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# The interplay between tectonics and karst in the formation of the canyons in the Al-Hajar Mountains (Sultanate of Oman)

**Session GM9.2** - Exploring the feedback between tectonics, climate, and surface processes from modelling and quantifying techniques

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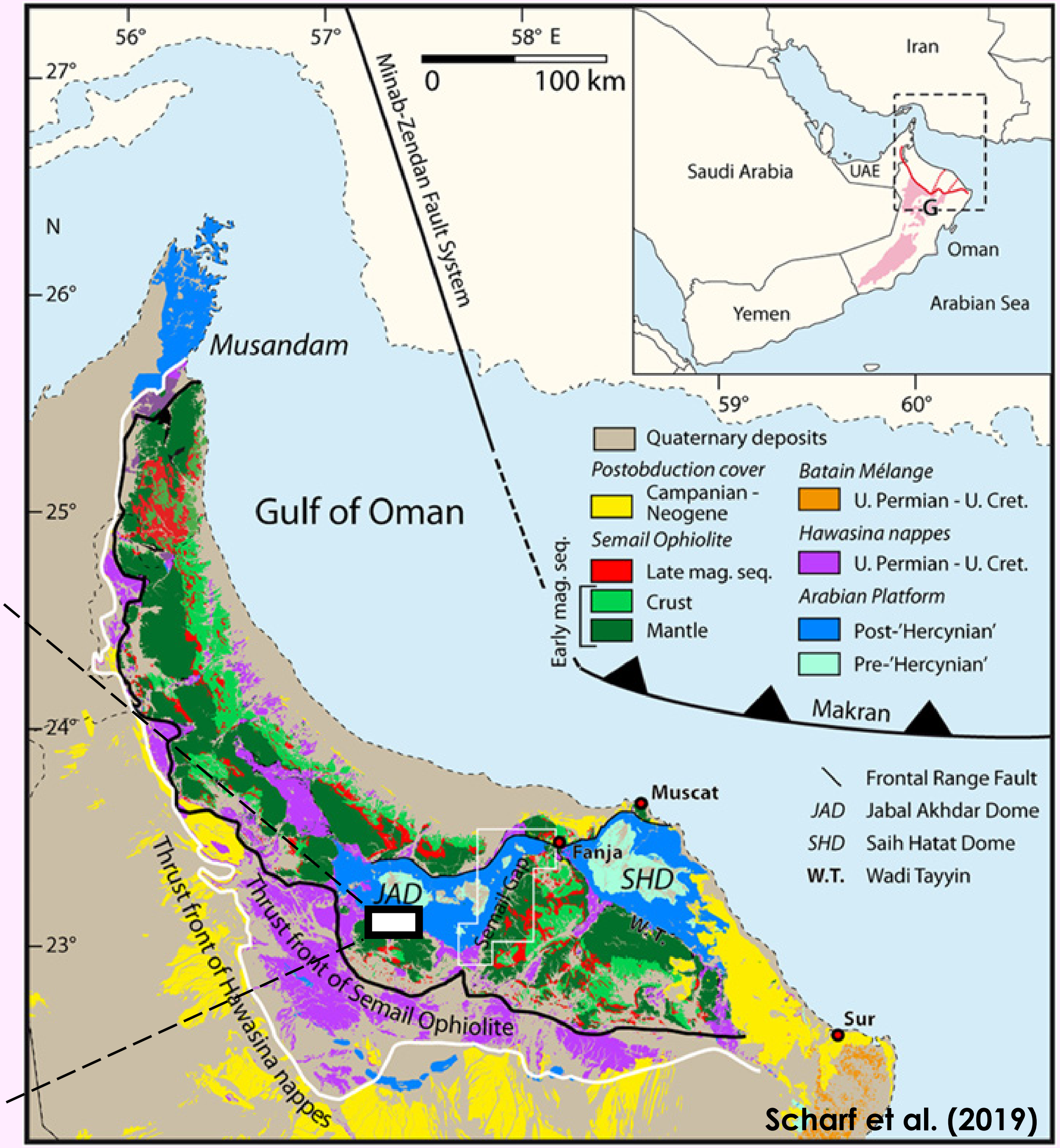
# Geological backgrounds

- **Al-Hajar Mountains** (Northern Sultanate of Oman)
- Characterising the **NE-Arabian Plate**
- **Complex tectonic history**
  - Obduction of the Semail Ophiolite and the slope-basin sedimentary sequences over autochthonous sedimentary cover and metamorphic units during Late Cretaceous
  - Post-orogenic history is characterised by extension and subsequent shortening, forming a series of regional-wide anticlines

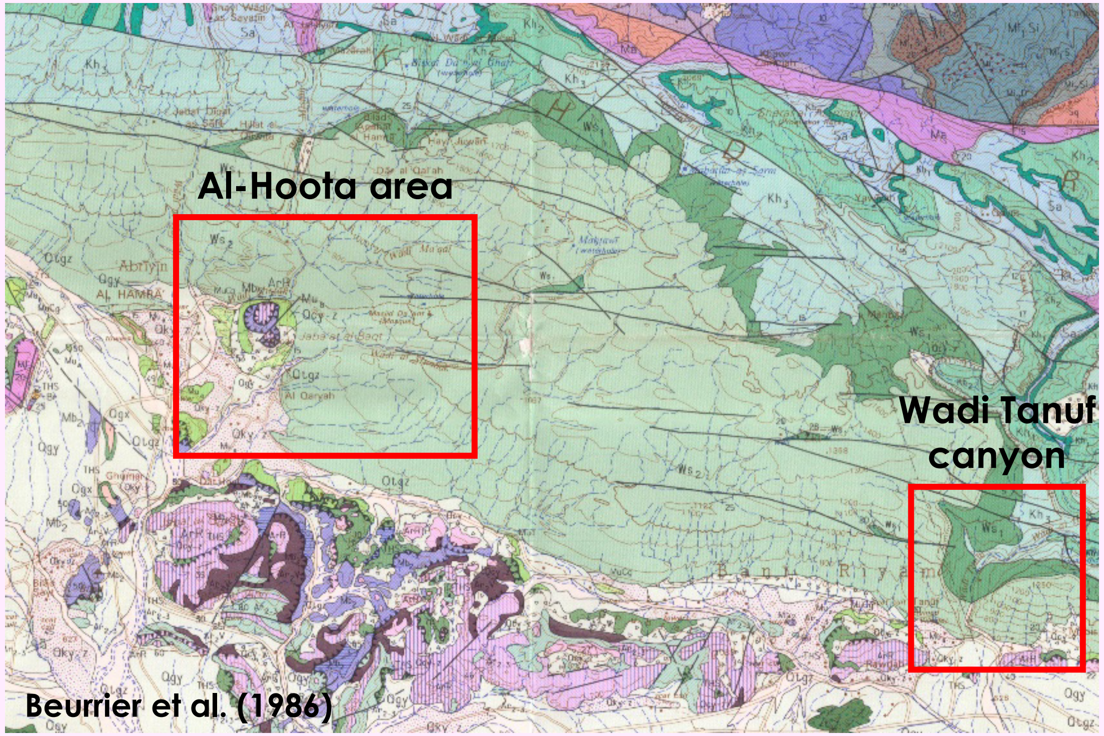
ESRI (2023)



Scharf et al. (2019)

# Geology of the area

- Southern flank of the **Jebel Akhdar dome**
- Mesozoic (Tithonian – Cenomanian) shallow-water **limestone**
- Network of narrow and sometimes meandering **canyons**



