GEOMORPHOMETRY 2021
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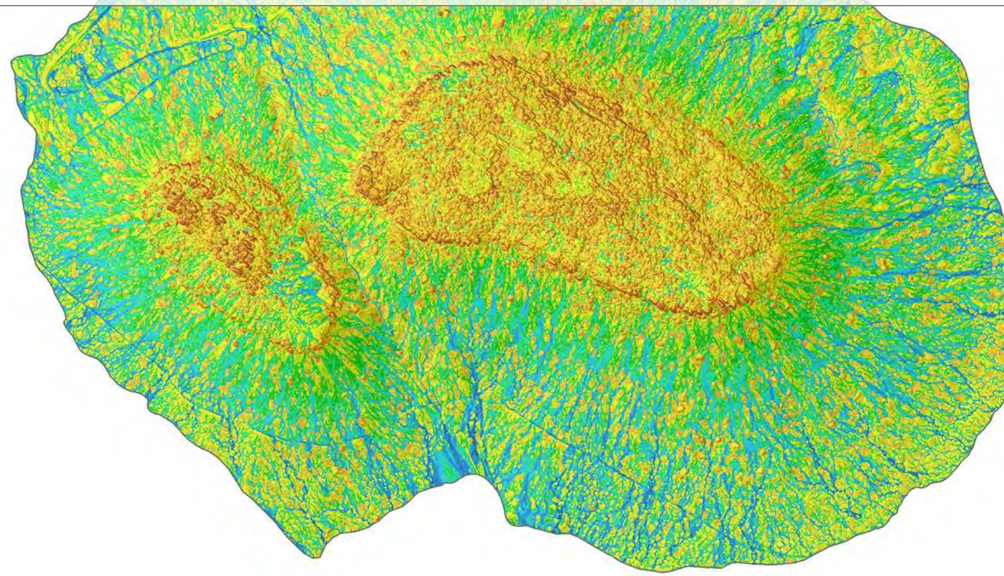
High-resolution geomorphometry

A tool for better understanding the genesis and contemporary processes in erosional sandstone landscapes



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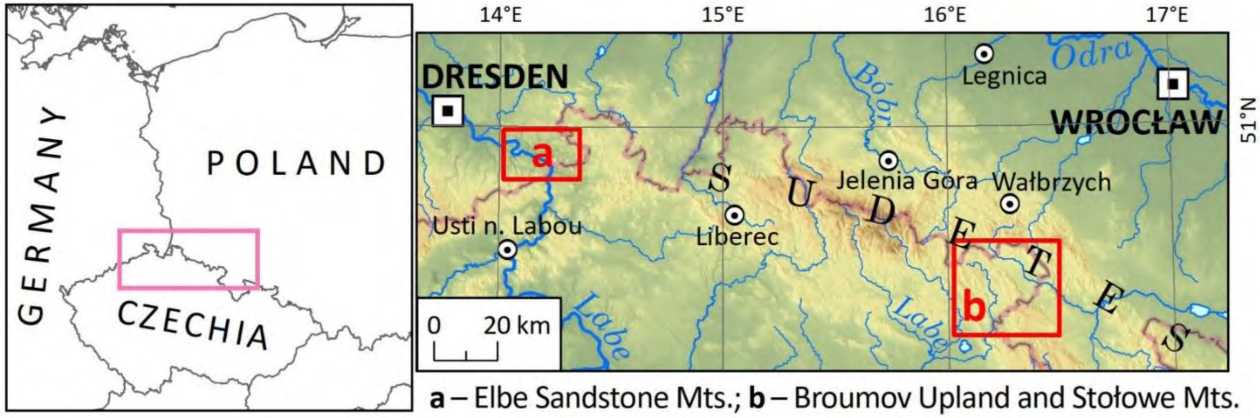
Introduction

- Sandstone landscapes of Central Europe represent extreme terrain ruggedness due to presence of specific landforms such as dissected plateaus, isolated tabular hills, canyons, joint-controlled cleft-and-valley systems and smaller convex forms like boulders or hoodoos.
- For many years these areas hampered quantitative relief studies and remained outside of the geomorphological research mainstream.
- The last decade have brought a gradual growth of scientific interest in sandstone geomorphology, mainly due to development of high-resolution LiDAR-based DTMs.

Today's topics

1. Selected **issues** concerning contemporary Central European **LiDAR data** of nationwide availability.
2. Examples of using the **morphometric indices in geomorphological research of sandstone areas**:
    - morphometric features of tabular hills
    - morphological diversity of cleft-and-valley systems
    - drainage connectivity patterns

Transboundary location of study areas

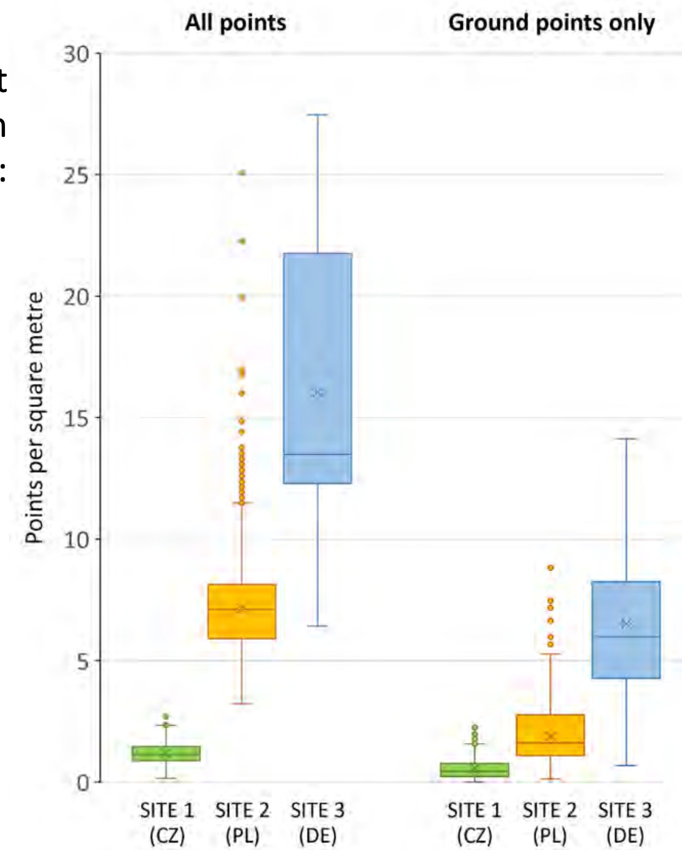


a – Elbe Sandstone Mts.; **b** – Broumov Upland and Stołowe Mts.

