5. Karst hydrogeology

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Karst investigation

What is karst?

Modern definition (Klimchouk, Ford, Palmer, Dreydrodt, 2000; p. 46):

The karst system is an integrated mass-transfer system in soluble rocks with a permeability structure dominated by conduits dissolved from the rock and organised to facilitate the circulation of fluid.

Huntoon, 1995: KARST IS A SPECIFIC KIND OF FLUID CIRCULATION SYSTEM CAPABLE OF SELF-DEVELOPMENT AND SELF-ORGANISATION

What is a cave?

Karst caves are defined as solution cavities larger than 5–16 mm in diameter.

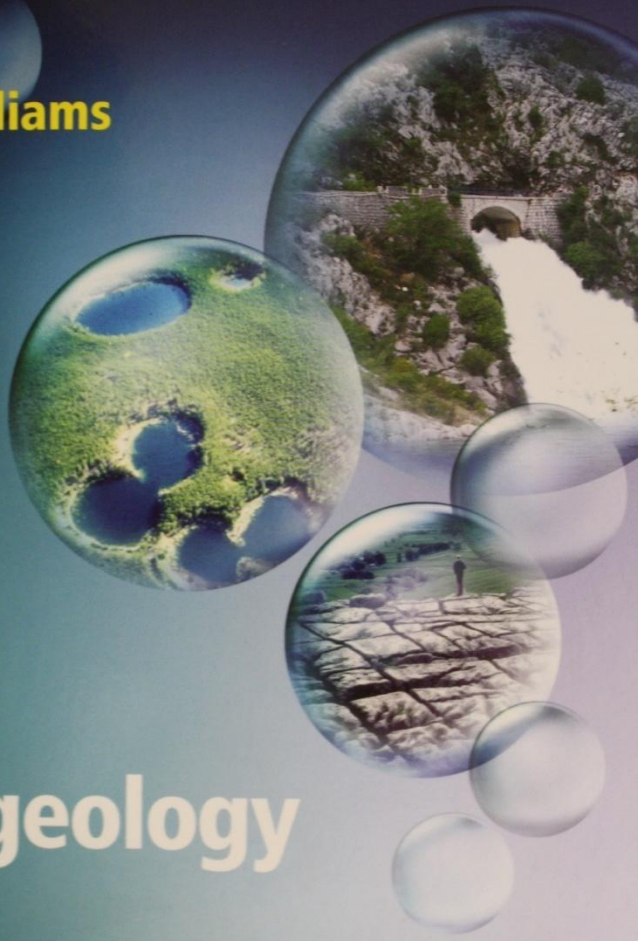
Three opposed sets of general genetic hypotheses ('the classical hypotheses') have been presented for such caves, arguing that the majority develop:

(1) in the vadose zone,

(2) in the phreatic zone, or

(3) proximate and parallel to a water table

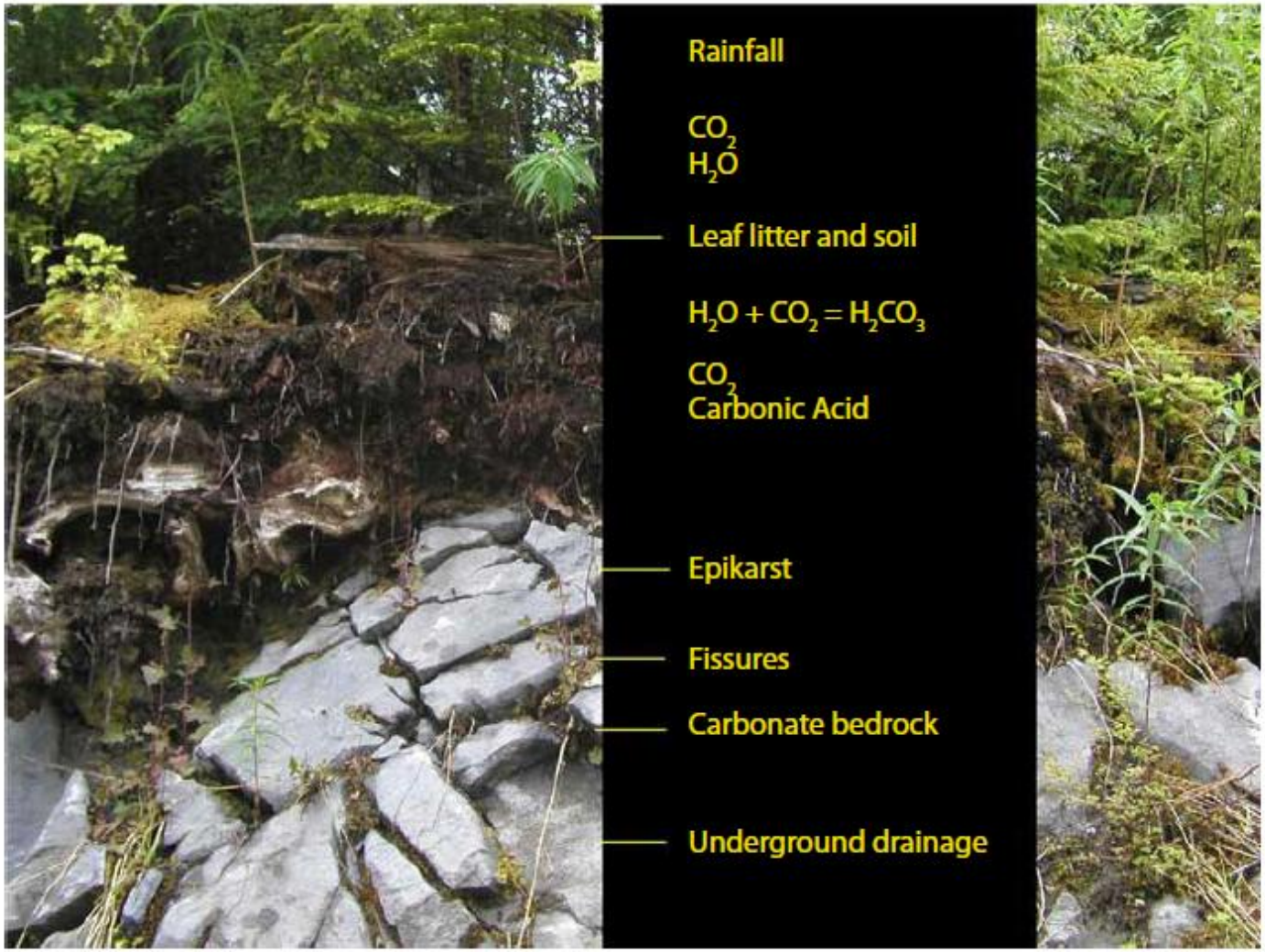
Derek Ford
and Paul Williams



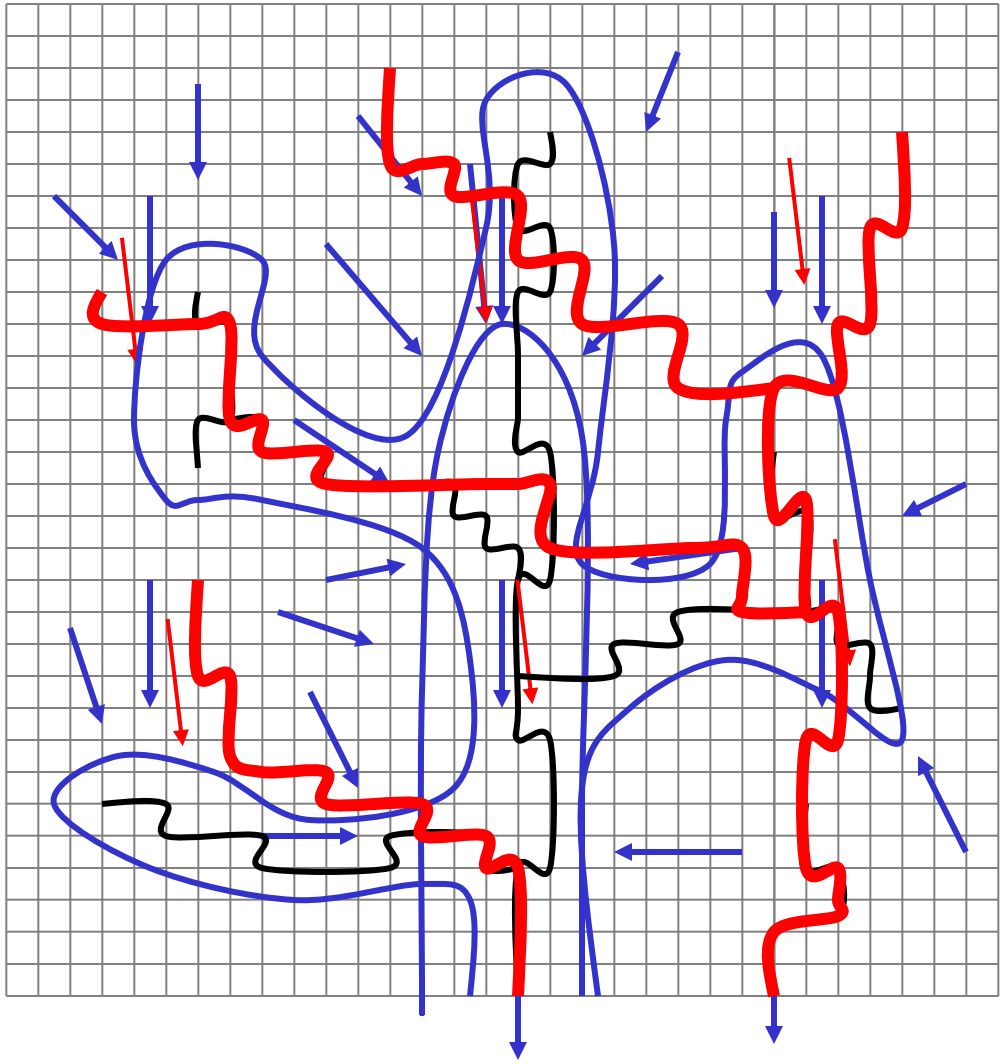
Karst Hydrogeology and Geomorphology

WILEY

Karstification proces in carbonate rocks



Ground plan of karst conduits development



-imagine the soluble rock with dense net of fractures

-fractures are enlarged by flow (corrosion) and karst conduits start to evolve

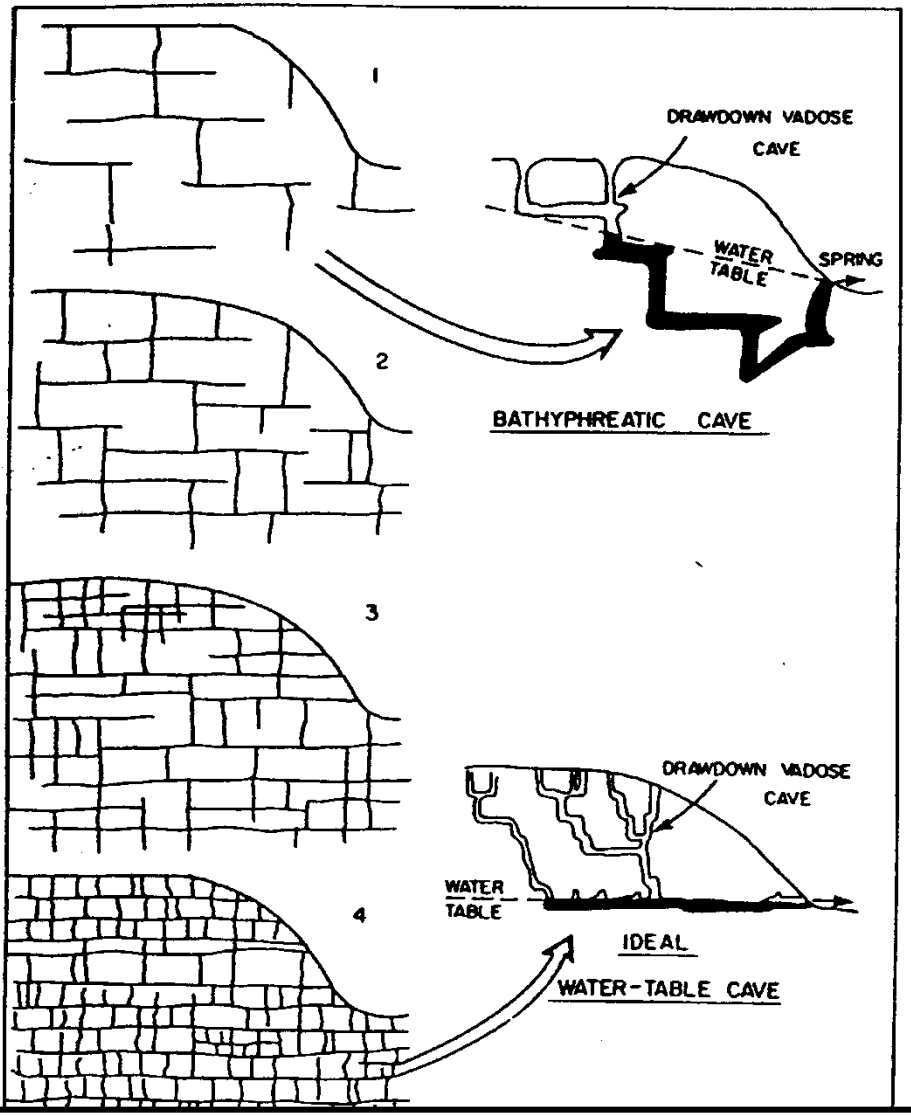
-as soon as first conduit reach the discharge zone the water table drop down in conduits and its surrounding

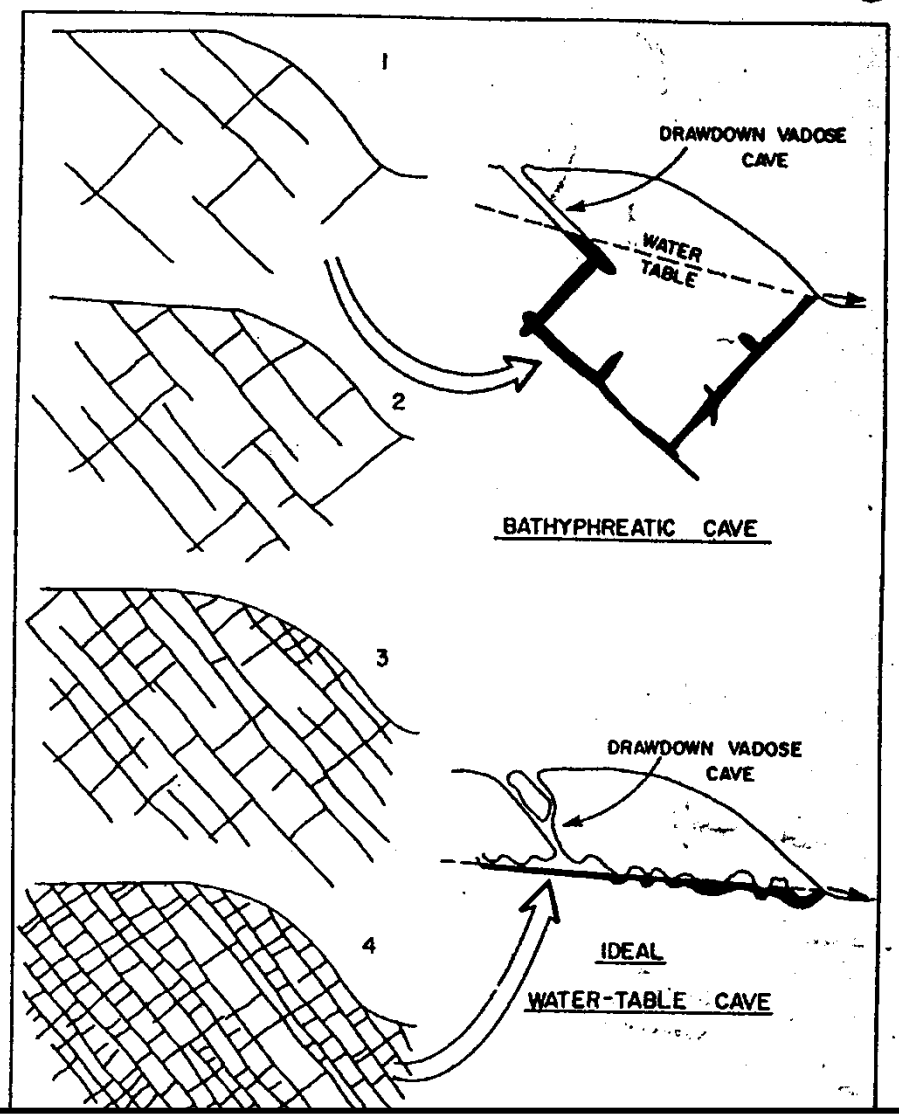
-other conduits are reoriented towards first conduit (changed piezometric field)

=> dendritic pattern of flow collecting majority of water is developed

Is clear that there is great difference between initial and final flow field

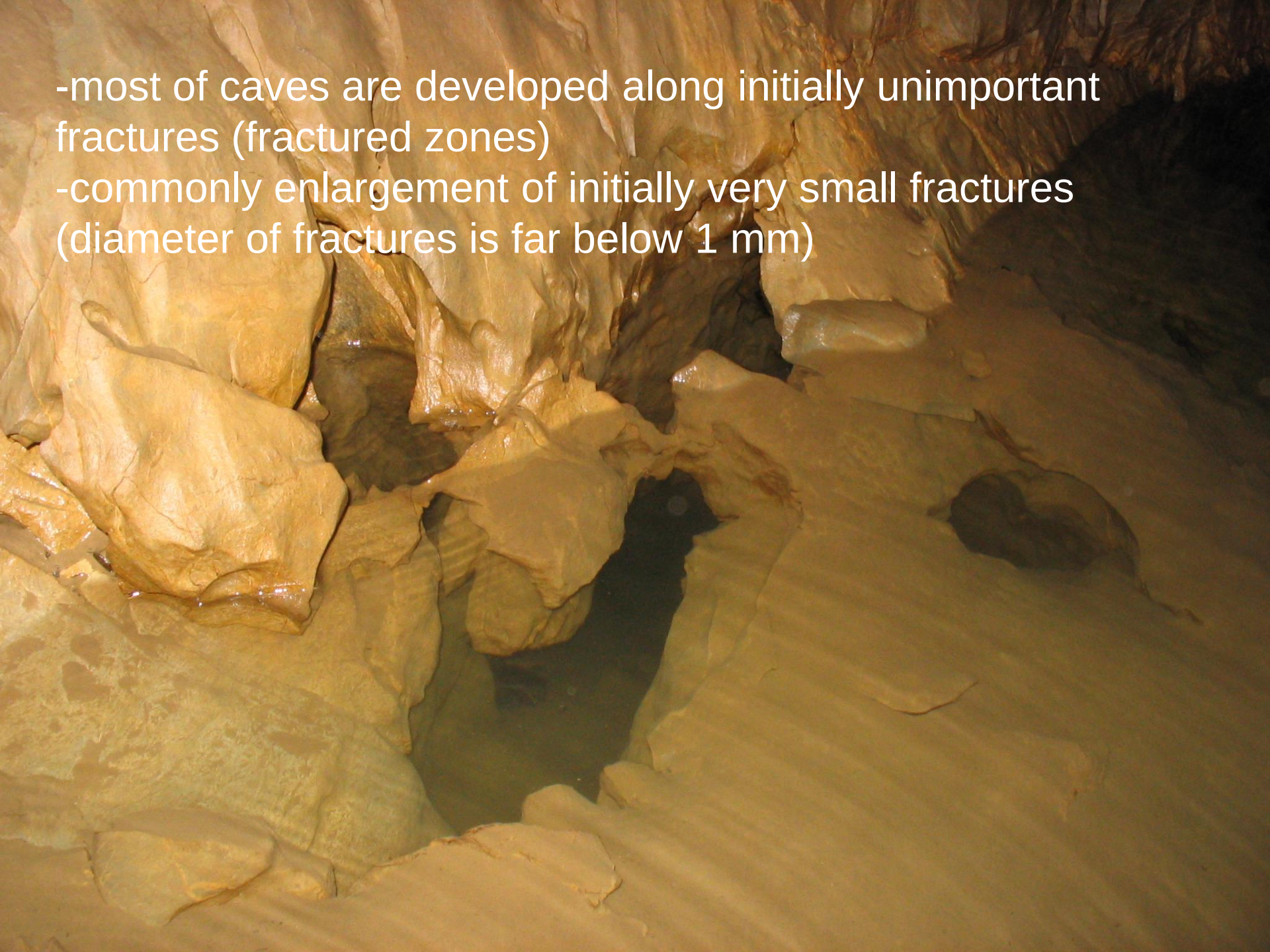
FORD AND EWERS 1978





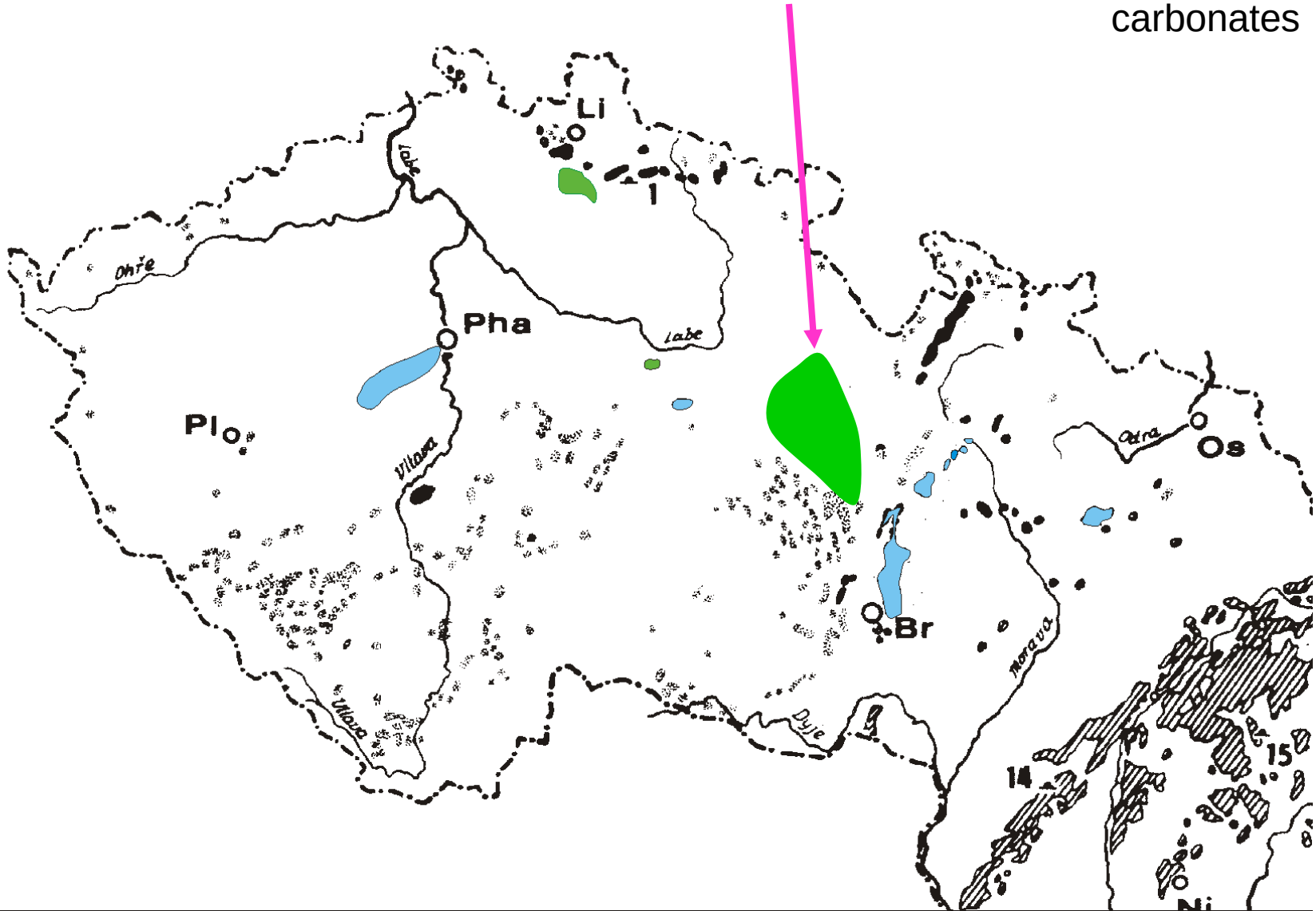
Longitudinal cave/ conduit section is function of fracture density (joints, bedding planes, faults...interconnected between recharge and discharge zone)

-main conduit will develop along the shortest possible route (if wide enough, etc.)