Beurrier et al. (1986)

# Main goals

- **Understanding canyons evolution**
    - Formation processes
    - Processes that oversaw their deep incision
    - Deformation mechanisms

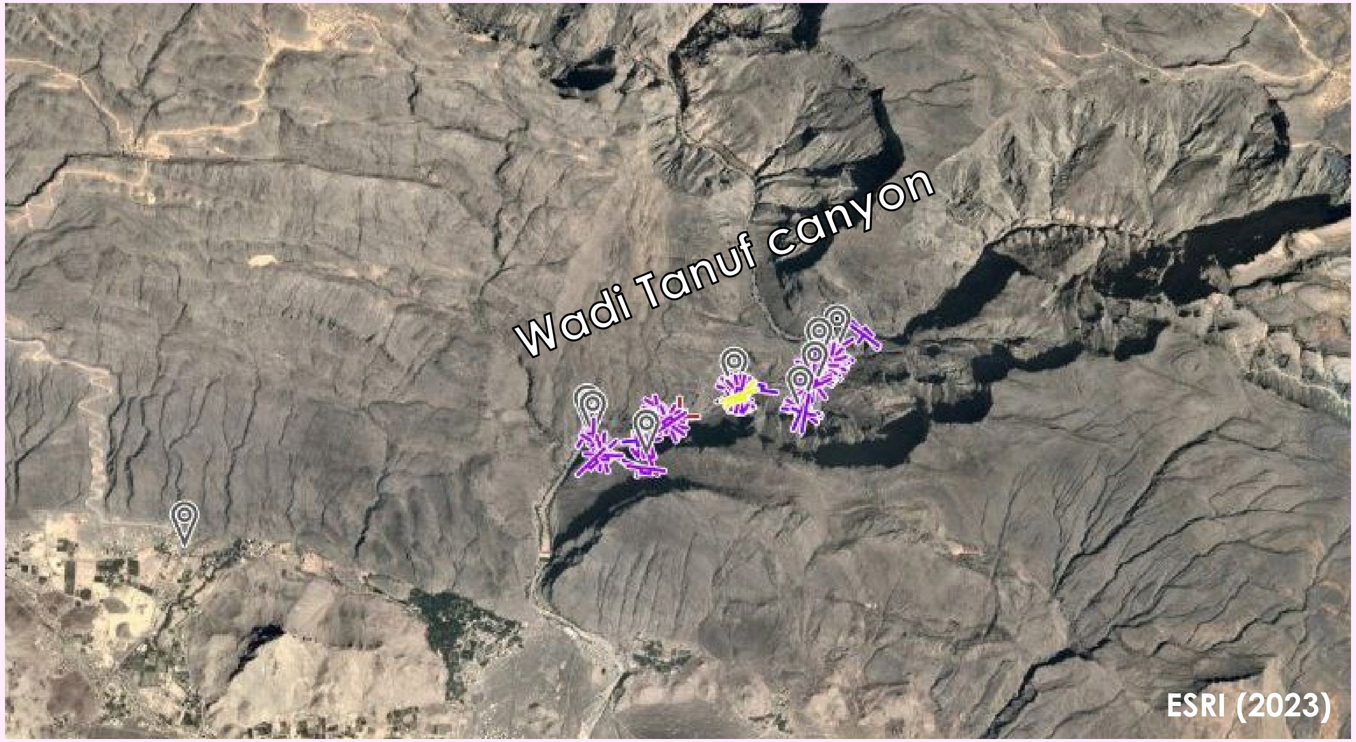
# Methodologies

- **Multidisciplinary approach**
  - Remote sensing
  - Geomorphometry
  - Field survey
  - Structural analysis

- **Software**
  - QGIS
  - Google Earth ™
  - Matlab (Topotoolbox, TAK packages)
  - Fieldmove Clino
  - Stereonet

# Wadi Tanuf Canyon

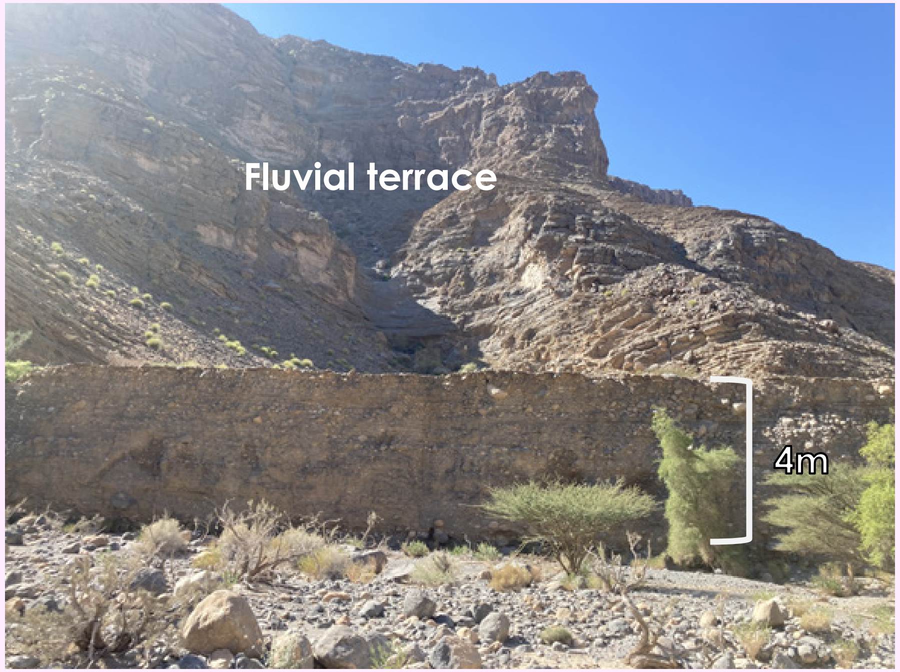
- Canyon width: ~ 200 m
- Canyon lenght: ~ 15 km
- Oolitic, limestone, bioclastic massive limestone (Upper Kahmah Gp.)
- Yellowish clayey limestone, bluish-black limestone (Middle Kahmah Gp.)