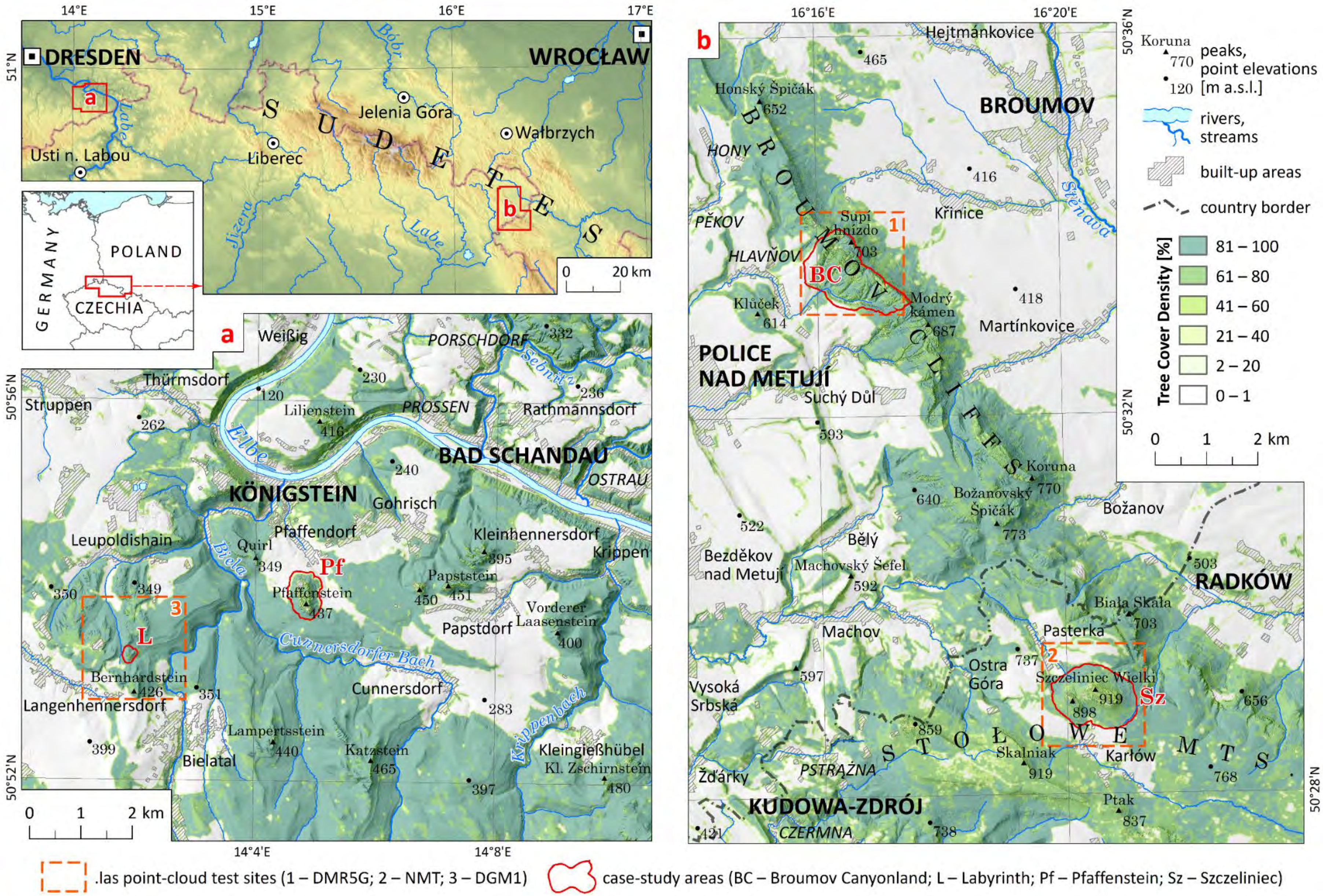
Use of multiple LiDAR datasets of different qualities <u>(Critical issue no. 1)</u>

Country	Czechia	Poland	Germany (Saxony)
Digital terrain model (DTM) name (acronym)	Digitální model reliéfu České republiky 5. generace **(DMR5G)**	Numeryczny Model terenu **(NMT)**	Digitale Geländemodell **(DGM1)**
DTM points spatial distribution	irregular	regular (1x1 m grid)	regular (1x1 m grid)
Declared vertical accuracy (mean error) [m]	0.3	0.15	0.15
<u>Declared</u> point-cloud density [pts/m^2]	1.6	4–6	10

Actual point density within study sites:

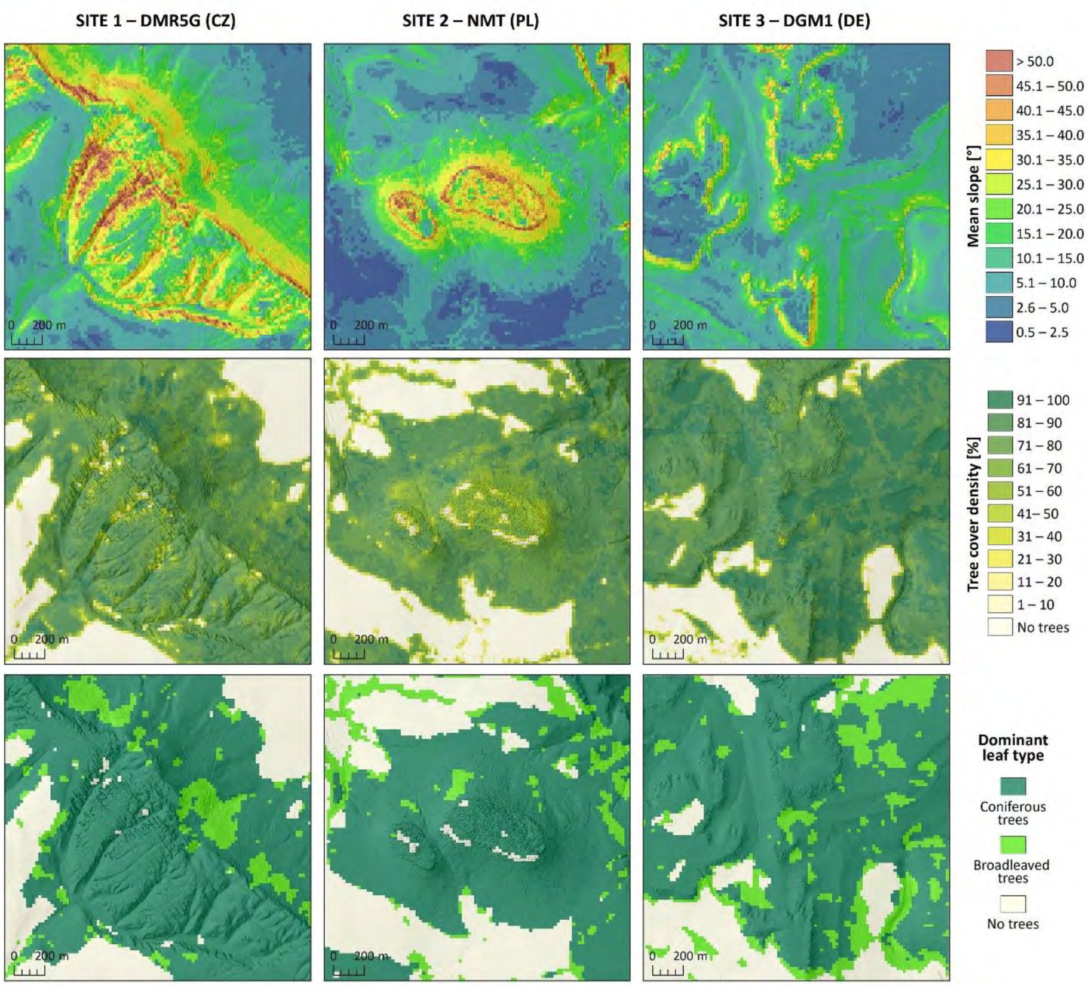


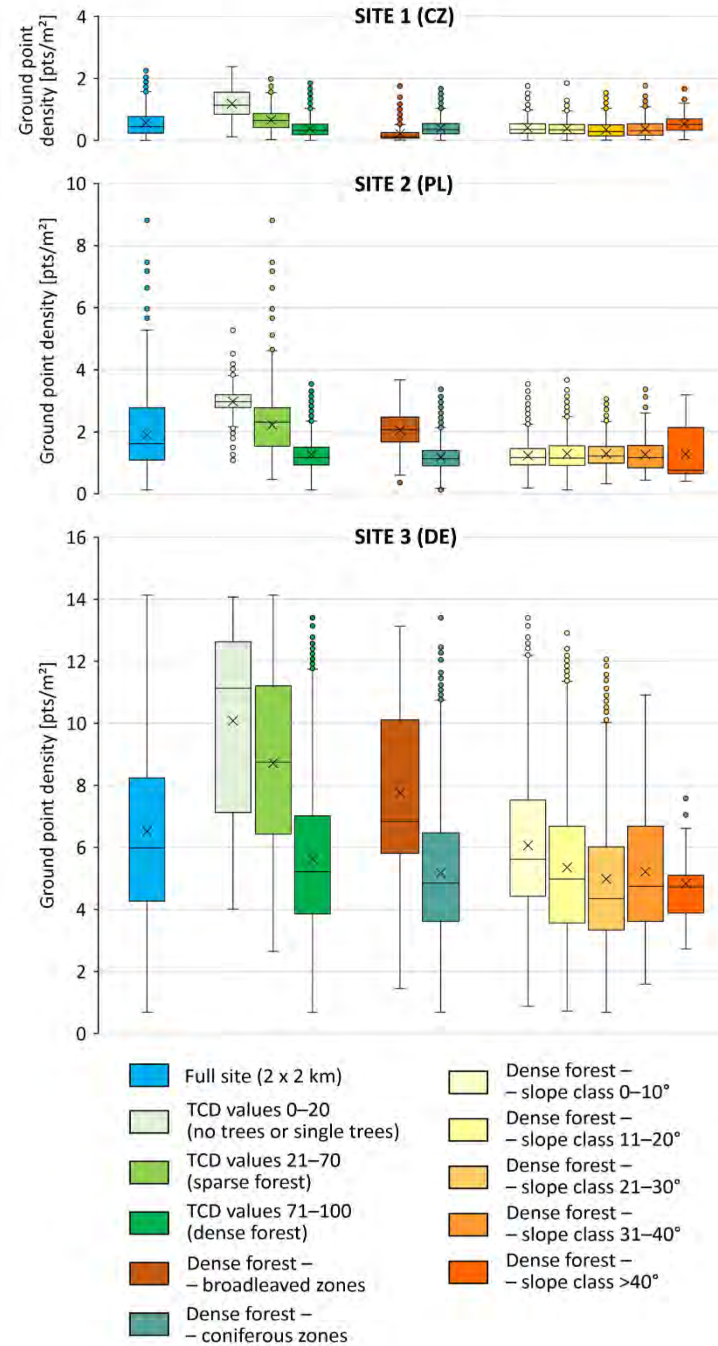
Critical issue no. 2: LiDAR data qualities vs land cover conditions