-most of caves are developed along initially unimportant fractures (fractured zones)
-commonly enlargement of initially very small fractures (diameter of fractures is far below 1 mm)

Area with some extend of karst porosity
(Vysoké Mýto Syncline, Ústí Syncline)



-developed along bedding planes BUT as visible from ground plan the vertical fractures were also very important (direct segments of cave passage)

-fractures are so small, that can not be seen on the ceiling of passages!!! (many of them in area =>enlargement of very small fractures with primary diameter less than 1 mm

Bartošova pec Cave, foto: Michal Novák

Primary fissured porosity ø less than 1 mm; by karstification enlarged to ø 1 m

now draining several km2!!!...originally 0,0000X l/s...now up to 100 l/s ...orders of magnitude

Karst contra other environments

-in **NONkarst** the porosity is related only to lithology, tectonics, weathering) and the **flow MUST follow it** (and not change it)

-in **KARST** the predominant part of water **flows by SECONDARY porosity (karst conduits**) (Atkinson, 1971)
-primary porosity became unimportant for regional flow

-recent flow paths are result of flow net history (those fractures mostly suitable placed between recharge and discharge areas became into largest conduits =>permeability rising in orders of magnitude)

Karst specifics

-extreme permeability of karst conduits

-dominance of turbulent flow in karst conduits

-boreholes and even geophysics have very limited possibility to capture the main paths of water flow (conduits)

-environmental tracers, tracer tests and study of springs can be very valuable instead pumping tests

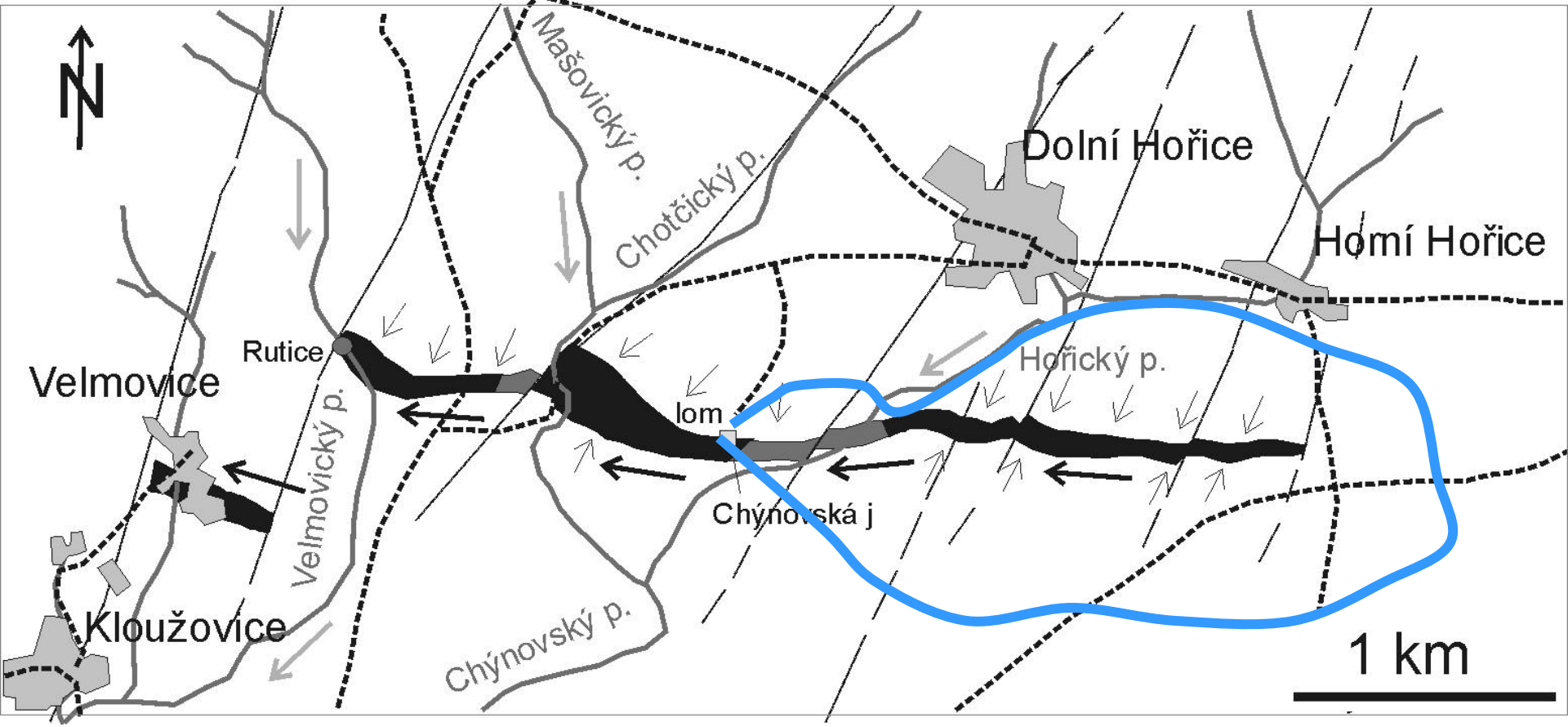
-the hydraulic gradient in karst aquifers is higher than in other aquifers

-steep hydraulic gradient in karst does not exclude the high permeability of such environment!!!

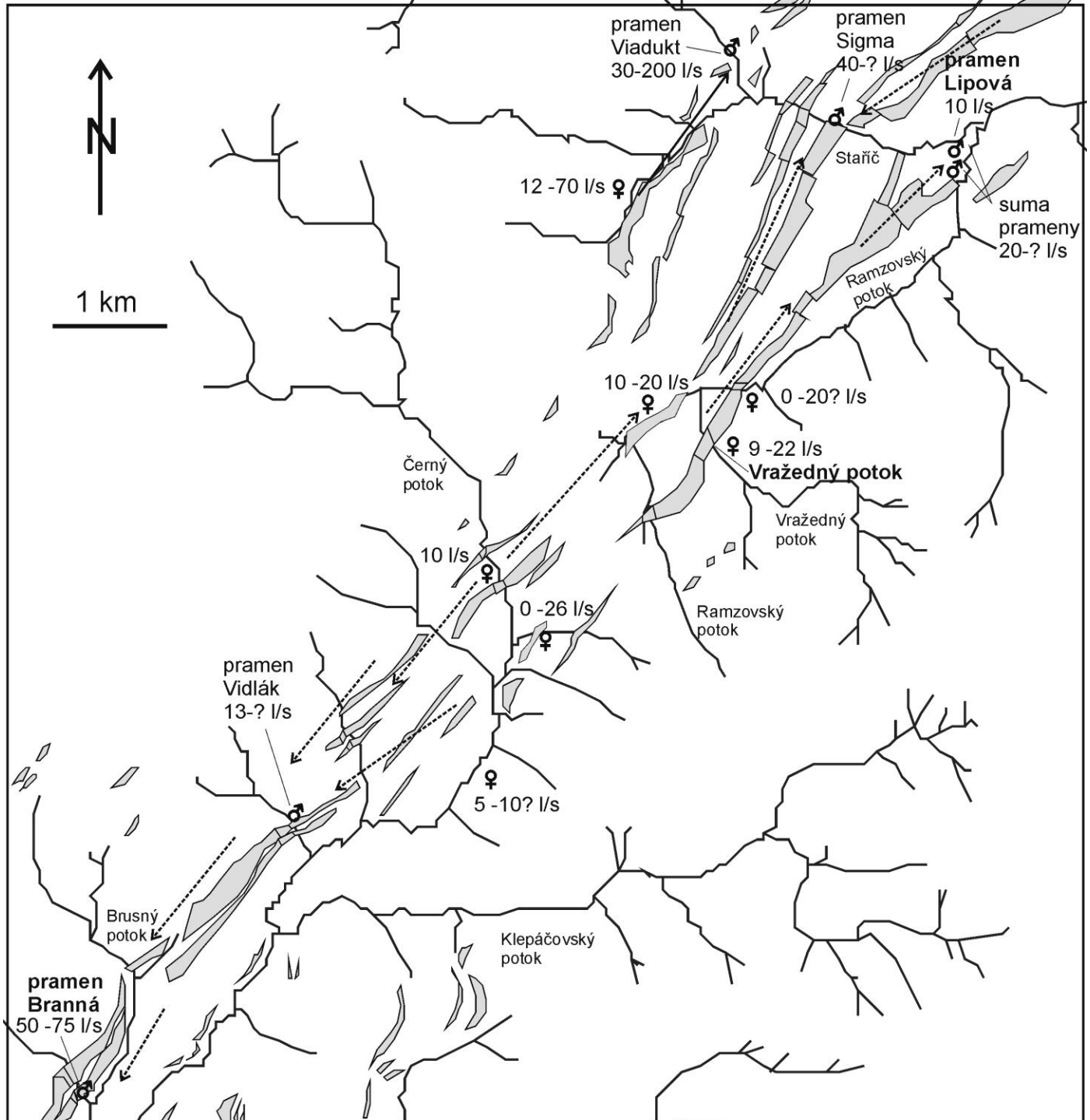
(commonly WEAK relationship between permeability and hydraulic gradient in karst

Karst conduits recently evolving on the side of main passage in Cetacile Ponoruluj Cave (Rumania, Bihor, Munti Apuseni)

Karst in metamorphosed carbonates



Chýnov Karst (southern Bohemia)
-more than 90% of water infiltrates on gneiss, only 5-10% on limestone
-carbonate strip act as drainage
-relatively productive sources for water supply can be found on marbles in crystalline regions


N
1 km
pramen
Viadukt
30-200 l/s
pramen
Sigma
40-? l/s
pramen
Lipová
10 l/s
Staříč
12 -70 l/s
suma
prameny
20-? l/s
Ramzovský
potok
10 -20 l/s
0 -20? l/s
9 -22 l/s
Vražedný potok
Černý
potok
Vražedný
potok
10 l/s
0 -26 l/s
Ramzovský
potok
pramen
Vidlák
13-? l/s
5 -10? l/s
Brusný
potok
Klepáčovský
potok
pramen
Branná
50 -75 l/s

sink of stream Pod Smrčníkem

Non carbonate openings - caves

- Gypsum
- Halite
- Marlstone
- Sandstone (hard rocks with development of opening along tectonic lines – groundwater flow preferential pathways)

Structures and environment – example from “Turnov karst”

-in NE Bohemia (close to Turnov town)

