Tectonics in river system

- Response of tectonic processes in fluvial systems, asymmetry of river basins, related increased erosion and accumulation, river pattern analysis

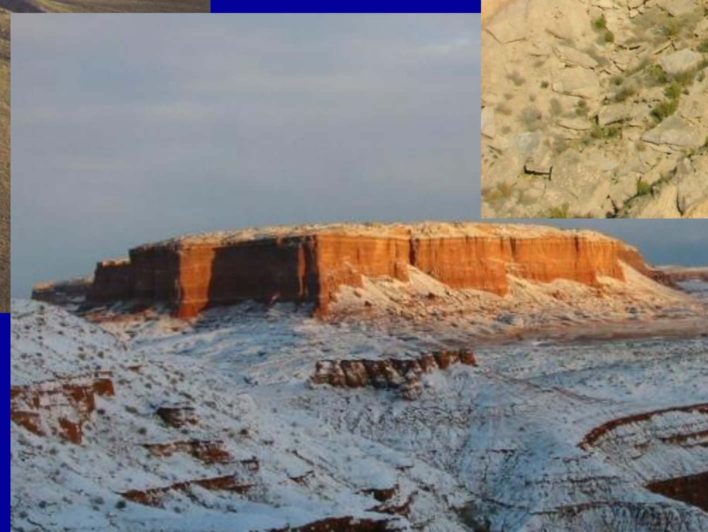
- Analyses of fluvial landforms affected by tectonic movements – river terraces, alluvial fans, analysis of longitudinal river profile and valley cross sections

Morphostructural analysis

- Tectonic geomorphology uses methods of morphostructural analysis:
  - Analysis of relationship between **geological structure** (lithology, structures – faults, folds) and **relief** => bedrock control

Structural relief controlled by bedding planes, differential weathering

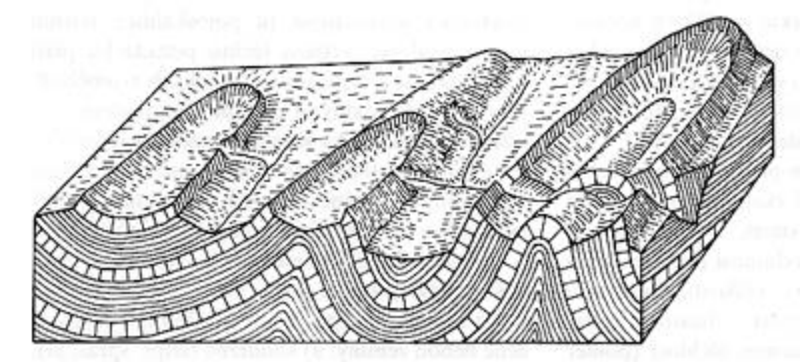
strukturní hřbet, skalní stěna (structural ridge, rock wall)



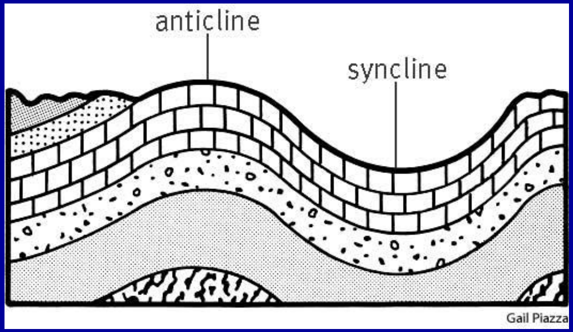
strukturní plošiny a stolové hory - mesa (šp. stůl) (table hills)

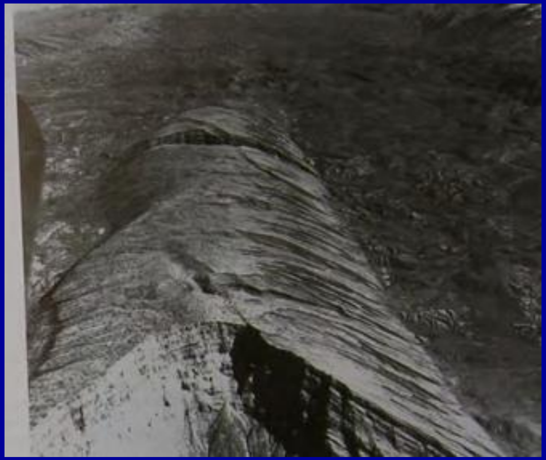
- Tectonic landforms – structural relief controlled directly by tectonic movements

- Fold landforms - conform landform - syncline valley, anticline ridge



Inverse relief – not tectonic





Morphostructural analysis of the relief

= overall assessment of relationship between geological structure and relief

- **Morphostructure** – part of bedrock with common evolution and structural characteristics, with maximum inner homogenity and different from the surrounding (e.g. part of mountains with similar uplift rate…)

- passive morphostructure - bedrock and older tectonics

- active morphostructure - young and recent tectonics of all kinds, recent volcanism, seismicity

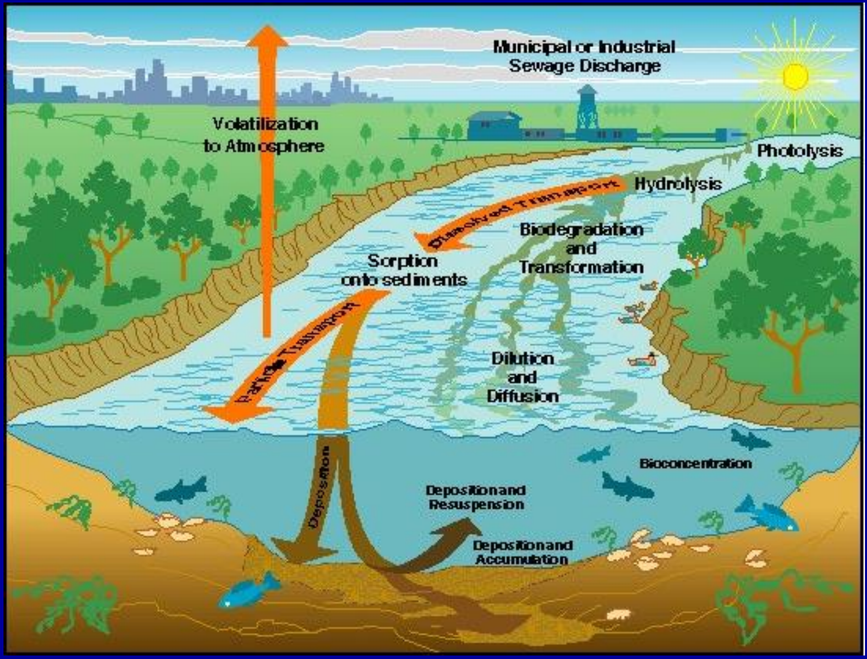
Tectonic landforms versus landforms influenced by tectonics

- Expression of tectonics in river system

- Valley system sensitive to endogenous and also exogenous processes – good information on tectonic movements

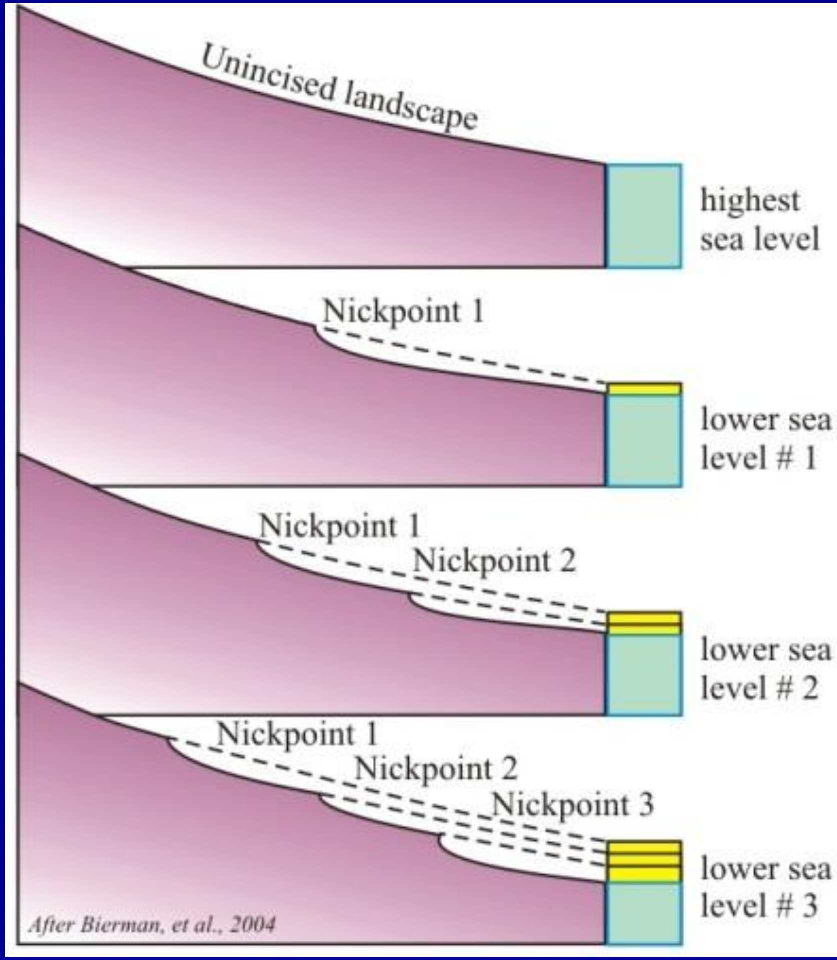
- Streams - parameters: width and depth of the channel, amount of transported material, slope of the channel, channel sinuosity, flow velocity

  These parametres are in balance in river system – sensitive to any changes

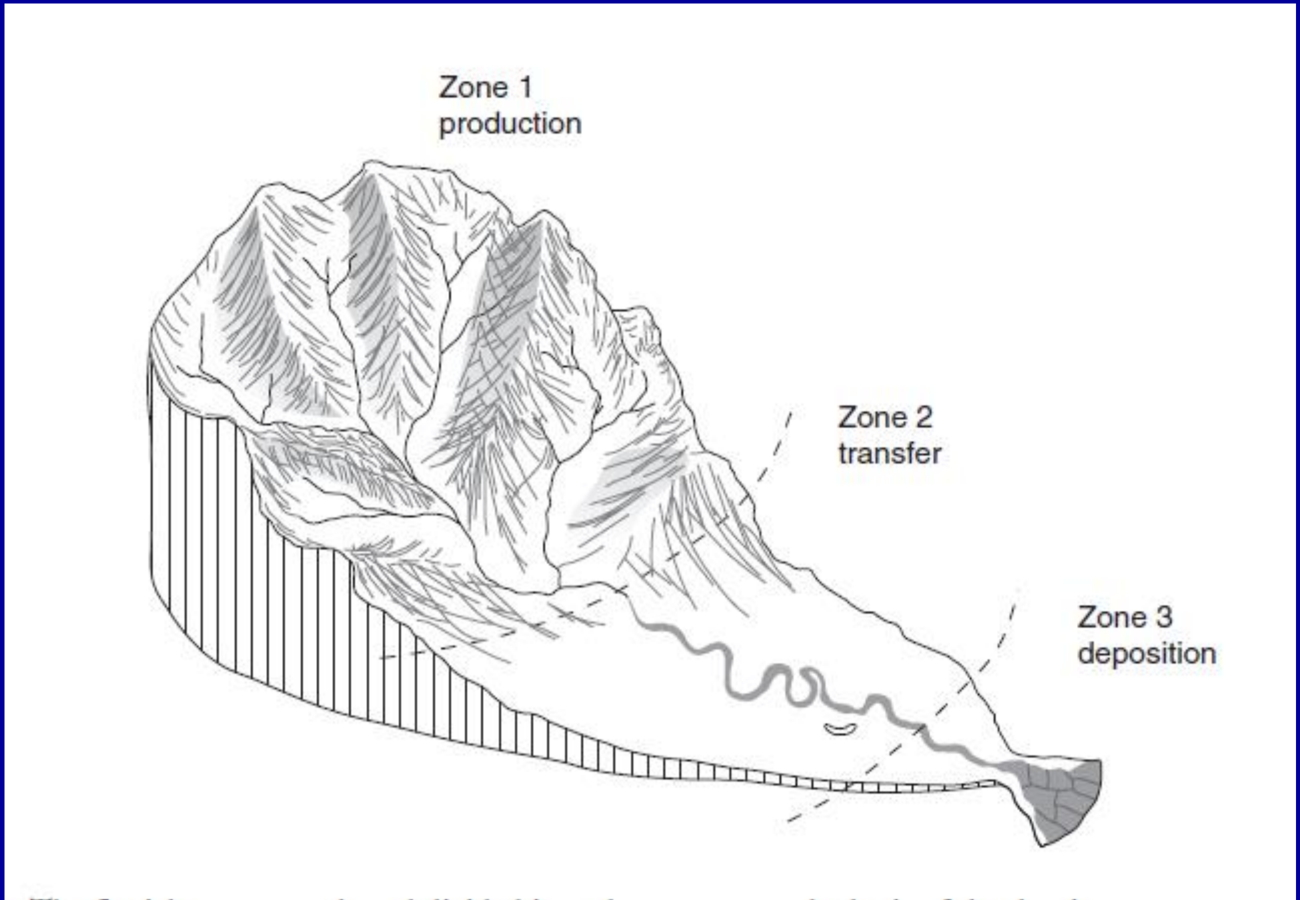


- Climate changes in Quaternary (2.6 mil yrs) – large effects on river system – global changes of ocean level – cycles of aggradation (accumulation) and degradation (erosion)

- = change of erosion base – the lowermost point of the stream, below this point river cannot erode (local erosional base on stream, sea level)



River actions: erosion, transportation, deposition



1) production of sediments (erosion prevails)
2) transport of material
3) deposition of material

River types based on transported material

- Alluvial rivers – parameters such as roughness of the channel bottom, viscosity, slope of channel etc. don´t allow to transport the material = river flow wittin their own sediments

  - more sensitive to tectonic movements, react to change of any parameter quickly, very young tectonics

- Bedrock rivers – material is transported, rivers erode and flow in exposed bedrock

  - less sensitive to tectonics, it takes longer when they are adjusted to tectonics, tectonics is obscured by local differences in lithology

- Graded river – rivers in dynamic balance, only transportation, no erosion, no accumulation

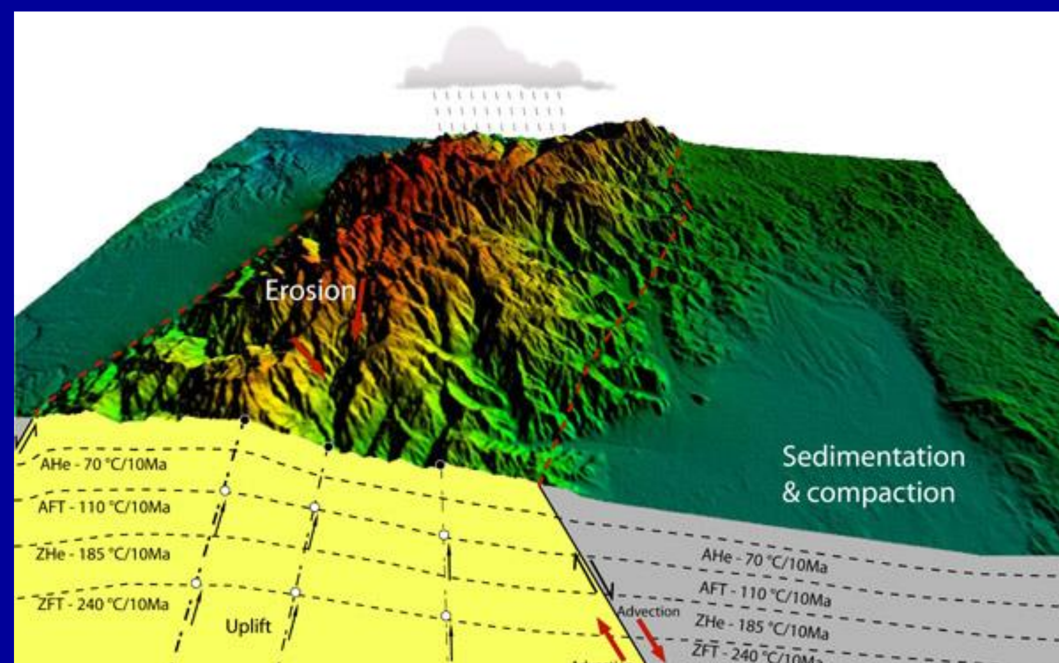
Accumulation and erosion

- Uplift – causes increased erosion or reduction in accumulation

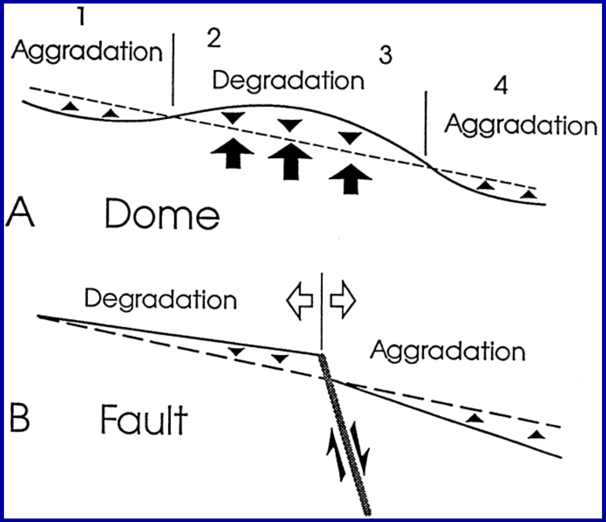
 - higher erosion = higher amount of material, sudden coarsening of material in alluvial fan sequences

Areas of high topography – other parameters remain the same but more coming material

Areas with common sedimentation – thinning of sediments suggests the uplift

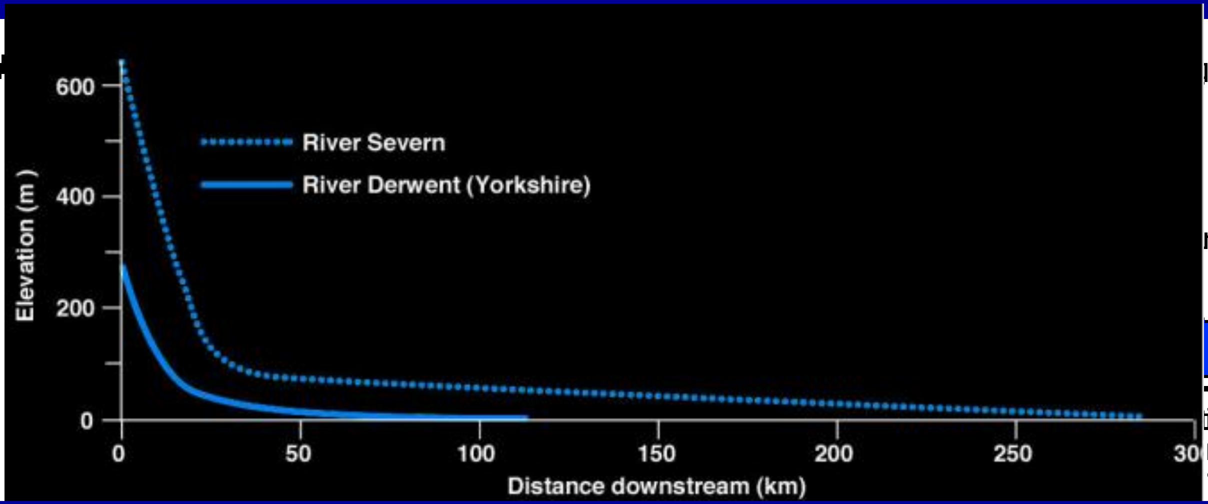


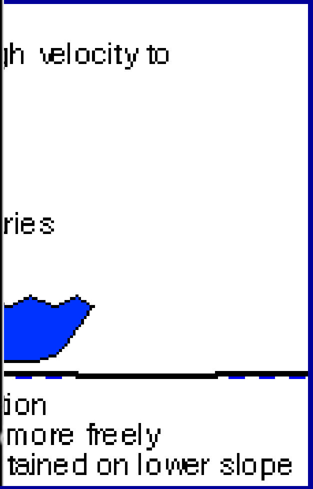
- Subsidence – favors sedimentation or at least increase existed accumulation



- Changes are expressed in longitudinal river profile
  Tectonics on regional scale – shape of the profile
  local scale– anomalies, knickpoints