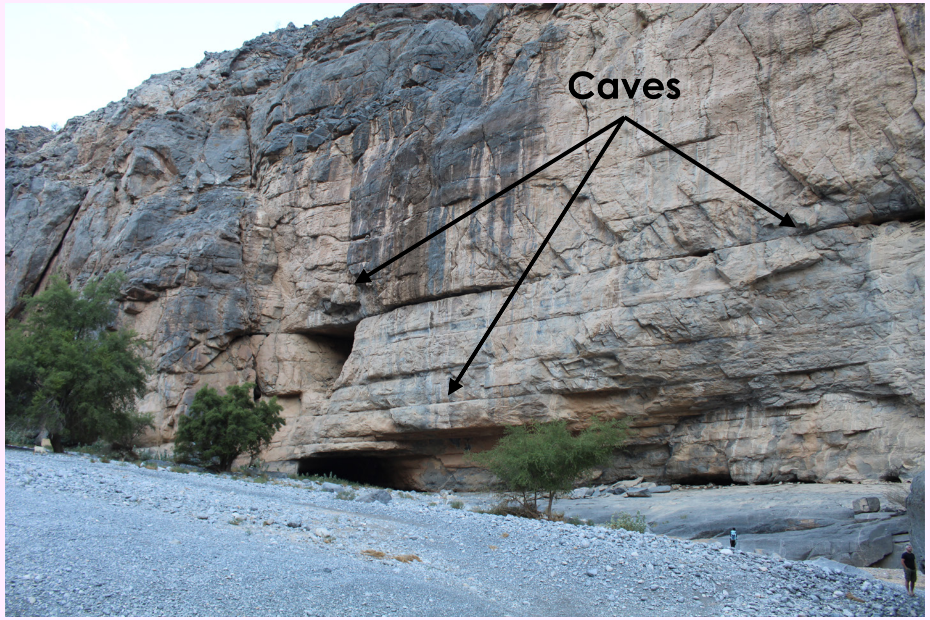


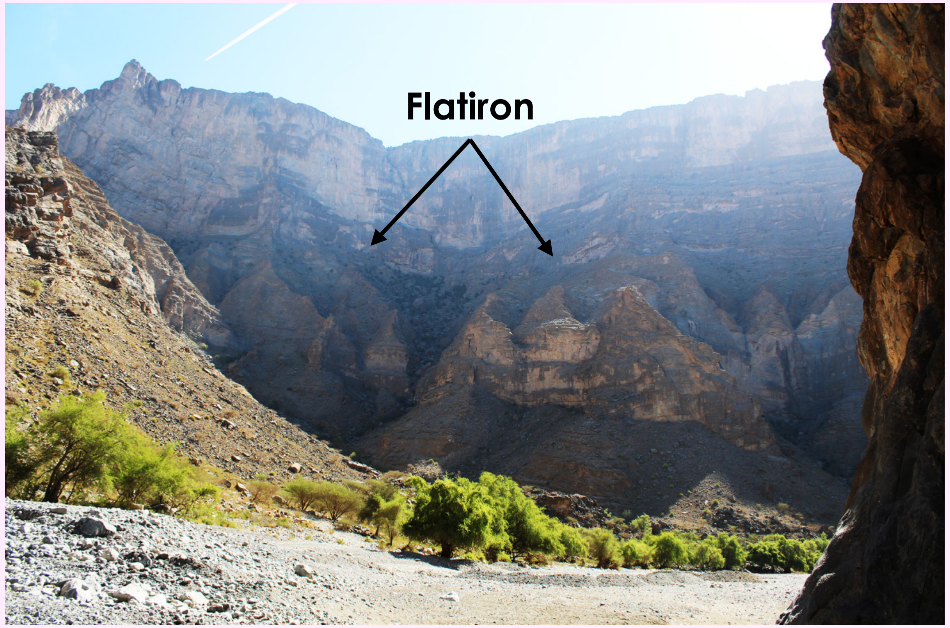
ESRI (2023)

# Wadi Tanuf Canyon

- Structural elements and landforms
- Karst landforms and features
- Fluvial landforms