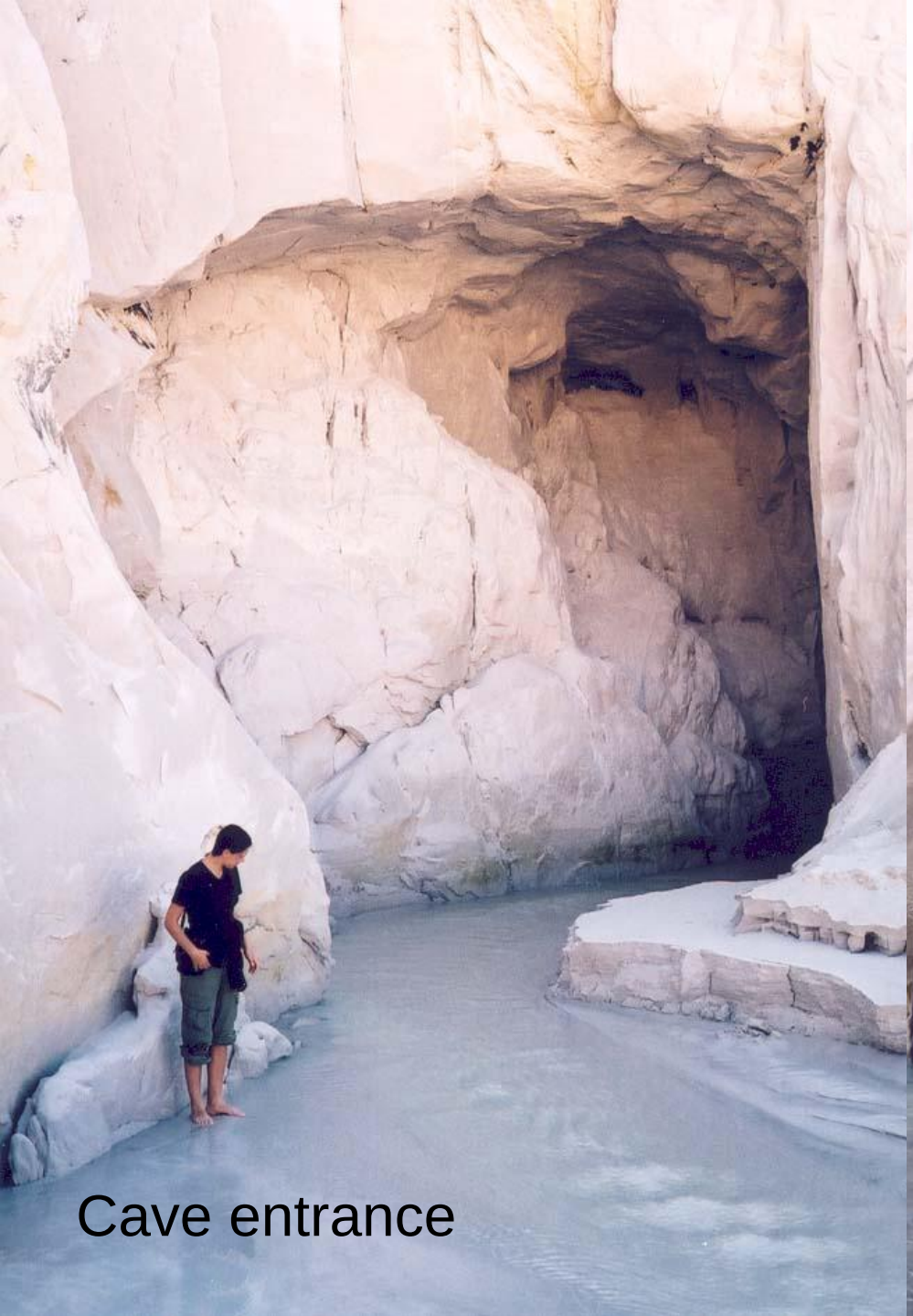
-marlstones of Jizera Fm (Czech Cretaceous Basin)

-$CaCO_3$ content 5 to 80%

-formed by aggressive water from overlying Teplice Fm (no $CaCO_3$ content – undersaturated to calcite)

-many karst features (semi blind valleys, sinkholes, sinks, caves, springs)

Open cast mine for pure quartz sand(stone) for glass-making (without $CaCO_3$) cemented by kaoline clay – circulating water transported sand out of sandstone – creating cave



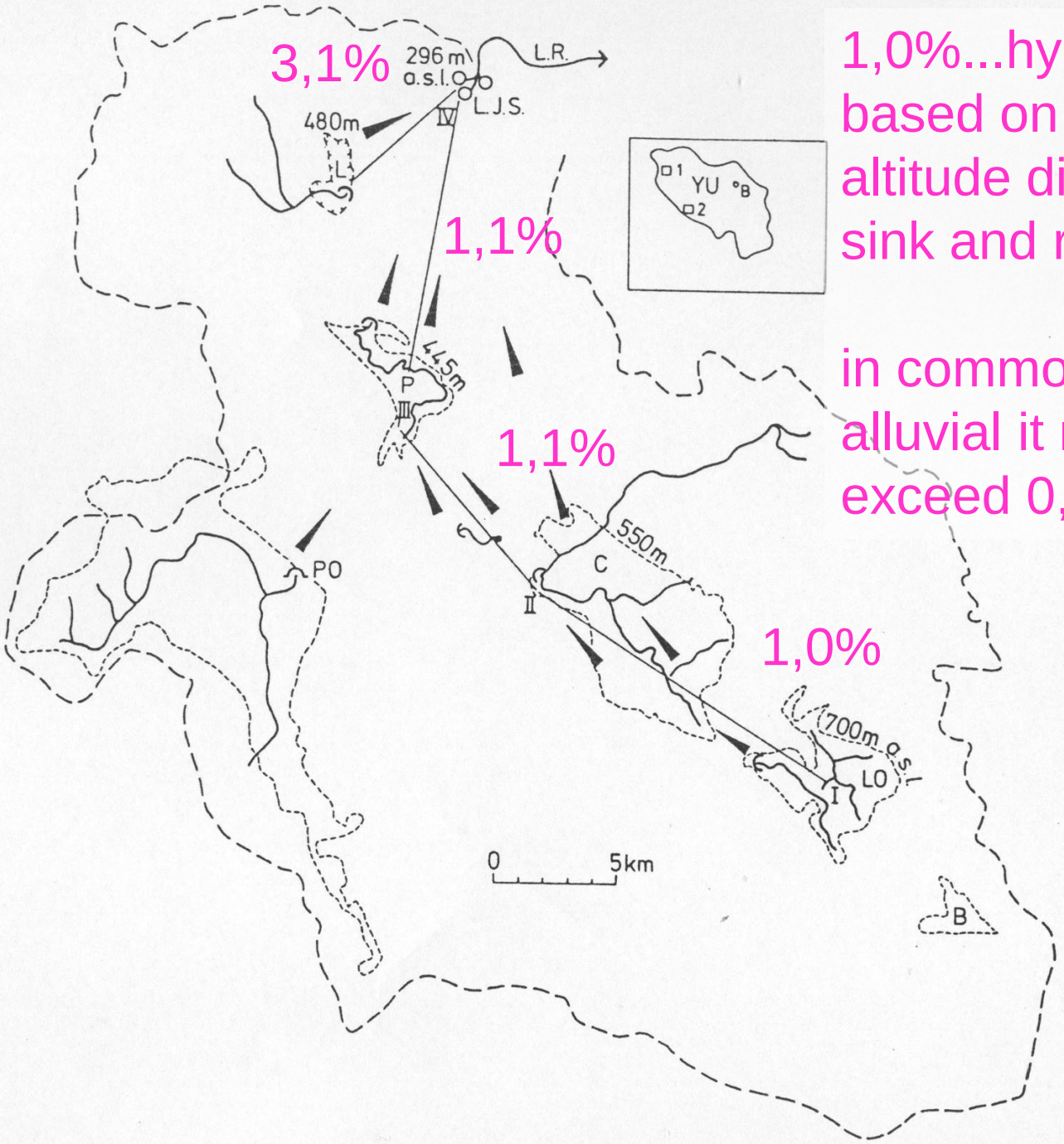
Cave entrance

main fractured zone

The relationship between **permeability** and **hydraulic gradient** is so obvious for hydrogeologists...

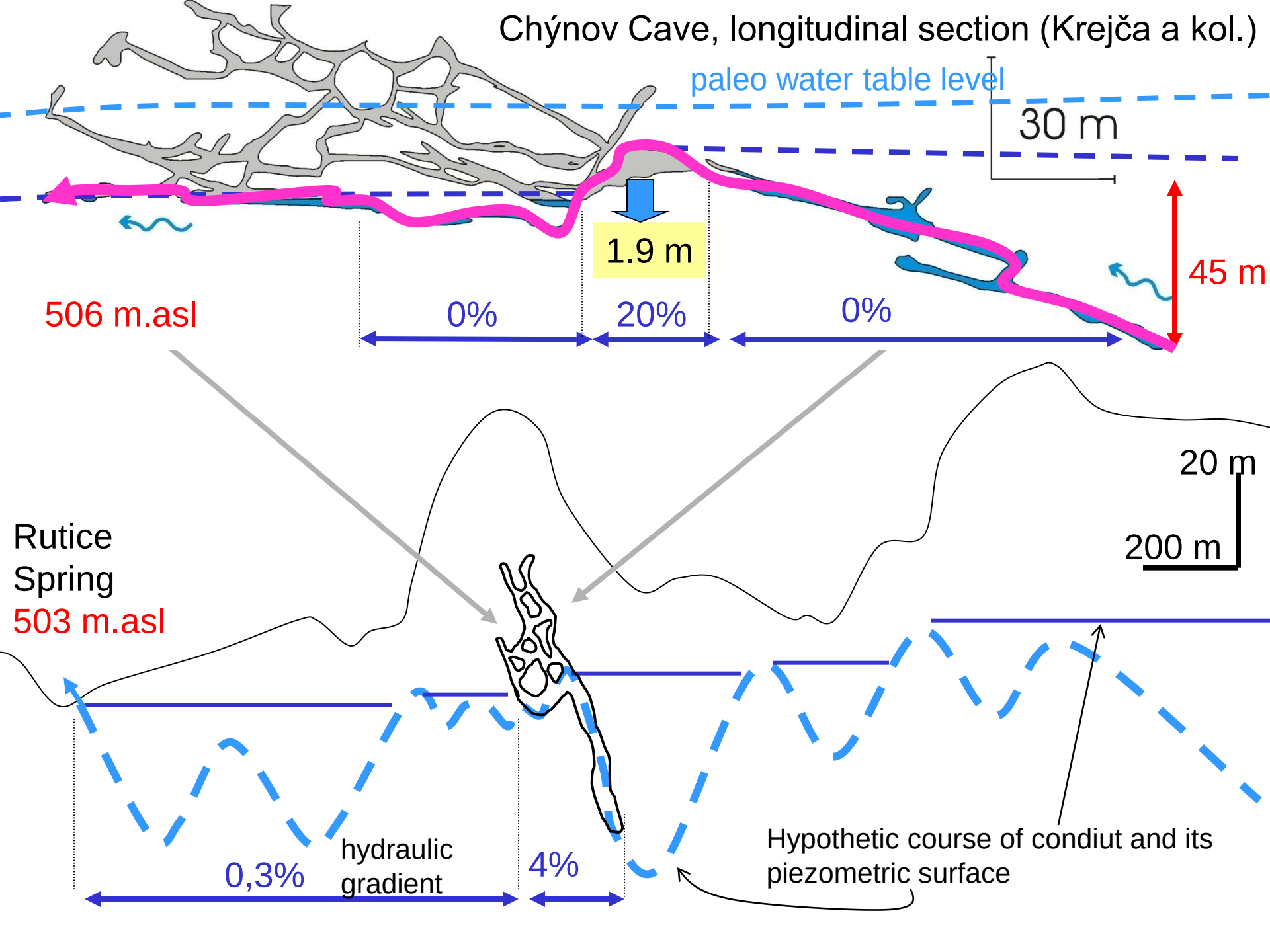
...however this premise is NOT valid in many karst areas

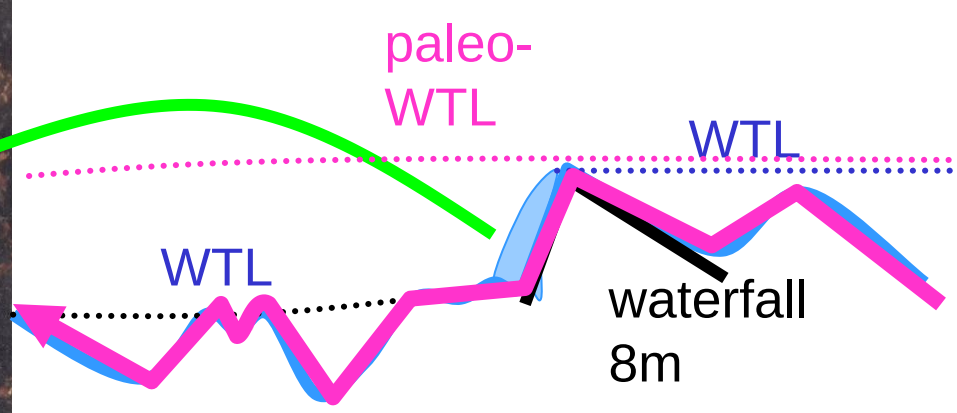
Why is it so?