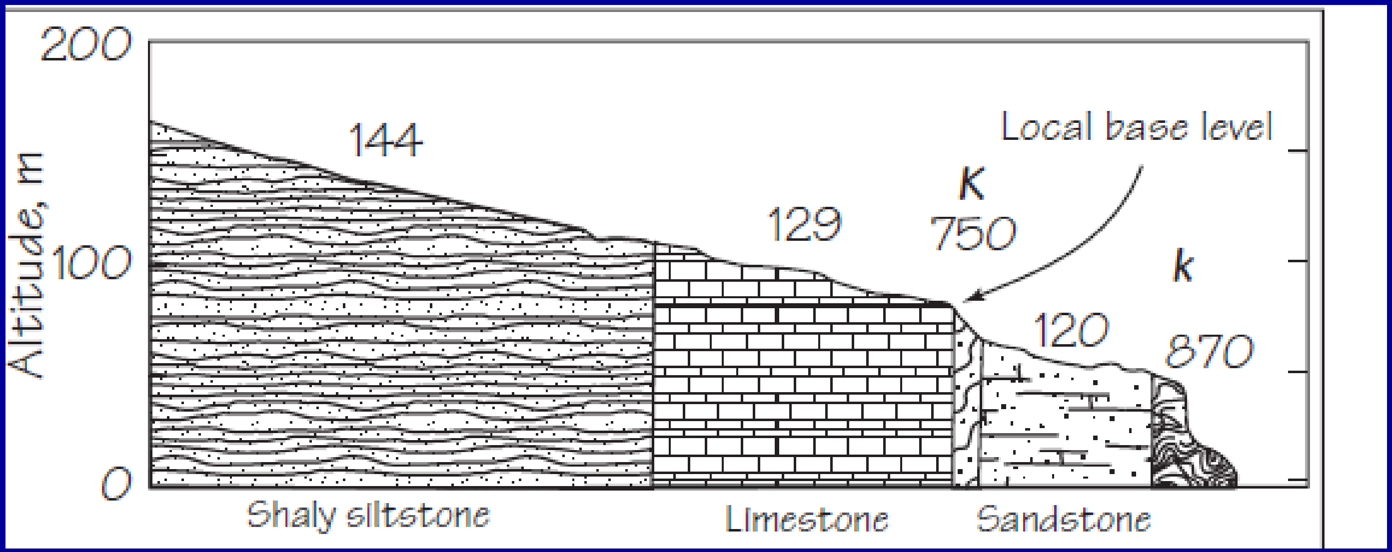
Graded river – concave shape



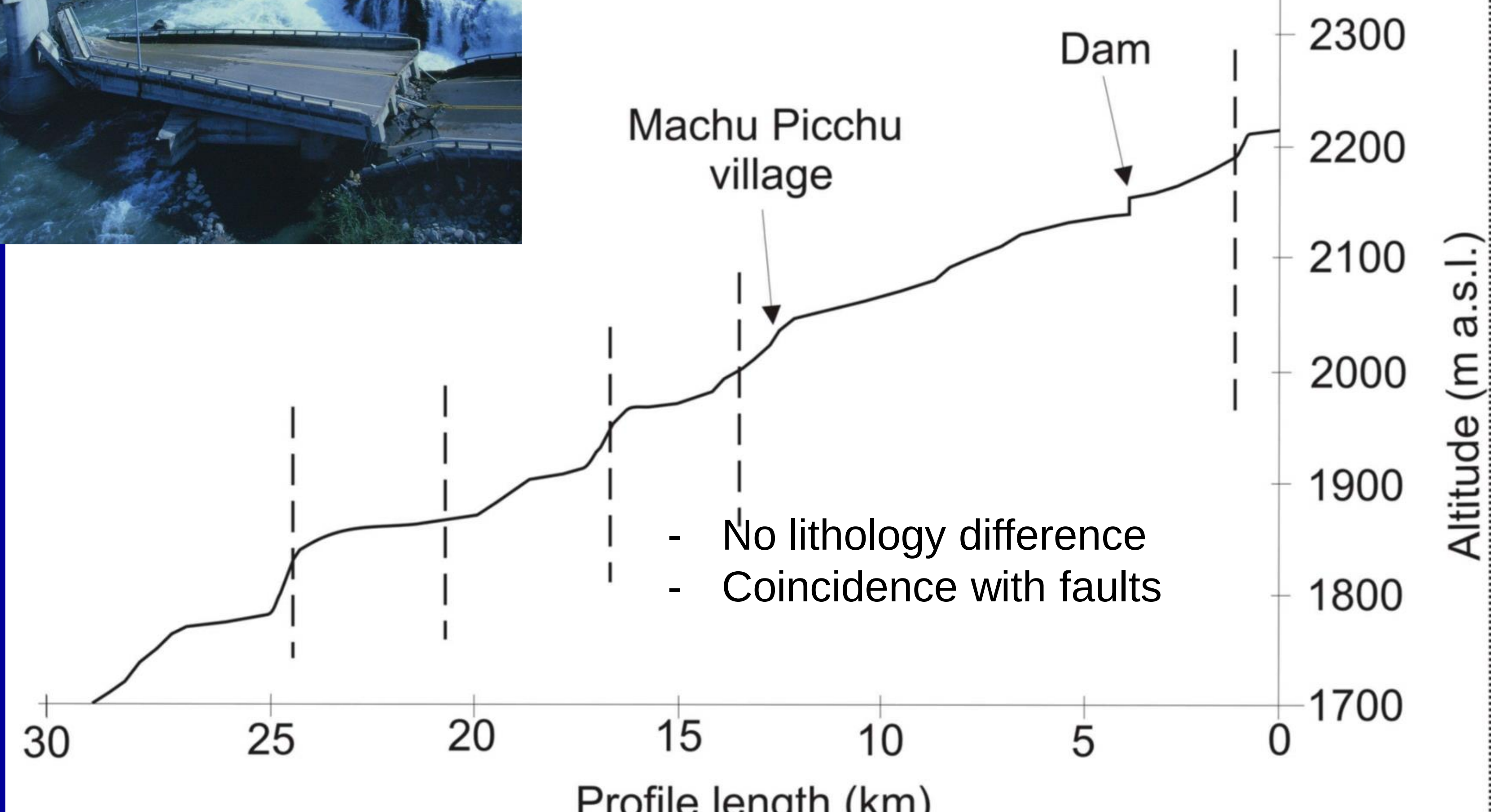


!! Causes of anomalies (knickpoints) in longitudinal river profiles:

- different lithology- more resistant / less resistant
- incision of the main river (hanging valley)
- reach of the headward erosion
- tectonic movements
- change of discharge (e.g. tributary)
- change in amount of transported material) (landslide, side erosion)
- antropogenic influence



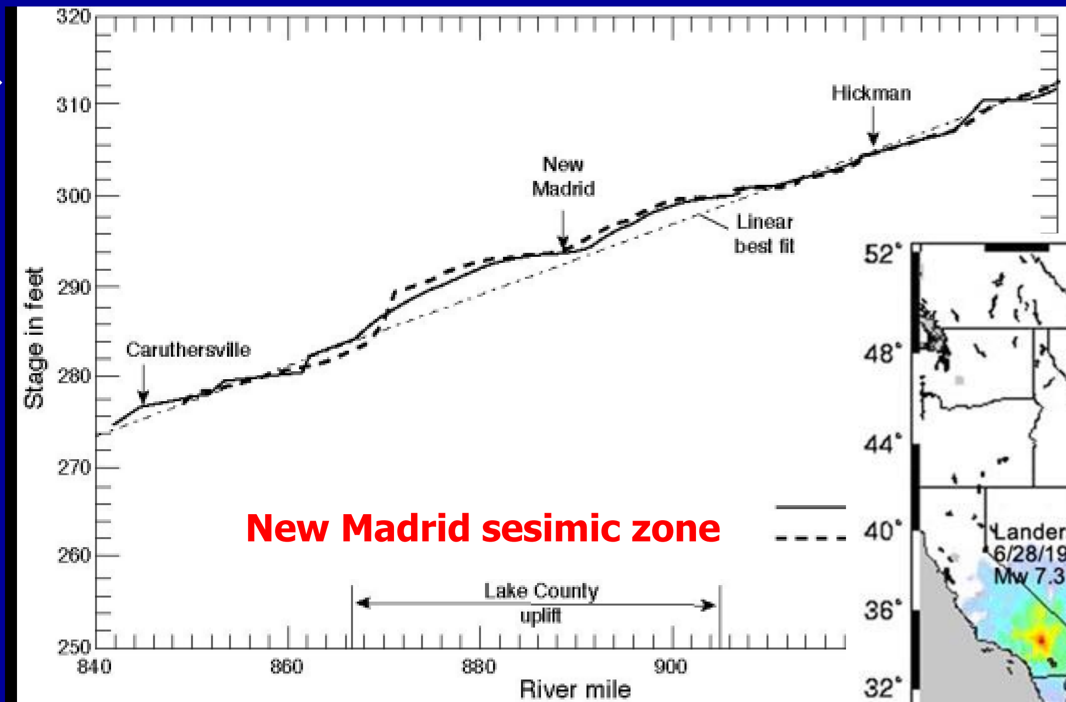
Lithologically controlled knickpoint

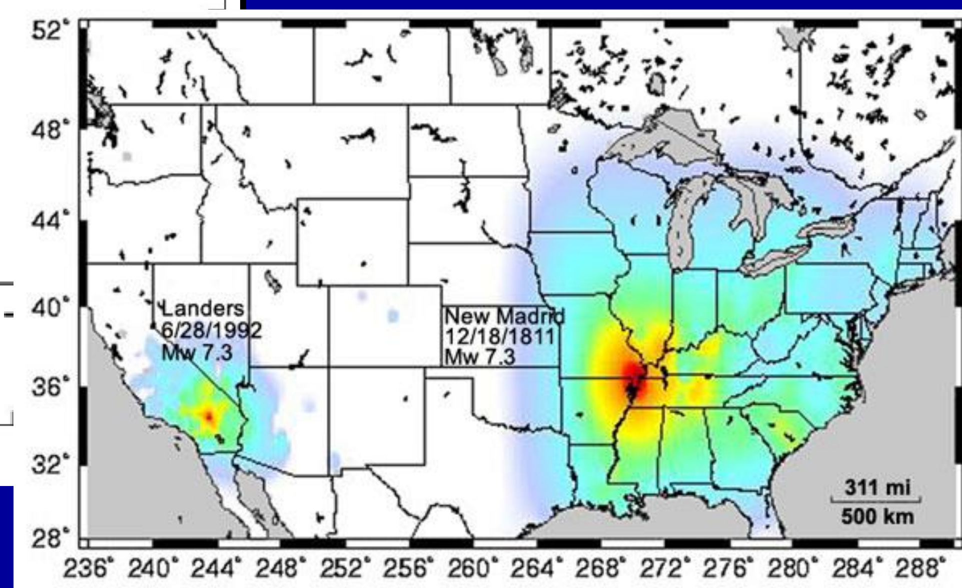


- No lithology difference
- Coincidence with faults

Anomalies tectonically controlled

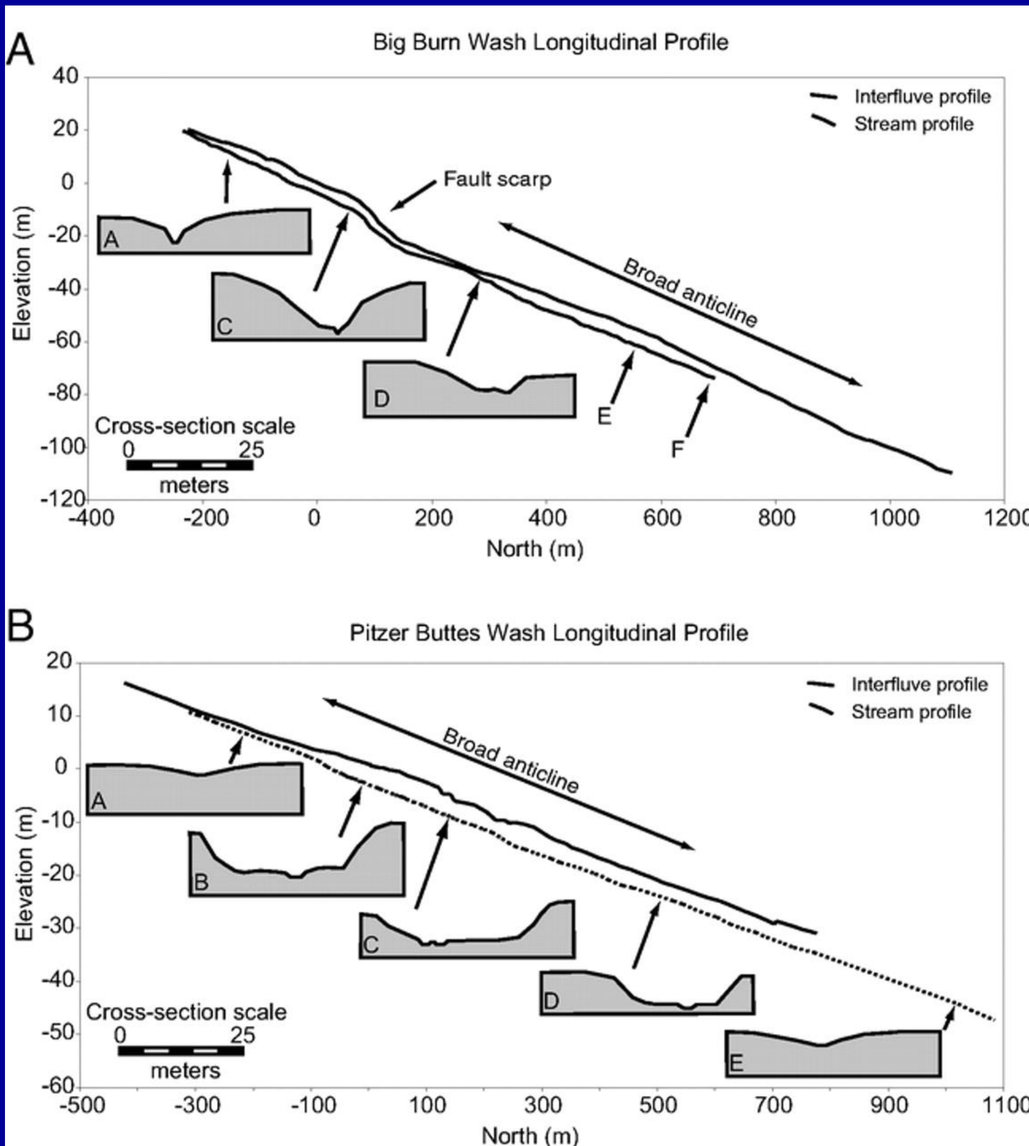
New Madrid 1811-1812 – during month 4 large earthquakes M = 7-8
Large regional changes in landscape – subsidence, uplift, fissures, landslides…

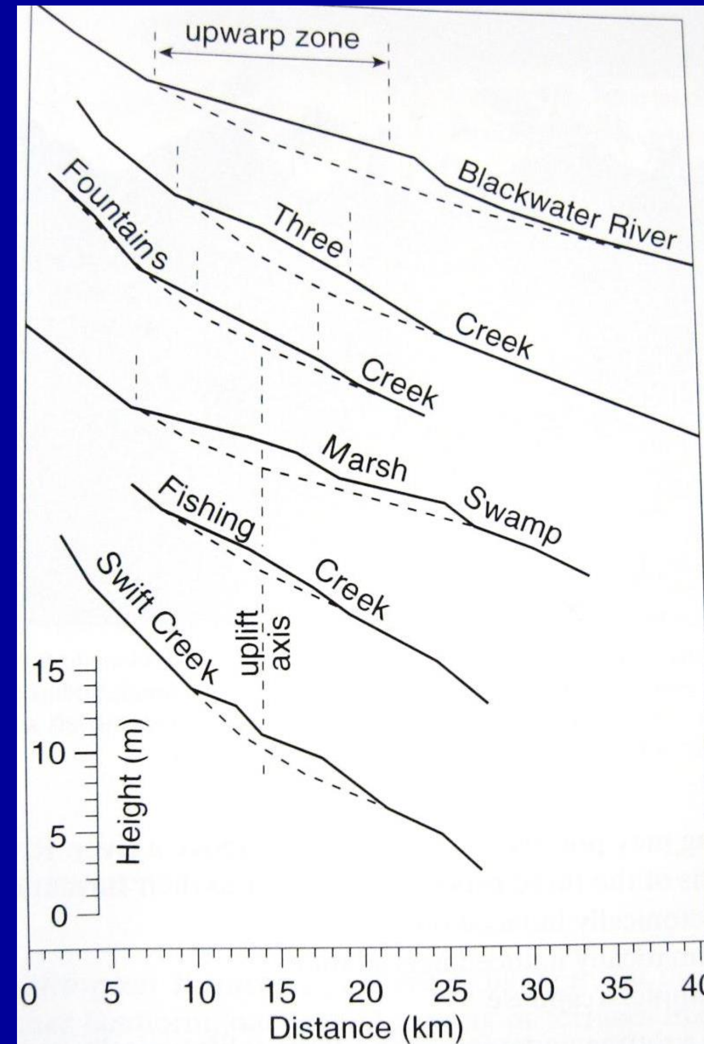




PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	None	None	None	Very light	Light	Moderate	Mod./Heavy	Heavy	Very Heavy
PEAK ACC.	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VELOCITY	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Present-day longitudinal profile
– response to uplift



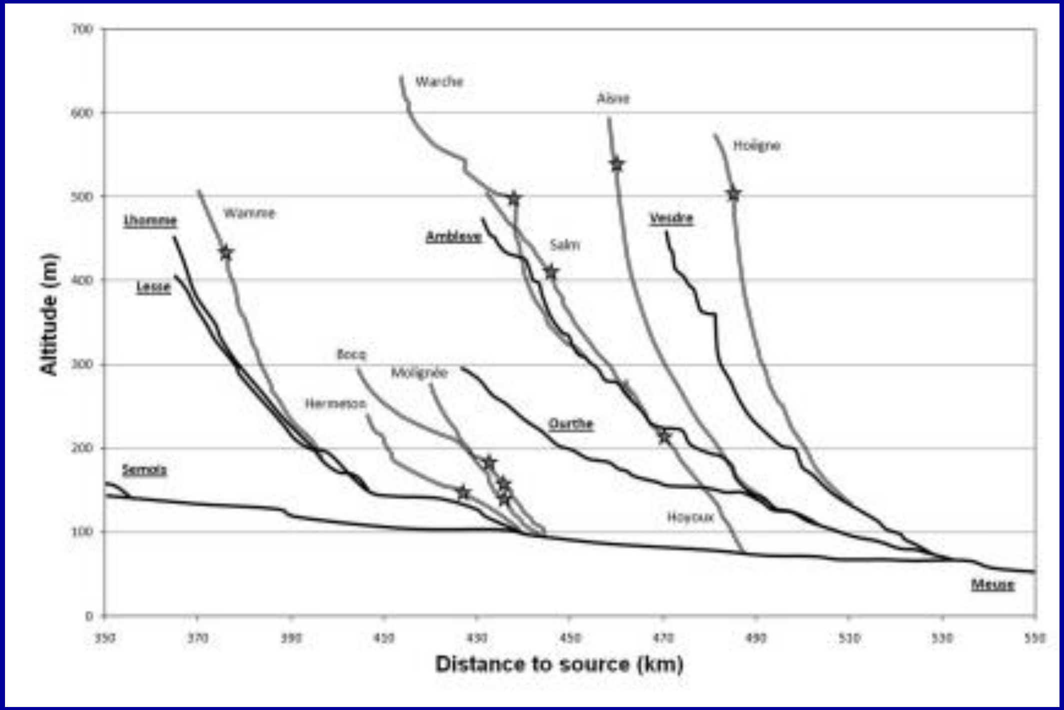


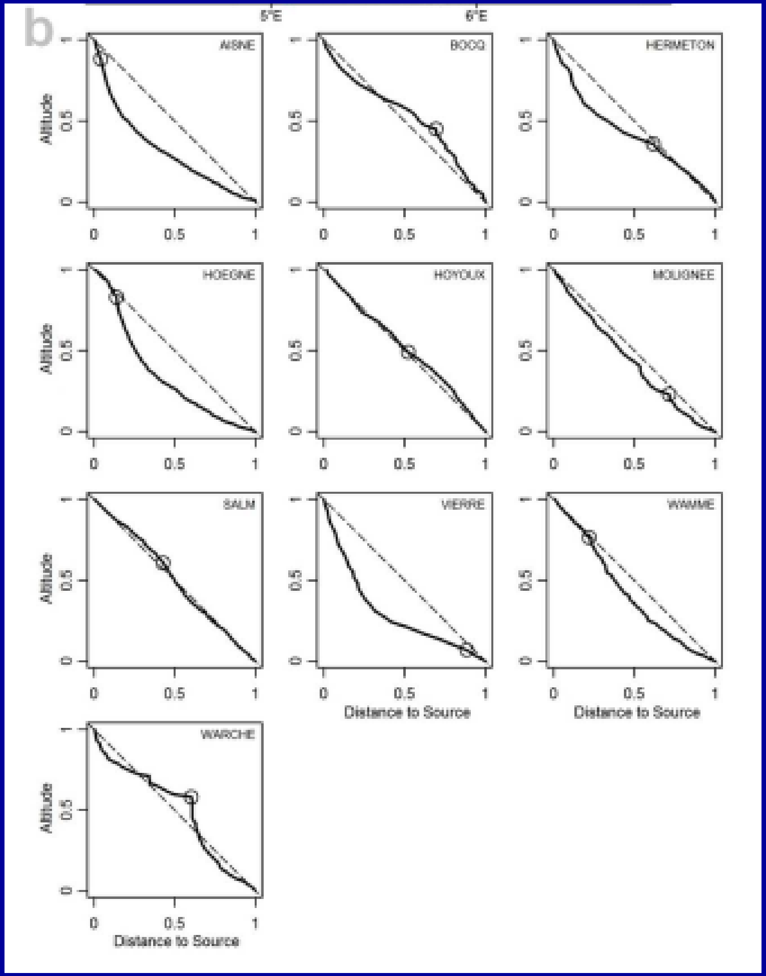
Rivers on Atlantic coast showing upwarping

Shape of longitudinal profile – reflects regional tectonics

profile convexity

River not afftected by tectonics – concave profile
- variabilIties: lithology, different uplift rate

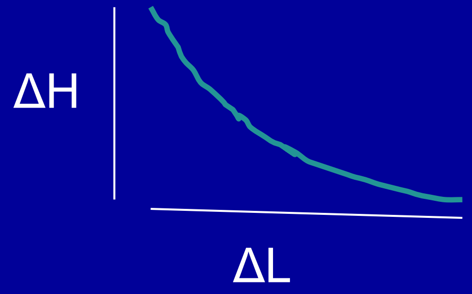




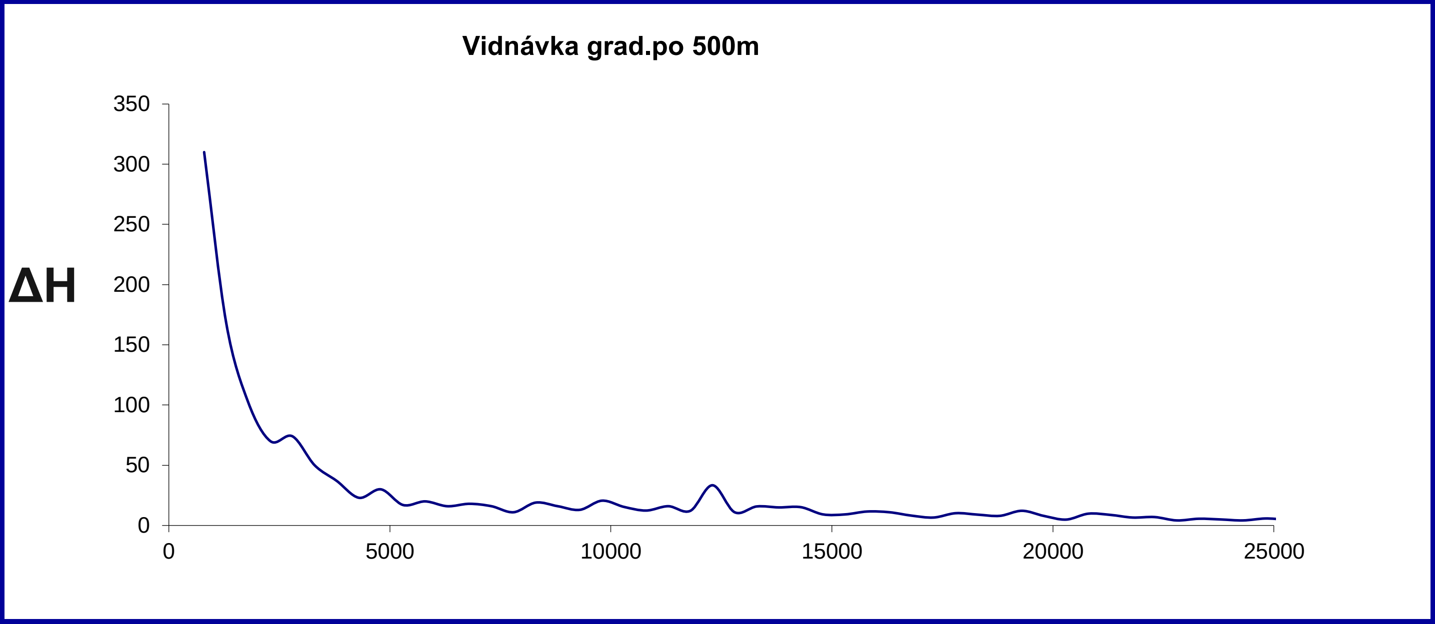
Normalized river profiles

- River analysis – several methods – construction of longitudinal profiles, gradient, SL gradient, convexity

- **Gradient** – m/km =(ΔH/ΔL)



ΔL … length of a segment (e.g. 100 m, 500m, ...)