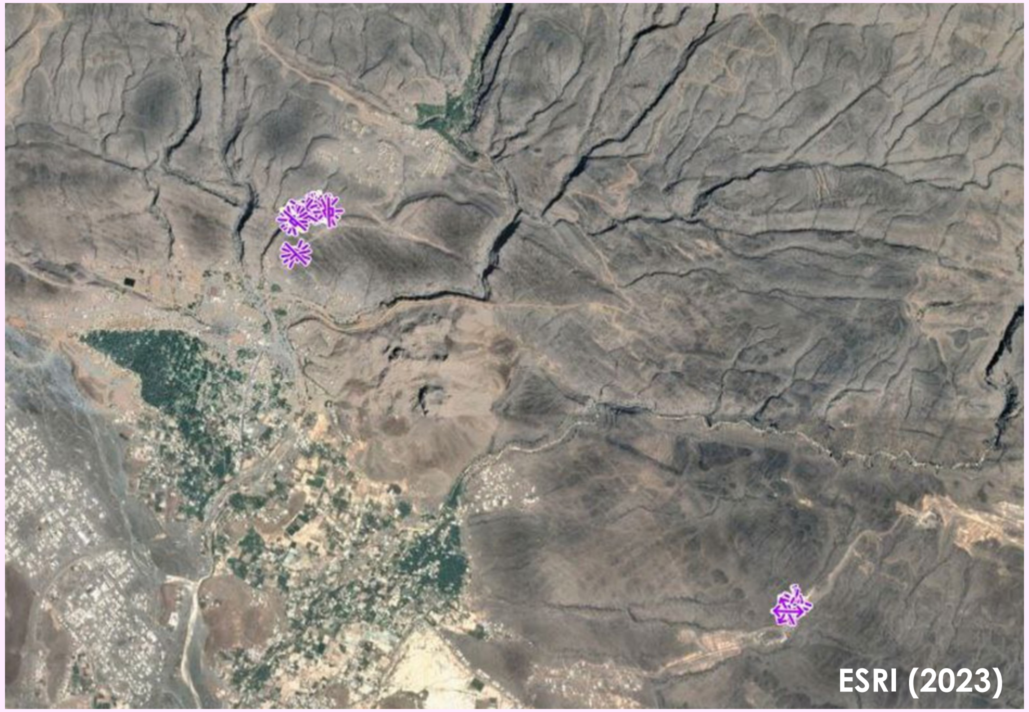






# Al-Hoota area

- Massive limestone with bentic foraminifera (Nath Fm.)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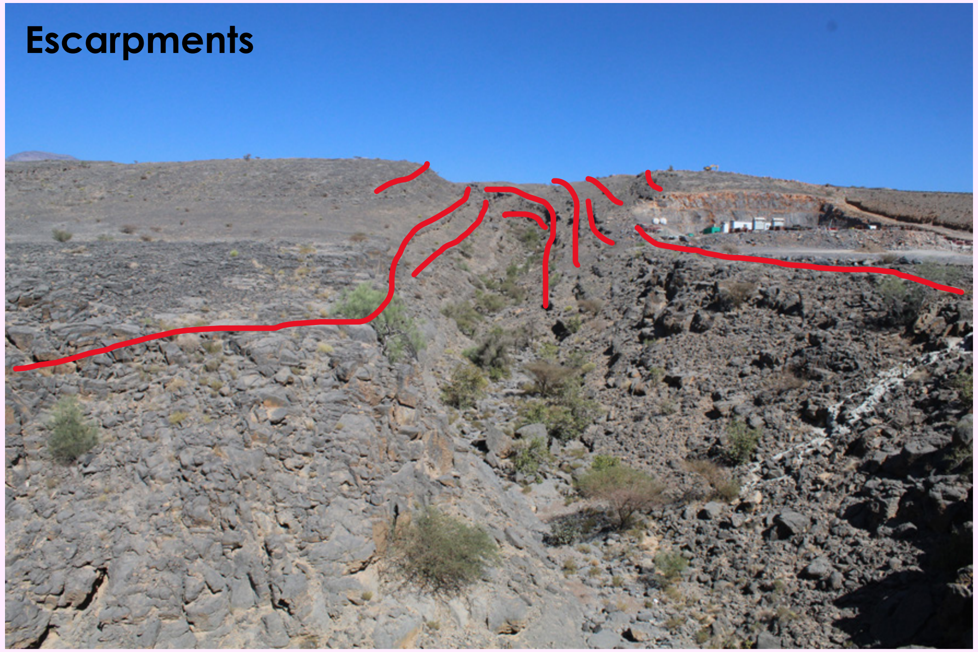
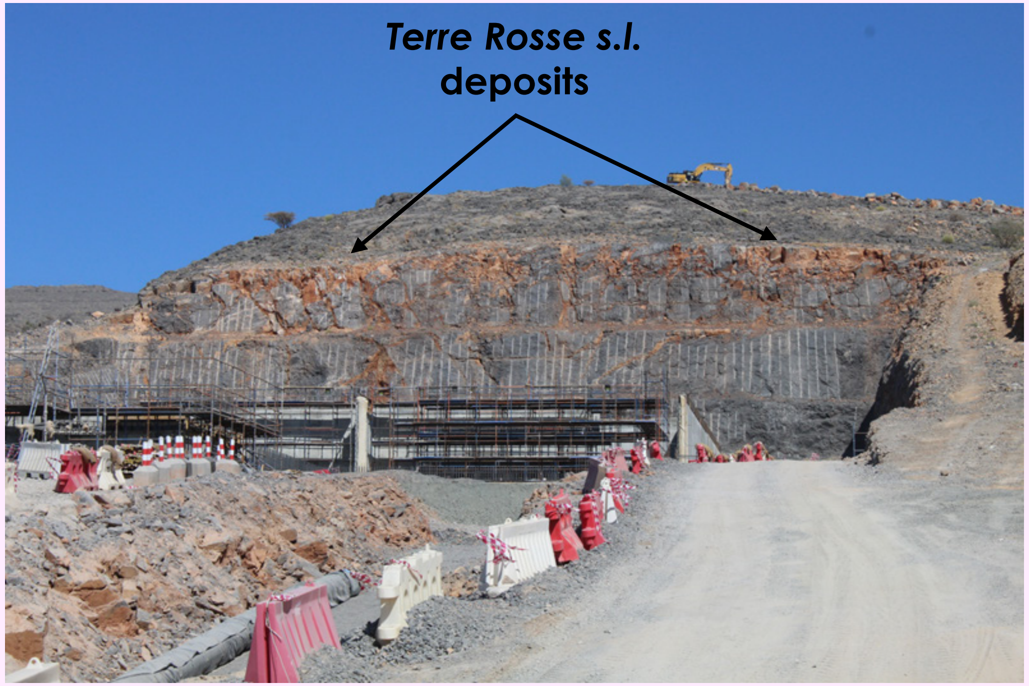
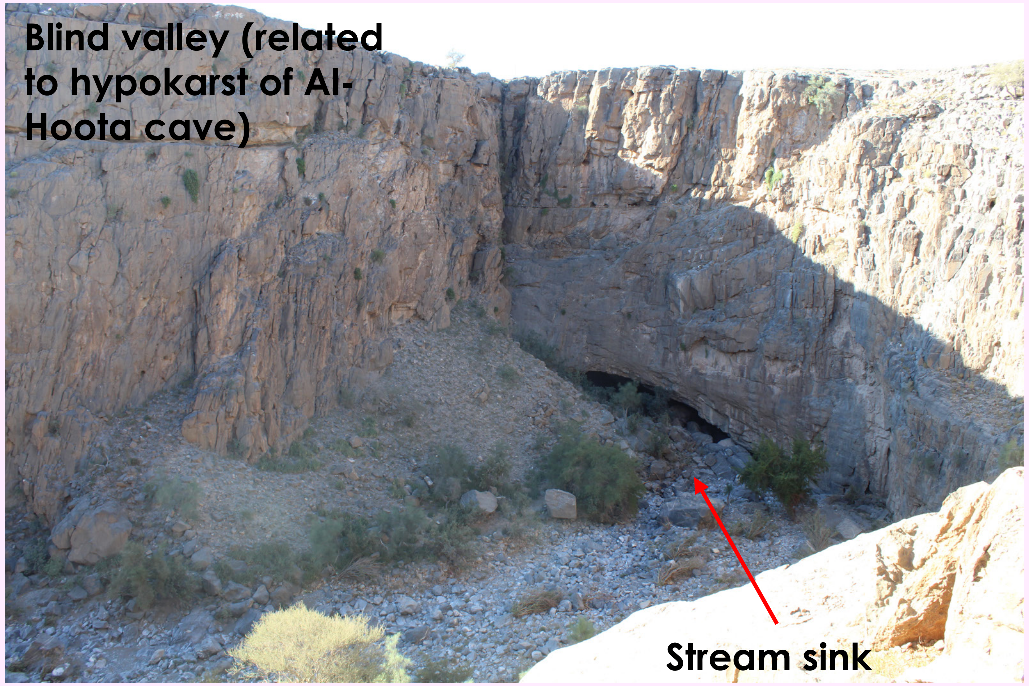


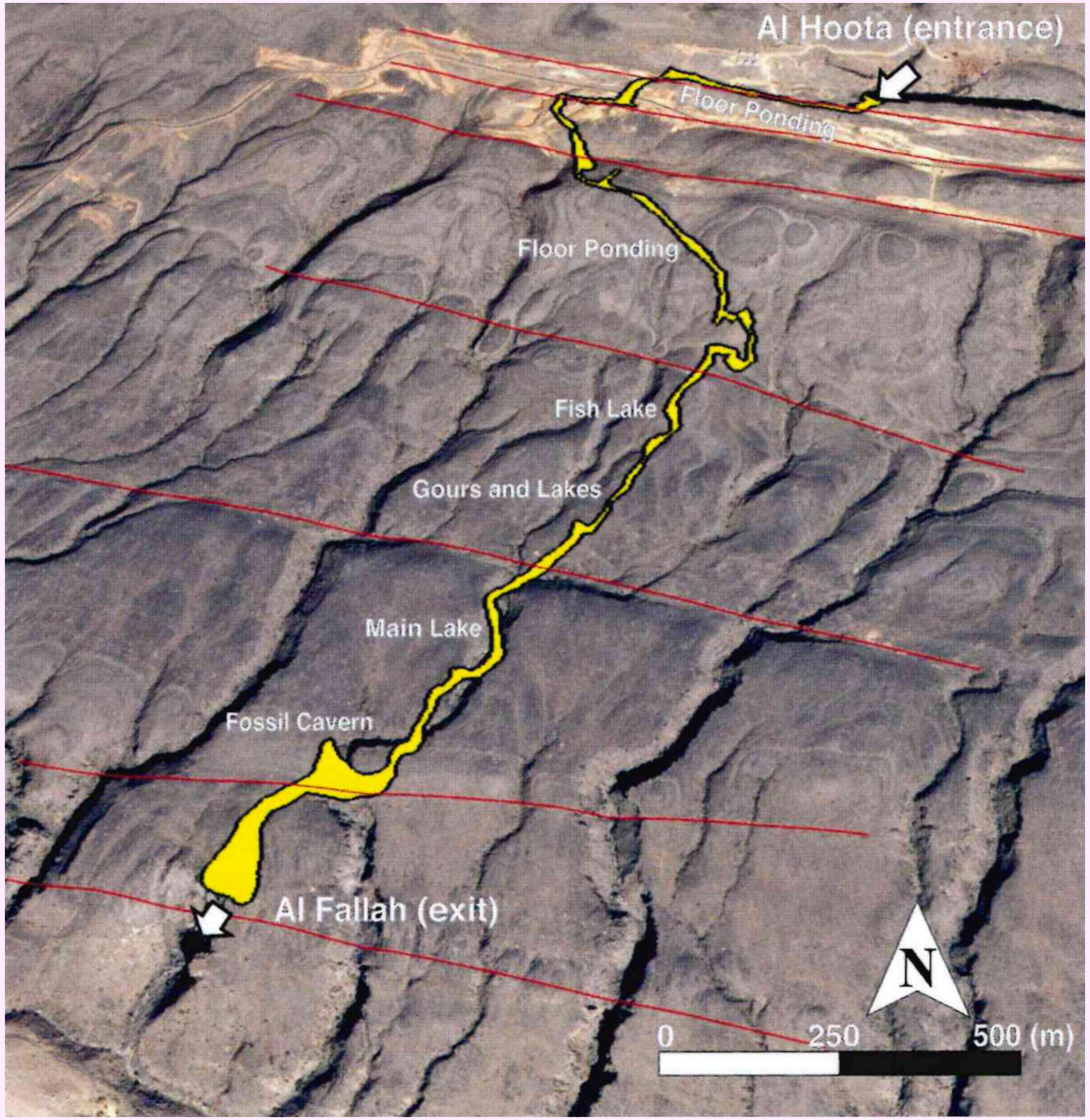
# Al-Hoota area

- Structural elements and landforms
- Karst landforms and features
- Fluvial landforms
- Gravitative elements and landforms





