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SHAPE AND POSITION OF ROCK FRAGMENTS IN A STONY SOIL: HOW MUCH CAN THEY AFFECT SOIL HYDRAULIC CONDUCTIVITY?

Hana Hlaváčiková[1], Viliam Novák[1], Jirka Šimůnek[2], Ladislav Holko[1], Zdeněk Kostka[1], and Michal Danko[1]

[1] Institute of Hydrology Slovak Academy of Sciences
[2] University of California Riverside

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Content

1/ Motivation and general information on stony soils

2/ The effective hydrophysical characteristics of stony soils – how to derive them?

3/ Numerical Darcy experiment – an illustration at plot scale

4/ Possible consequences at hillslope scale

5/ Some challenges for further research




Motivation

- Soils containing a significant fraction of rock fragments (RF), generally denoted as stony soils, are located in many forested and mountainous areas.
- The size, shape, degree of weathering and geological origin, position, and spatial distribution of RF can strongly influence the stony soils‘ properties (mainly the soil´s water retention and hydraulic conductivity) and can affect soil water movement, infiltration, and the occurrence of runoff.

The Institute of Hydrology has been conducting for a long time a hydrological research in a small mountain catchment (in The Western Tatra Mts.), where are prevailing shallow soils (soil depth of 70-100 cm) with large amount of RF (40-70%).

There is not available a standardized methodology:

1/ how to estimate hydrophysical properties of stony soils, and

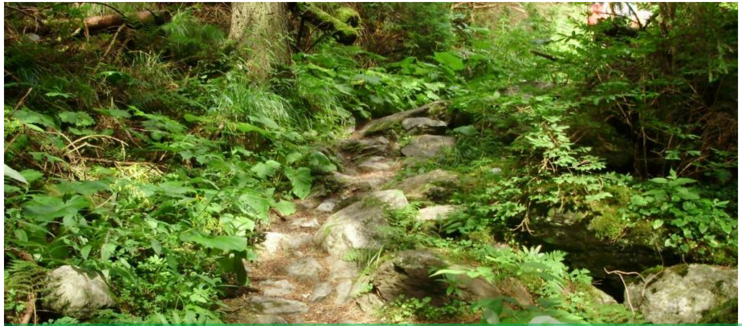
2/ how to incorporate the influence of rock fragments into soil water flow modeling

➢ In water balance modeling or water storage estimations rock fragments are often neglected

Typical problems with measurements in stony soils

1/ Rock fragments and many tree roots in stony soils which complicate soil sampling and infiltration measurements, problems with inserting probes or installing lysimeters

2/ Large variability of a stony soil´s characteristics even on a small plot



3/ Problematic accessibility of study sites - problems with transportation of measurement devices and water supply

4/ Large slope angle

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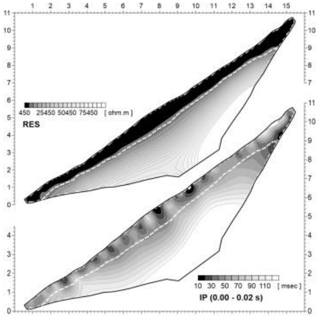

Specific feature of stony soils

Two different components:

Fine soil

+

Rock fragments

Therefore enough large REV is needed for integral stony soil hydrophysical characteristics measurements which may be m^3 and larger

Important characteristic of stony soils: SOIL STONINESS

Relative volume or relative mass of rock fragments

The ways how to estimate hydrophysical properties of stony soils

1st method:

To measure characteristics of both components (fine soil and RF) separately and then incorporate them in proper equations like:

Ravina and Magier (1984)

$$K_s^{\,b} = (1 - R_v) K_s^{\,f}$$

$$K_{rs} = \frac{K_s^{\,b}}{K_s^{\,f}} = 1 - R_v$$

Other equations for K_s^b calculations: Corring and Churchill (1961) (for spheres and cylinder inclusions), Brakensiek et al. (1986)