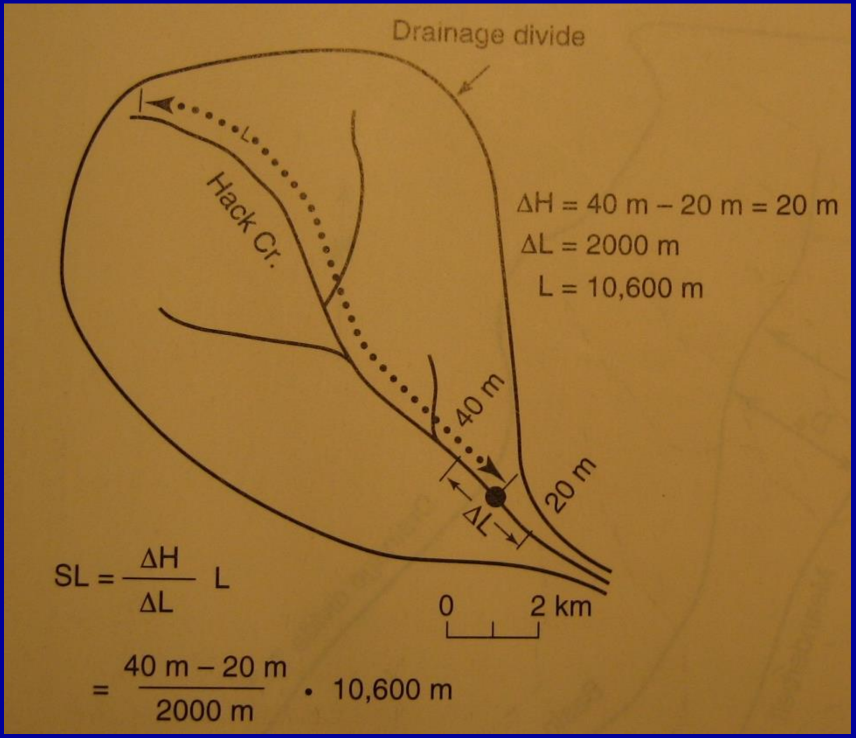
Distance from the spring

SL-index (stream-length gradient) (Hack (1973))

Indicator of anomalies on long profile

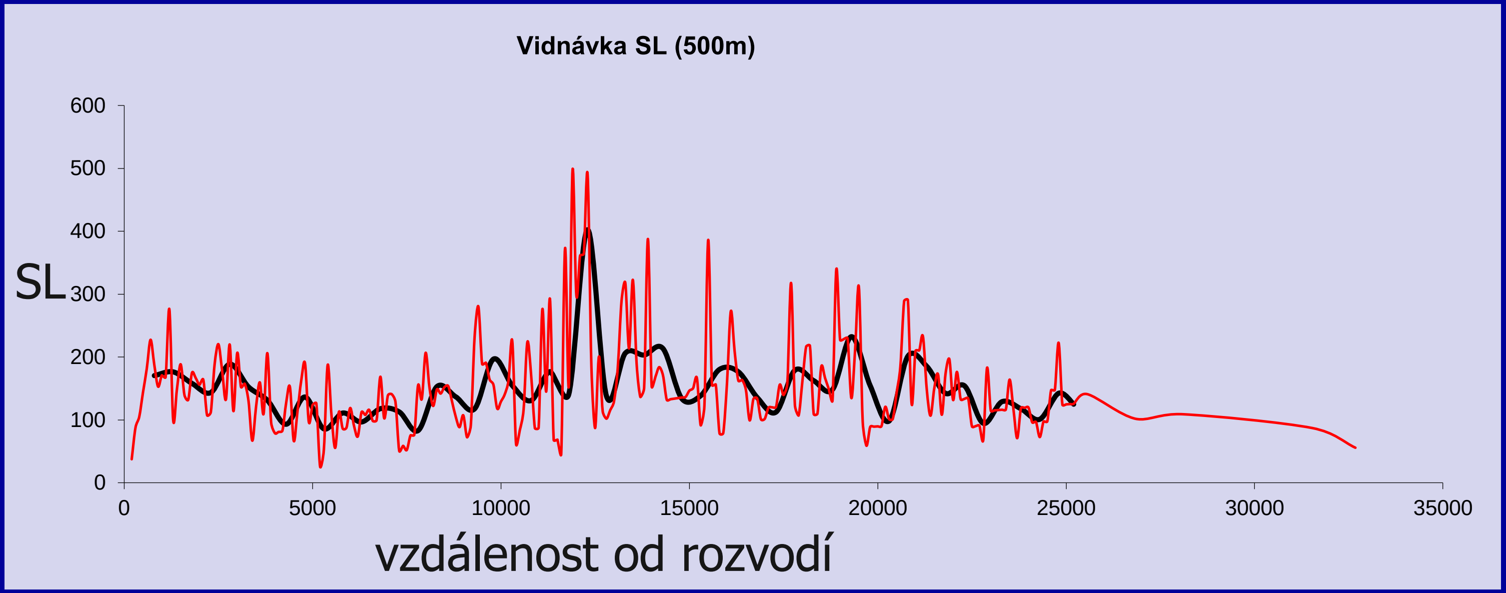
$$SL = (\Delta H / \Delta L) \times L$$

ΔH … height difference in a segment
ΔL … length of segment (e. g. 100m)
L … distance of the segment centre from the water divide



There is a relationship between discharge, basin area and stream length

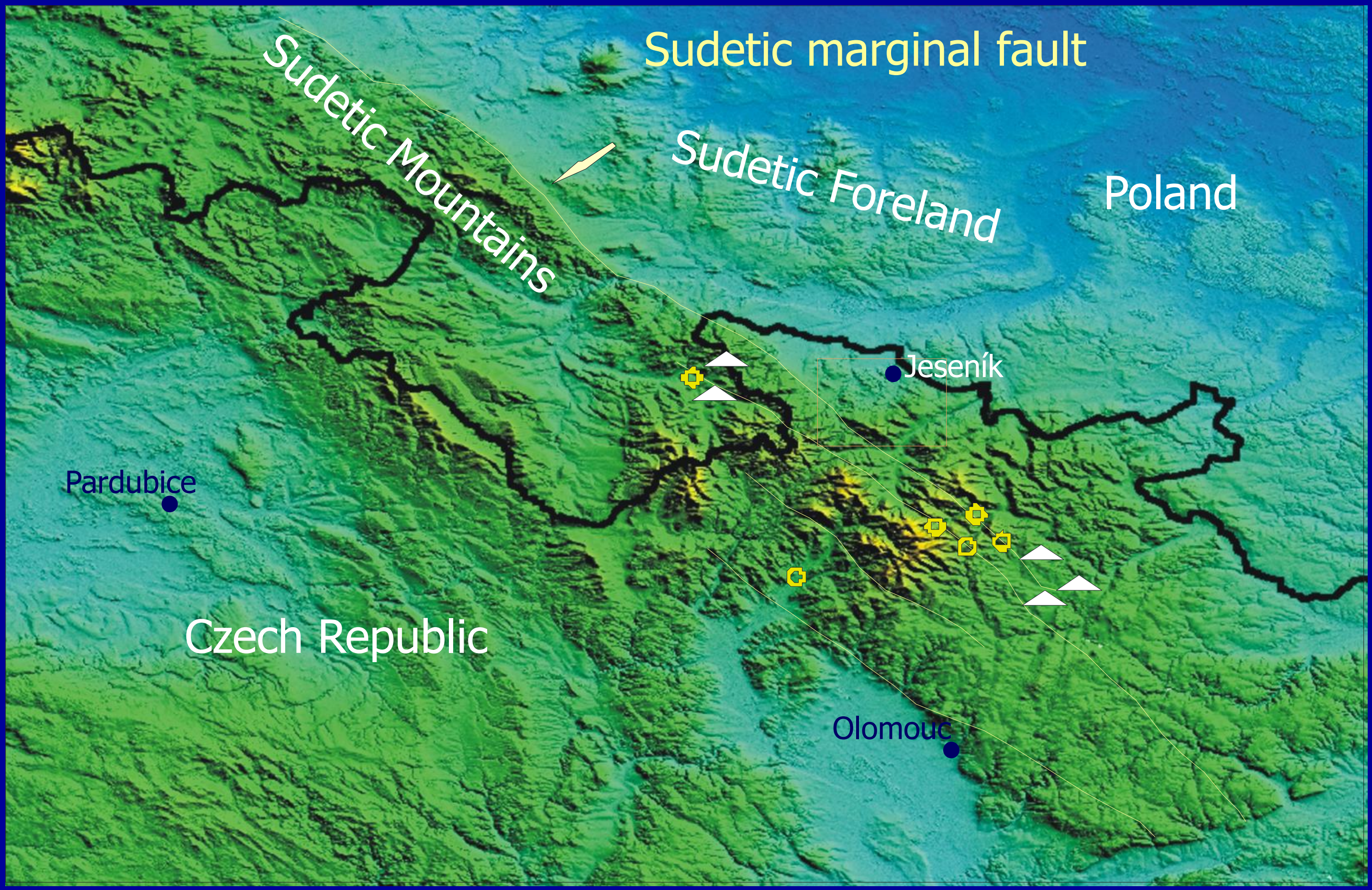
Farther from spring (source) – smaller gradient, higher discharge,
SL – respects the distance from source area



Graded rivers – SL index constant along the stream

Changes in index value can reflect:

- lithology change
- tectonic activity
- local changes – headward erosion
    - joining of tributaries
    - antropogenic influence

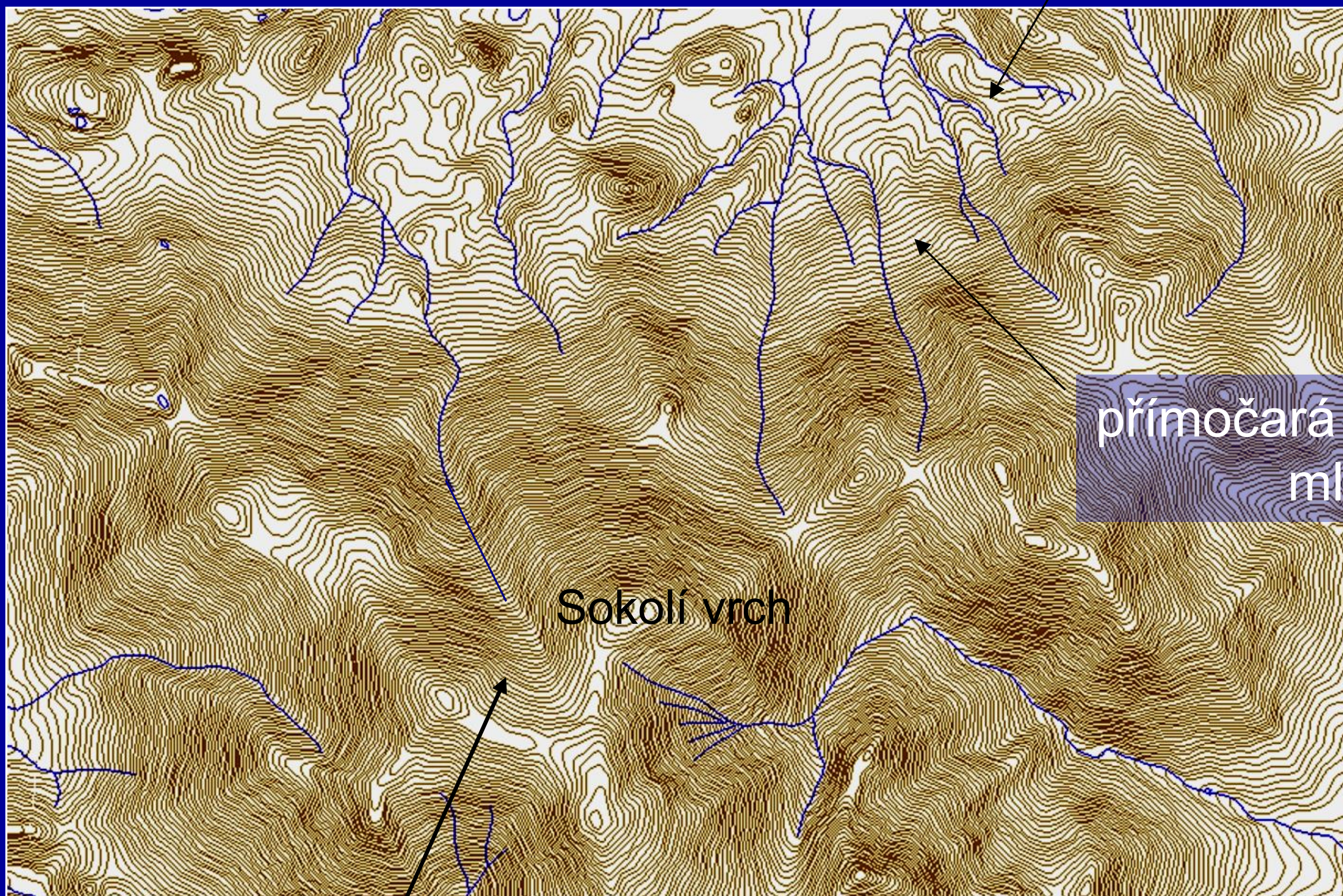


Neogene to Quaternary volcanism

mineral springs with CO_2

➢ analysis of valleys in Sokolský Ridge

rozčleněné úpatí (dissected foothill)

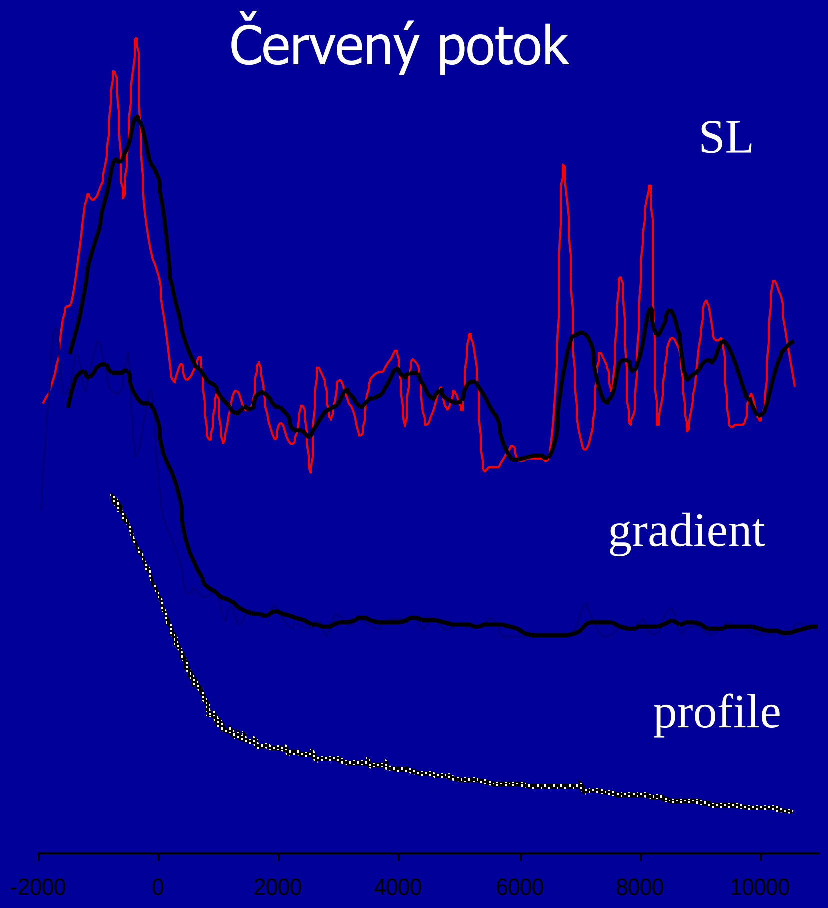


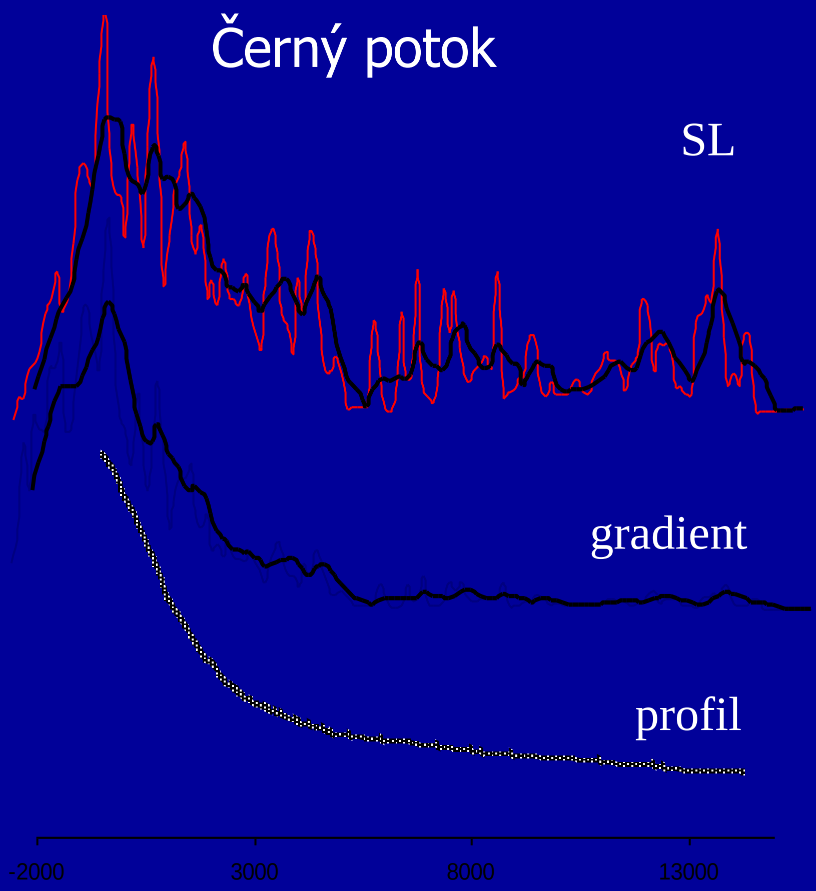
přímočará část svahu – mladší fáze výzdvihu