Critical issue no. 2: LiDAR data qualities vs land cover conditions

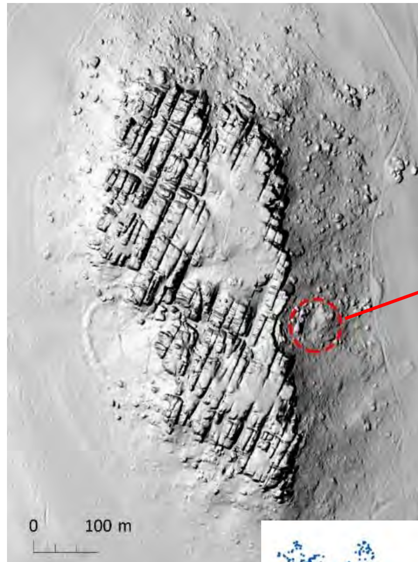
In dense forest the ground point density can be two times lower comparing to the open space (e.g. pasture, grassland).
Forest areas of predominantly broad-leaved species are of higher ground point density if ALS data are acquired during leaf-off conditions.

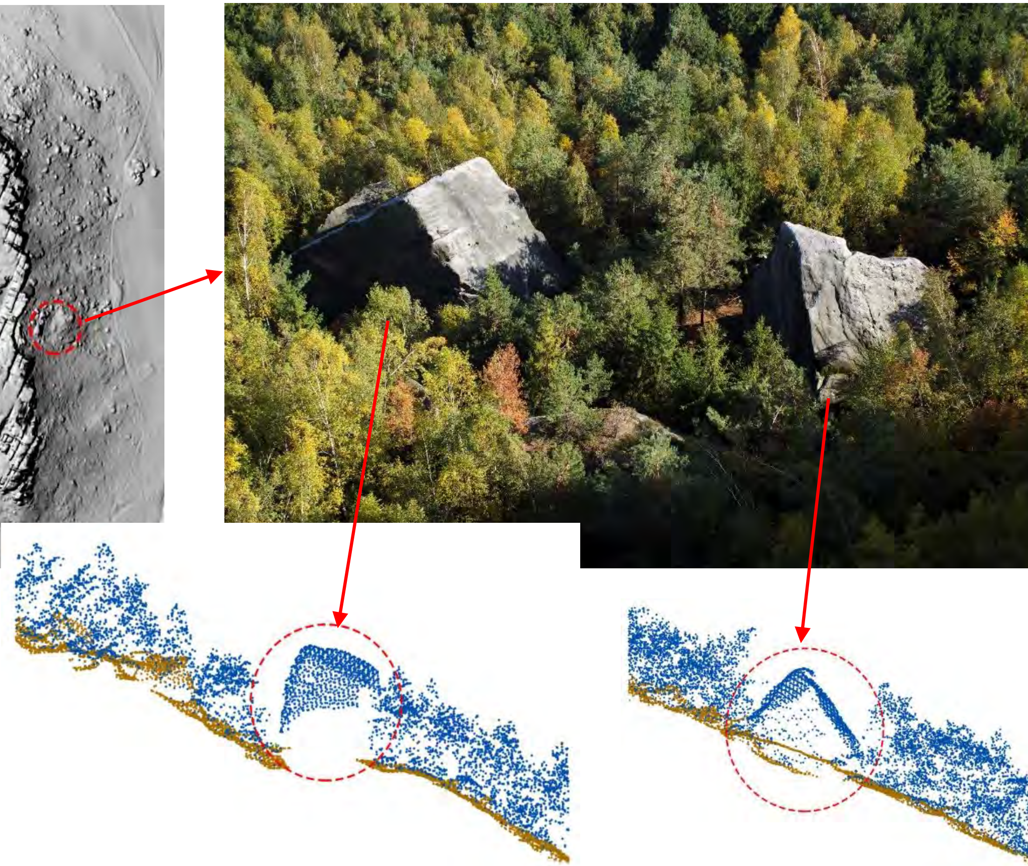


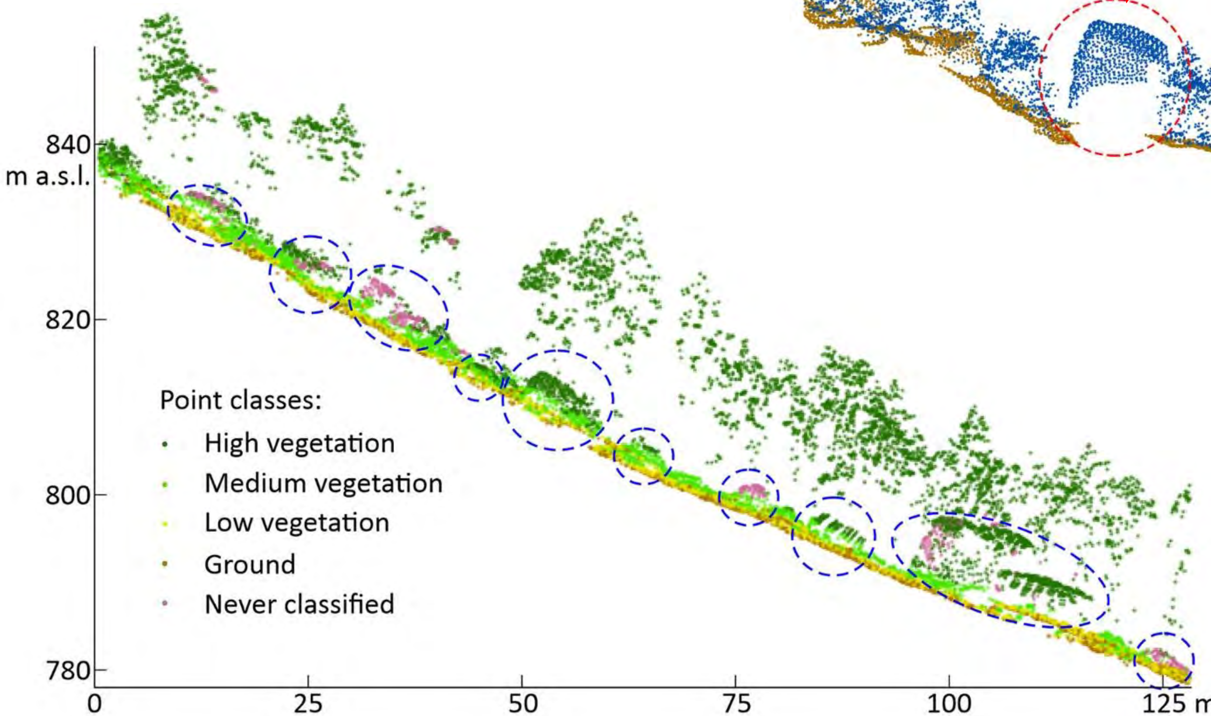


Critical issue no. 3: Landforms removed by point classification errors

Right: Klamotte and Pfaffenhütchen – huge blocks located on the slopes of the Pfaffenstein mesa – misclassified as non-ground elements in German LiDAR dataset.





