively recent uplift of a section of the old stream drainage

- **River captures**

  Are frequent and often associated to fault offset

- **Stream flow reversal**

  Is observed in correspondence of river captures due to headward erosion of an adjacent sub-basin



Zoomed-in view of a portion of Panj river drainage basin (left) with simplified scheme of the main flow directions (right).

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Conclusion

- Geodetic data indicate activity along the Darvaz fault
- Existing slip rates are prone to high uncertainty (Δ300%)
- Paleoseismology -incl. trenching- to determine number and ages of rupture events → slip history
- Deep, clustered seismicity suggests ongoing slab break-off below Hindu-Kush
- Landscape response can be investigated through geomorphic analysis
- Geomorphic analysis will also provide more information about Late Quaternary activity of main active structures

Thank you for listening!

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