Hlubší údolí – vázána na zlomy

široké závěry údolí – starší fáze vývoje údolí

Longitudinal profiles, gradient, SL index

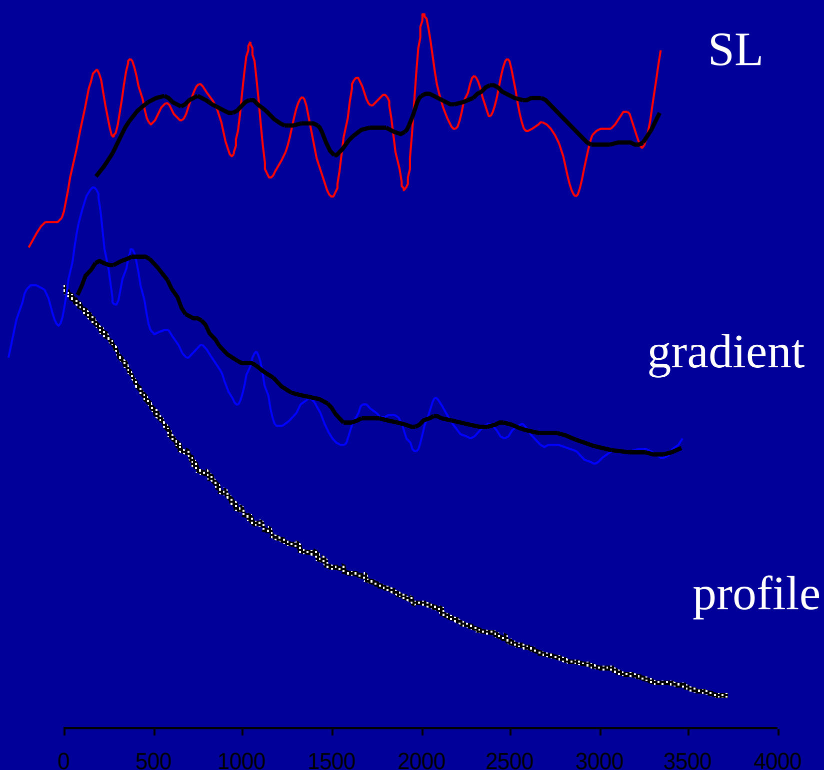


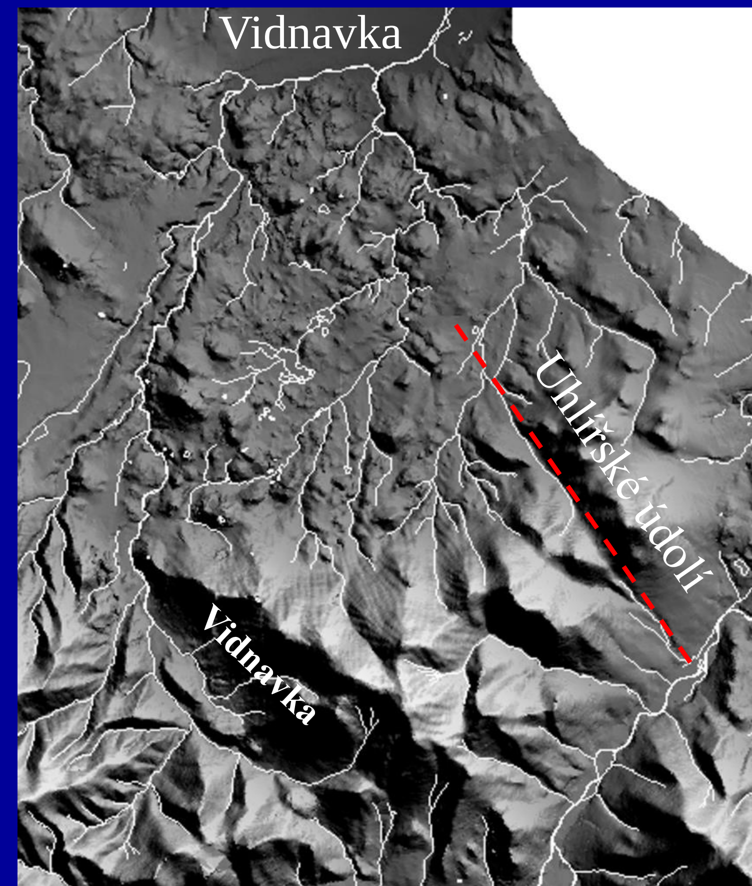

Černý potok
SL
gradient
profil
-2000
3000
8000
13000


Černý potok
Vidnavka

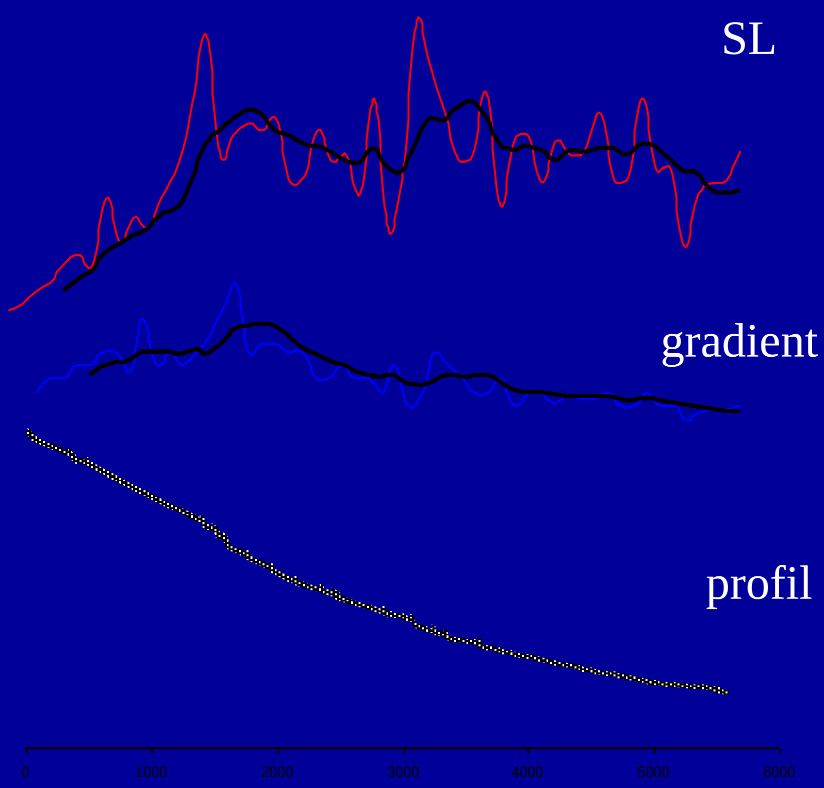
x exemption

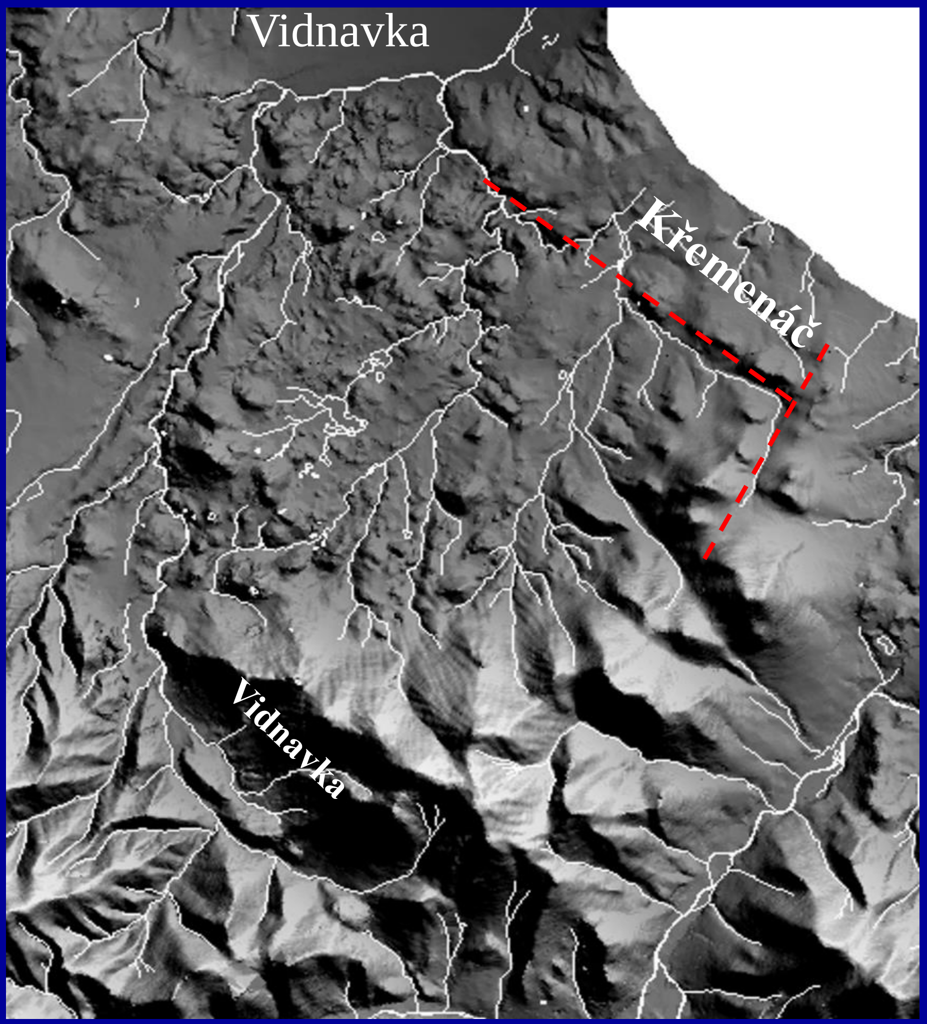
Uhlířské údolí



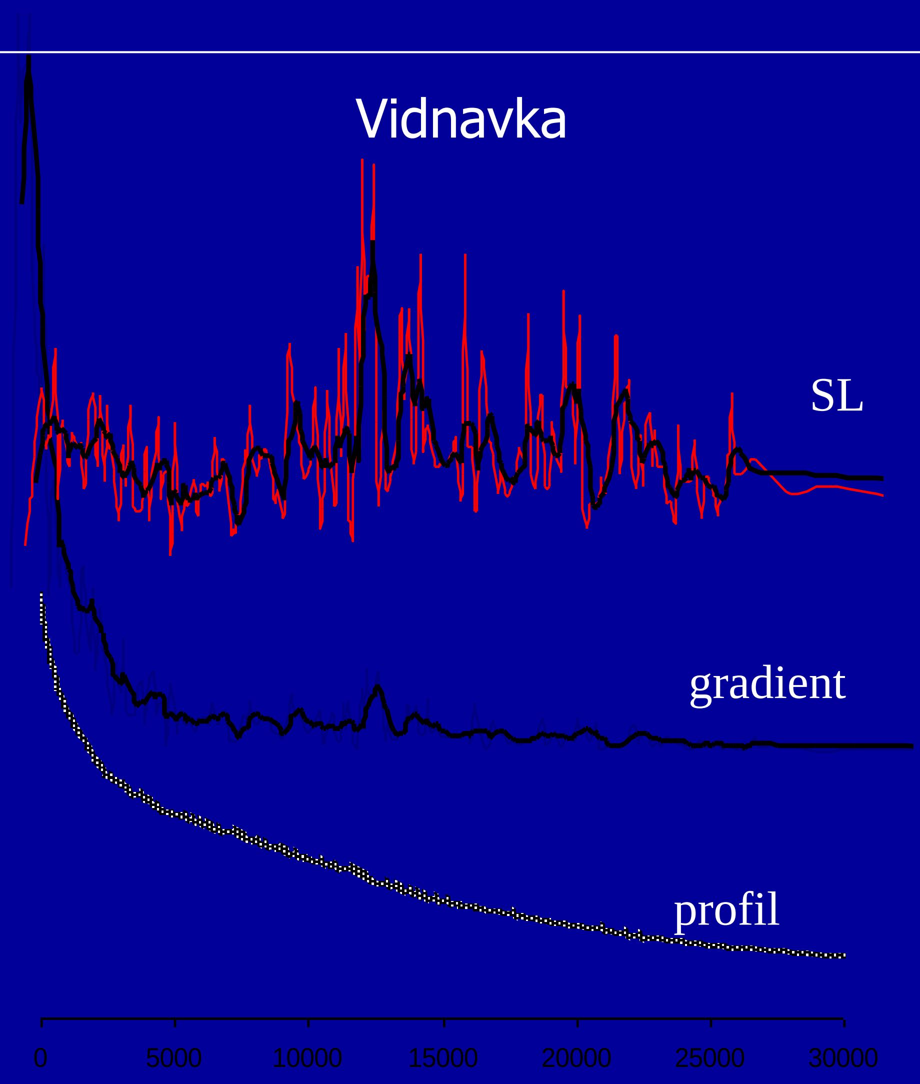


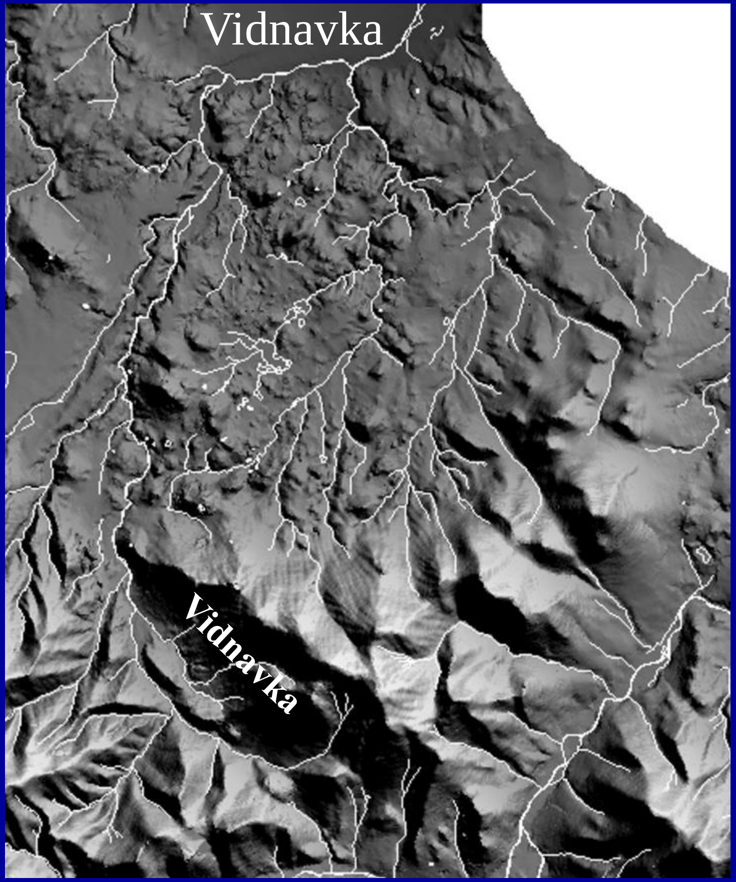
Křemenáč


SL
gradient
profil
0
1000
2000
3000
4000
5000
6000

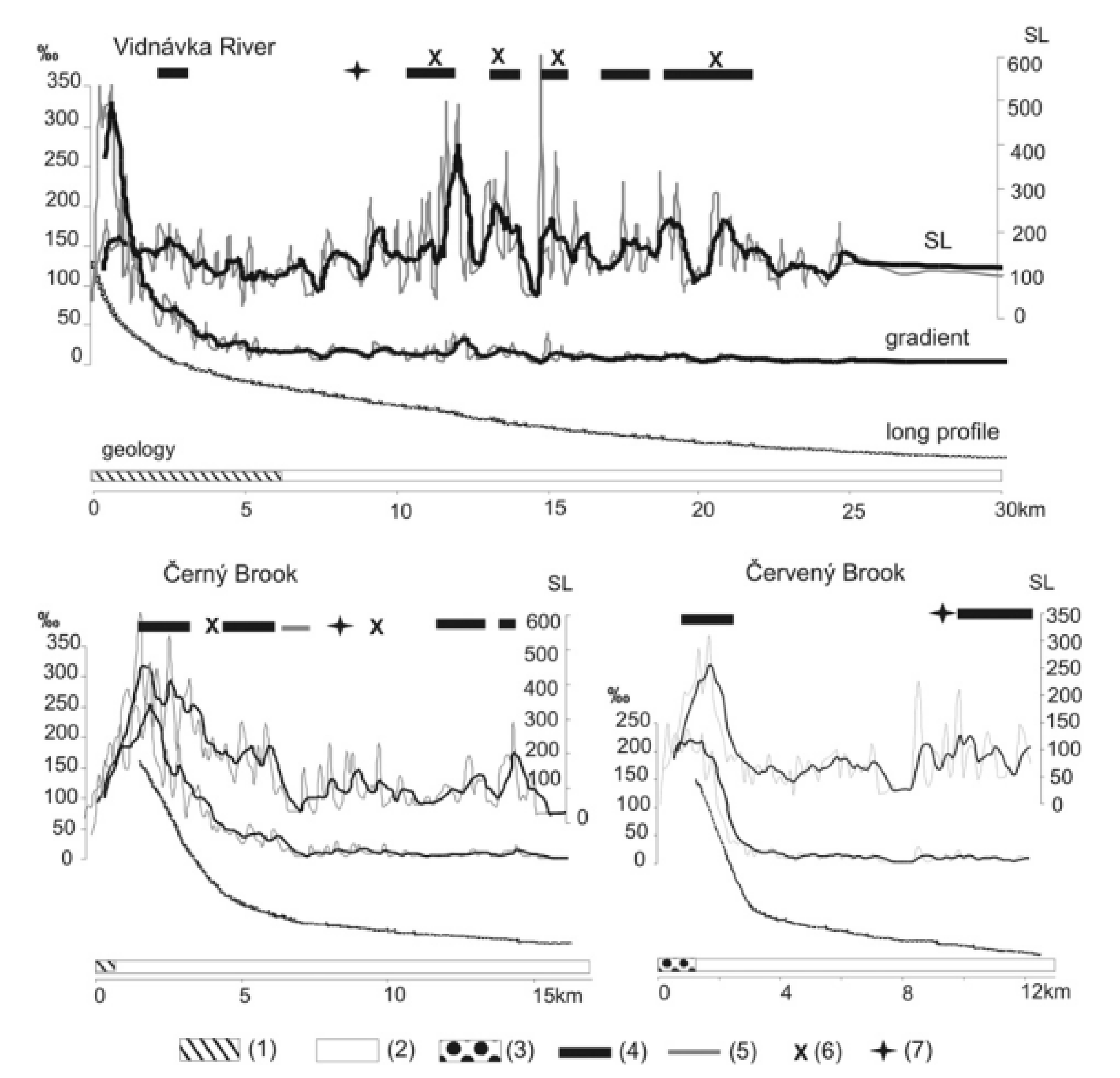

Vidnavka
Křemenáč
Vidnavka

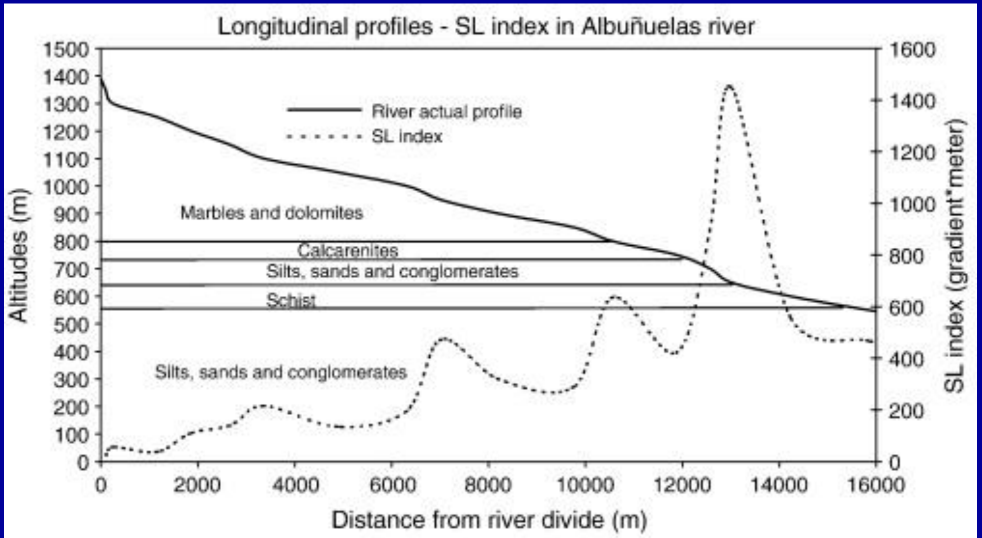
Vidnavka


SL
gradient
profil
0
5000
10000
15000
20000
25000
30000

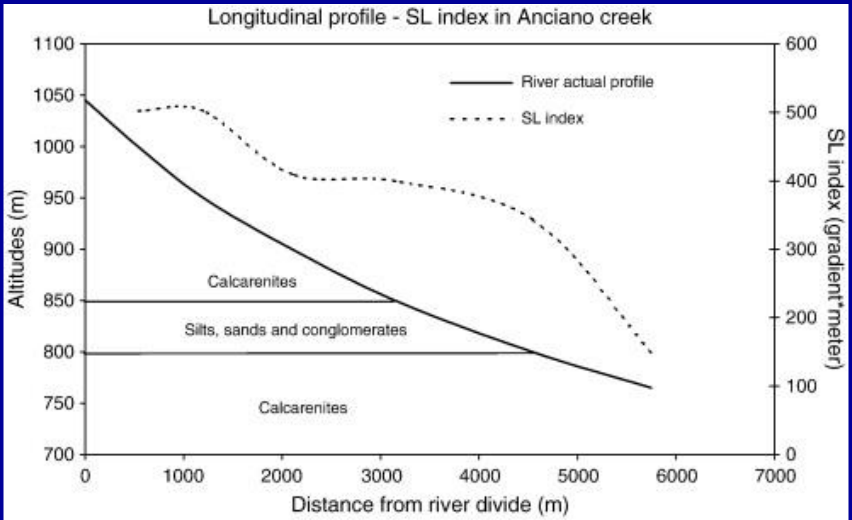

Vidnavka
Vidnavka

(1) — metamorphic rocks (gneisses, marbles, phyllites, amphibolites),
(2) — granitoids,
(3) — segment of stream flowing along the lithological boundary;
(4) — stream follows a morpholineament/fault,
(5) — river crosses a morpholineament/fault,
(6) — beginning of the deepened valley,
(7) — river flows into the planation surface (etchplain).

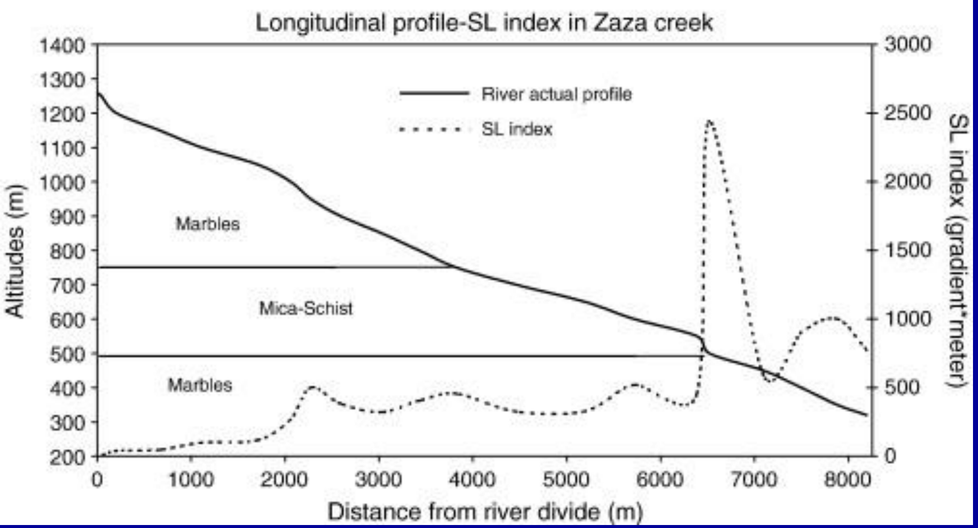




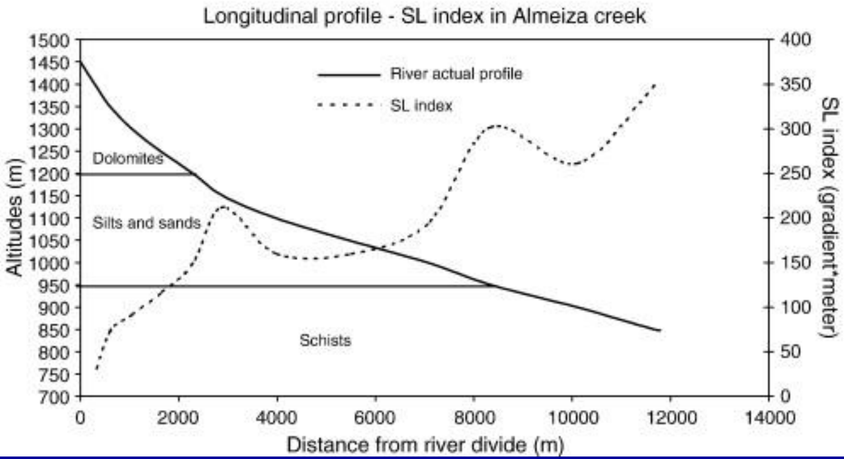
Longitudinal profiles - SL index in Albuñuelas river
River actual profile
SL index
Marbles and dolomites
Calcarenites
Silts, sands and conglomerates
Schist
Silts, sands and conglomerates
Altitudes (m)
SL index (gradient*meter)
Distance from river divide (m)