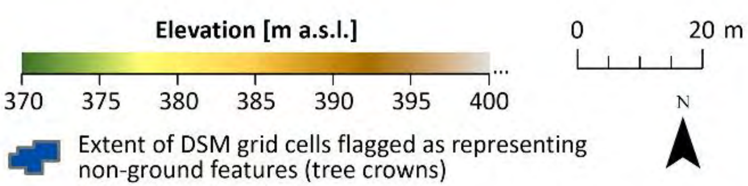


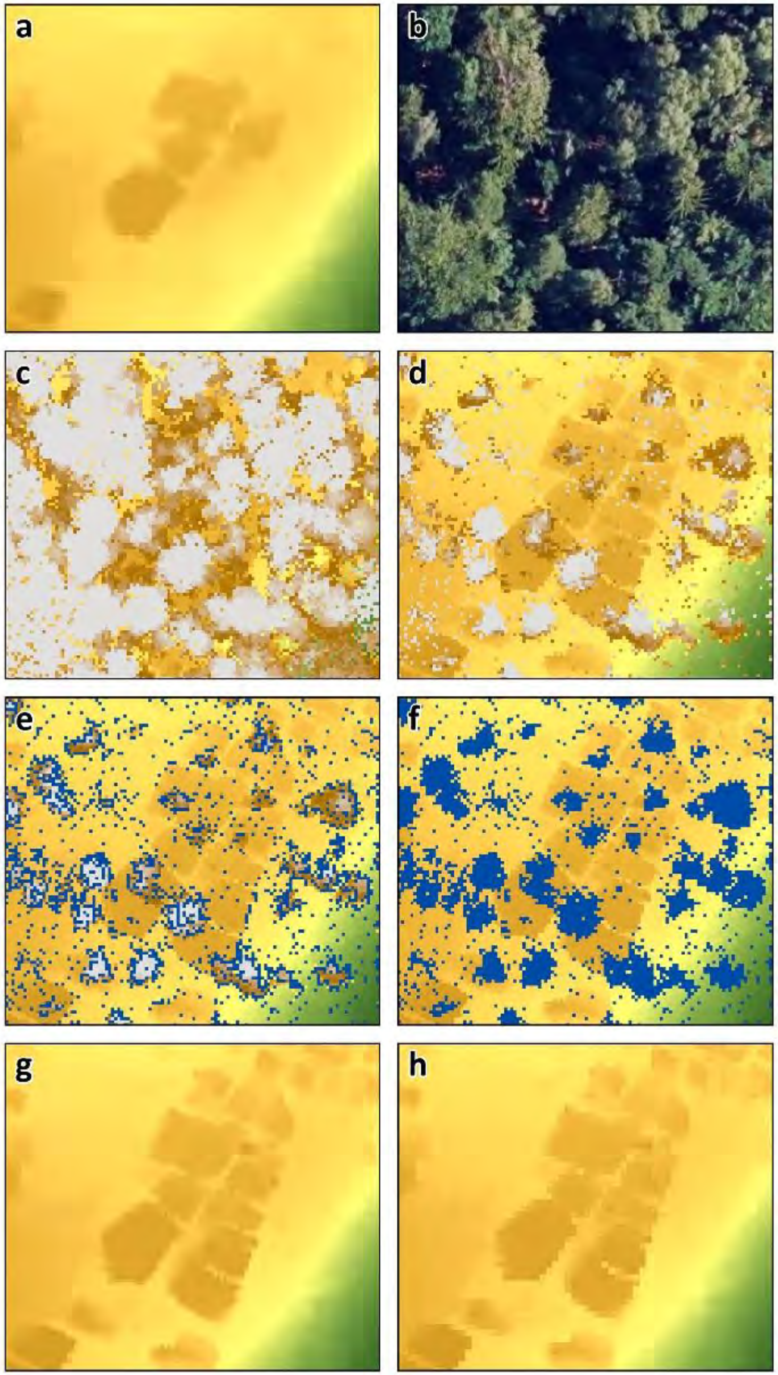
Left: Numerous boulders on slopes of the Szczeliniec Wielki (Stołowe Mts., Poland) mesa classified as elements of vegetation (high or medium).

Solving the critical issue no. 3…
DTM upgrade based on available .las datasets

Example of DTM generation workflow using semi-automatic filtering of the DSM derived from the high-density point cloud – Labyrinth hill, Elbe Sandstone Mts., Germany:

a – visualization of the reference DGM1 DTM;
b – orthophoto;
c – visualization of DSM (result of binning with use of maximum elevations setting), grey colour stands for tree crowns;
d – visualization of DSM (result of binning with use of minimum elevations setting) including unfiltered cells representing non-ground elevations;
e – results of automatic filtering stage, note that all single “noise” cells have been removed (marked by blue colour);
f – final results of manual filtering stage
g – interpolated DTM of 0.5 x 0.5 m resolution
h – resampled DTM of 1 x 1 m resolution.