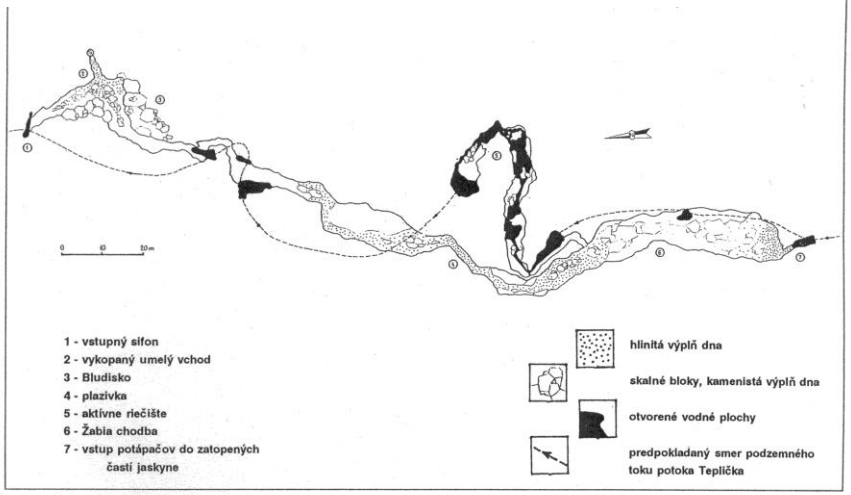
1,0%...hydraulic gradient based on distance and altitude difference between sink and resurgence

in common fissured and alluvial it mostly does not exceed 0,6 promile


Chýnov Cave, longitudinal section (Krejča a kol.)
paleo water table level
30 m
1.9 m
45 m
506 m.asl
0%
20%
0%
20 m
200 m
Rutice
Spring
503 m.asl
0,3%
hydraulic
gradient
4%
Hypothetic course of condiut and its
piezometric surface



Teplica Cave, Tisovec, Slovakia



!!! steep hydraulic gradient is often caused by shortcut (water falls) between various cave levels

=>steep hydraulic gradient does NOT mean low permeability of environment!!!

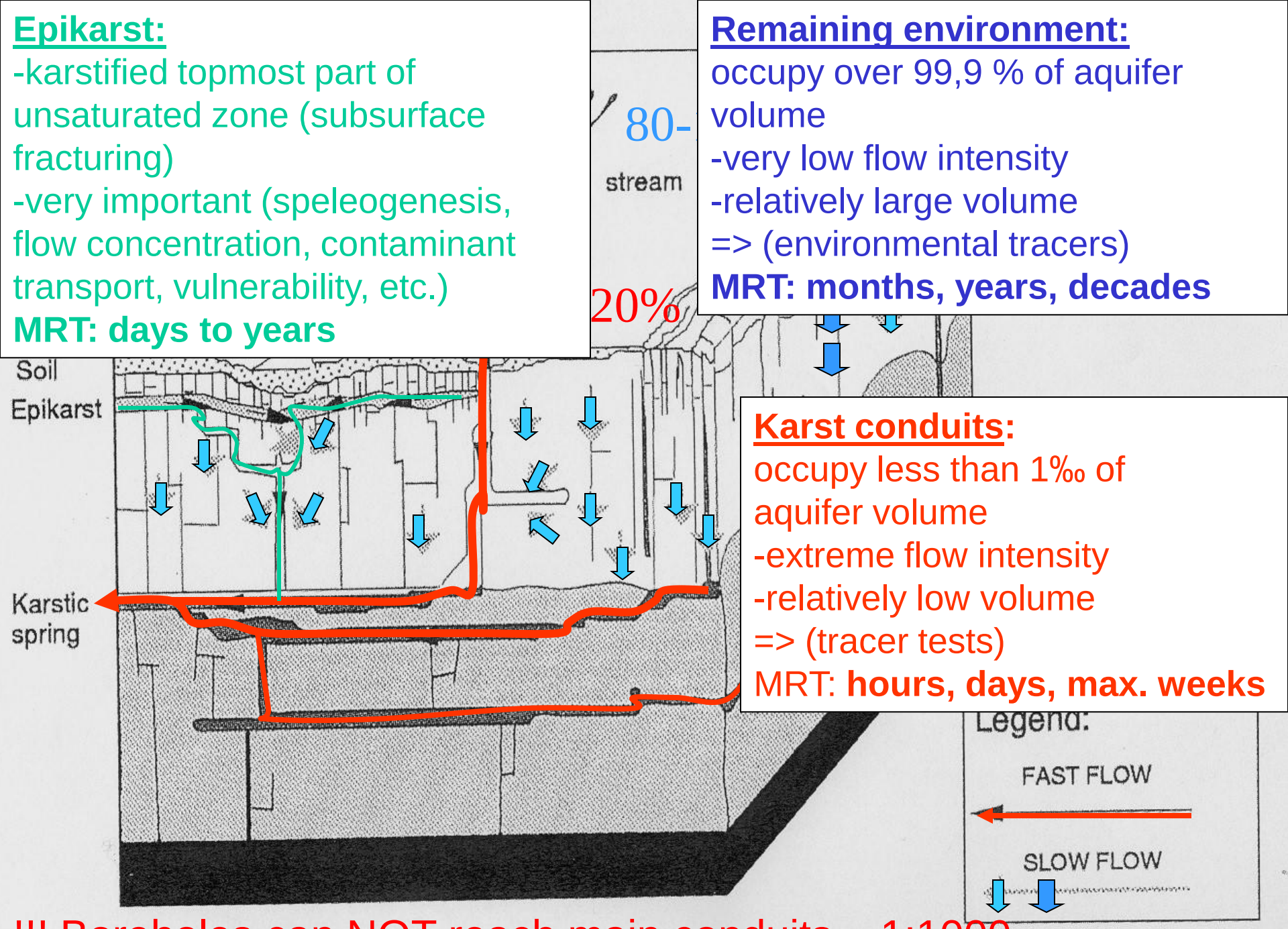
Karst environment

-epikarst
-vadose (unsaturated) zone
-phreatic (saturated) zone

-flow pattern and velocity, residence time

Epikarst:
-karstified topmost part of unsaturated zone (subsurface fracturing)
-very important (speleogenesis, flow concentration, contaminant transport, vulnerability, etc.)
MRT: days to years

Remaining environment:
occupy over 99,9 % of aquifer volume
-very low flow intensity
-relatively large volume
=> (environmental tracers)
MRT: months, years, decades



Karst conduits:
occupy less than 1‰ of aquifer volume
-extreme flow intensity
-relatively low volume
=> (tracer tests)
MRT: **hours, days, max. weeks**