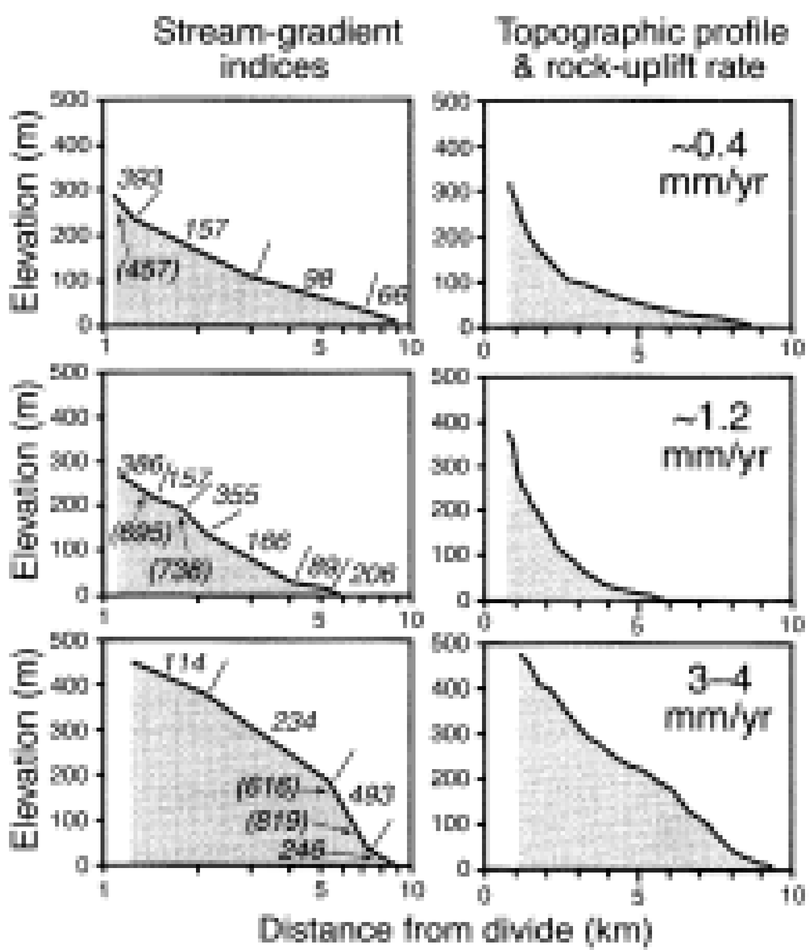
Longitudinal profile - SL index in Anciano creek
River actual profile
SL index
Calcarenites
Silts, sands and conglomerates
Calcarenites
Altitudes (m)
SL index (gradient*meter)
Distance from river divide (m)



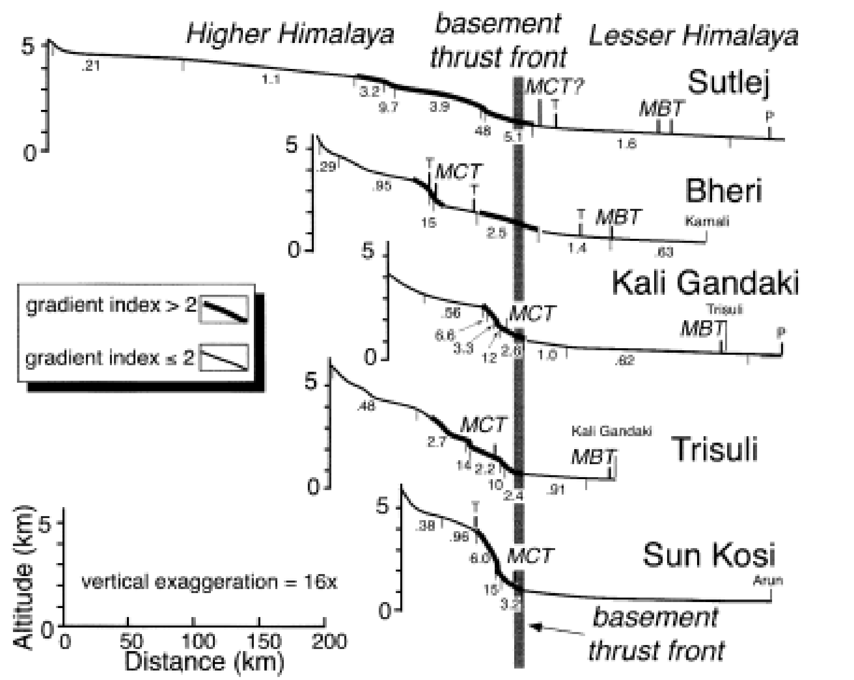
Longitudinal profile-SL index in Zaza creek
River actual profile
SL index
Marbles
Mica-Schist
Marbles
Altitudes (m)
SL index (gradient*meter)
Distance from river divide (m)



Longitudinal profile - SL index in Almeiza creek
River actual profile
SL index
Dolomites
Silts and sands
Schists
Altitudes (m)
SL index (gradient*meter)
Distance from river divide (m)



Note that the zone of rapid rock uplift has a steeper gradient, higher relief, and higher gradient indices. Modified after Merritts and Vincent (1989)



Thicker segments of the profile indicate reaches where the local gradient index (SL) is more than twice the index (k) for the entire profile: SL / k = 2. The steepest gradients are not associated with the Main Boundary thrust or active deformation to the south. Rather they occur near the Main Central thrust and appear to result from upward ramping of the overthrusting Himalayas above a deep-seated basement thrust. Modified after Seeber and Gornitz (1983).

- Valley cross sections

- Anomalies in long profiles => changes in valley cross - sections

- Valley slope asymmetry – different lithology
  - climate (various erosion – variously oriented slopes)

- Height asymmetry of valley slopes – lithology, tectonics, evolution of the region

- Valley types – erosional phases, different erosion intensity
  controlled by - tectonic activity
  structural-lithological conditions
  river gradient and hydrology

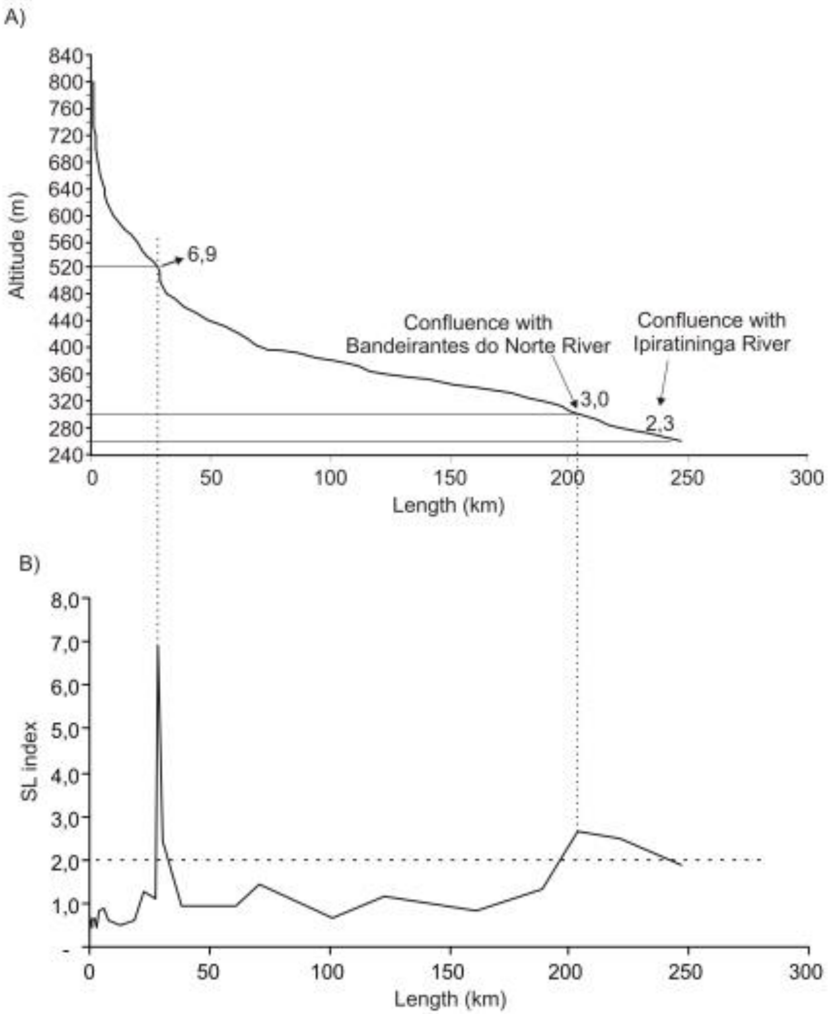


FIGURE 4. Longitudinal profile (A) and SL index of the Pirapó River (B).

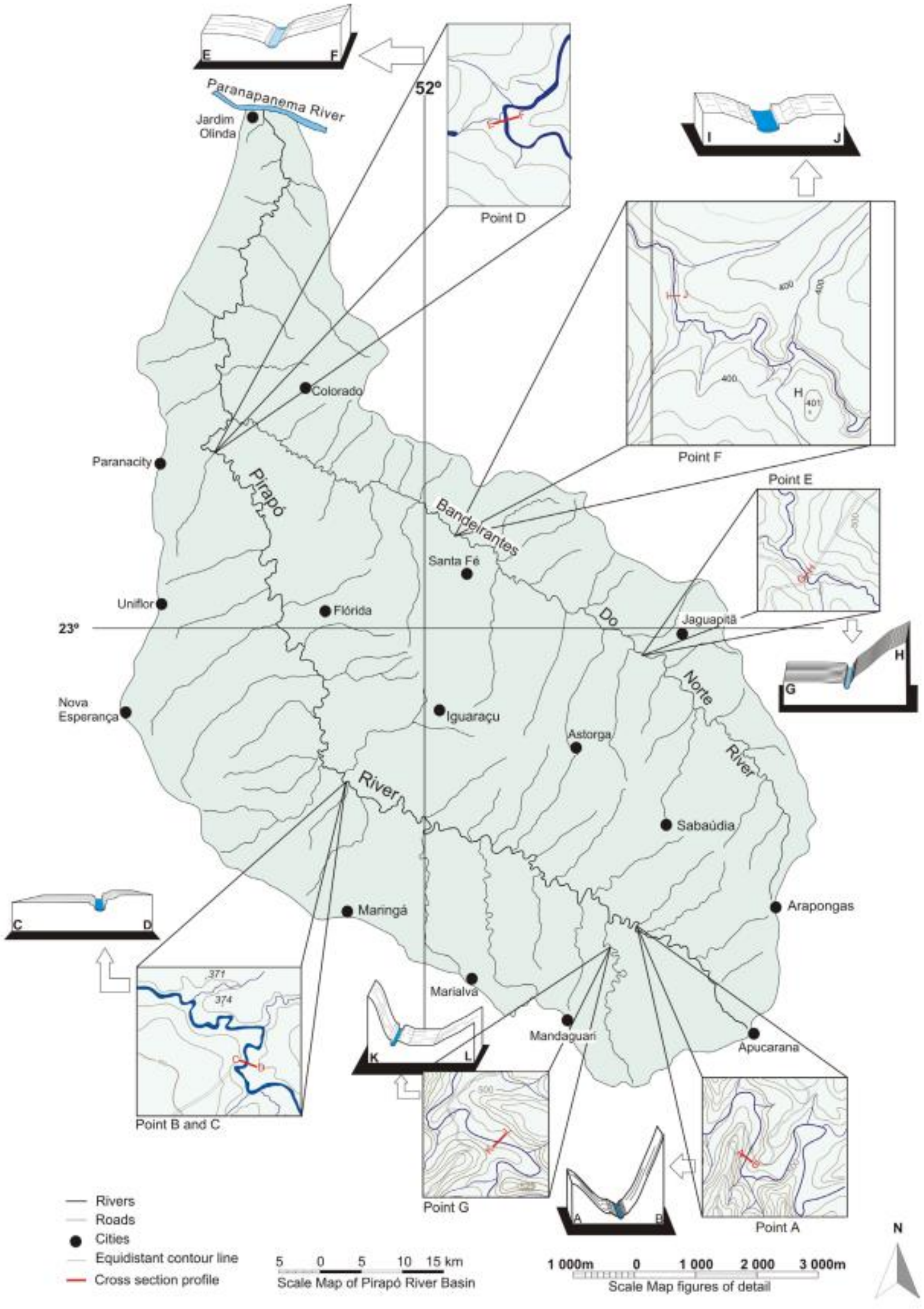


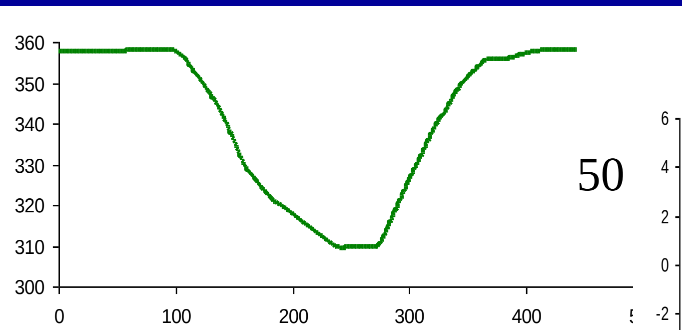
FIGURE 7. Hydrographic basin of the Pirapó River with anomalous points and valley cross sections.

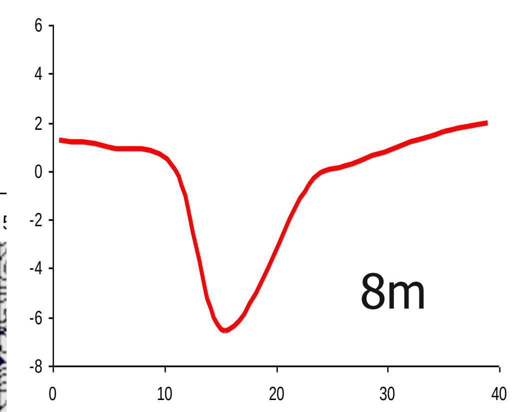
Valley types based on cross section

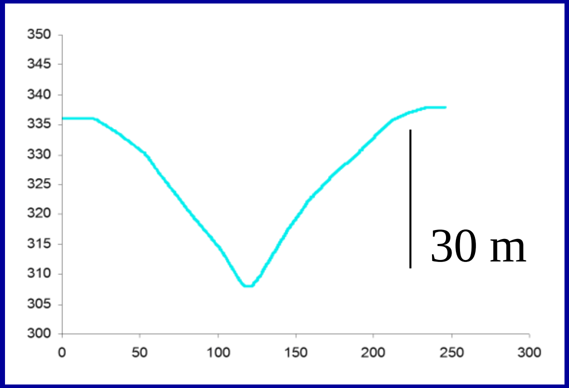
Ongoing uplift of the mountains

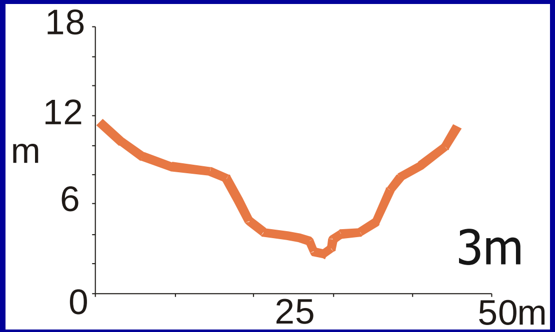
úpatí zlomových svahů

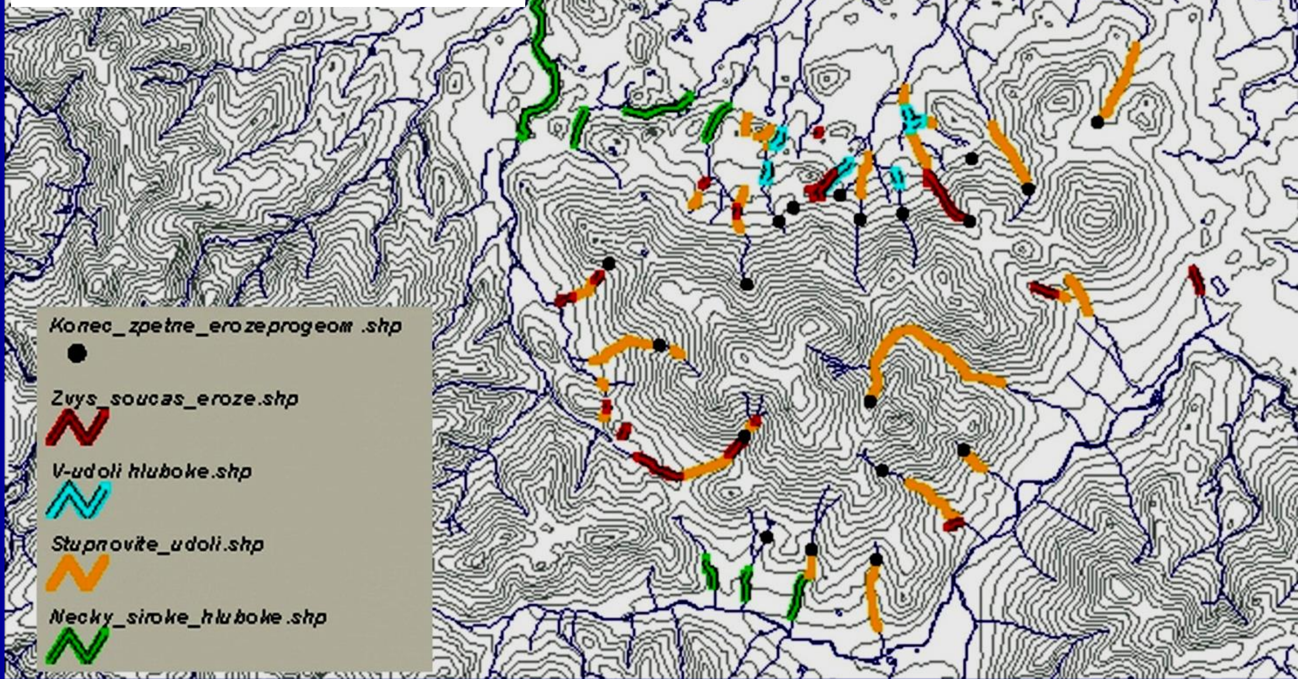
- začátky
- ❖ zvýšené současné eroze,
- ❖ nejmladší erozní fáze











River terraces

- Former floodplain

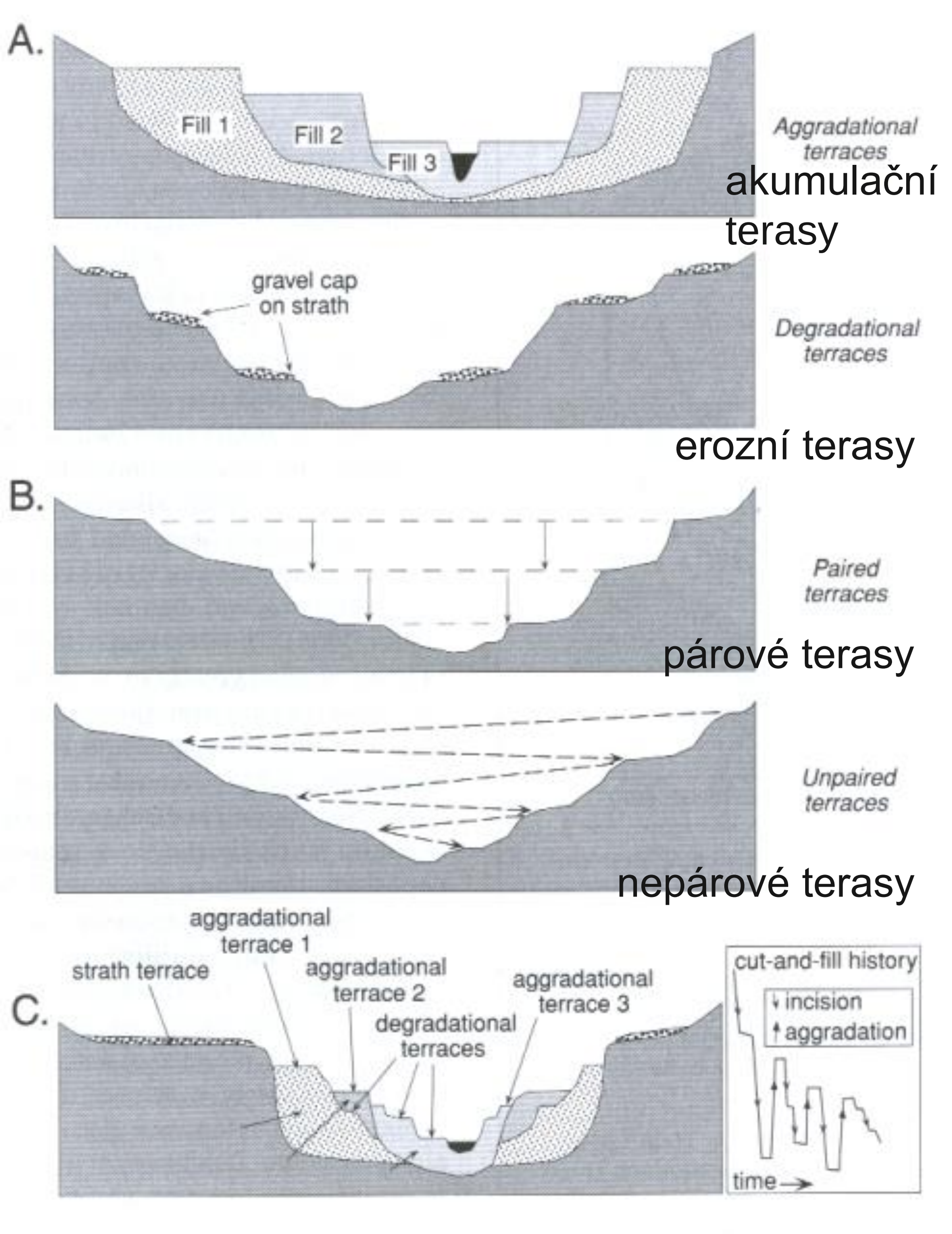
- Terraces origin– complex response, many causes

  - Repeated tectonic uplift

  - Slow continuous uplift combined with alternating of glacial period and interglacial period