# Structural influence on cave development

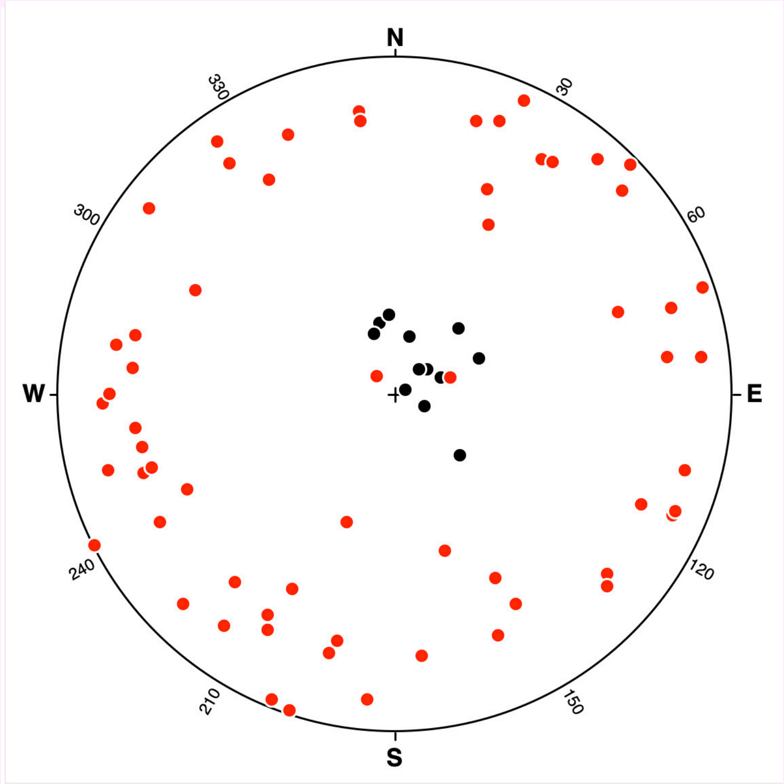


Modified after Al Kindi et alii (2023)

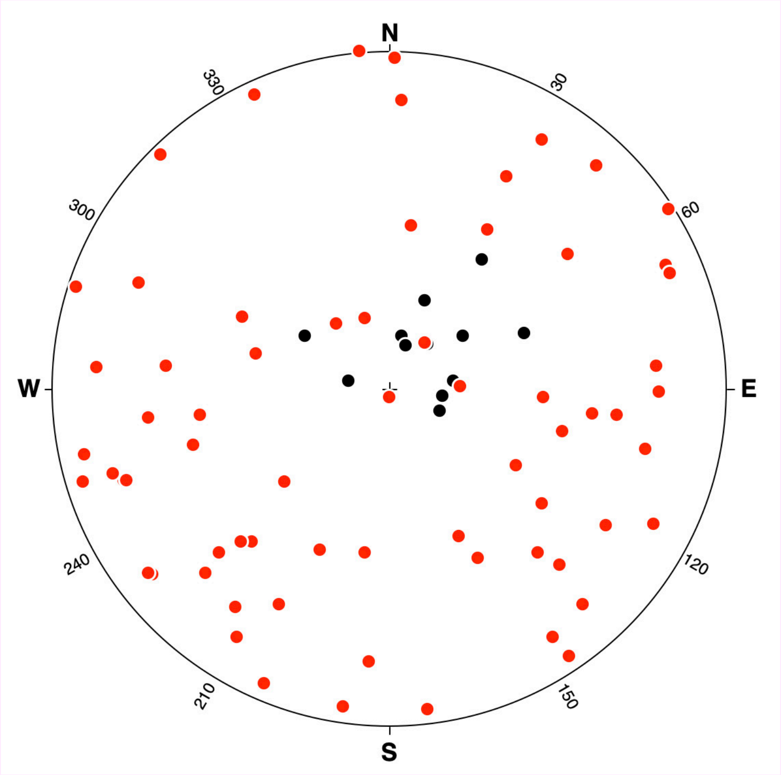
# Structural analysis

Analysis of field data retrieved

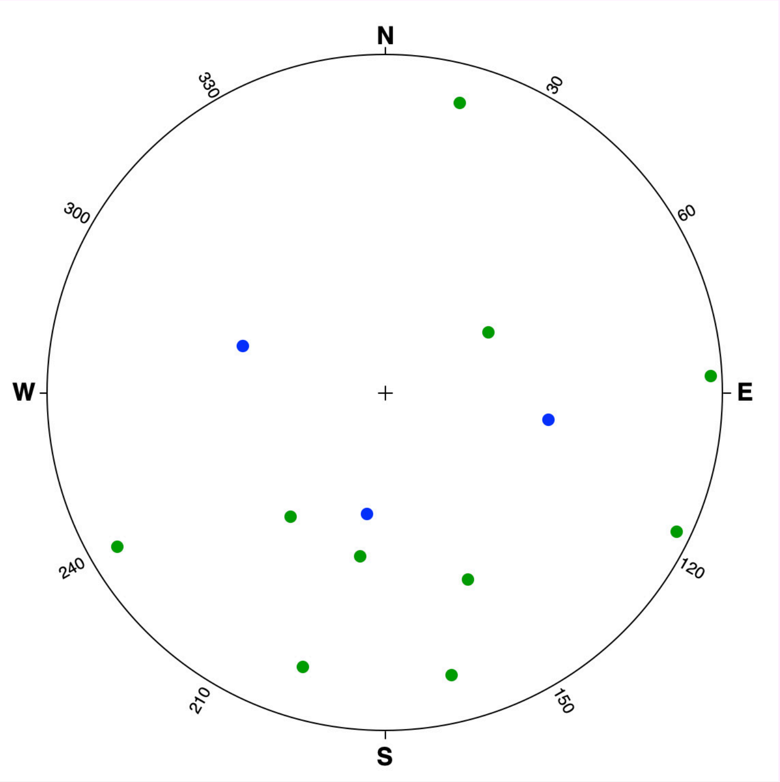
**Bedding = black** **Cleavage = blue**
**Joint = red** **Fault = green**