!!! Boreholes can NOT reach main conduits... 1:1000

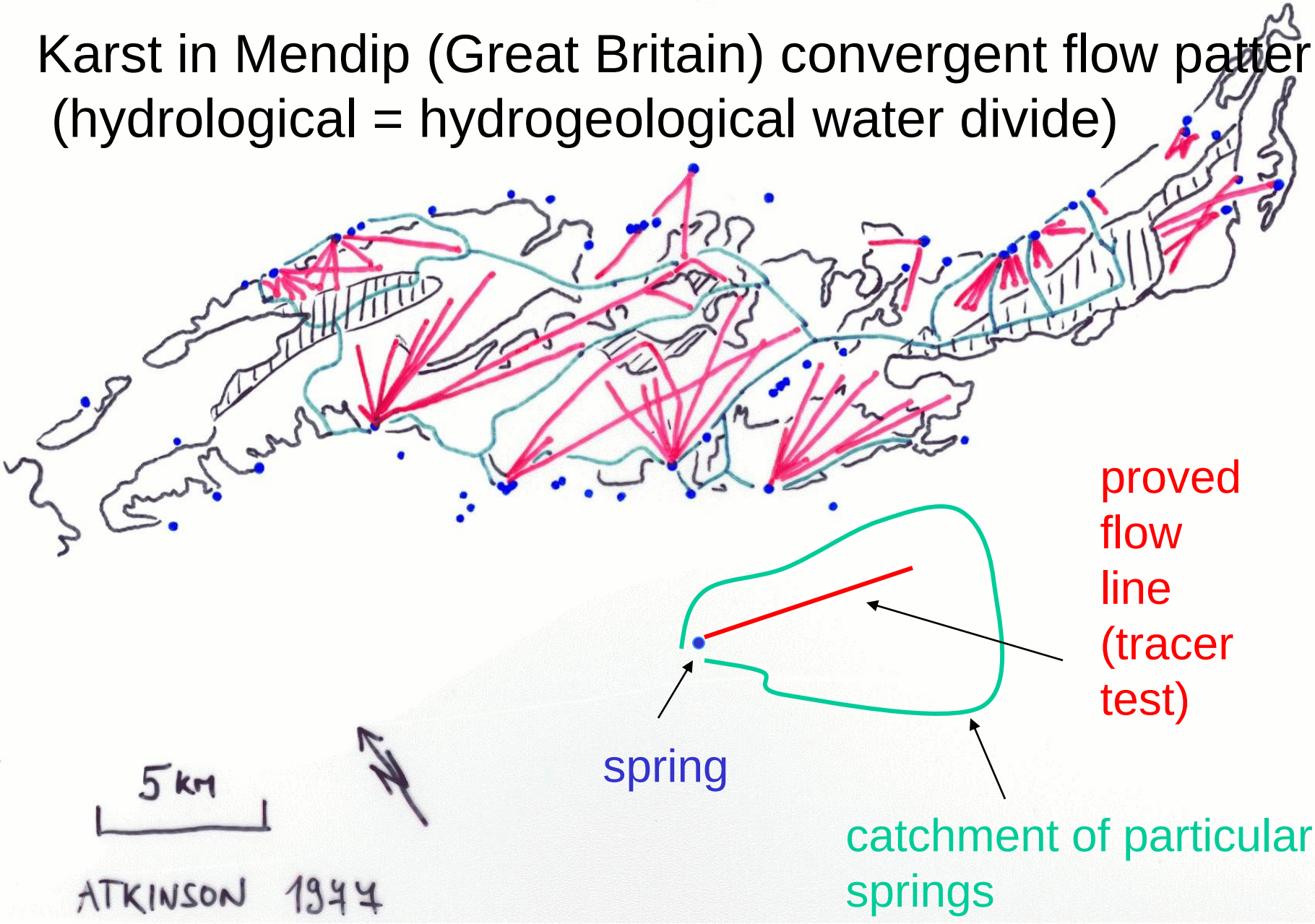
Karst conduits and regional flow

-flow pattern

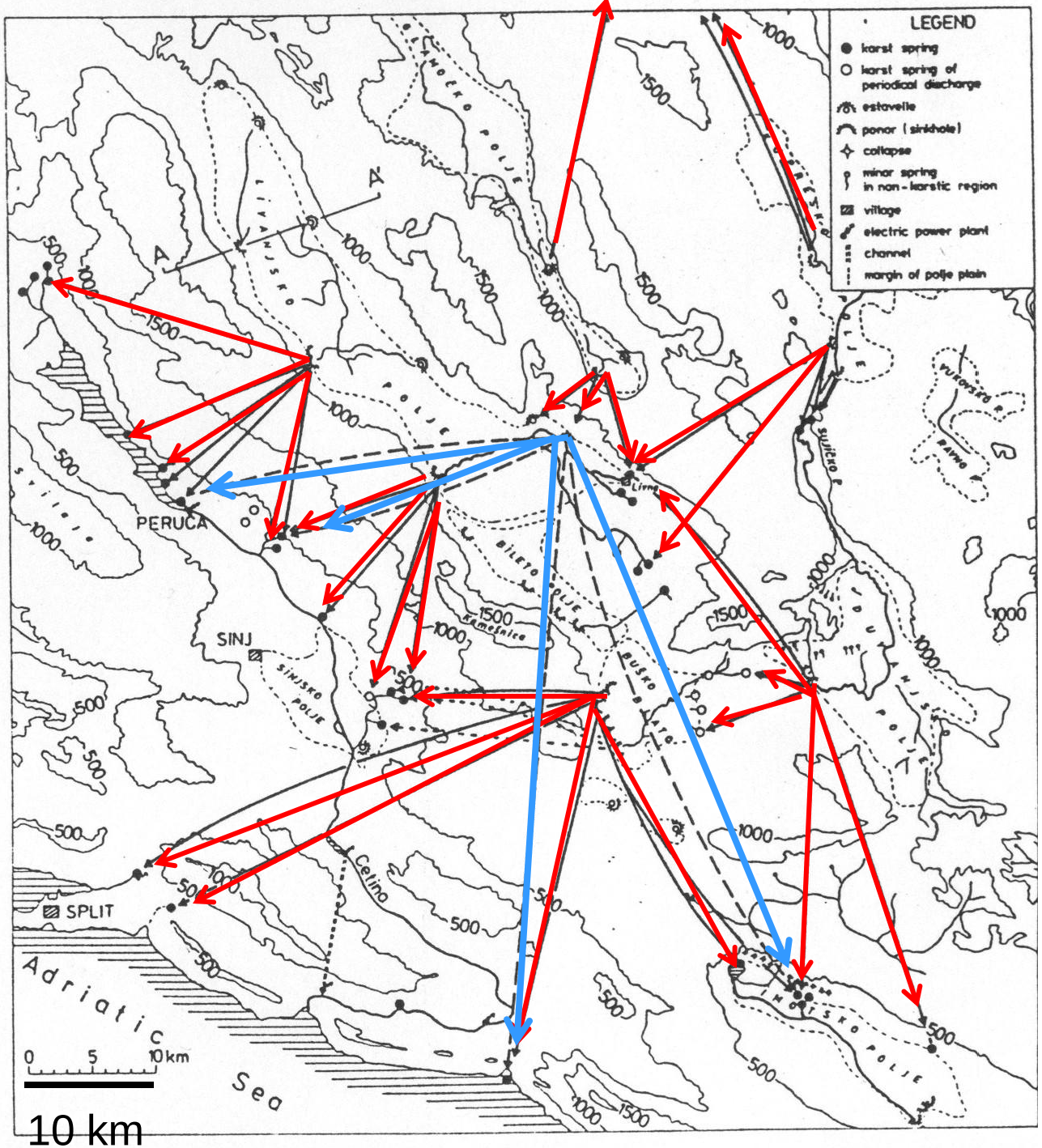
-flow velocity

- Surface water and groundwater divide

Karst in Mendip (Great Britain) convergent flow pattern (hydrological = hydrogeological water divide)



Springs have clearly defined catchments



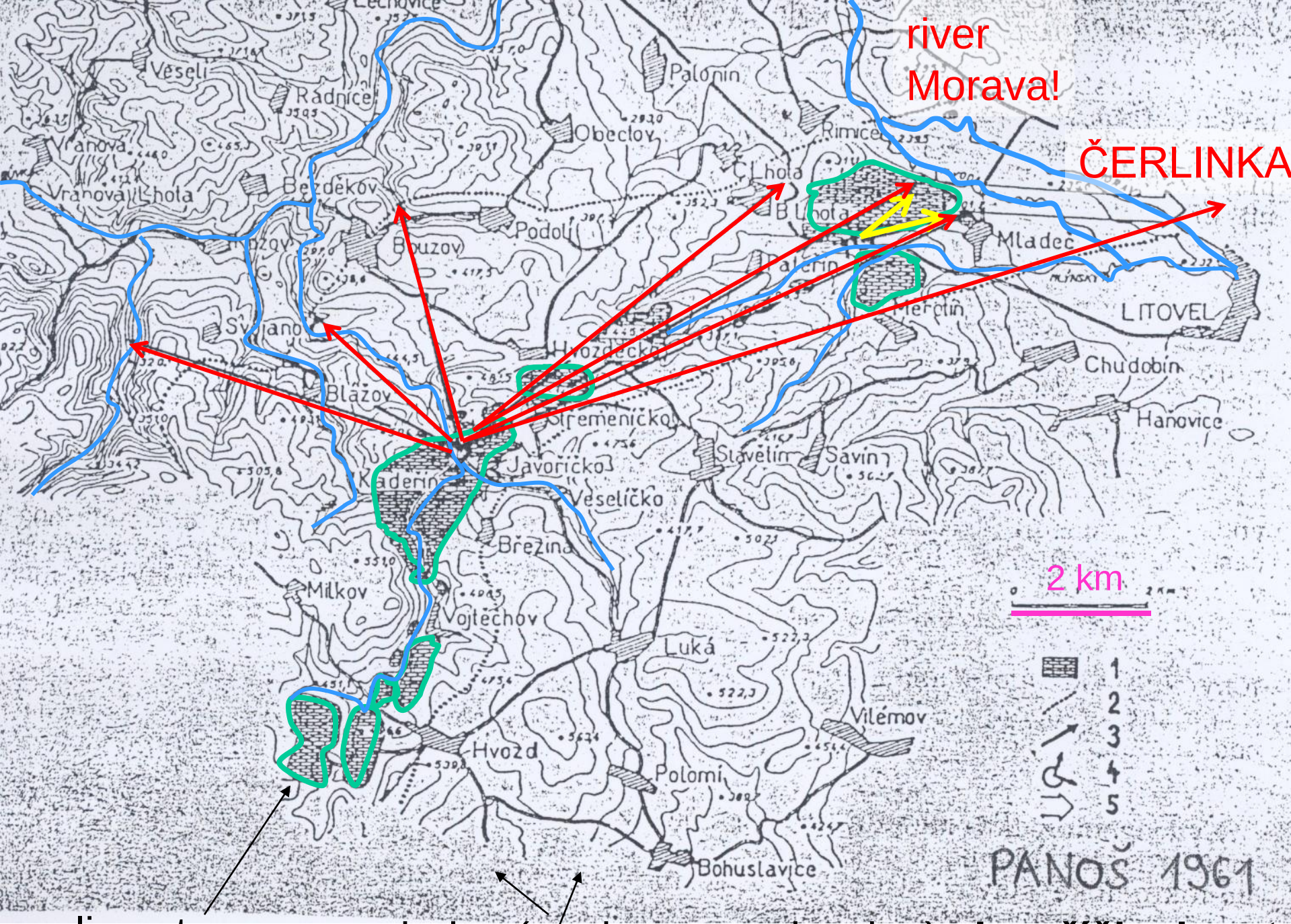
(Dinaric Karst)

-strong tendency to polyfurcation

(more common than convergent pattern)

-large rivers sinking in the area, water from sink flows to spring which is up to 50 km apart

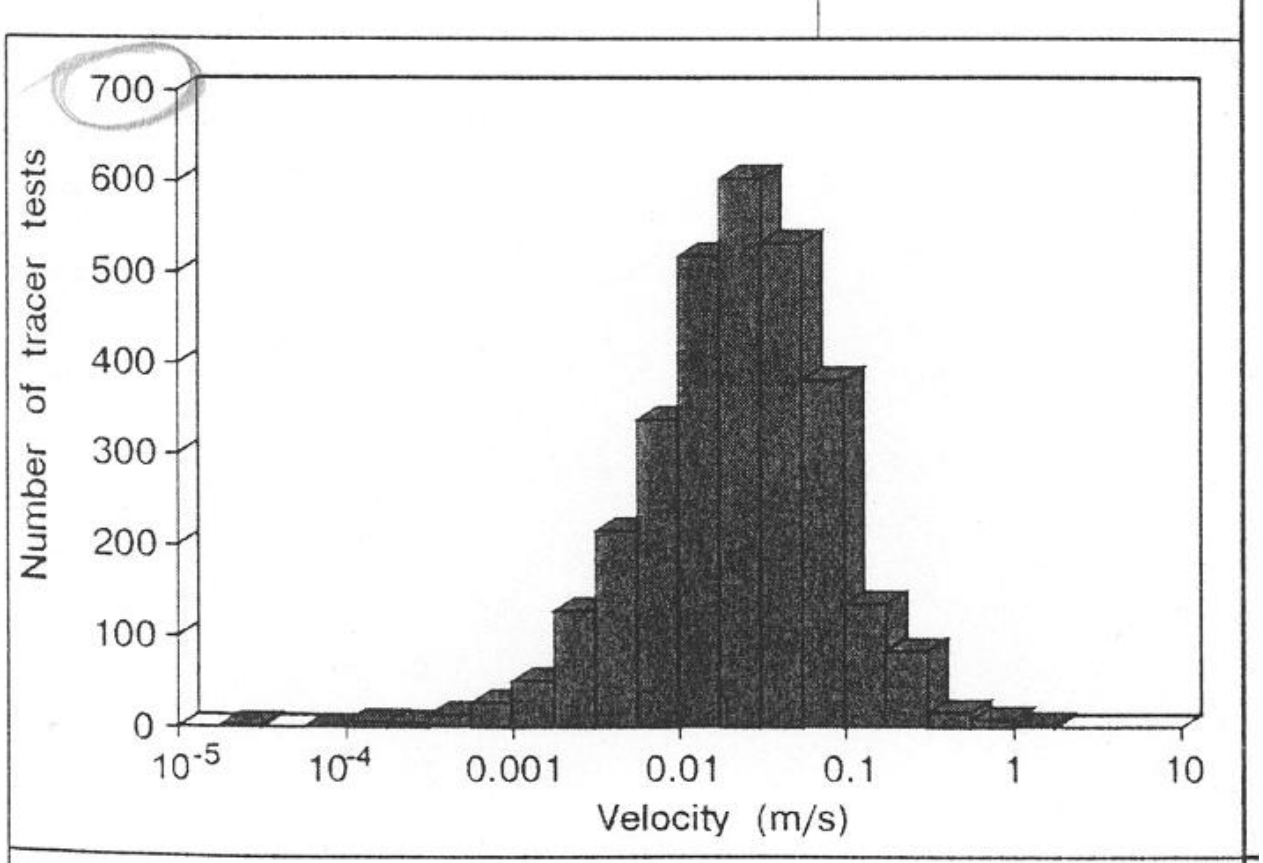
-impossible to delineate catchments and to determine the flow directions without tracer tests



limestone

shales (nonkarst overburden)