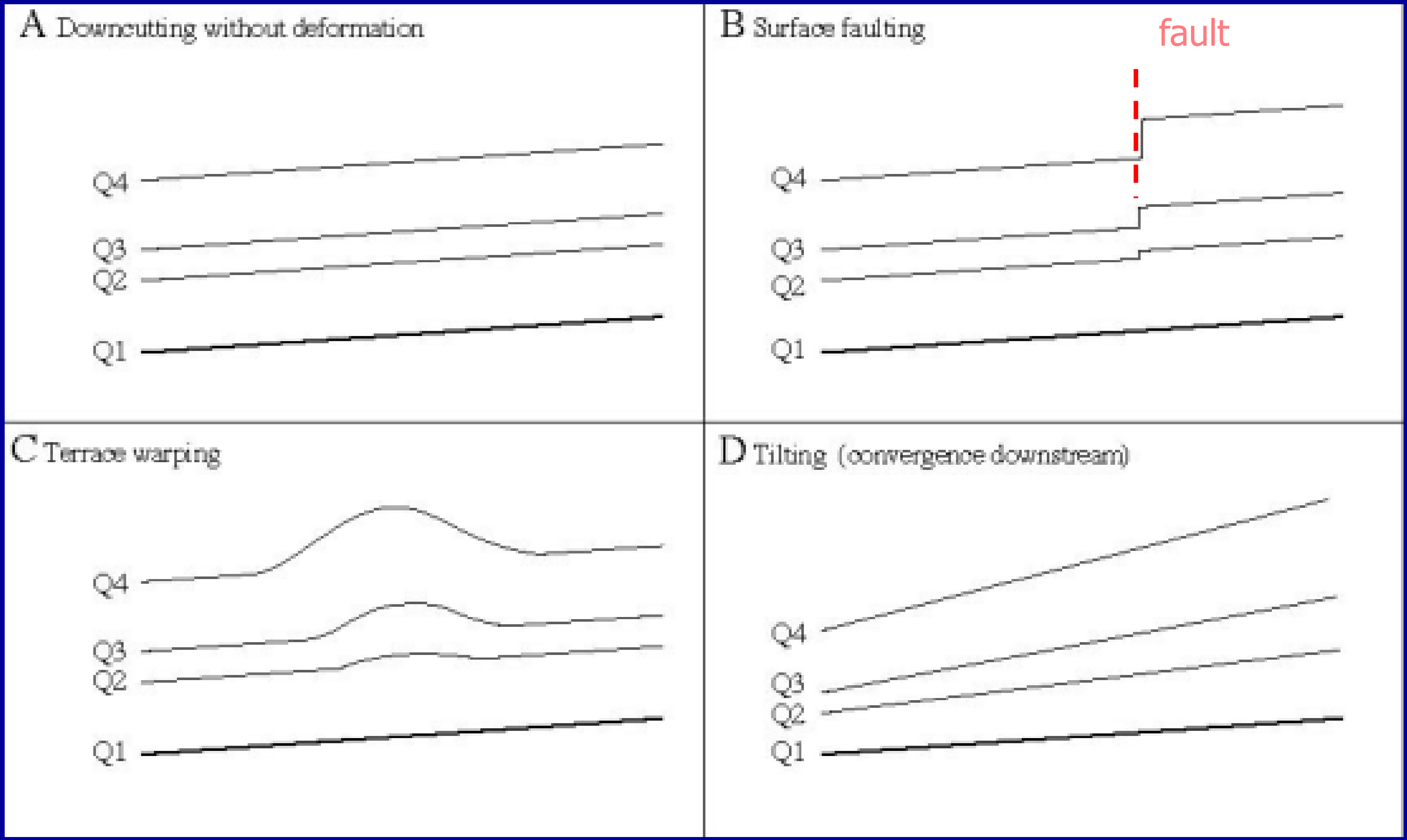
  - Climate influence - =/= plus drop of the erosional base

- Terraces – important potential indicator of tectonic activity
  - more to the past



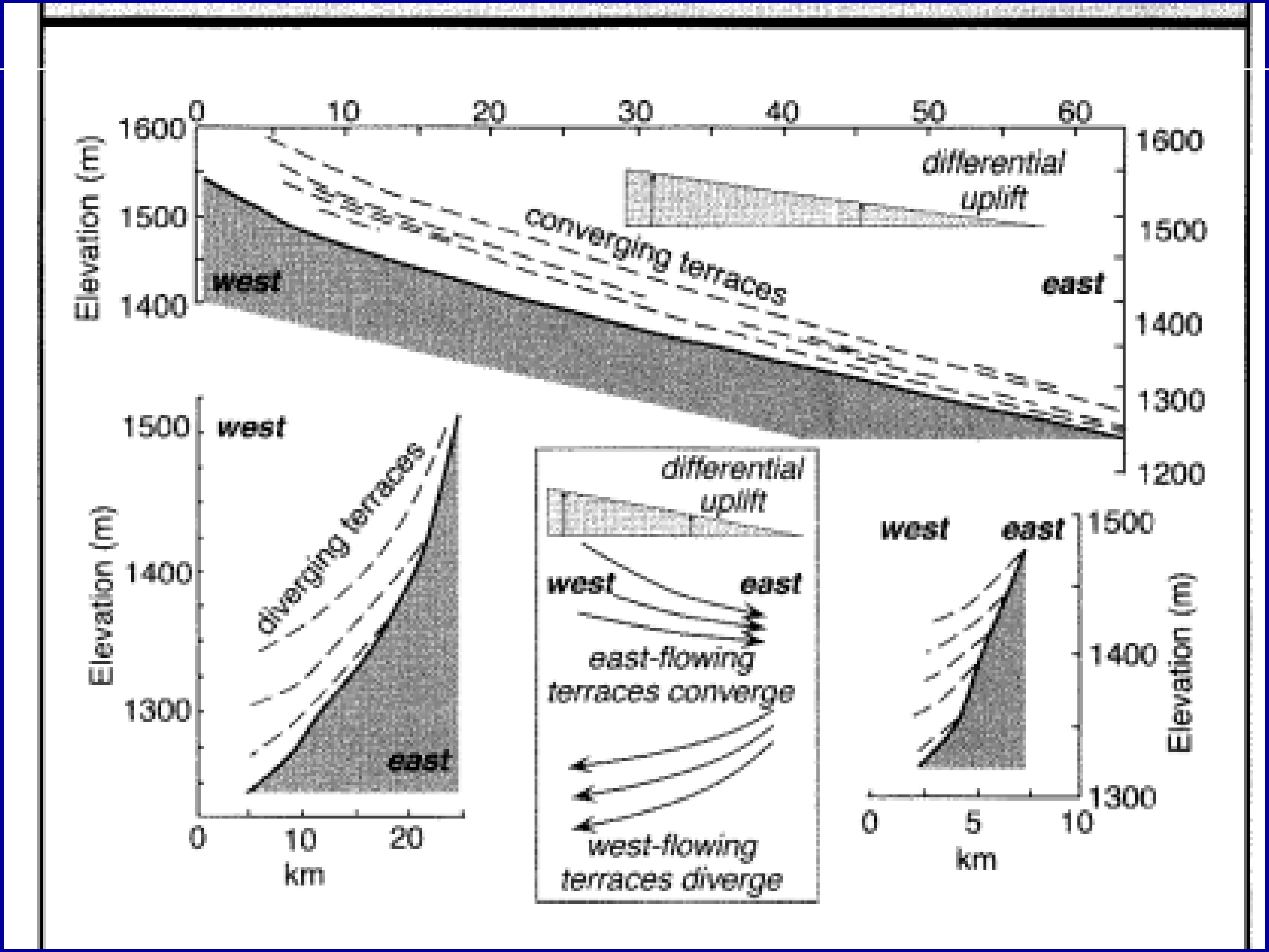
Terraces of river Mijar in Kyrgyzstan
– Trans Alai Range

Four types of tectonic deformation of fluvial terraces



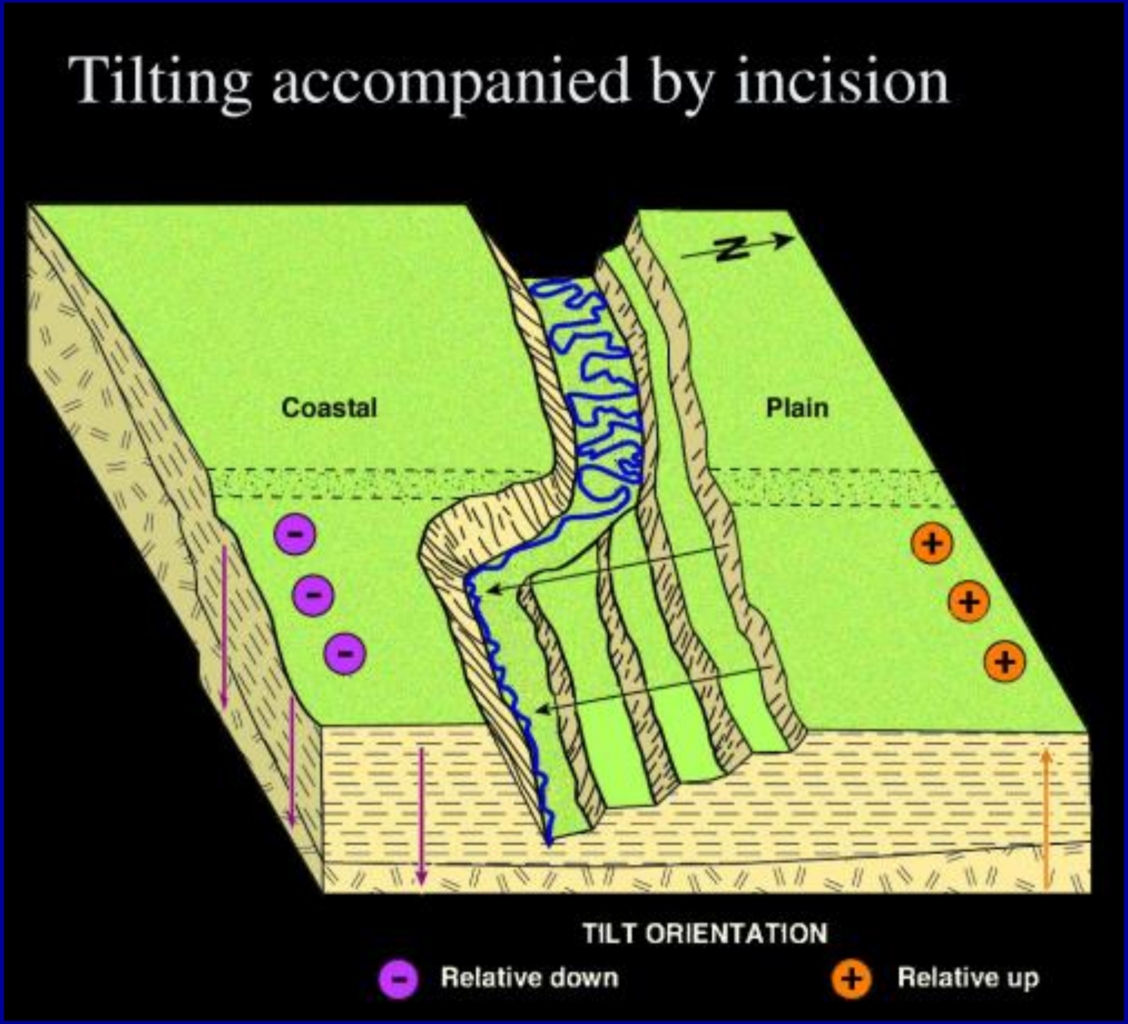
up-warping

tilting

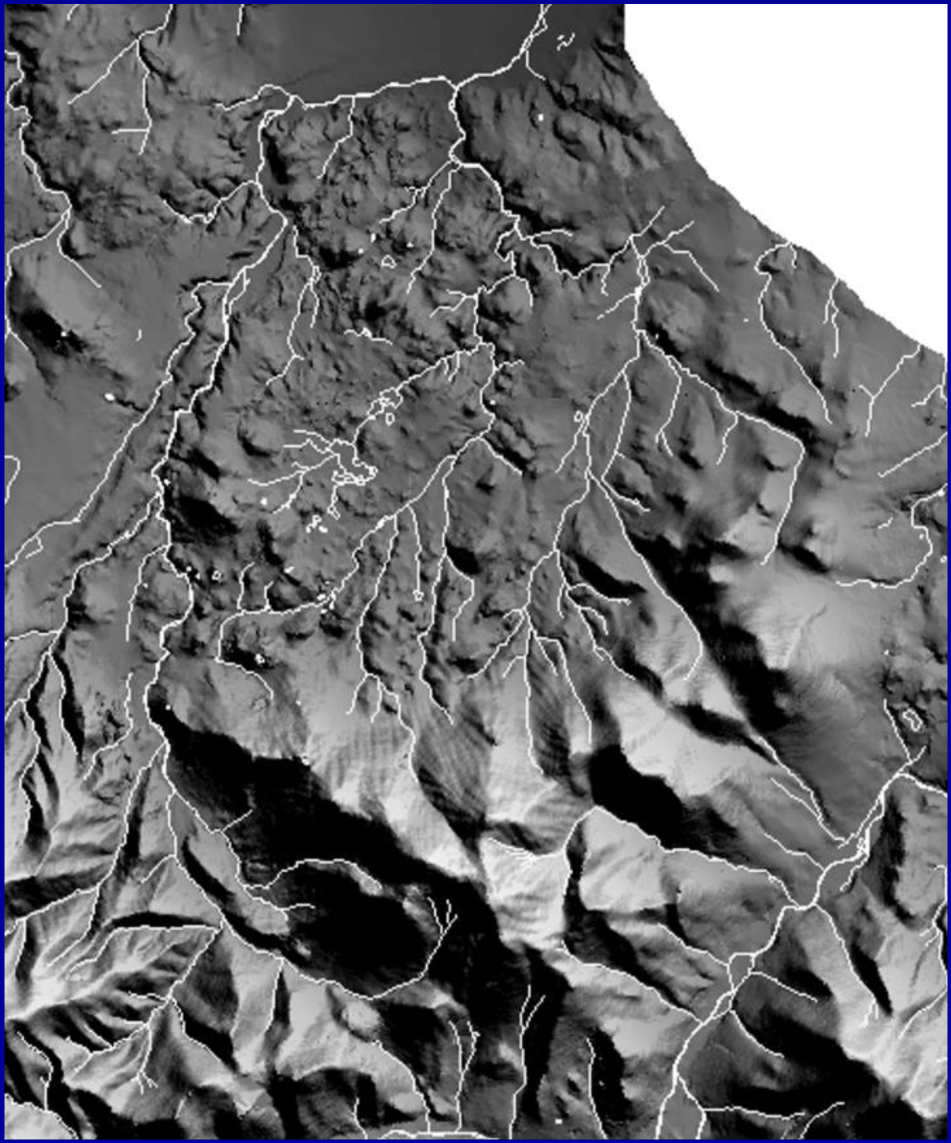


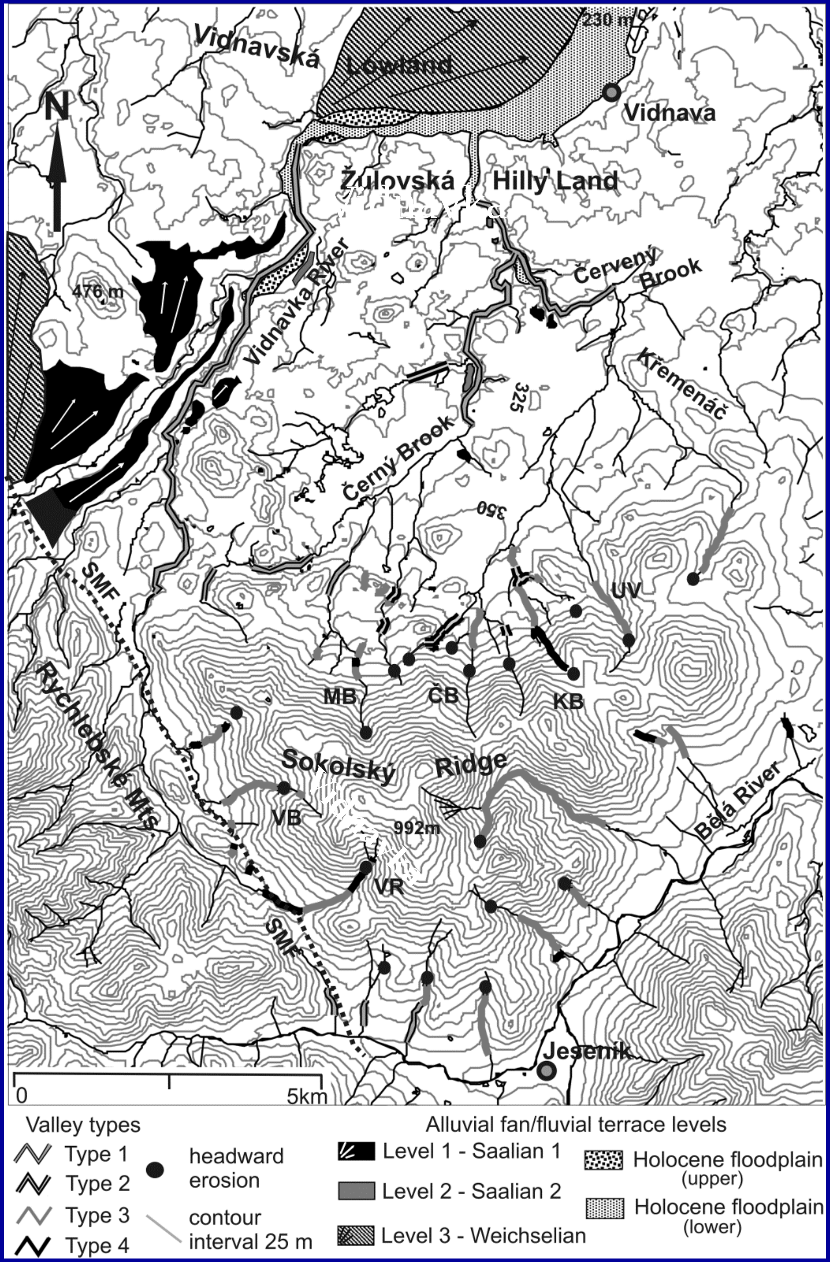
Converging terraces down to the river – uplift of lower part
Diverging – subsidence in the lower part

Transversional tilting – unpaired terraces



River terraces of Vidnavka river

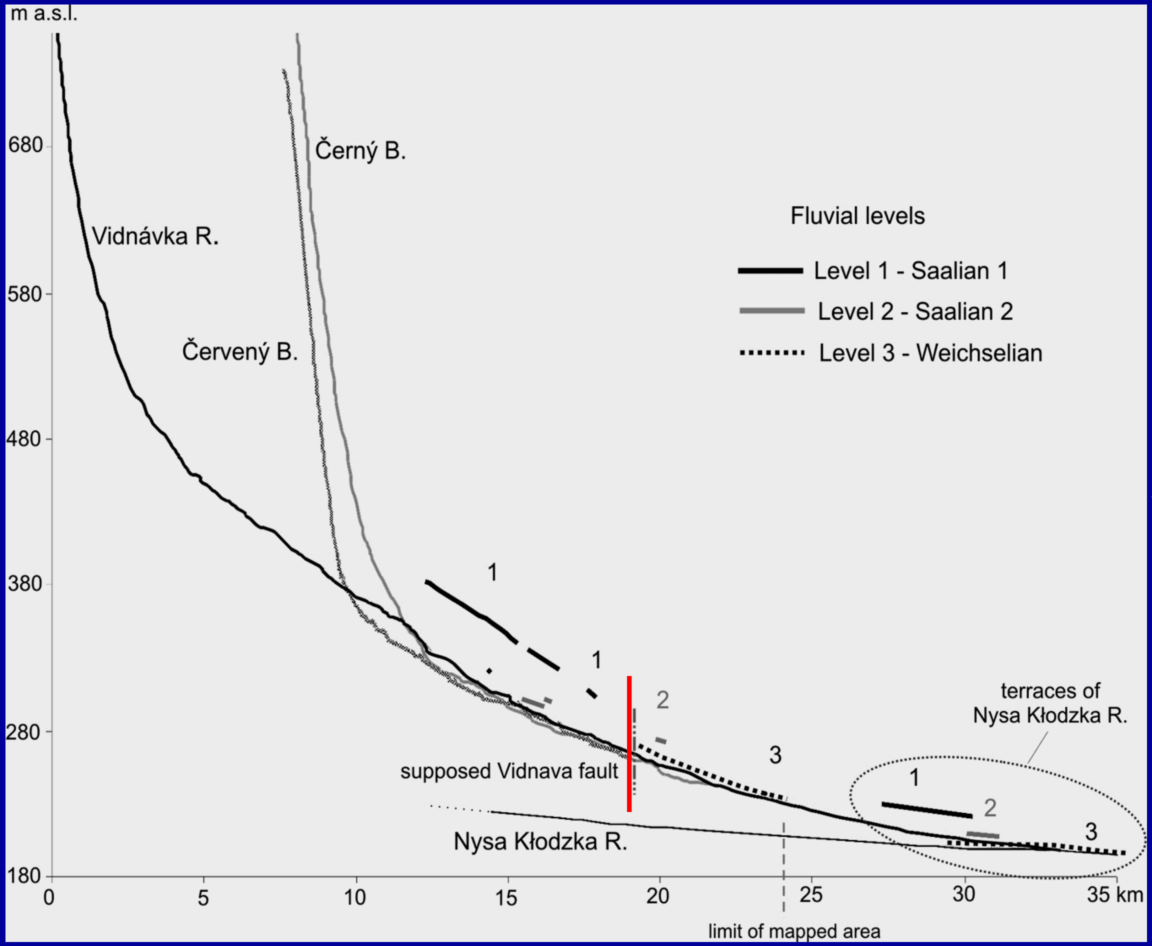




Terraces of tributaries – usually lower relative height above the river than in the main river

Uplift of Žulovská Hilly Land
(?glacioisostasis)

Fluvial sediments -3 post-glacial (po deglaciaci) Pleistocene terrace level and alluvial fan



Úroveň 1 – Saale 1 *Upper Terrace*
Vidnavka - 38 – 48m (relative height)
Černý potok - 20m
Červený potok - 35 – 40m

Úroveň 2 – Saale 2 *Middle Terrace*
Černý potok - 13 – 22m

Úroveň 3 – Weichselian *Lower Terrace*

Vidnavka - 4 – 8m

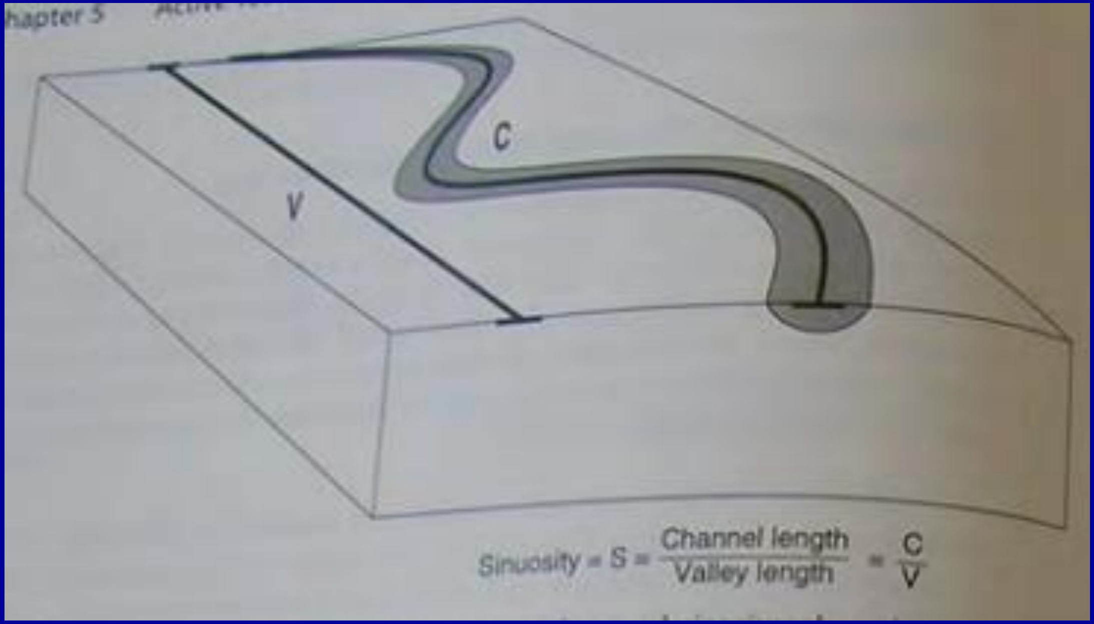
Anomaly in river terraces profile (Kladská Nysa)