**Al-Hoota**
Vertical fracturing
De-tensioning?



**Wadi Tanuf**
More dispersal joint
Tectonic component?

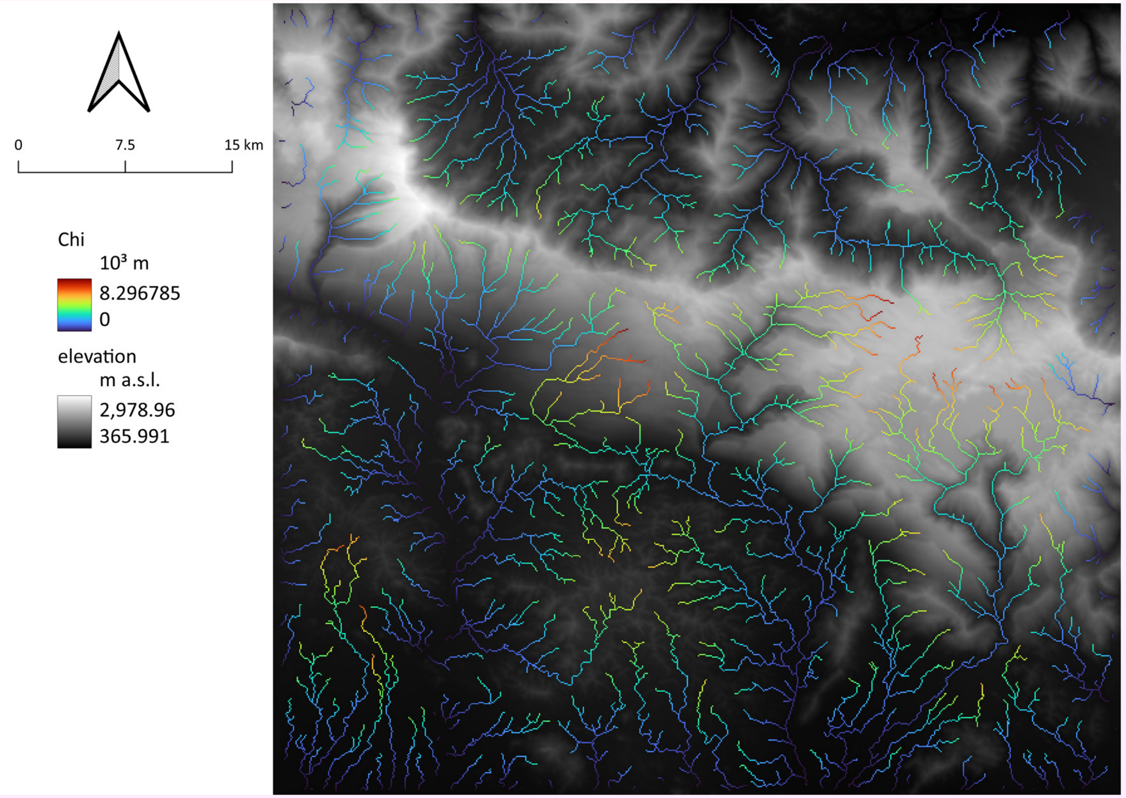


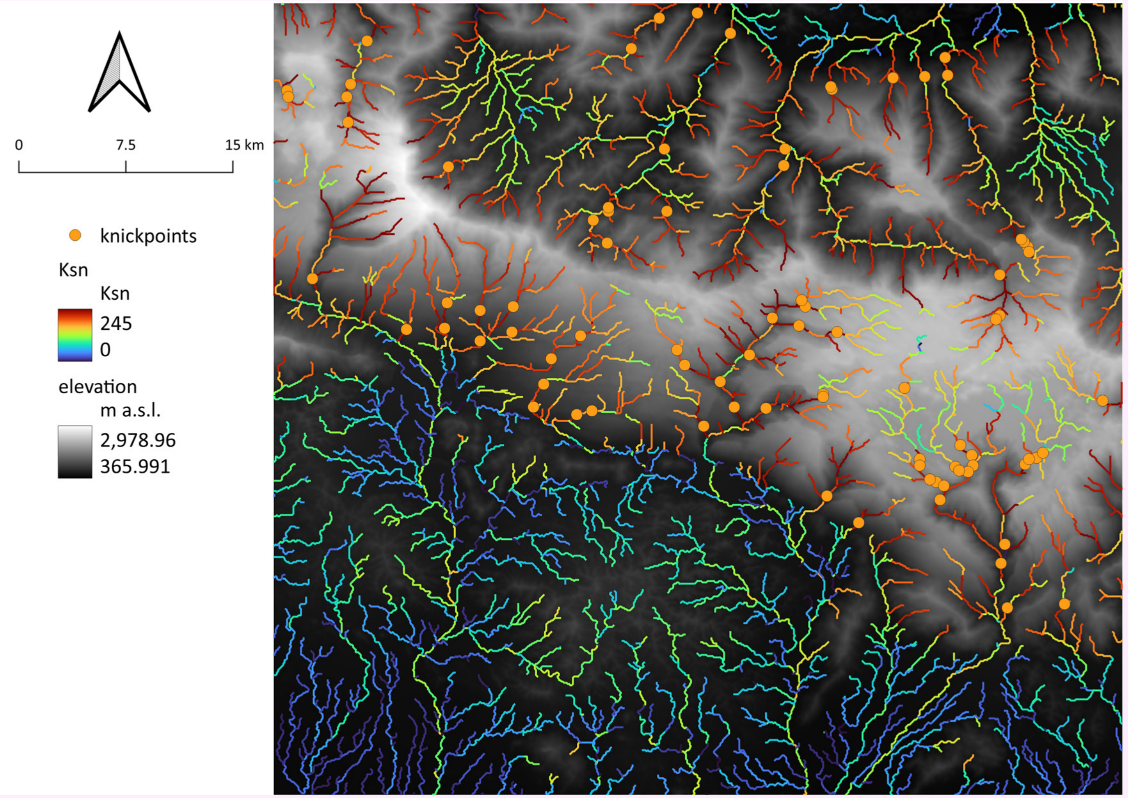
**Wadi Tanuf**
Tectonic component confirmed
Shear movement/thrust?

# Morphometrical analysis

**Drainage network analyses**

- Drainage divide stability (χ-mapping)
- Normalised steepness index ($k_{sn}$)
- Knickpoint detection





# Drainage divide stability (χ-mapping)

Differences in channel incision rates on opposite sides of the divide force the horizontal migration of drainage divides, leading to a disequilibrium.

Proxy for steady state drainage divides.