Javoříčko karst



8.1 Figure 1. Velocities of 2877 traces in carbonate bedrock between sinking streams and springs.

velocity in conduits in Czech Republic
80 m up to 9 km/day
0.001 up to 0.1 m/s

-very high velocity
-once the contamination enters the sink it appear in hours or days in some spring or water supply

↑ the largest sinks of stream
in CR up to 20 m3/s (Bílá voda)

karst conduit Amatérská Cave
transport of coarse gravel →

timbers float into Coiba Mare Cave (Rumania). More than 500 m far from entrance
 => example of extreme flow capability

Groundwater development

Development of groundwater in karst aquifers by wells

Do not try to drill into the main conduits (not filtrated water, high variability in volume of water in conduits

Consider water level in conduits or in spring at the end of conduits as maximum depths to groundwater level (drainage level)

Do not be afraid of karst aquifers – good for development – basement araeas

Vulnerability of karst areas

„Groundwater vulnerability“ = natural sensitivity of groundwater occurrence to contamination (Daly et al., 2002)

Intrinsic vulnerability	**Specific vulnerability**
-geological, hydrogeological and hydrological properties of environment	- intrinsic vulnerability + properties and behaviour of contaminant in environment
Resource vulnerability	**Source vulnerability**
-target (for contaminant) is the water table (whole body of groundwater)	-target is the source (spring, borehole)...water supply

Vulnerability mapping as a tool for landuse management

Method **GOD**

- **G**roundwater occurrence
- **O**verall lithology
- **D**epth to groundwater table

Method **EPIK**

- **E**pikarst
- **P**rotective cover
- **I**nfiltration conditions
- **K**arst network development

„European approach“

- Faktor **O** (***o****verlying layers*)
- Faktor **C** (*flow* ***c****oncentration*)
- Faktor **K** (***k****arst network*)
- Faktor **P (*p****recipitation***)

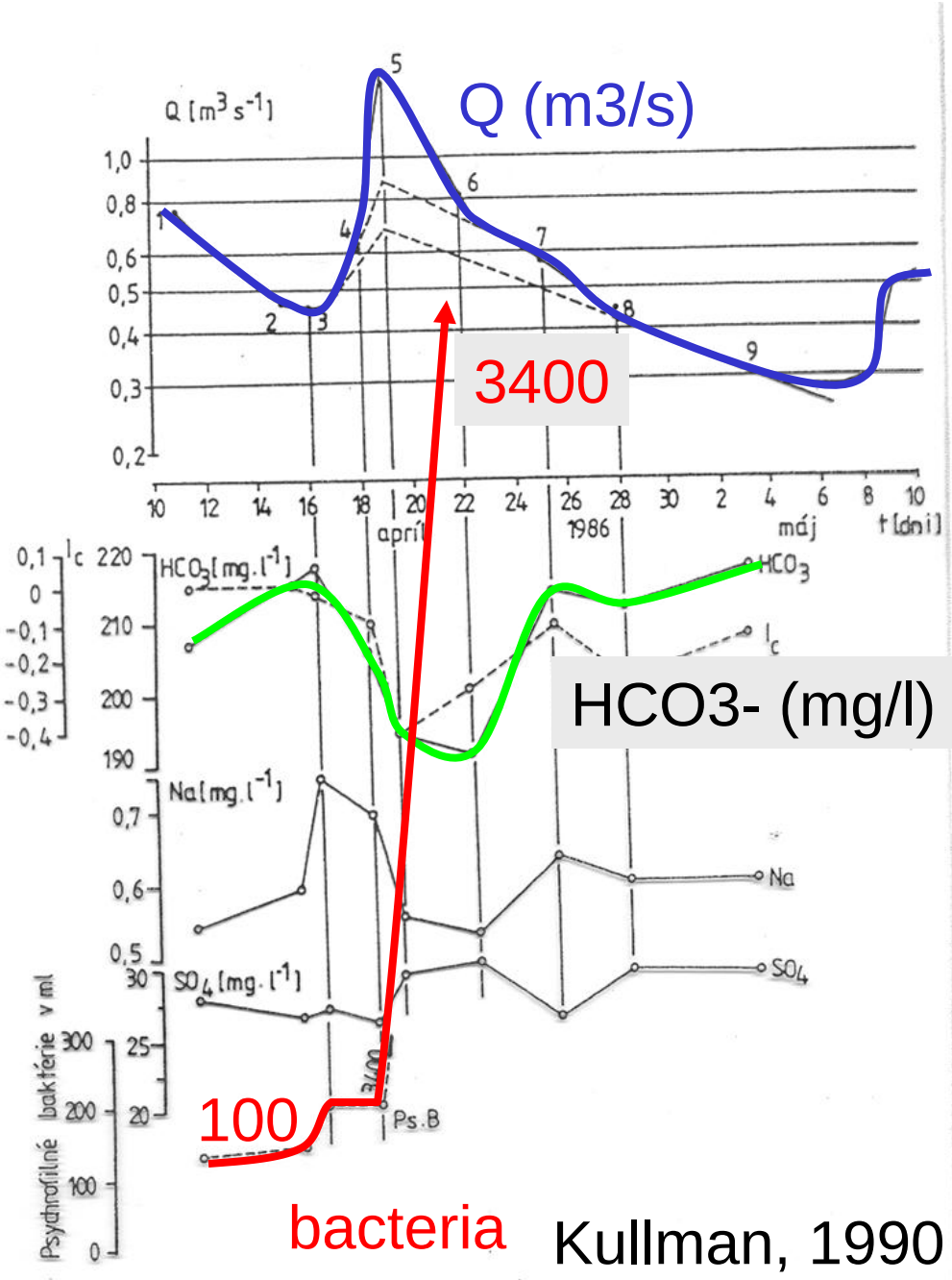
Spring development

-mostly there is NO dilution of pollutants content during recharge events...

-strong increasing of bacteria number in spring water after rain events

-in karst areas the quality of water can be good due to impropriety sampling (is necessary to sample also during and after strong recharge events... many pollutant flushed into underground by concentrated recharge

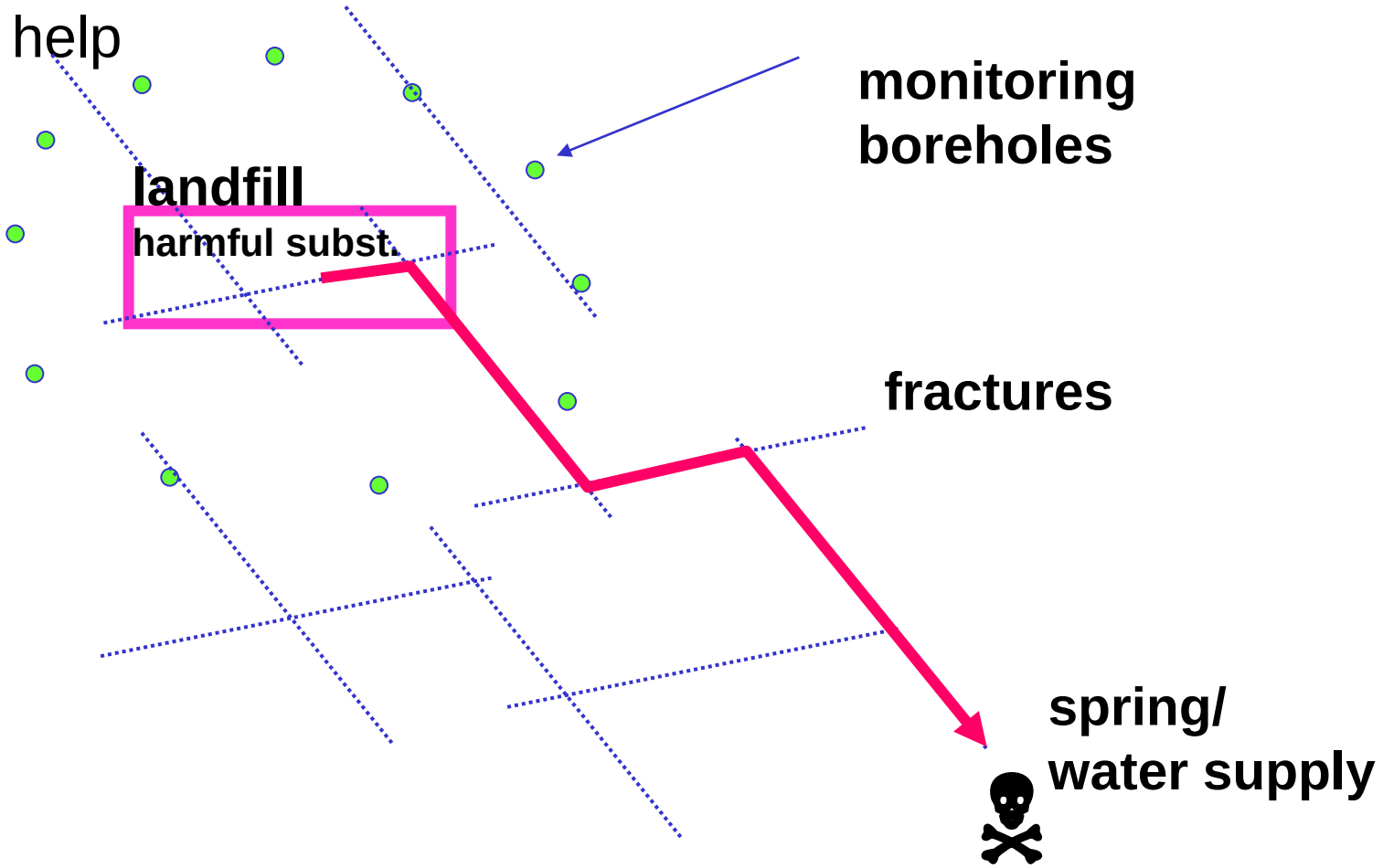
-during most of time, only diffuse recharge is taking place



Karst OR strongly heterogenous environment

= improbable to catch the most permeable zones by boreholes....springs MUST be monitored also