Level 1 – difference 20m
Level 2 – difference 8m
Level 3 – difference 2-3m

Stream sinuosity

- Rivers are meandering to balance the slope of the channel with discharge and transported material

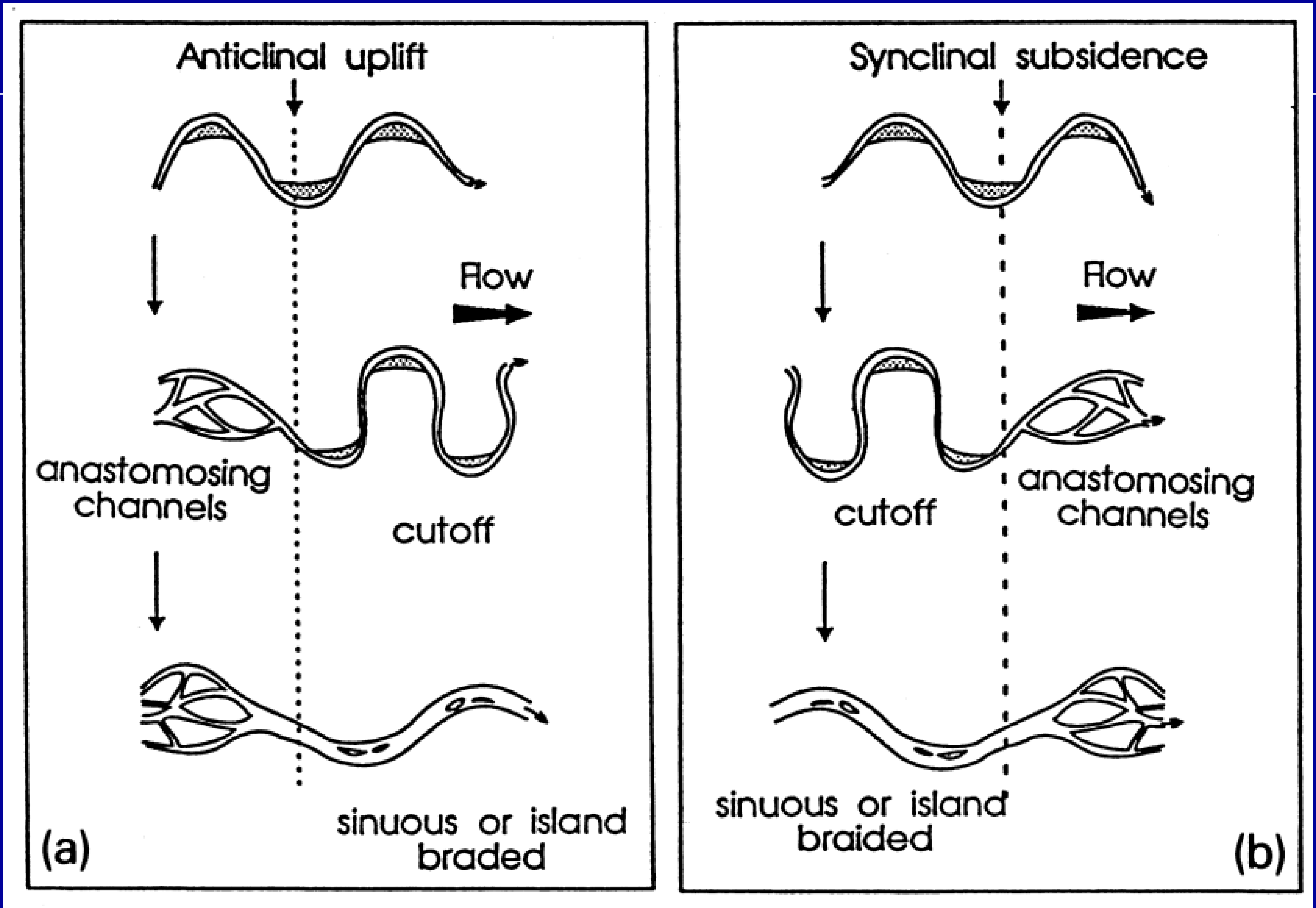
Sinuosity = channel length : valley length



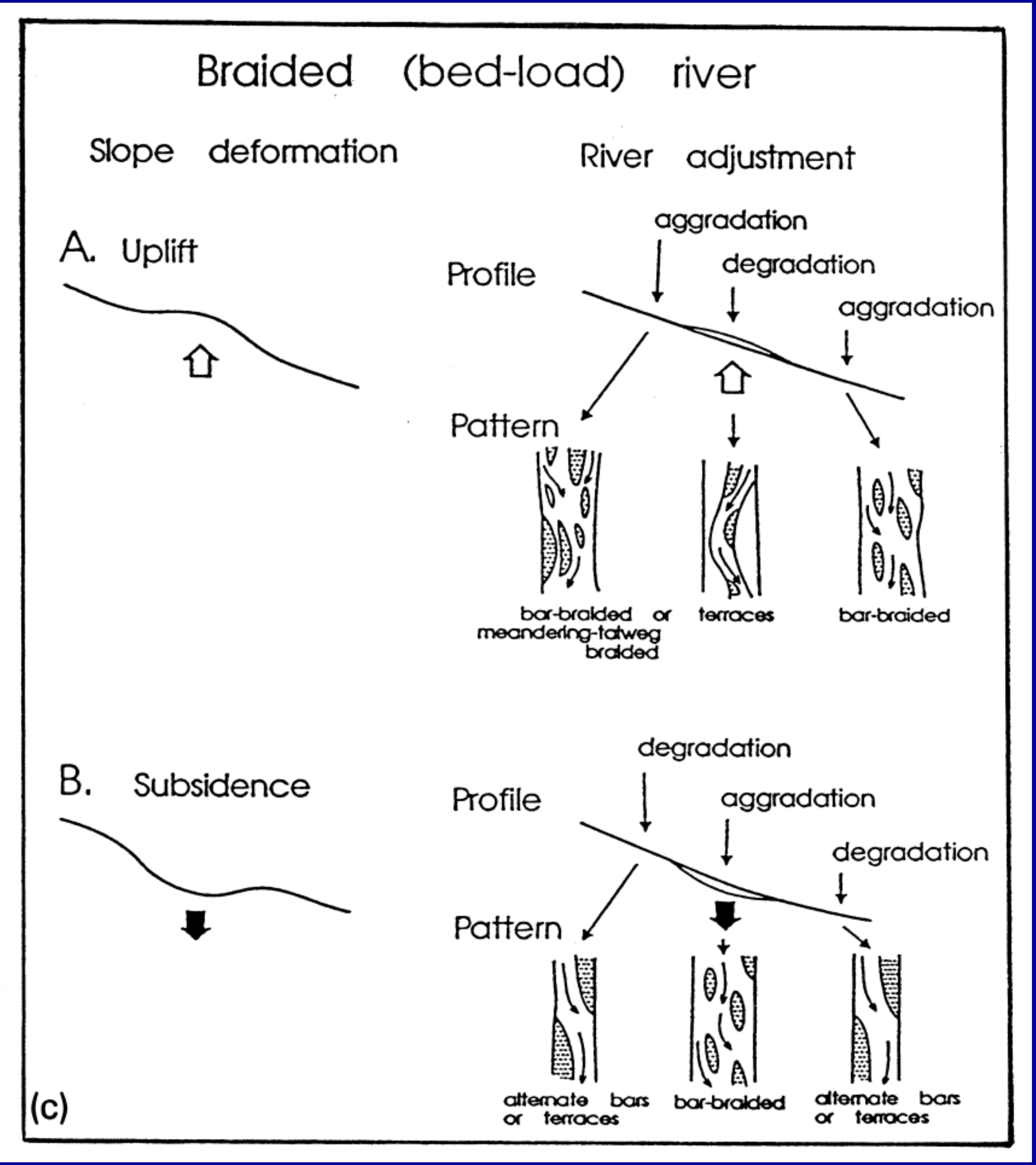
River meanders when the valley length is too steep to keep the balance

- Meandering (curving) decreases the channel slope (stream is longer – less steep profile)

During flowing through upwarping area – on the higher part – less curved, in the lower part more curved

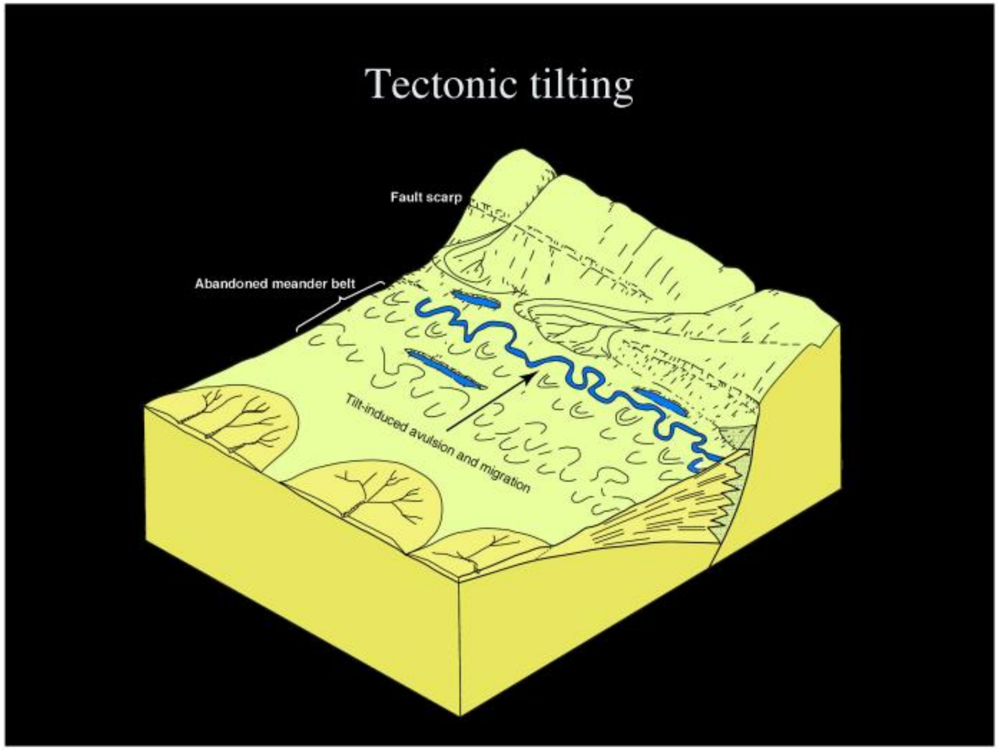


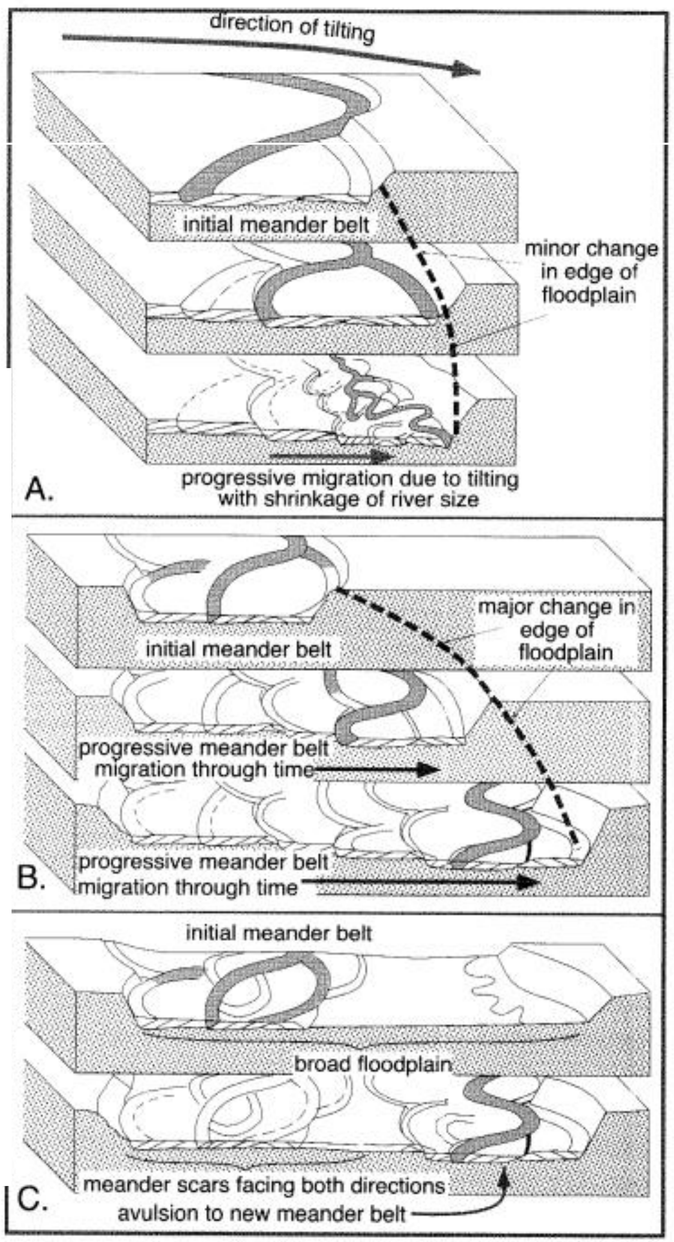
Response of meandering or straight stream in uplifted area (A) or subsided (B)



Response of braided streams (C) (Ouchi, 1983)

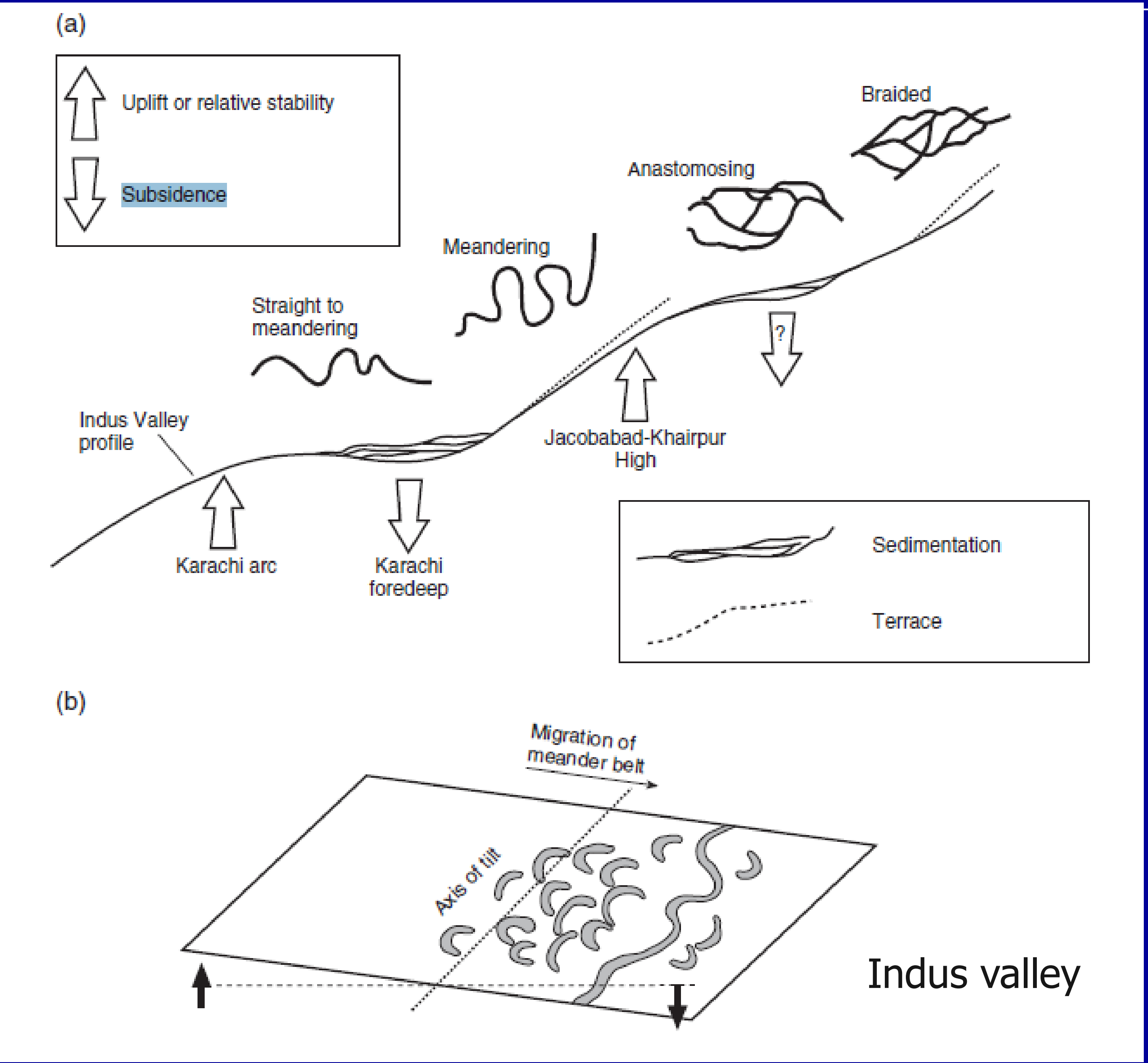
Cross sections





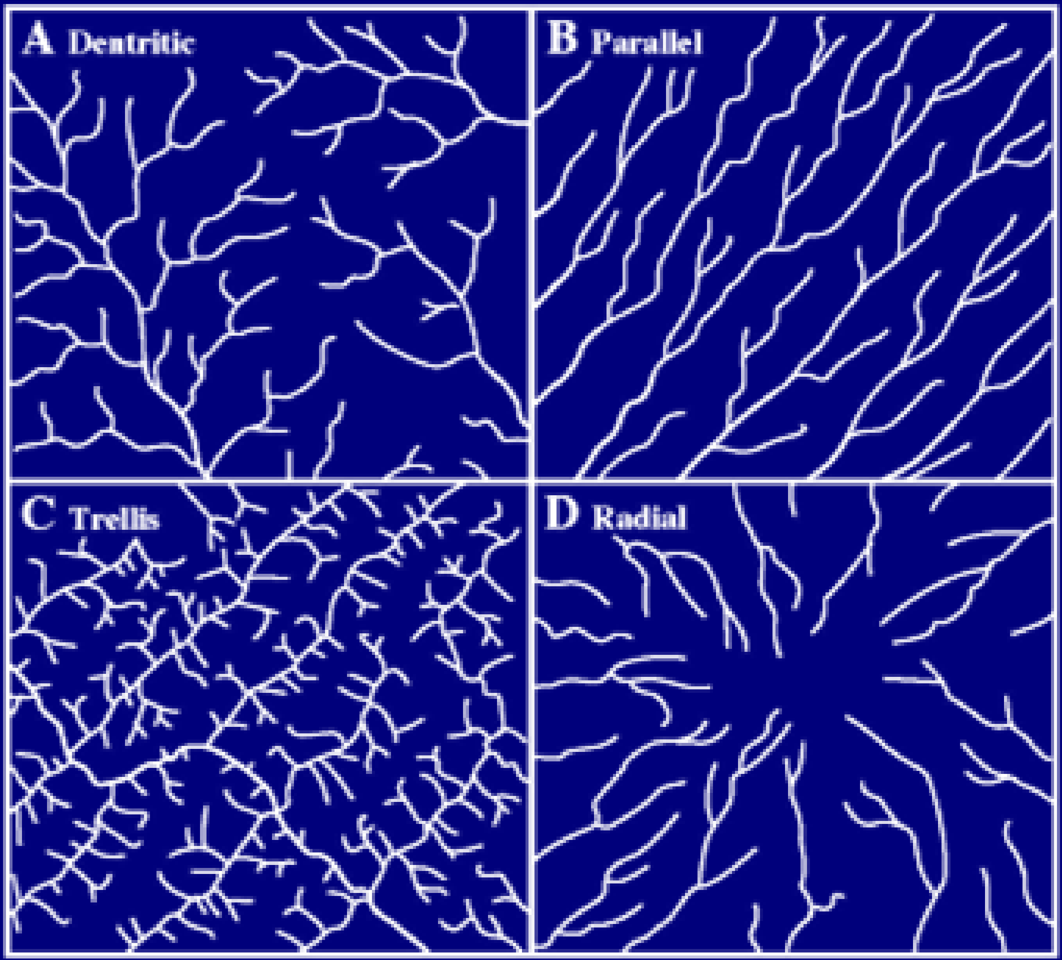
A. Steady tilting with shrinkage of river size. B. Steady tilting and migration. C. Abrupt tilting and avulsion across a floodplain. Modified after Alexander et al. (1994).

Tectonically deformed river

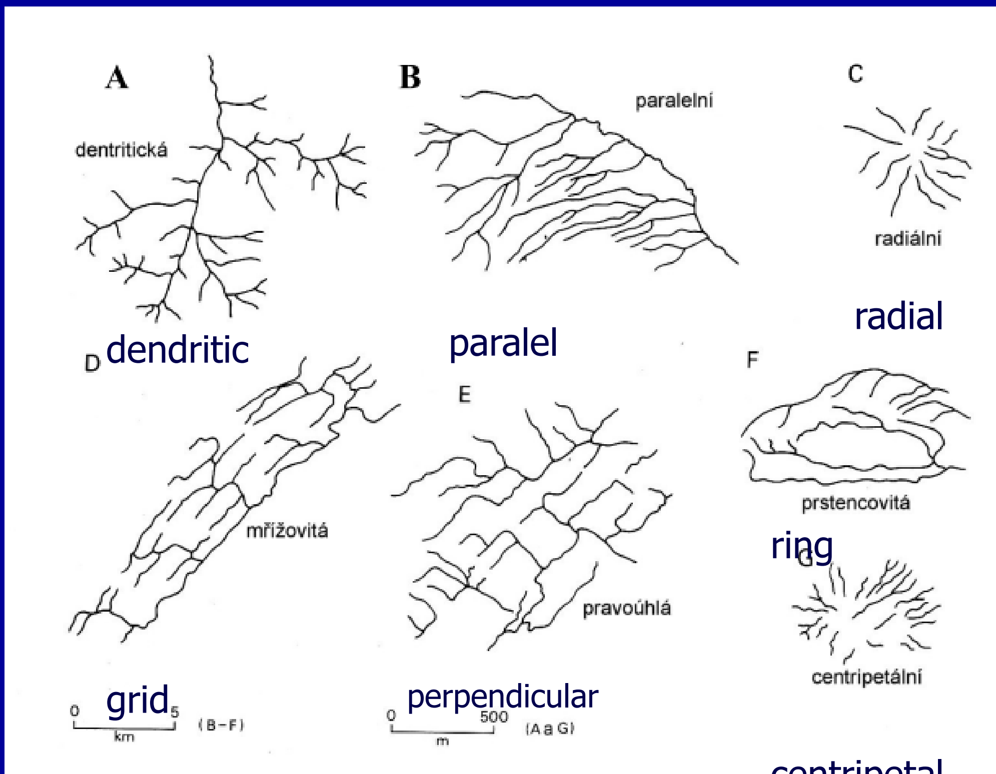


Indus valley

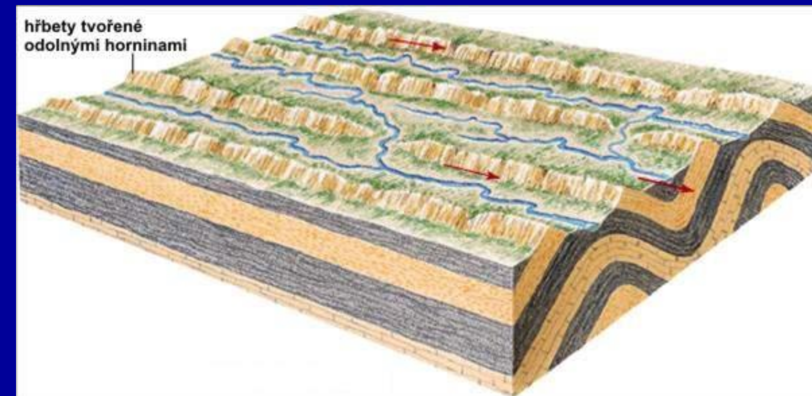
Changes in drainage and stream pattern



Dendritic	This drainage pattern forms on homogeneous bedrock or loose sediments in areas with gentle regional slopes.
Parallel	Parallel drainage pattern forms on steep slopes and where bedrock or landforms trend parallel to the regional slope.
Trellis	Pattern forms where underlying rock has one or more planes of weakness oblique to regional slope, such as on folded sedimentary rocks, or where linear landforms like beach ridges control drainage.
Radial	Pattern forms around structural high points such as volcanoes, salt domes, or tectonic upwarps.