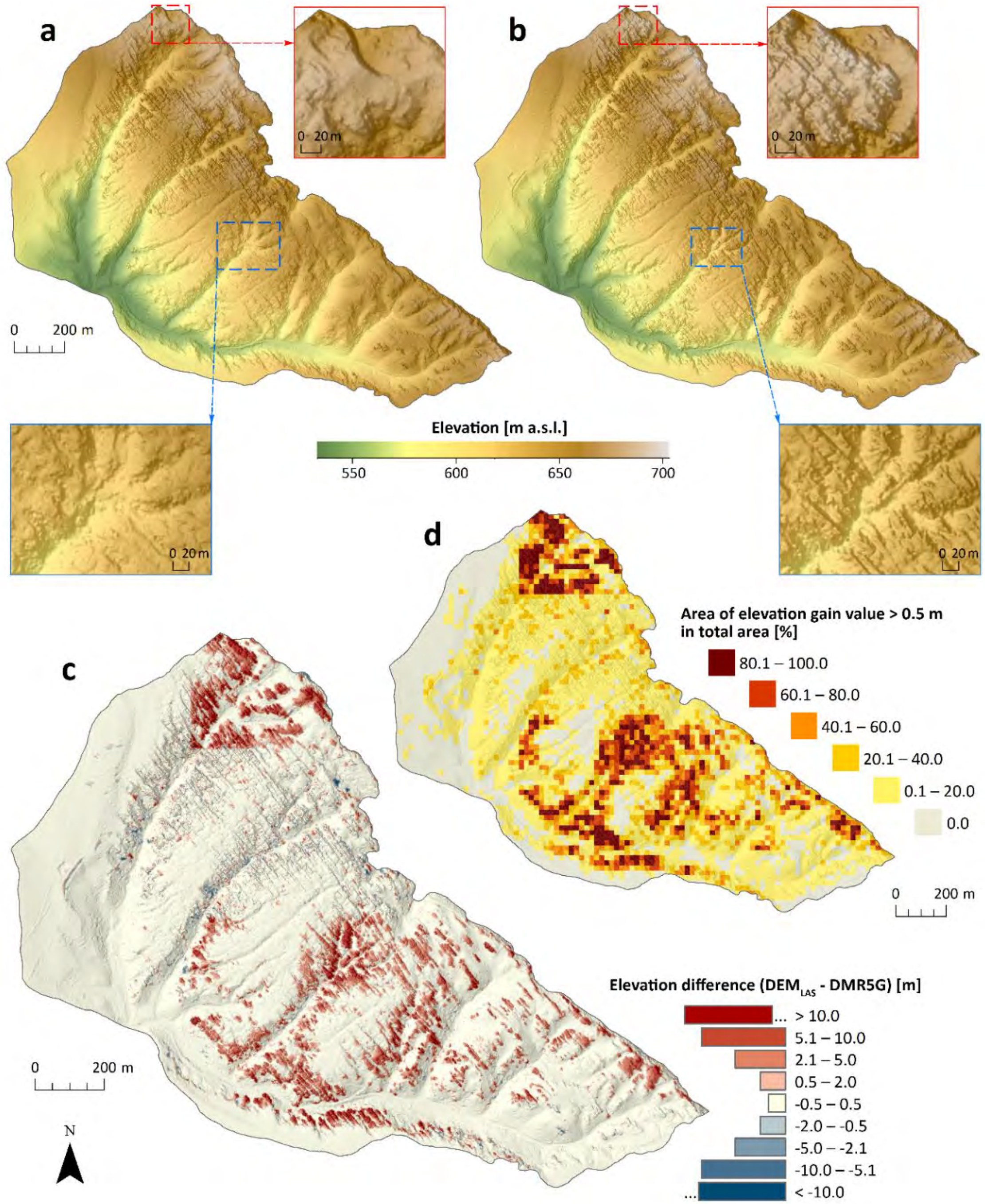


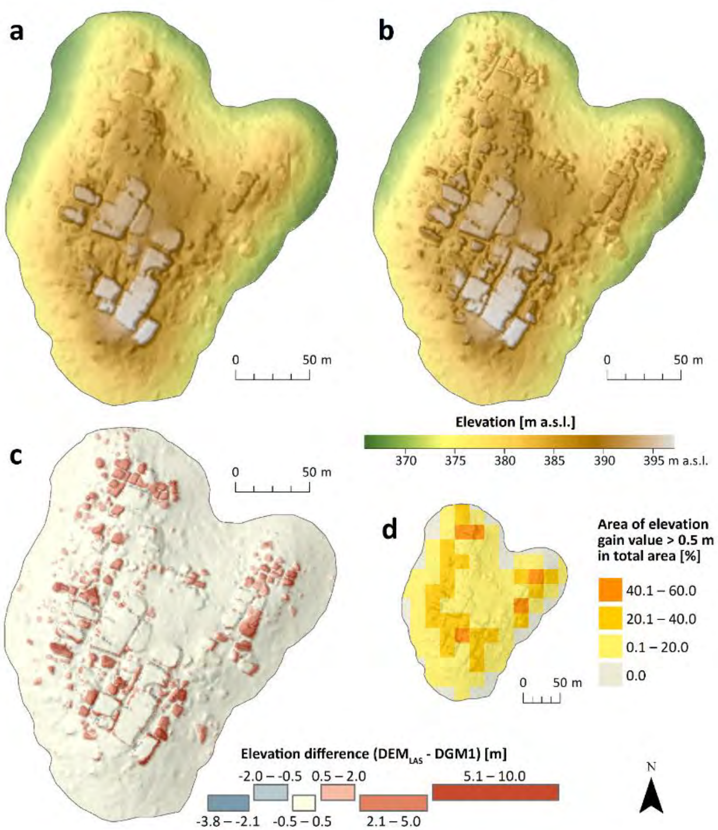


Results of semi-manual DTM upgrade – worth the effort!

Visualization of: **a** – ready-to-use DTM product, **b** – DTM derived from point cloud data, **c** – DEM of Difference, **d** – elevation gain index

Right: canyonland of Broumov Cliffs cuesta backslope (Czechia)
Below: Labyrinth hill (Elbe Sandstone Mountains, Germany)





Useful morphometric indices

Topographic Wetness Index (TWI) (Beven and Kirkby, 1979), has been recently used **to model spatial distribution of potential surface drainage patterns and to detect flow discontinuities**; TWI is defined as

$$TWI = ln\frac{SCA}{tan\,\beta}$$

where SCA is the specific catchment area calculated using the Multiple Flow Direction method (Quinn et al., 1991) and β is the local slope in degrees.

Terrain Ruggedness Index (TRI) (Riley et al., 1999), which was used as **an indirect measure of boulder cover density**:

$$TRI = \sqrt{\frac{1}{n+1}\sum_{i=1}^{n}(z_c - z_i)^2}$$

where z_c is elevation in the cell for which we perform the calculation (central cell), z_i is elevation in the neighbouring cell and n is number of neighbouring cells.

Morphometric Protection Index (MPI) is an indicator of positive openness (Yokoyama et al., 2002; Prima et al., 2006), obtained by calculating maximum angles of inclination (ψ) for eight compass directions (0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°) from the central cell to the cell at given horizontal distance and taking the mean:

$$MPI = ({}_0\psi_L + {}_{45}\psi_L + \cdots + {}_{315}\psi_L)/8$$

where ψ is a maximum angle of inclination between the cell for which we perform the calculation (central cell) and one of the eight cells at a given distance, and L is a distance. All negative ψ_L values are reclassified to 0 during the calculation.

MPI highlights enclosed areas such as narrow, deep canyons and slots, and is an indirect measure of the fragmentation of the area.

Morphometry of mesas

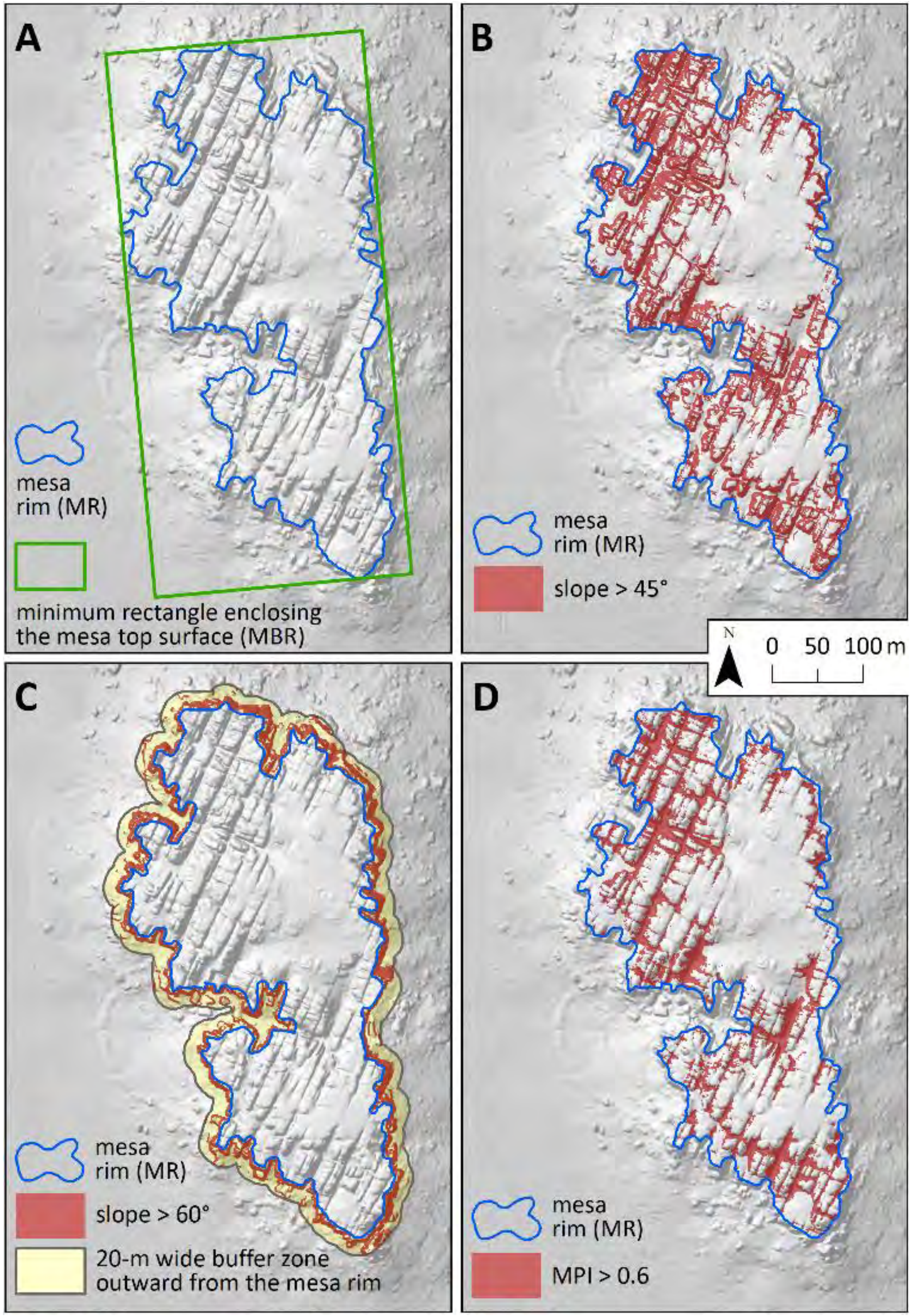
The question „how to measure and compare tabular hills” is the one of big importance as these landforms represent various sizes and shapes, depending on the evolutionary stage.

While the set of measures is still under development – initially it consisted of the following indices:

- area of the mesa top surface
- Sinuosity Index of mesa rim (SI), defined as: $SI = PMR/Pmbr$

where: PMR – perimeter of mesa rim, $Pmbr$ – perimeter of minimum bounding geometry enclosing mesa top Surface **(A)**

- percentage of slopes > 45° within the mesa top surface **(B)**
- percentage of slopes > 60° within the bounding escarpments **(C)**
- percentage of surface where MPI > 0.6 within the mesa top surface **(D)**.