Bouwer and Rice (1984)

$$\theta^b = (1 - R_v)\theta^f$$

Such derived characteristics later used in water flow modeling (applied by Novák et al. (2011), Coppola et al. (2013), Wegehenkel et al. (2017))

2nd method:

To derive hydrophysical characteristics (namely hydraulic conductivity) by numerical modeling:

First time suggested and performed by Novák et al. (2011) – numerical Darcy experiment using Hydrus-2D model

These studies examined:

1/ the role of stoniness, size of RF (Novák et al., 2011),
2/ the effect of different shapes, positions and distributions of RF (Hlaváčiková et al., 2016) on saturated hydraulic conductivity , and
3/ the unsaturated hydraulic conductivity (Beckers et al., 2016) of stony soils.

Other methods:

evaporation experiments (Beckers et al., 2016)

other ideas ???

Numerical Darcy experiment

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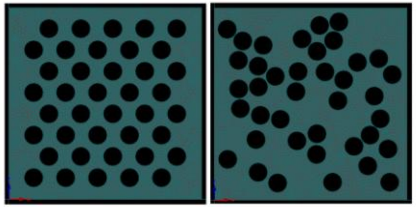
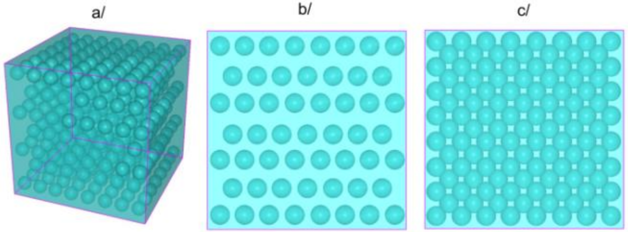


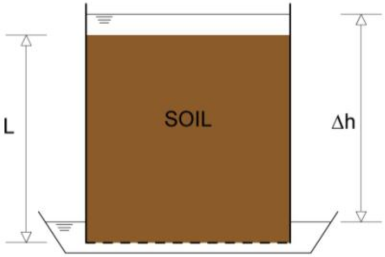


The principle

- Vertical steady state water flow through cross section of 1 x 1 m^2
- Initial condition - full saturation,
- Pressure head gradient: 1 m,

upper and lower boundary condition: +1 cm pressure head

RF incorporated as impermeable objects in 1 x 1 m^2 cross section



$$v = -K_s \cdot \frac{\Delta h}{L}$$

HYDRUS-2D/3D model

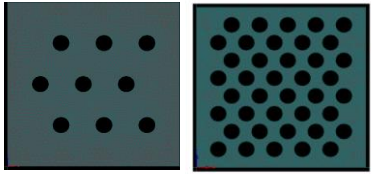
If L = 1 m and Δh = 1 m → $v = K_s$

Hlaváčiková, H., Novák, V., Šimunek, J. (2016): The effects of rock fragment shapes and positions on modeled hydraulic conductivities of stony soils. Geoderma 281,39-48.

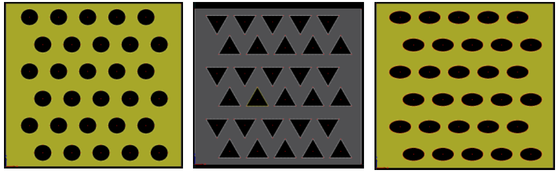
Numerical Darcy experiment

The main objectives

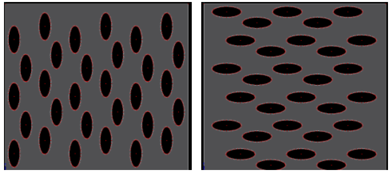
- The influence of stoniness



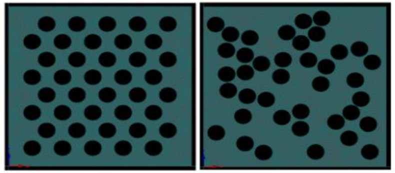
- The influence of different shapes



- The influence of position (vertical / horizontal)