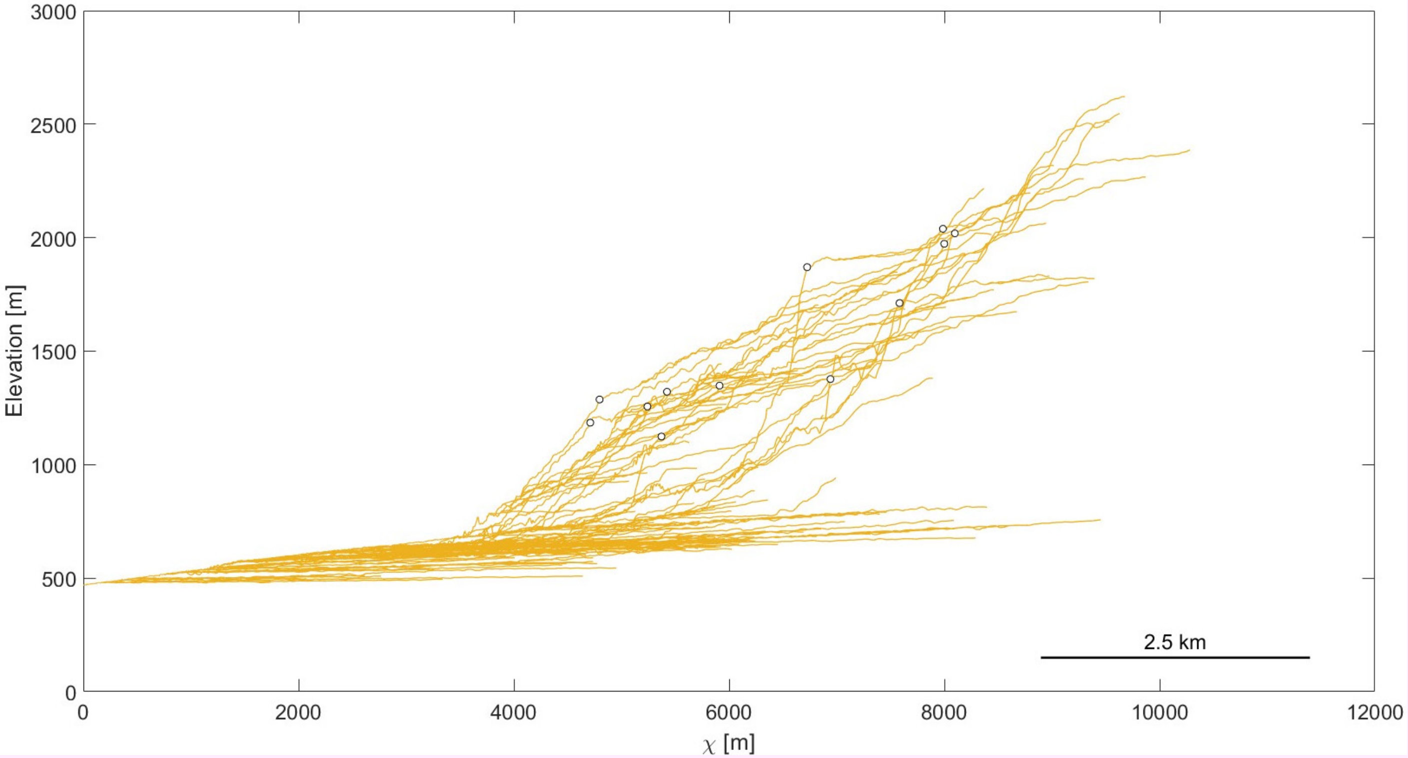
If streams on opposite sides of the drainage divide have different values of χ, the divide is in disequilibrium, resulting in horizontal migration.

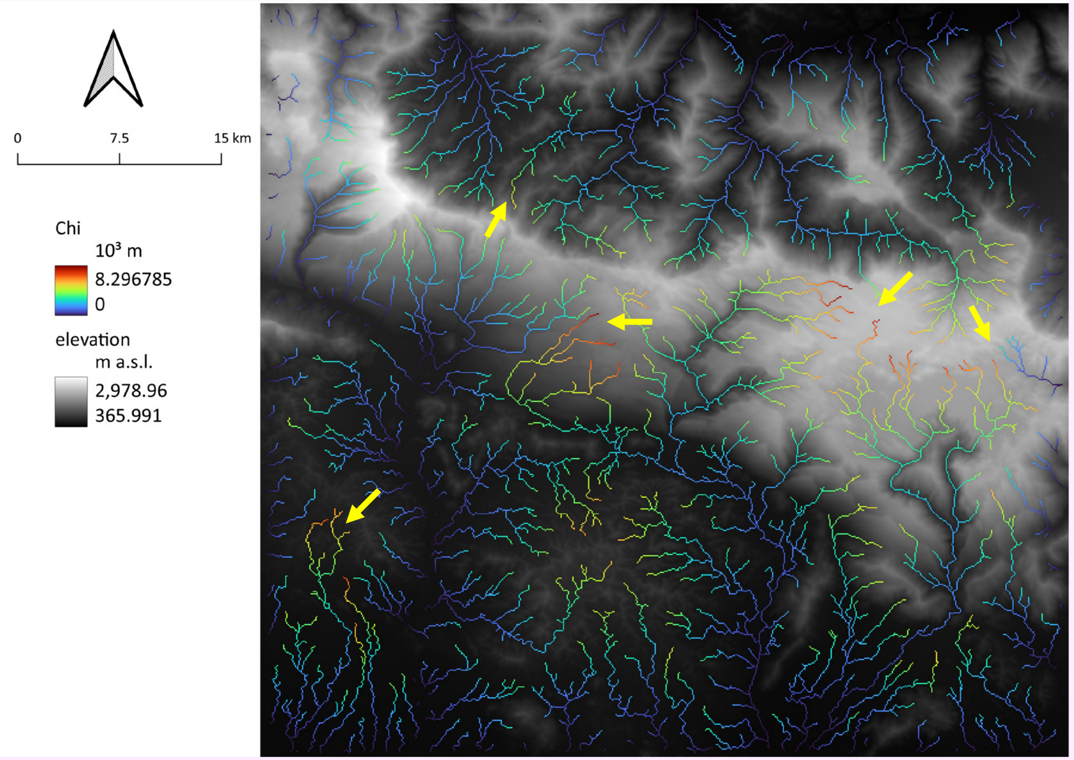
The drainage divide is shifted towards the drainage basin with lower χ values.

In order to re-equilibrate, the drainage divide is assumed to migrate in the opposite direction (towards higher χ values) in the future

(Perron & Royden, 2013; Willet et al., 2014; Forte & Whipple, 2018; Trost et al., 2020; Diercks et al., 2021)

$$\chi = \int_{xb}^{x} \left(\frac{A_0}{A(x)}\right)^{\frac{m}{n}} dx$$





# Normalised steepness index & knickpoint detection

## Normalised steepness index ($k_{sn}$)

Measure for tectonically driven deviations in river profiles as it varies with spatial differences in rock uplift, climate or substrate lithology.

The $k_{sn}$ is only constant in steady-state longitudinal stream profiles, hence elevated $k_{sn}$-values indicate temporal or spatial variations of either rock uplift (U) or erosion (K) within the stream profile

(Wobus et al., 2006; Kirby & Whipple, 2012; Diercks et al., 2021)

$$k_s = \left(\frac{U}{K}\right)^{\frac{1}{n}} \rightarrow k_{sn} = S*A^{-\theta_{ref}}$$