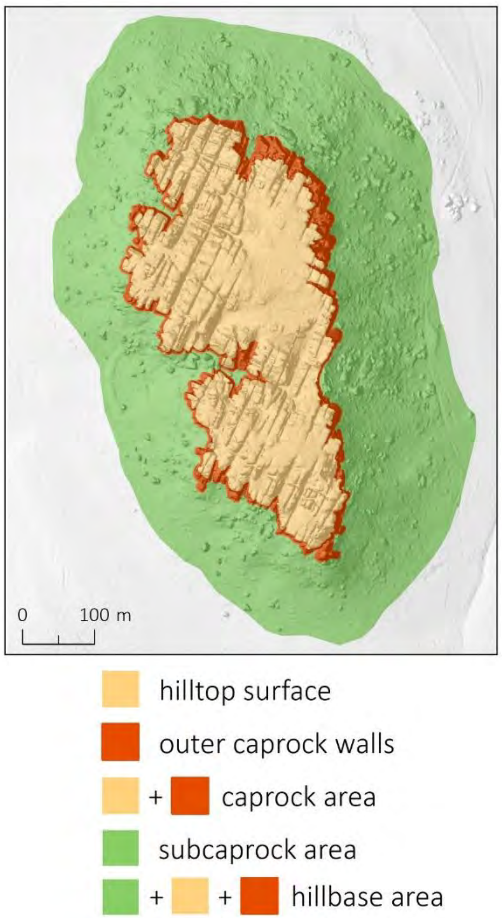
Selected morphometric parameters of a tabular hill on the example of Pfaffenstein (Elbe Sandstone Mts., Saxony, Germany).

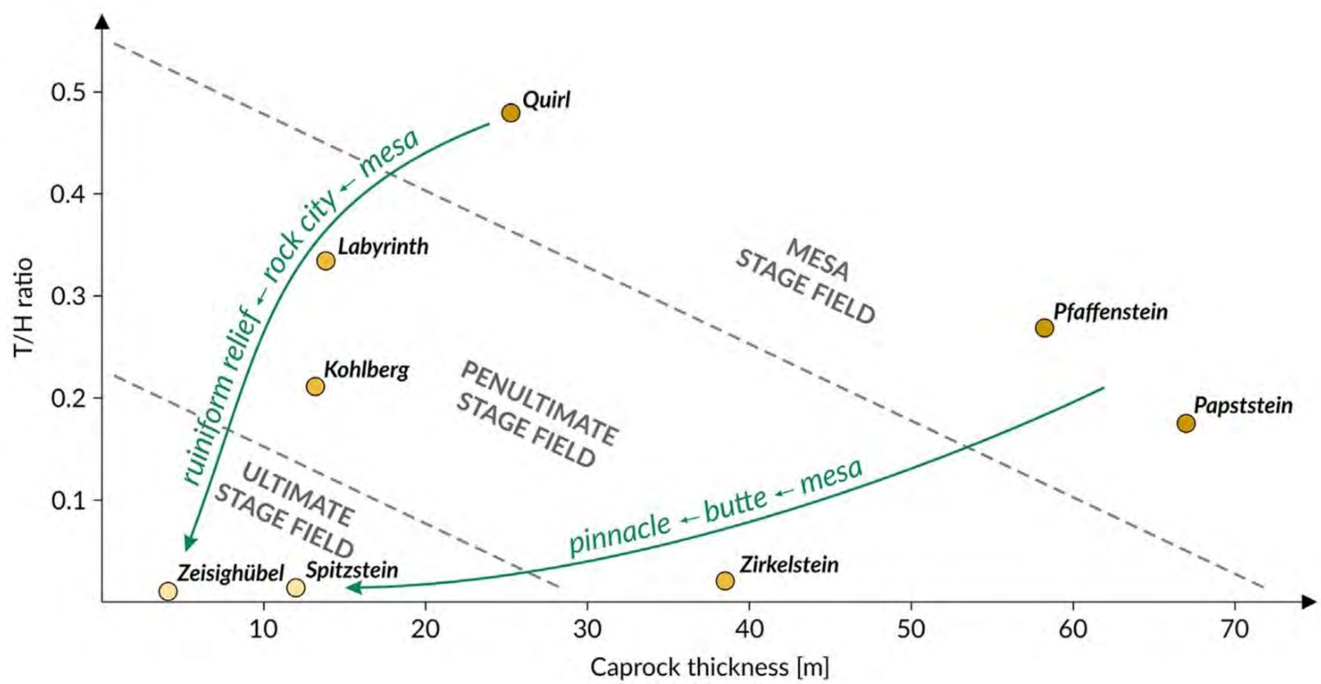
Morphometry of mesas

Proper delimitation of elements of mesa's anatomy is necessary (see below) – arbitrary decisions are sometimes indispensable, based on the expert geomorphological knowledge…

		1	2	3
		Quirl	Pfaffenstein	Papststein
	Max altitude [m a.s.l.]	349.34	430.28	451.27
Height [m]	Hill	54.65	111.80	132.00
	Caprock	25.25	58.22	66.97
	%	46.20	52.08	50.73
	Subcaprock	29.40	53.58	65.03
	%	53.80	47.92	49.27
Area [ha]	Hill base (H)	36.27	37.35	36.04
	Caprock (C)	20.27	11.92	7.00
	Hilltop (T)	17.38	10.02	6.30
	T/H ratio	0.48	0.27	0.17

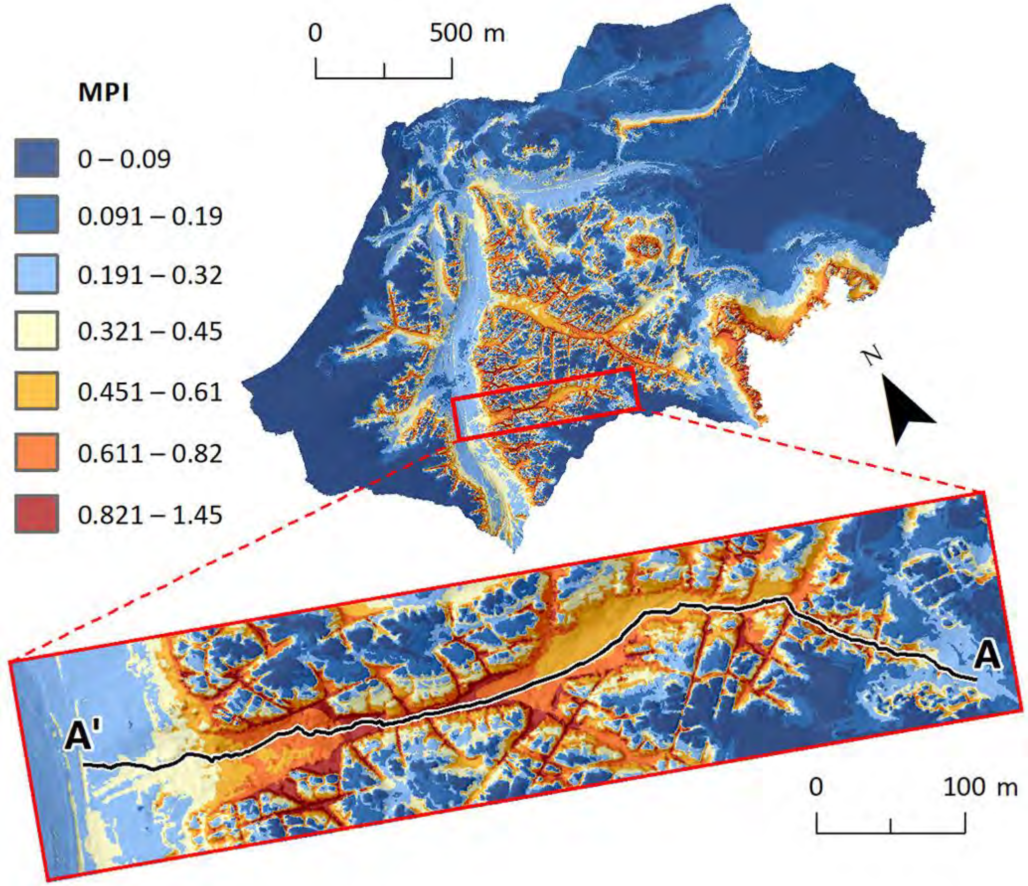
Analysis of simple morphometric properties of selected mesa elements gave way to the reinterpretation of classic *mesa-butte-pinnacle* landform evolution scheme.