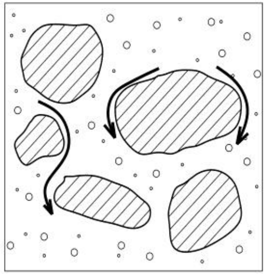


- The influence of distribution (regular / irregular)



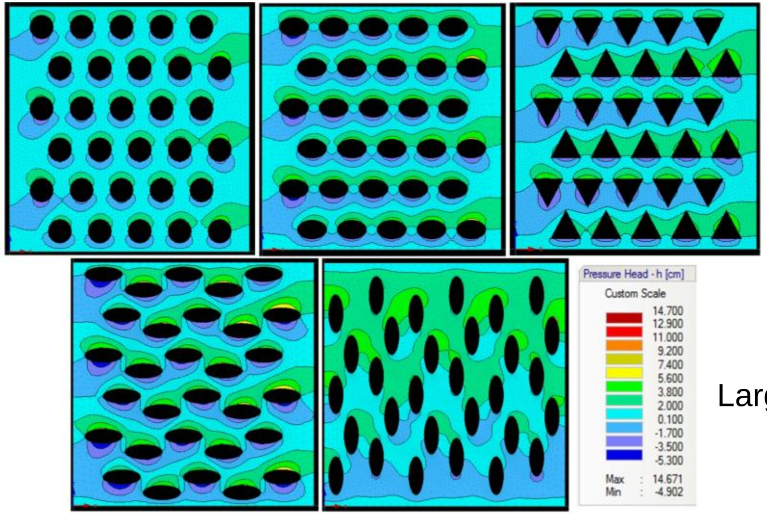
Modeling assumptions:
1/ zero retention capacity of RF
2/ tight contact between RF and soil matrix

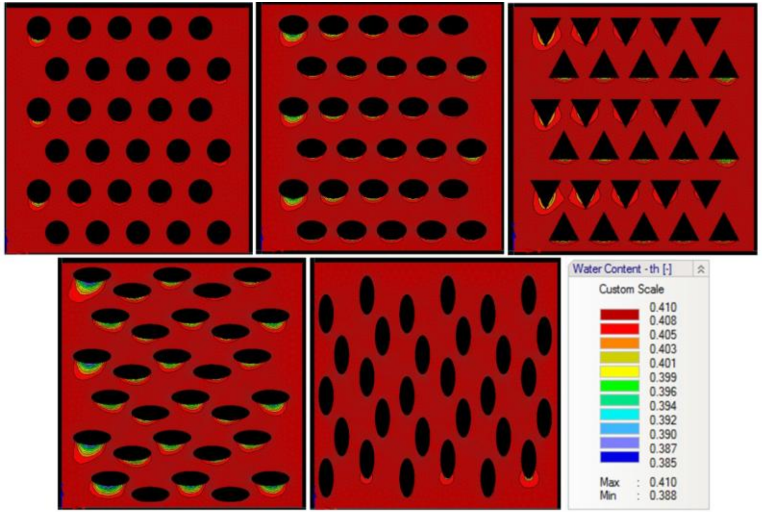
We have studied the influence of reduced effective cross-sectional area (the area available to water flow), and the effect of enlarged curvatures of water flow paths caused by water flowing around stones.



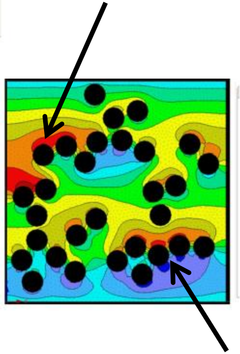
HYDRUS-2D/3D model (Šimunek et al., 2016)

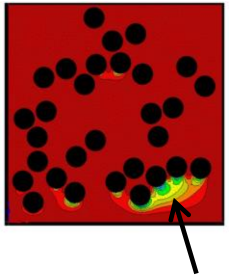
Numerical Darcy experiment





Largest positive pressure heads above RF





HYDRUS-2D (Šimunek et al., 2016)