-in heterogenous fracture environment ....geophysics can help



Karst in Ethiopia

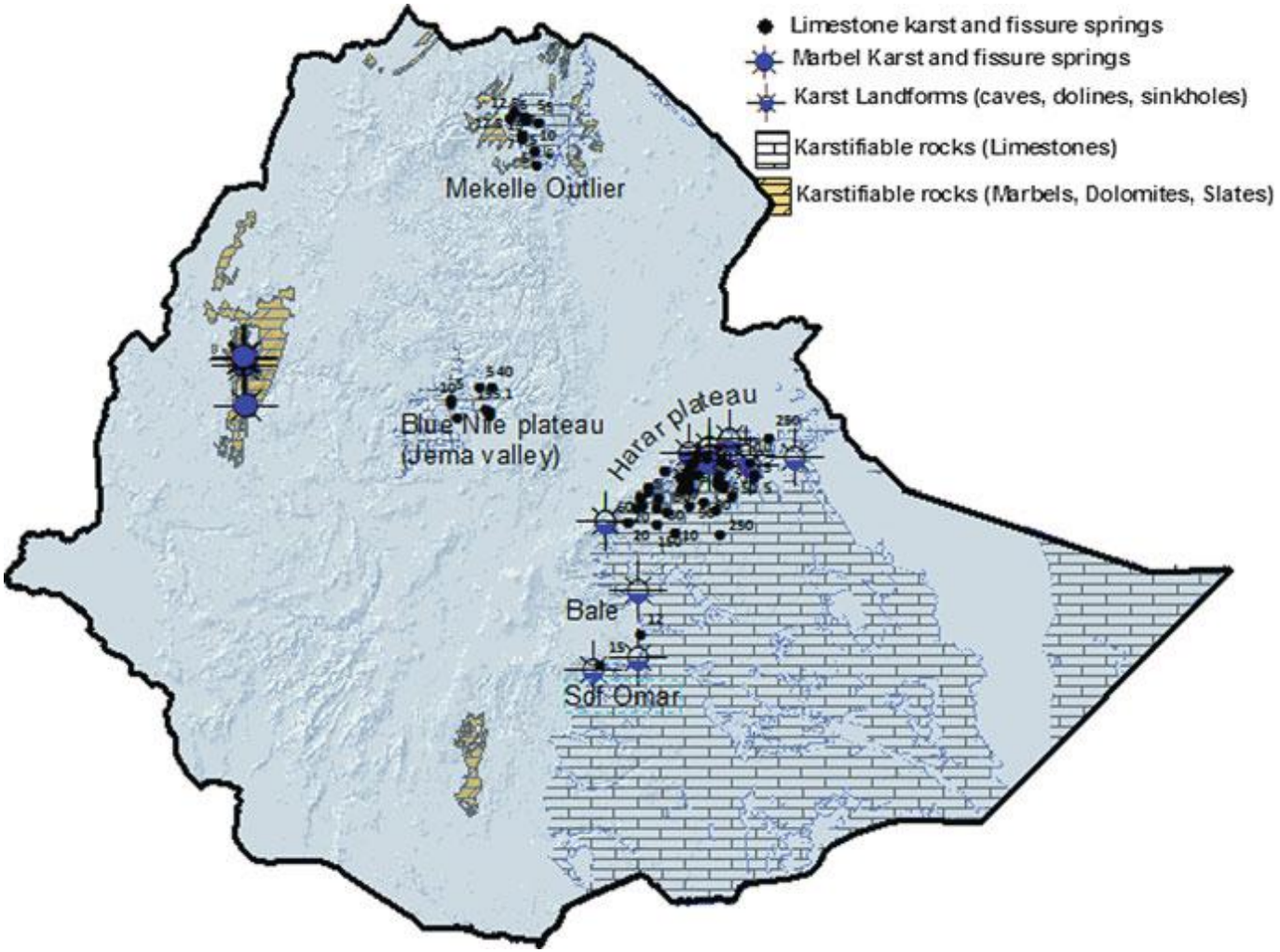
Karst areas in Ethiopia – limestone/marble

- Mekele and Afar
- Blue Nile gorge (Jemma),
- Eastern plateau (Harar- Bale -Sof Omar) water supply for Kersa, Bedesa, Mechera – Hakim spring – Harar Brewery,
- Marble in west (Dalati in Asossa area)

Caves – caverns in volcanic rocks

The territory of the Wolayta region includes many geological strata of volcanic origin. Following the river valleys or getting in the vicinity of the meeting point of different geological strata, we can find little rock shelter or little caves

Karst areas (Seifu Kebede)



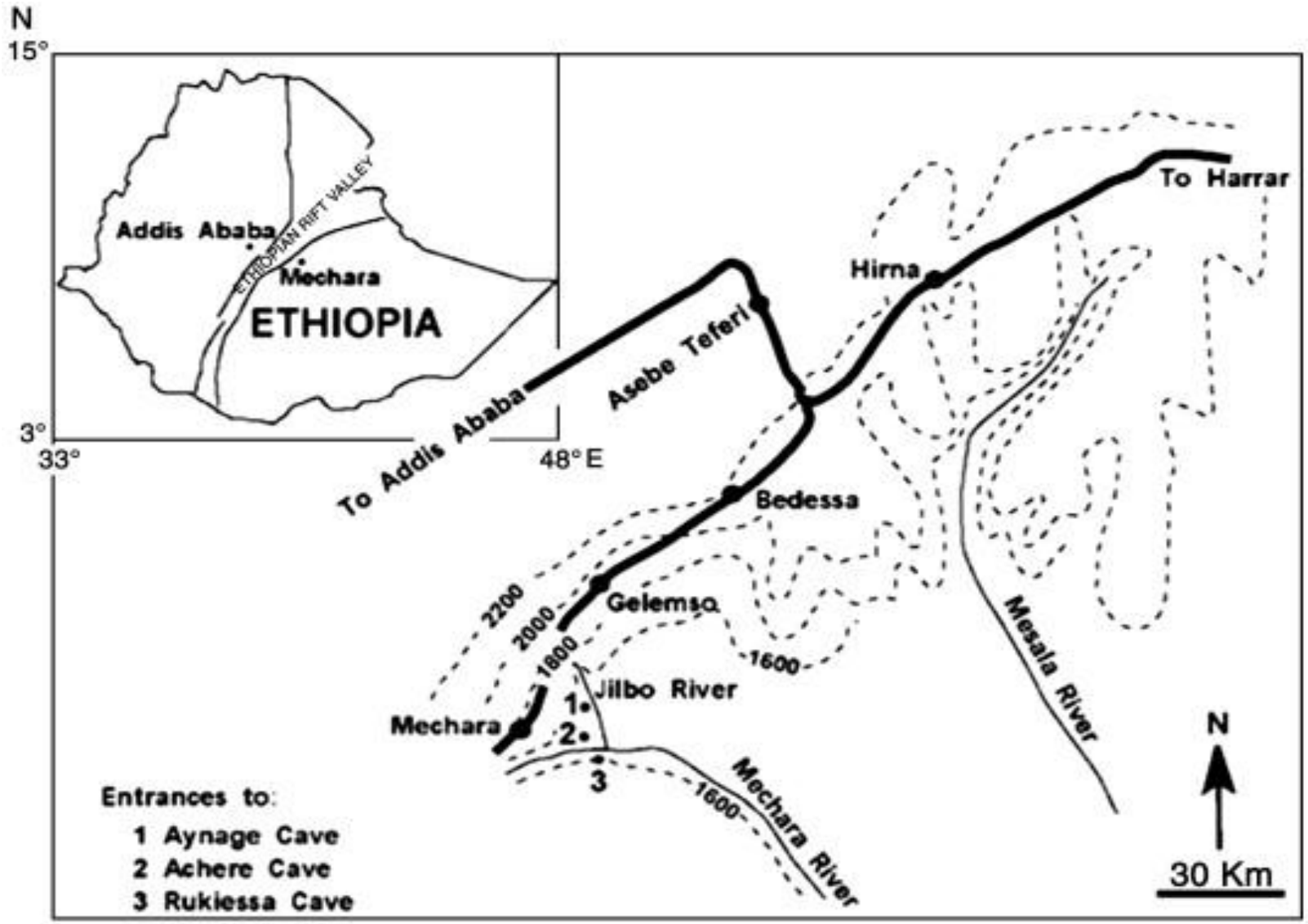
SE Plateau –eastern part

Named 'THE GURSUM PEARL' at a meet of the local Gursum Action Group, explored on February 13-14 2009. Ethiopia's first cave with a huge number of stalactical feutures - speleothems. An active spring. It is one of Africa's three best speleological finds. And, according to the five experts first in, definitely amongst the best they visited in the world.
PHOTOGRAPH BY MARCO ADORNO

Gursum cave „Perl“

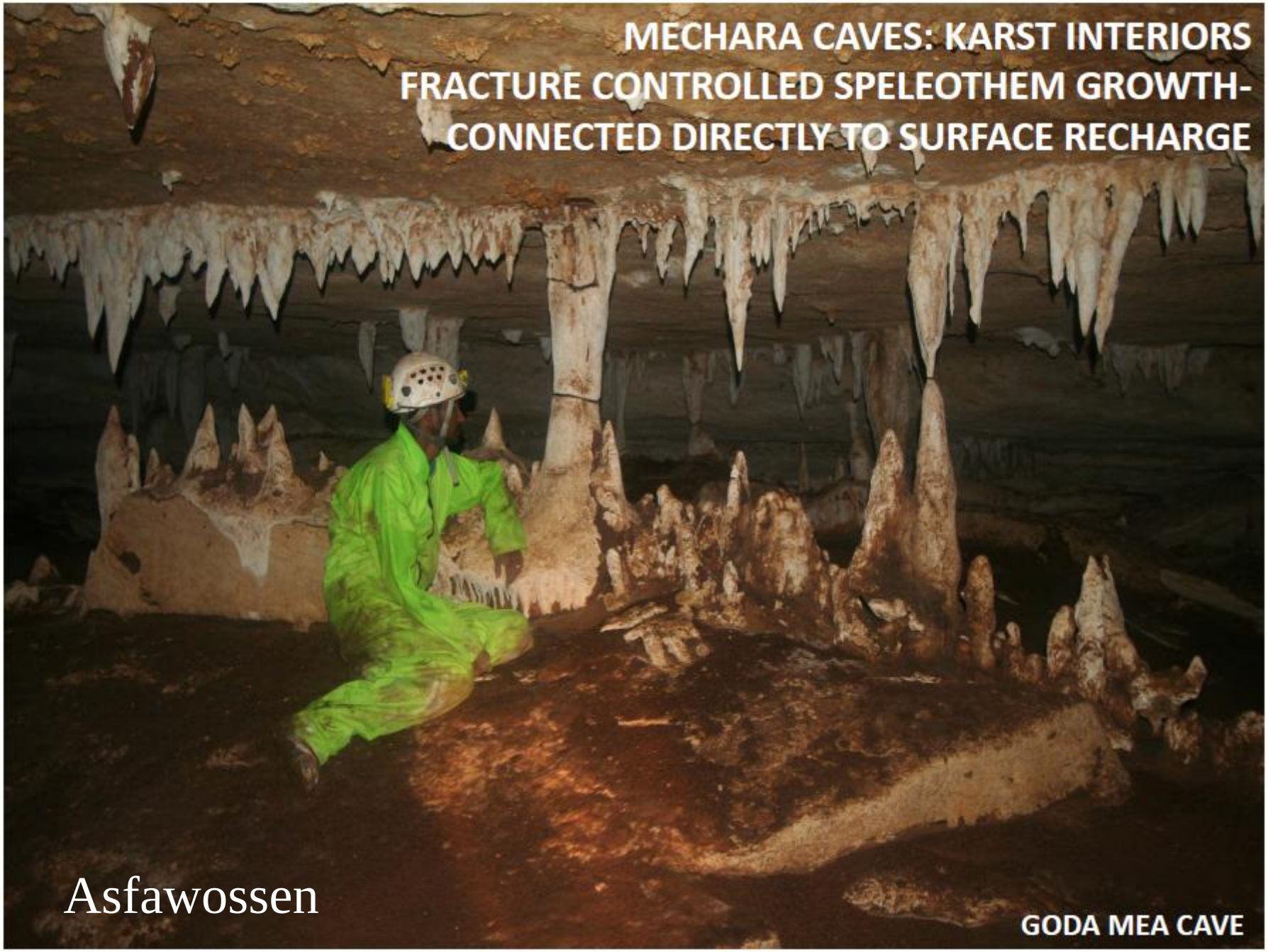
Pearl cave

SE Plateau – western part



Karst spring – Kunturur area


MECHARA CAVES: KARST INTERIORS
DECORATED WITH SPELEOTHEMS
Asfawossen
GODA MEA CAVE


MECHARA CAVES: KARST INTERIORS
FRACTURE CONTROLLED SPELEOTHEM GROWTH-
CONNECTED DIRECTLY TO SURFACE RECHARGE
Asfawossen
GODA MEA CAVE

Sof Omar cave – no stalactical features (speleothems)

Sof Omar – collaps of roof

Karst investigation – future challenge for hydrogeology

- Stalactical features non stalactical features (speleothems) in caves
- Extent and flow dynamics of karst systems and aquifers
  - Tracing tests
  - Speleological investigation
- Method for investigation and well drilling
- Vulnerability assessment and resources protection principles

Thank You