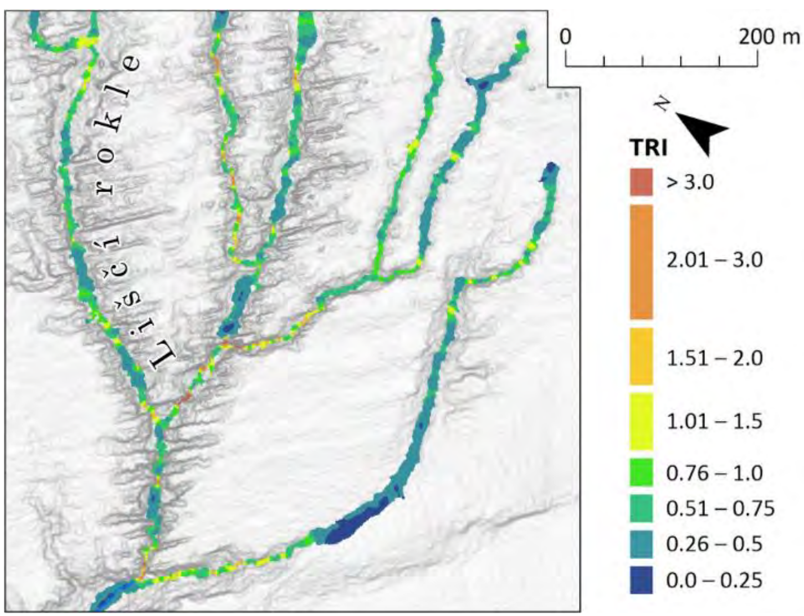


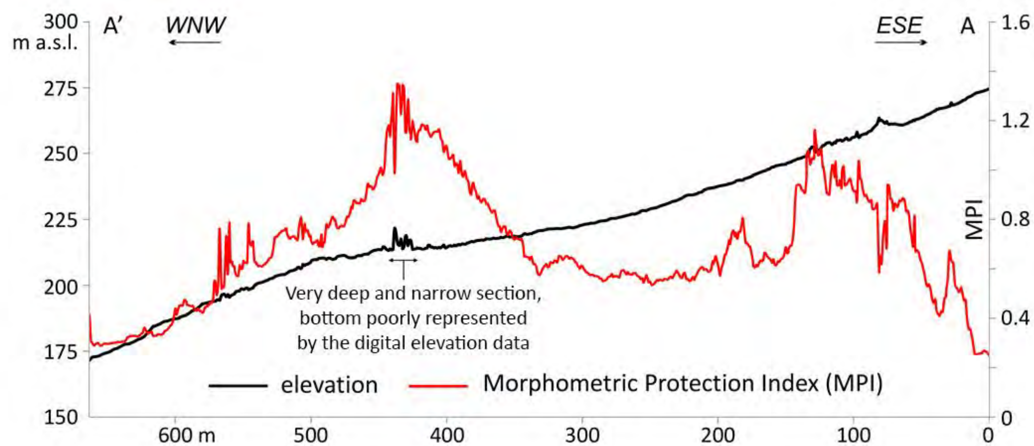
Cleft-and-valley systems

Diversity of the MPI values along canyon longitudinal profile depicts morphological changes, as its high values coincide with narrow and deep sections (Right: drainage basin located NE from Bad Schandau. Elbe Sandstone Mts., Germany).



High TRI values as an indicator of canyon sections with boulder-filled bottom (Below: Liščí rokle cleft-and-valley system, Broumov Cliffs, Czechia).

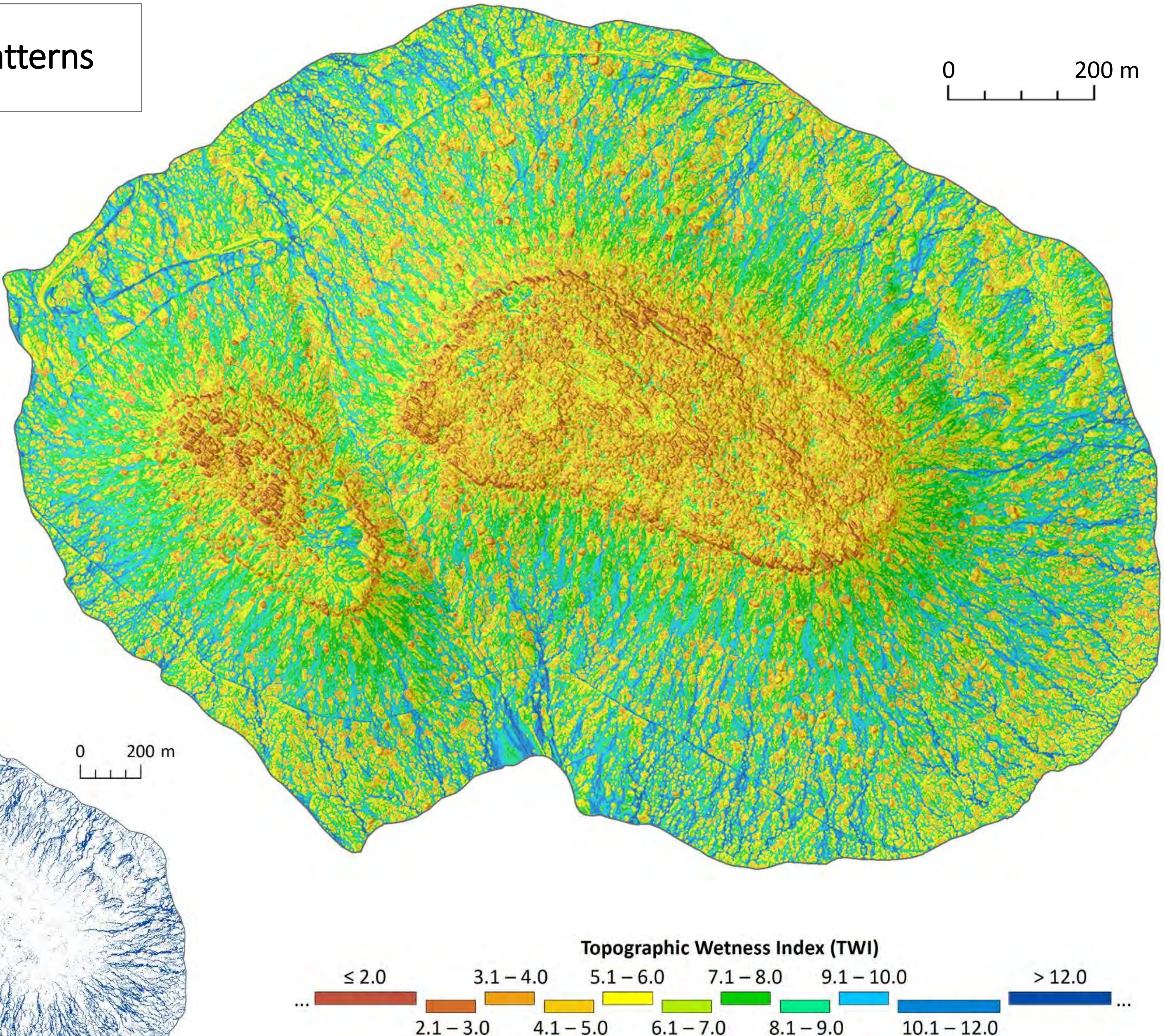


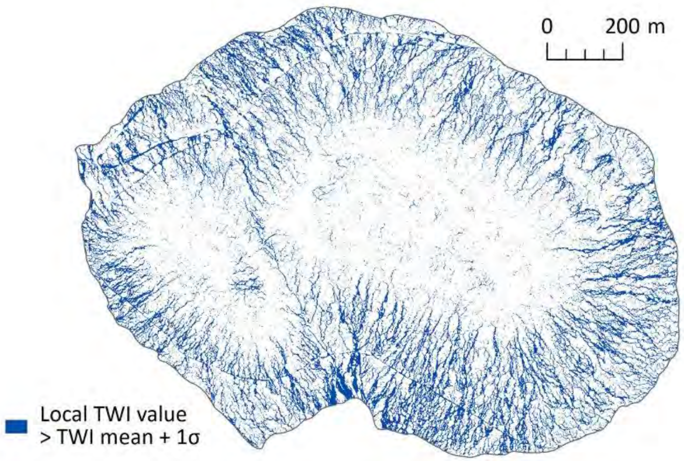


Surface drainage patterns

The Topographic Wetness Index was found useful for delimitation of zones of predicted surficial flow where TWI values exceed the threshold value (mean + 1 std dev).