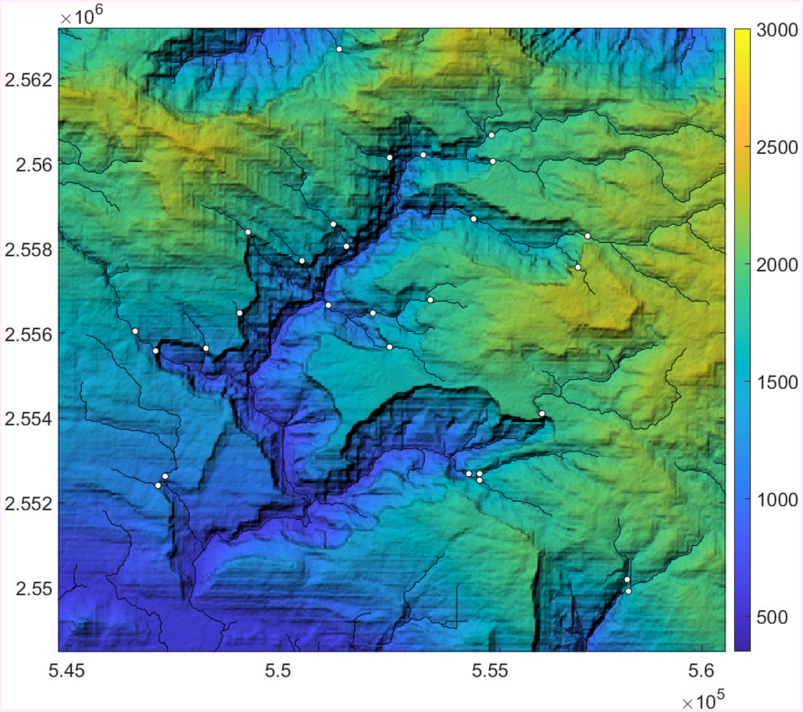
## Knickpoint detection

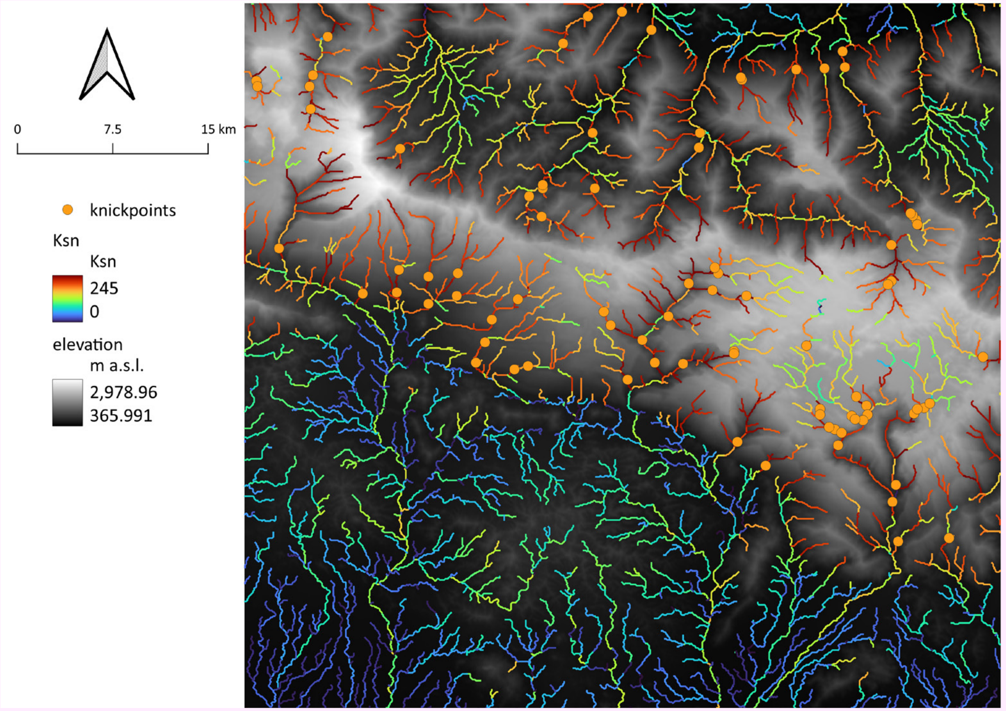
Part of a river or channel where there is a sharp change in channel slope.

Knickpoints reflect different conditions and processes on the river, often caused by previous erosion.

Check whether a knickpoint is a break-in slope knickpoint (accelerated erosion or bedrock uplift) or a vertical-step knickpoint

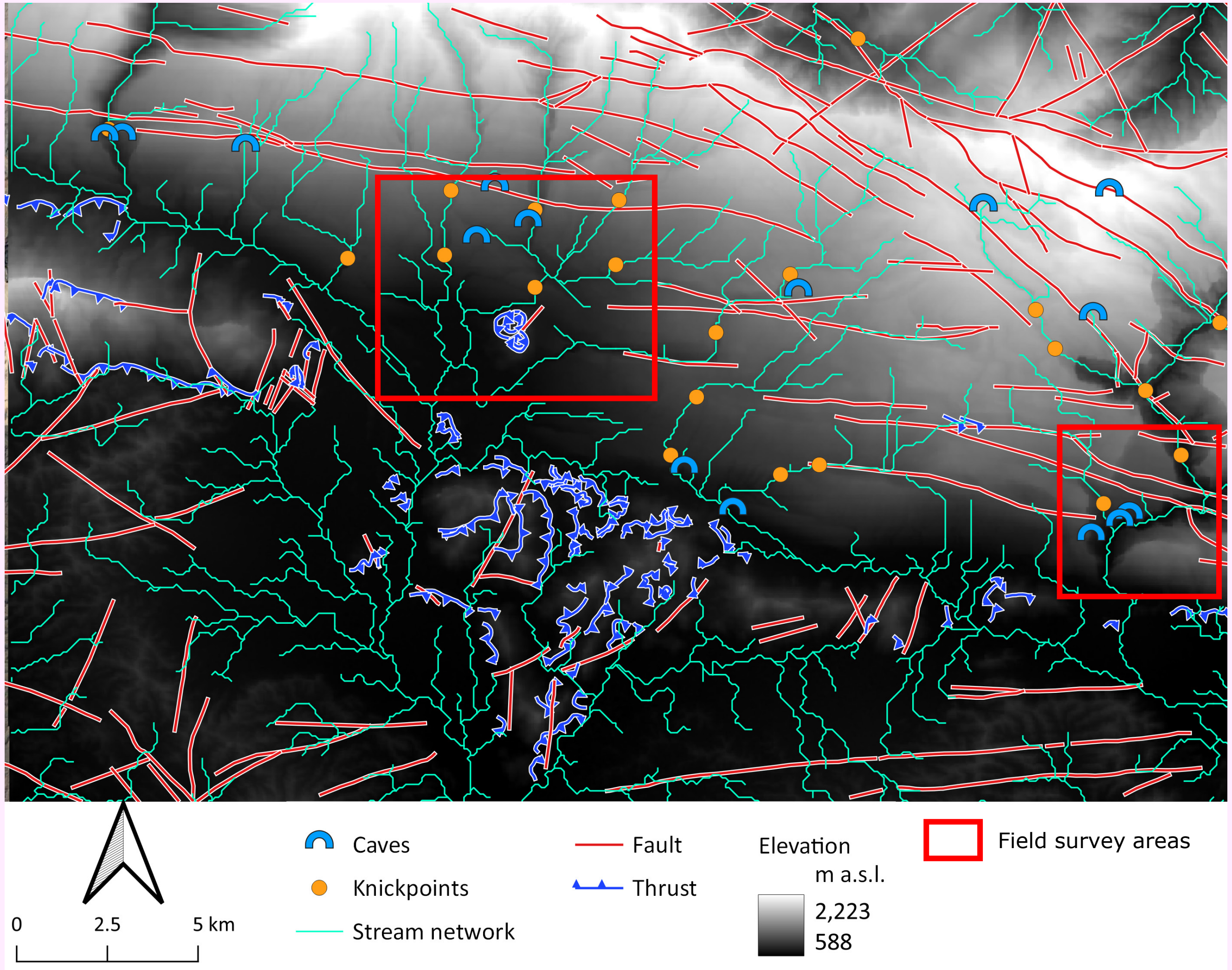
(Whipple & Tucker, 1999; Diercks et al., 2021; Clementucci et al., 2023)





# Conclusions

- Identification at **various scales** of:
  - A group of **joint and fault** sets
  - **Morphostructural lineaments**
  - Inactive **karst features** (both in the epikarst and in the hypokarst)
- Evidence for canyons **overdeepening** respect to the present-day watershed basins
- **Reconstruction** suggests:
  - Ancestral action of **karst dissolution** along the structural weaknesses (along the phreatic zone)
  - This led to the formation of a **complex network of conduits**
  - Later exhumation and occasional reworking by **fluvial processes** and linear erosion
  - Processes dynamic: tuned by **(pre-) Quaternary climatic changes**



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