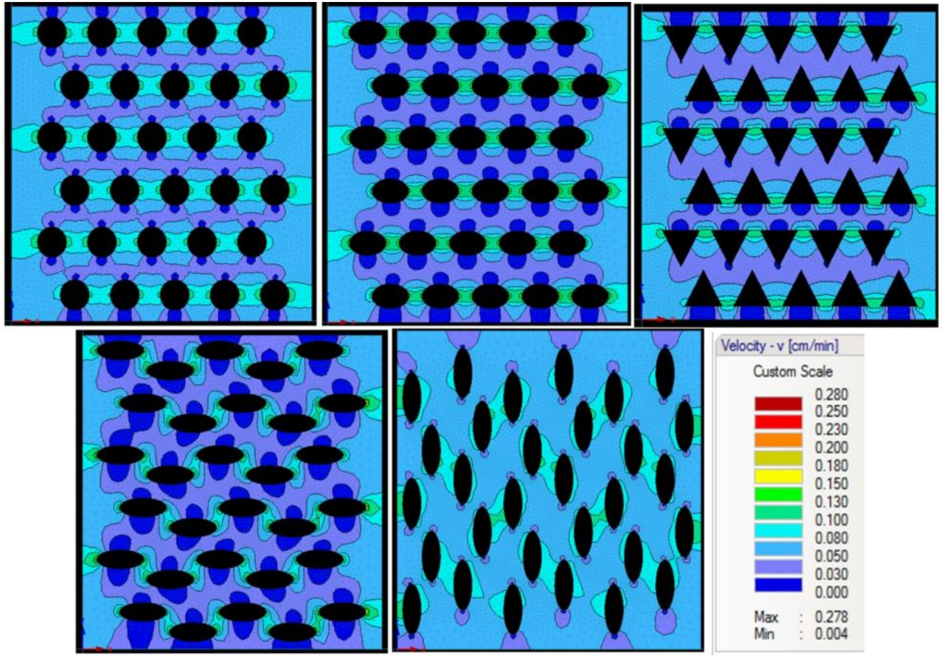
Small negative pressure heads below RF

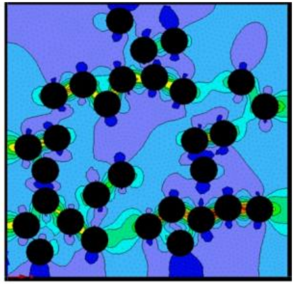
Unsaturated zones below RF

PRESSURE HEADS AND WATER CONTENTS

Numerical Darcy experiment

Non-uniform water fluxes

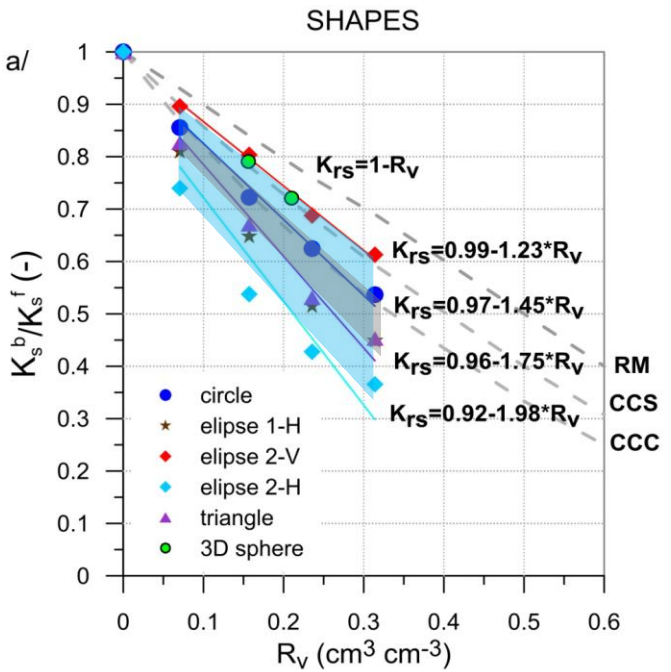


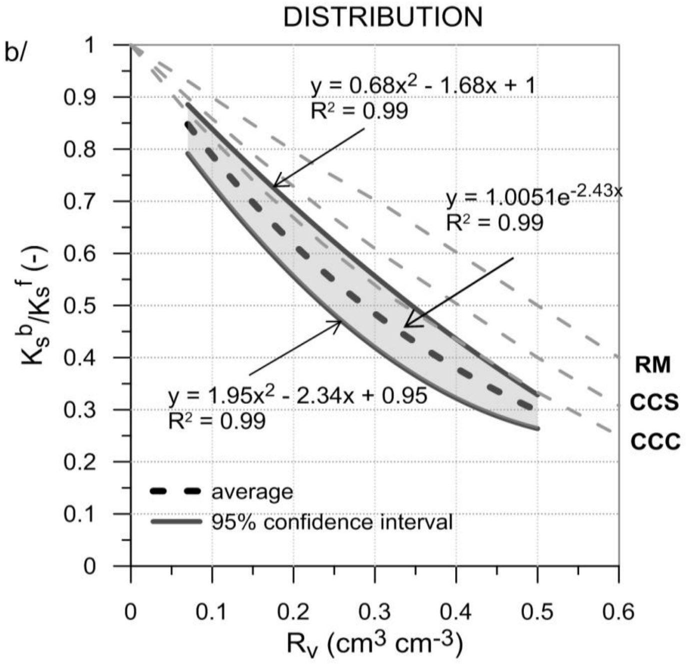


Minimum water fluxes, approaching zero, above and below RF

HYDRUS-2D (Šimunek et al., 2016)

Numerical Darcy experiment





1/ The stoniness was found as the most important factor (decrease by almost 70% at stoniness of 0.5)

2/ The second important factor was the orientation of the large ellipses (vertically, the lowest decrease by 40%, horizontally, the largest decrease by 70% in K_{rs})

3/ Different shapes of RF (circles, small ellipses, triangles) showed the similar influence on K_{rs} as regular / irregular distribution of RF

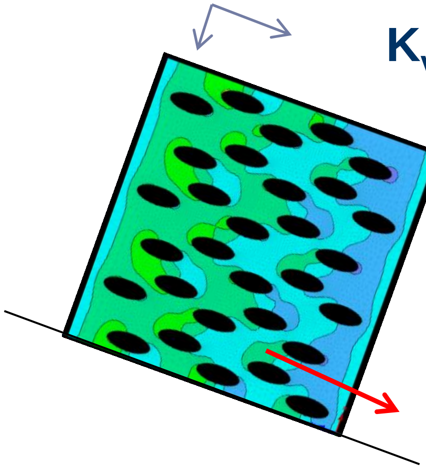