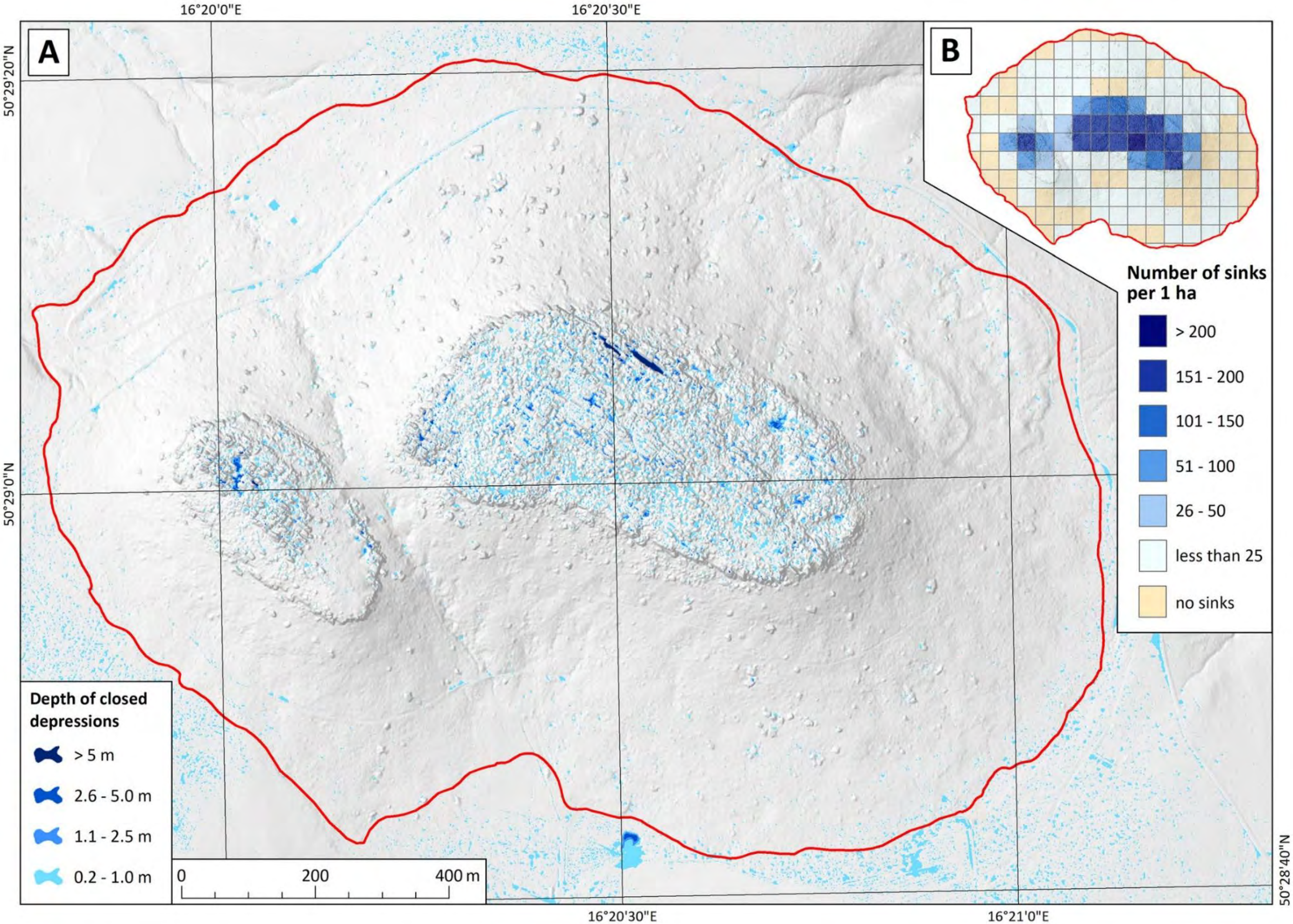
The example of Szczeliniec Wielki & Szczeliniec Mały shows numerous disconnectivity sites of the surface drainage system, especially within the caprock zone.





Surface drainage patterns

Closed depressions distribution and sink density within Szczeliniec Wielki & Szczeliniec Mały twin mesa, Stołowe Mts., Poland



Final remarks

1. Any attempts to high-resolution morphometric analyses of sandstone landforms, based on airborne LiDAR data, should be preceded with **analysis of data quality** (point density), detection of **DTM errors** and **DTM upgrade** based on **.las data** (if available).
2. Airborne LiDAR data do provide a **valuable quantitative information** which, however, it is **not standalone (fieldwork is mandatory!)**. Up to now, using LiDAR data has enabled us to tackle such issues as:
   - reevaluation and enhancement of classic schemes of sandstone landform evolution (pathways of mesa decay)
   - distribution and genesis of thick boulder fills within valley floors in the canyonlands,
   - assessment of the variety of surficial and subsurface drainage patterns, depending on the topographic position within the specific landform types
3. Plans for the nearest future include further development of morphometric protocol supporting **typology of tabular hills** and **cleft-and-valley systems**.

JCR publications

Migoń P., Duszyński F., Jancewicz K., Kotwicka W., 2020, **Late evolutionary stages of residual hills in tablelands (Elbsandsteingebirge, Germany).** ***Geomorphology,*** vol. 367 ID 107308 s. 1–16

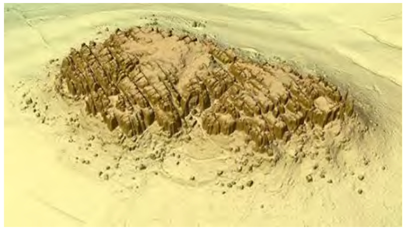
Jancewicz K., Migoń P., Kasprzak M., 2019, **Connectivity patterns in contrasting types of tableland sandstone relief revealed by Topographic Wetness Index. *Science of the Total Environment***, vol. 656 s. 1046–1062

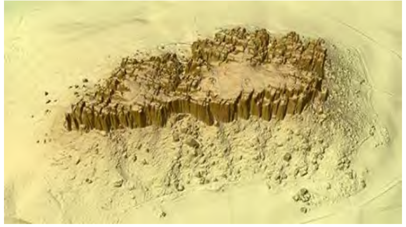
Migoń P., Duszyński F., Jancewicz K., Różycka M., 2019, **From plateau to plain - using space-for-time substitution in geoheritage interpretation, Elbsandsteingebirge, Germany. *Geoheritage***, vol. 11, iss. 3 s. 839–853

Duszyński F., Jancewicz K., Migoń P., 2018, **Boulder caves, roofed slots and boulder-filled canyons – evidence for subsurface origin, Broumov Highland, Czechia**. ***International Journal of Speleology***, 47 (3) s. 343–359

Migoń P., Różycka M., Jancewicz K., Duszyński F., 2018, **Evolution of sandstone mesas – following landform decay until death**. ***Progress in Physical Geography***, vol. 42 (5), s. 588–606

Duszyński F., Jancewicz K., Kasprzak M., Migoń P., 2017, **The role of landslides in downslope transport of caprock-derived boulders in sedimentary tablelands, Stołowe Mts, SW Poland. *Geomorphology,*** vol. 295, s. 84–110





Other publications

Jancewicz K., Migoń P., Kotwicka W., Różycka M., 2020, High-resolution geomorphometry: towards better understanding the genesis and contemporary processes in erosional sandstone landscapes. Proceedings of the Geomorphometry 2020 Conference. - Perugia, CNR Edizioni s. 107-110

Jancewicz K., Kotwicka W., Różycka M., Migoń P., 2019, Geomorphology of Elbe Sandstone Mountains in light of the high-resolution digital elevation model. *Regional Conference on Geomorphology Athens 2019*, 19–21.09.2019 Athens, Greece (poster)

Jancewicz K., Kotwicka W., Różycka M., Migoń P., 2019, Sandstone geomorphology of offered by high-resolution DEM. *Český ráj ´19: State of geomorphological research in 2019*, 3–5.04.2019 Holín, Czechia (poster)

Kotwicka W., Duszyński F., Jancewicz K., 2019, Morfologia progu piaskowcowego na wschodnim stoku wzniesienia Bronisz w Górach Bystrzyckich. *Przyroda Sudetów*, t. 22, s. 161–188.

Jancewicz K., Różycka M., Migoń P., Duszyński F., 2018, Sandstone erosional topography – morphometric approach. *Central European Conference on Geomorphology and Quaternary Sciences*. 23–27.09.2018, Giessen, Germany (poster)


Thank you for your attention!