An example:

Ks of fine soil: 106 cm/day, sandy loam soil

The influence of stoniness:	Rv	0.31 0.5
	Ks	57 36 cm/day
Orientation of ellipses:	Rv	0.31
	Ks	39 (horizontal) 65 (vertical) cm/day
Irregular distribution:	Rv	0.31
	Ks	41 - 57 cm/day

POSSIBLE CONSEQUENCES AND OTHER CHALLENGES

ANISOTROPY



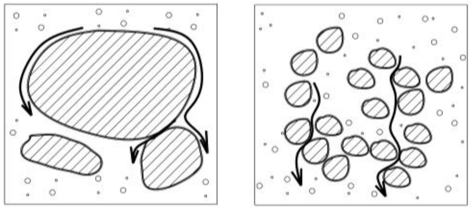
$K_{vertical} < K_{horizontal}$

Ellipsoidal RF cause local anisotropy producing faster lateral outflow

Preferential flow is certainly important phenomenon at hillslope scale, but the presence of RF alone can also contribute to speed-up outflow formation

Other challenges: ?

- ❑ The effect of different RF porosities (tuffs, chalk, limestones)
- ❑ The effect of lacunar pores (when do prevail their effect on Ks (smaller stones) compared to the effect of larger hydraulic resistances caused by flowing off larger stones?)



- ❑ The effect of RF on subsurface outflow formation

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Our future plans and references

Ongoing work: There has been conducted hydrological research in a small mountain catchment in The Western Tatra Mts. (Slovakia) since 1980´s by The Institute of Hydrology of SAS (components of water balance, snow melt, rainfall / runoff relationship etc.) - see **www.uh.sav.sk** – The Jalovecký Creek Catchment

We currently deal with subjects like:

measurements of hydrophysical properties of stony soils, measurement of water content in stony soils, and modeling of water flow in stony soils

Our plans: ***Try to find out a relationship between soil water dynamic and catchment runoff***
To elucidate more the influence of RF on runoff formation

Our references related to the topic:

Hlaváčiková, H., Novák, V., Šimunek, J. (2016): The effects of rock fragment shapes and positions on modeled hydraulic conductivities of stony soils. Geoderma 281,39-48.
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Thank you for your attention!

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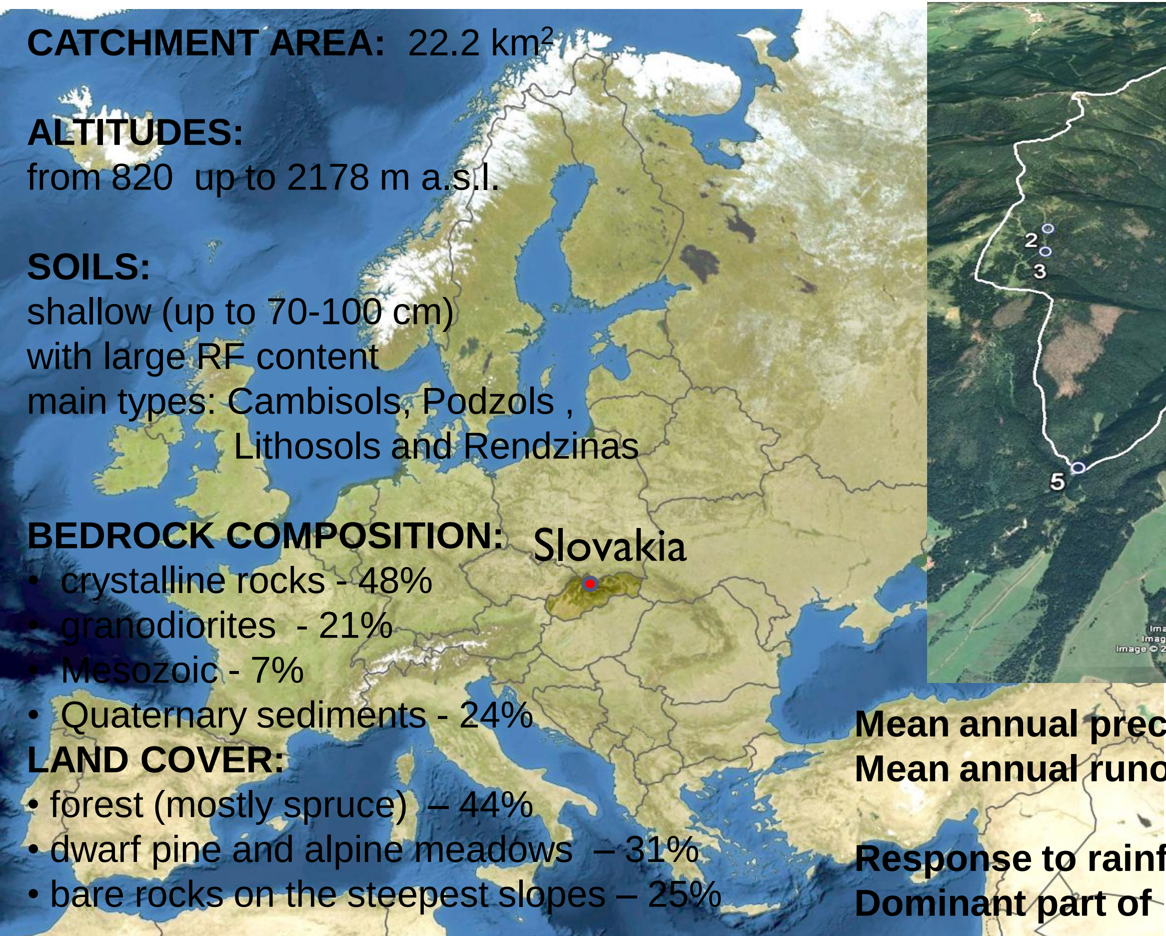
The Jalovecký Creek Catchment in The Western Tatra Mountains, Northern Slovakia, Central Europe



CATCHMENT AREA: 22.2 km^2

ALTITUDES:
from 820 up to 2178 m a.s.l.

SOILS:
shallow (up to 70-100 cm)
with large RF content
main types: Cambisols, Podzols , Lithosols and Rendzinas

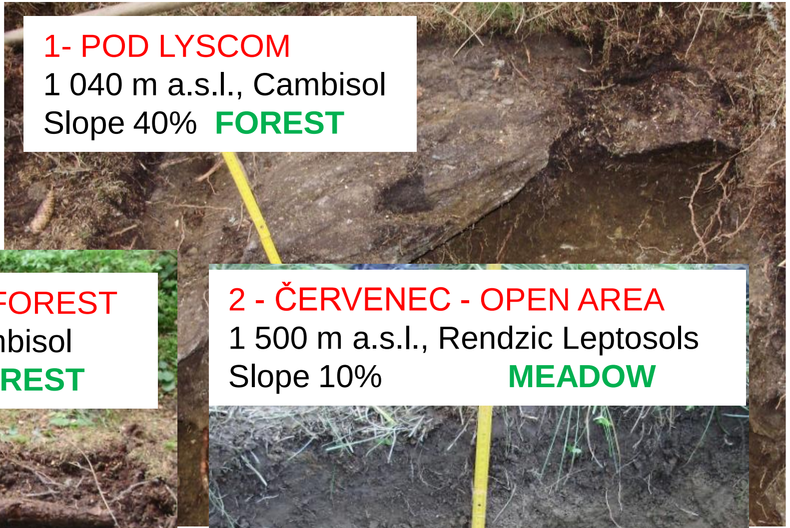
BEDROCK COMPOSITION:
- crystalline rocks - 48%
- granodiorites - 21%
- Mesozoic - 7%
- Quaternary sediments - 24%

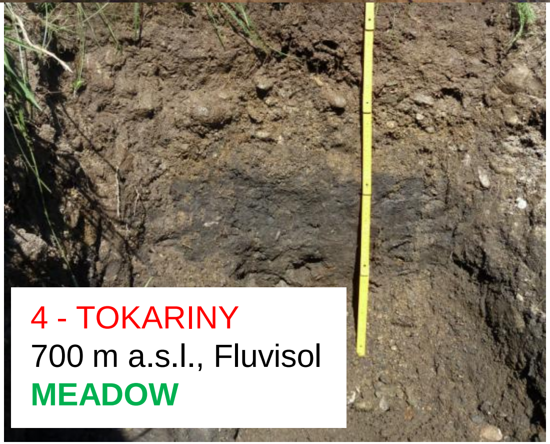
LAND COVER:
- forest (mostly spruce) – 44%
- dwarf pine and alpine meadows – 31%
- bare rocks on the steepest slopes – 25%

Mean annual precipitation: 1 570 mm
Mean annual runoff: 1 004 mm

Response to rainfall is fast (1.4 – 3.4 hrs)
Dominant part of runoff is formed by subsurface outflow

Representative soil profiles





SOIL STONINESS (R_v)

Relative volume of rock fragments:

measured directly in the field

Large spatial and also profile variability of this characteristic

Soil stoniness is the result of specific pedogenesis processes taking place on each site (deluvial, glacial and fluvial sediments)