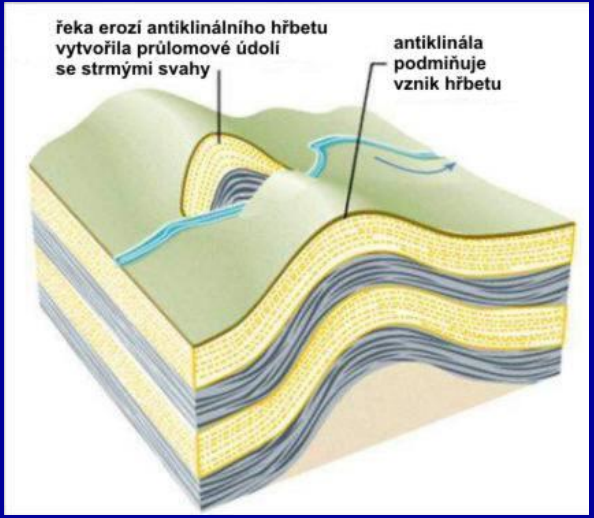
Obr. 3.8 Typy říční sítě dle Summerfield (1991).

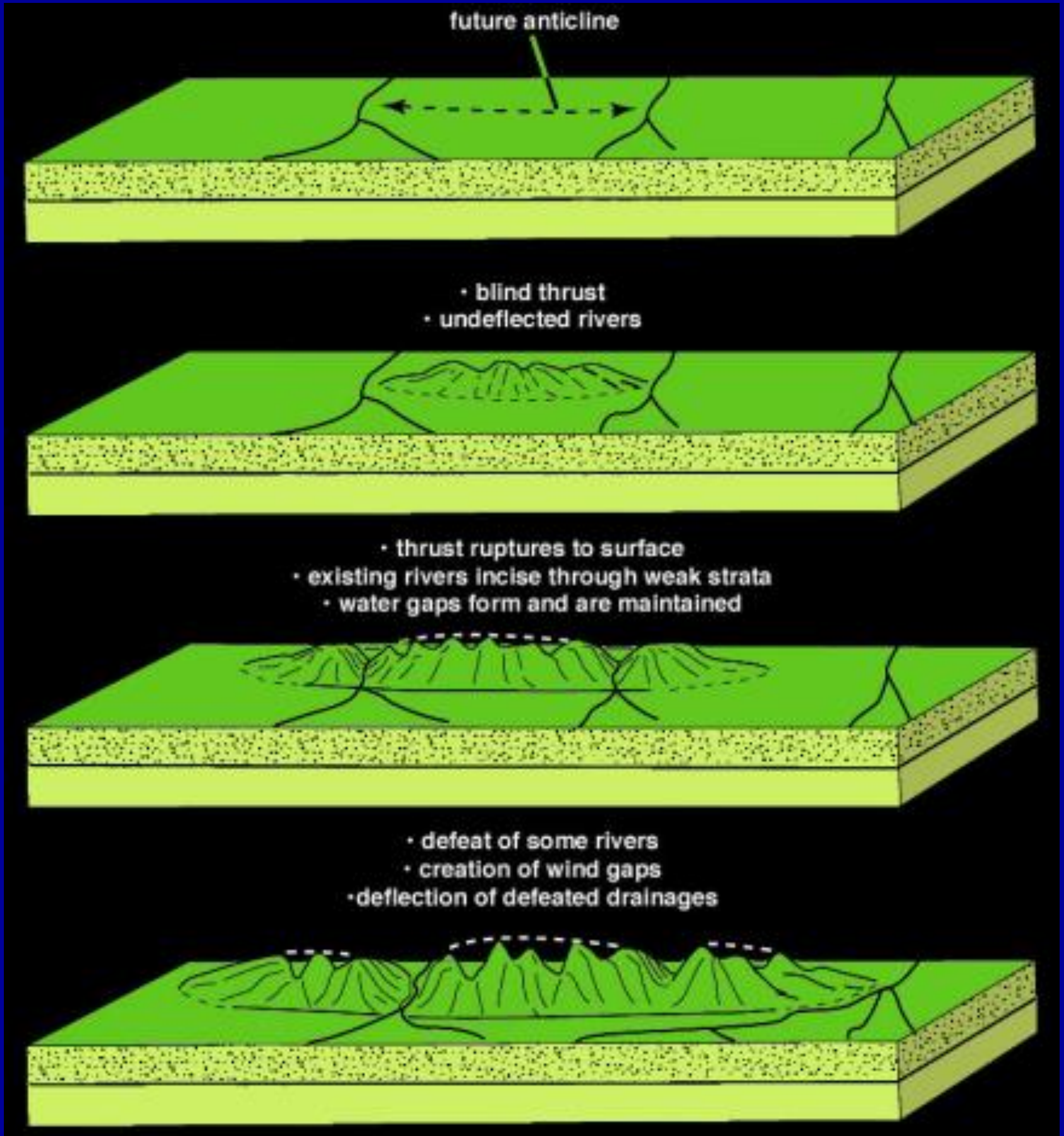


paralel

Changes in river pattern – response to uplift and erosion

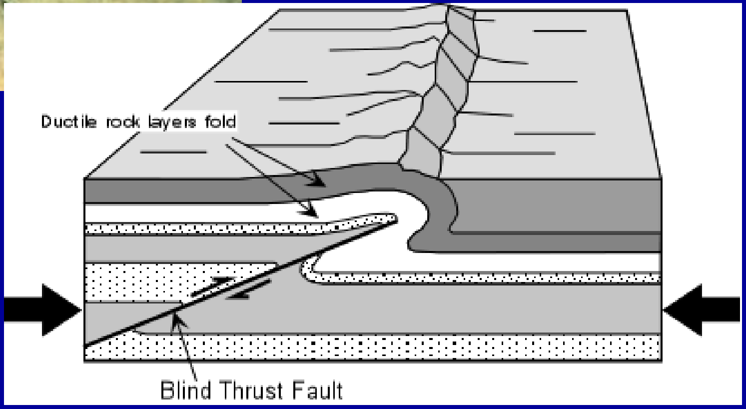
- Antecedent valley
  - water gap
- Abandoned valley
  - wind gap
- Stream deflection/diversion
- River capturing





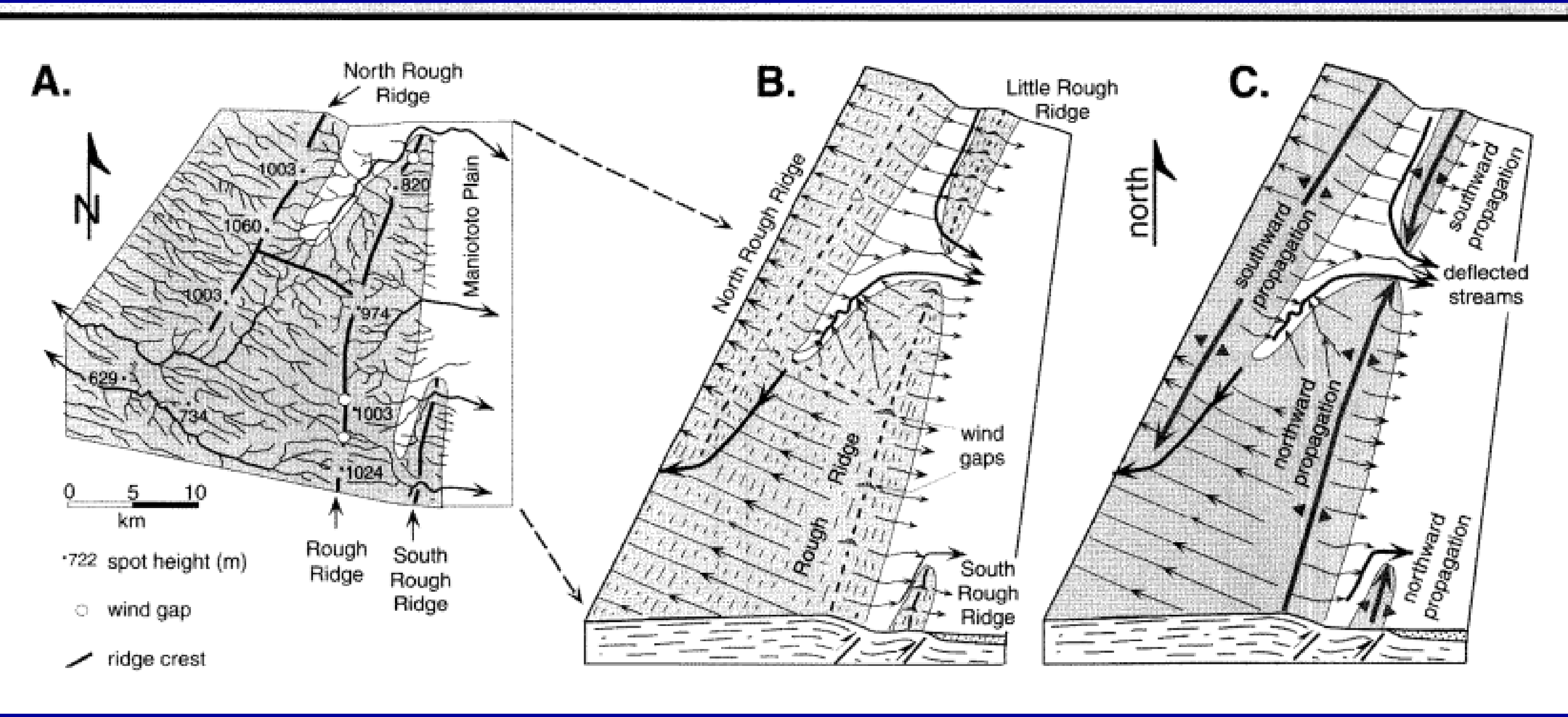
Active folding

Fault-propagation fold
- fault related fold



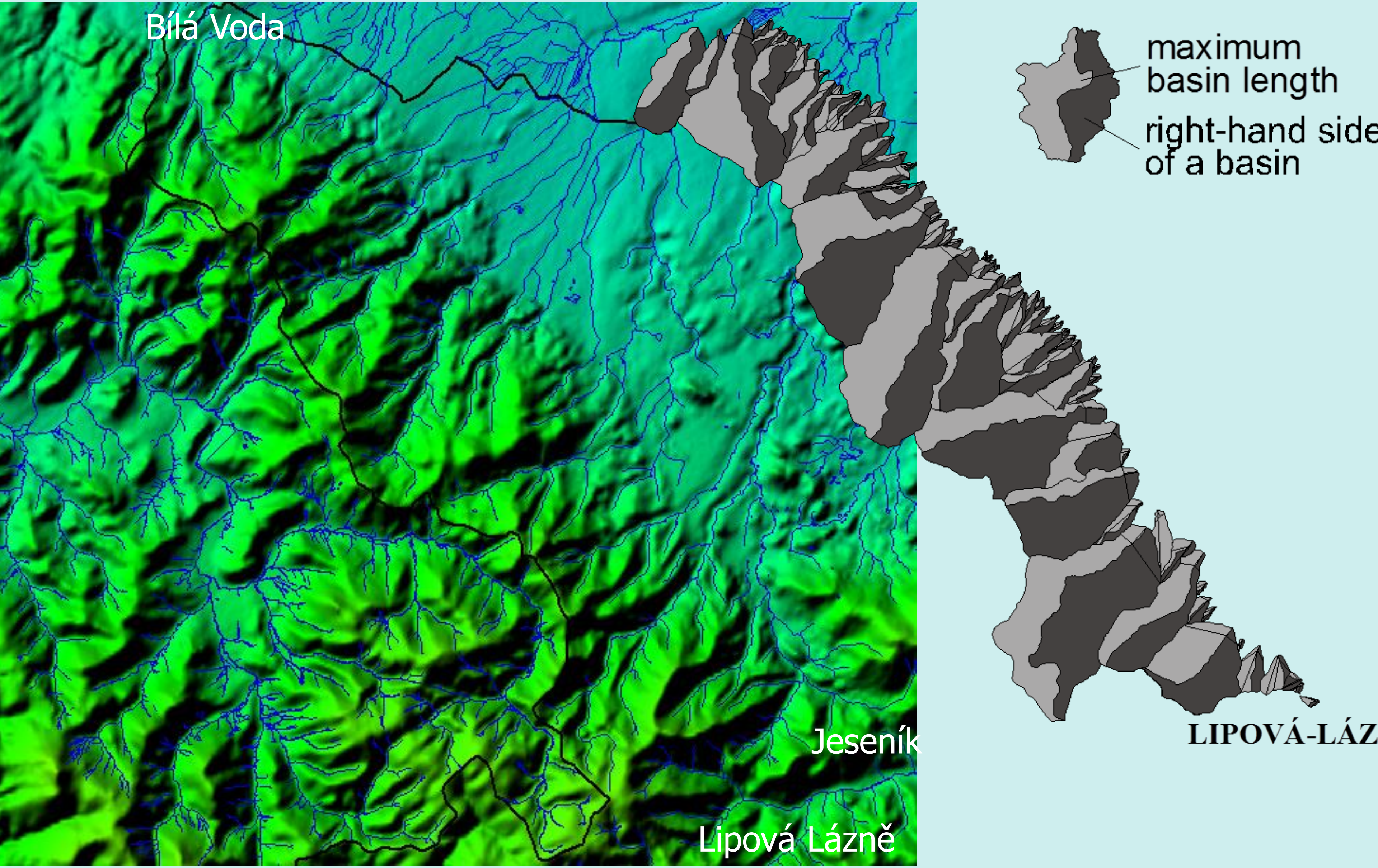
„**Blind thrust fault** that does not rupture all the way up to the surface so there is no evidence of it on the ground. It is "buried" under the uppermost layers of rock in the crust. „USGS

Basin asymmetry in active folding-faulting region



Fold axis is tilted – wind gap – decreasing hight, diversion of streams close to the limit of the fold

Bílá Voda


Bílá Voda
maximum basin length
right-hand side of a basin
Jeseník
Lipová Lázně
LIPOVÁ-LÁZ

Active mountain front

Active mountain front

- Straight, linear (normal faulting) or sinuous and embayed (thrusting)
- Triangular facets (*faceted spurs*, *flatirons*)

  - origin due to uplift and dissection of normal fault scarp by gullies

  - bases are parallel to the fault trace (Cotton 1950; Bloom 1978; Stewart, Hancock 1990)

  - slope of facets - 25 – 35° whereas slope of the fault 50 – 90° (Wallace 1978)

- - spacing of facets along range fronts depends on the evolution of drainage basins
- - flights of faceted - result of

  a) episodic uplift (Hamblin 1976; Anderson 1977)

  b) distributed faulting along the parallel faults within the main marginal fault (Menges 1988; Zuchiewicz, McCalpin 2000)

Active mountain front

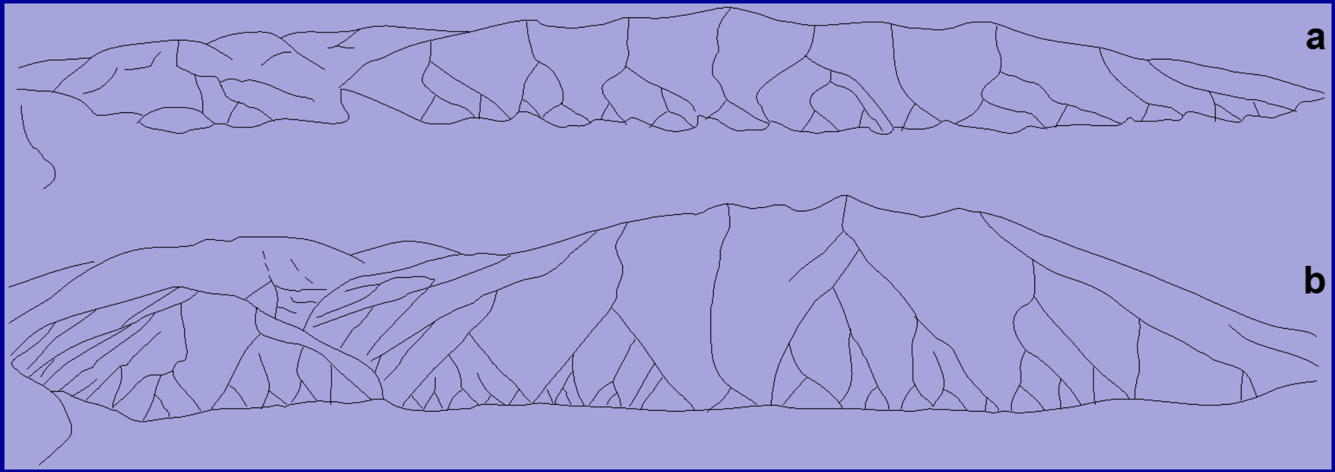
Multiple triangular facets aligned on the fault scarp of Maple Mountains, Utah

Active mountain front

- Formation of faceted spurs – result of

  a) fluvial erosion and the uplift of the foothill at the same time (Hamblin 1976; Wallace 1978)

  b) slope retreat and the gravitational mass movements (Anderson 1977)



Spanish Fork – fault segment Wasatch (Anderson 1977)

a) Paleogene and Neogene

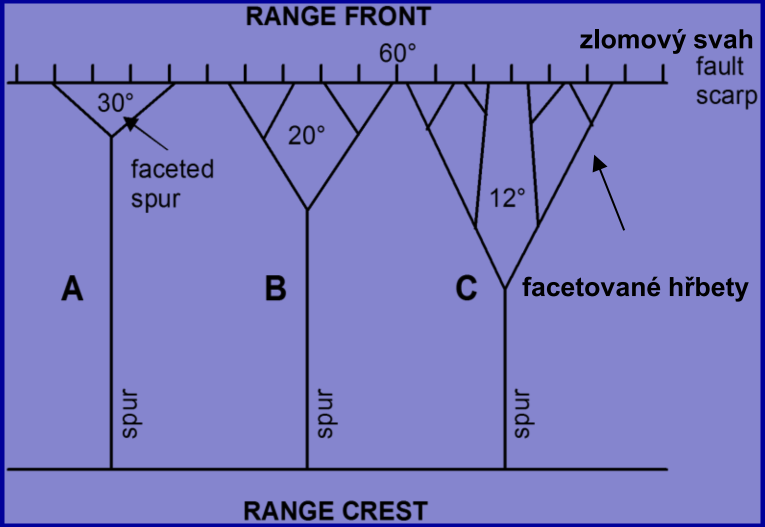
b) Present day

- Size of the faceted spurs - function of the distance between major canyons incised into the mountain front and of the spur's height

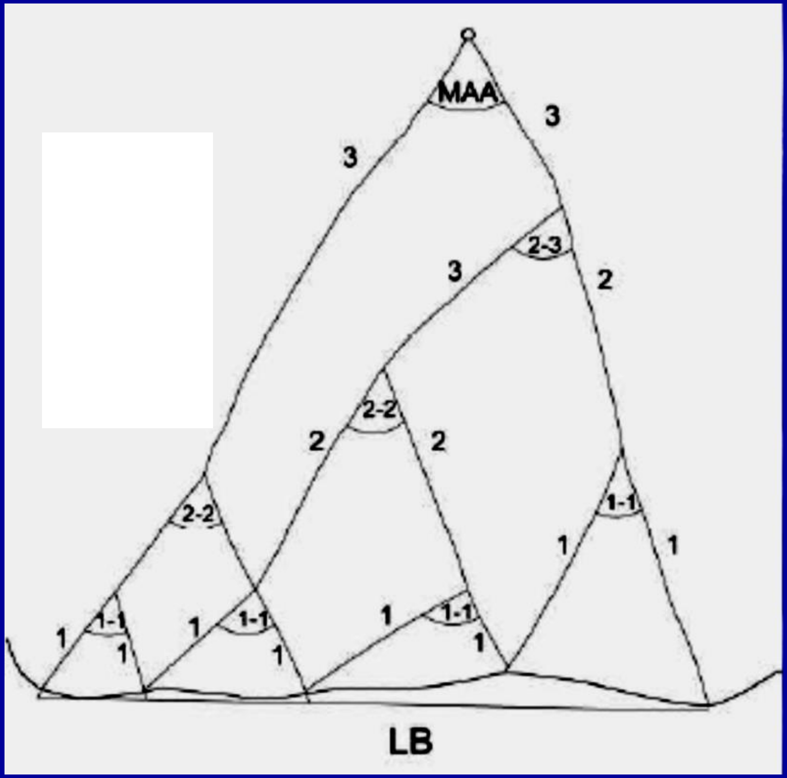
Active mountain front

Height of faceted spurs - function of uplift

Average inclination - rate of slope degradation based on the time, rock resistance, inclination of the original fault scarp, width of the fault zone (Wallace 1977)



Evolution of faceted spurs, slope decrease, more dissected



Dissection of compound faceted spurs - 3 generations

Active mountain front

Facets of the Rychlebské hory

Studied segments – different hight of fault scarp (altitude of faceted spurs)

Triangular or trapezoidal facets – two to five tiers (2 – 5 generation), similar to Polish part of the Sudetic Marginal fault and they are in different stage and re-modelation (Badura et al. 2007).

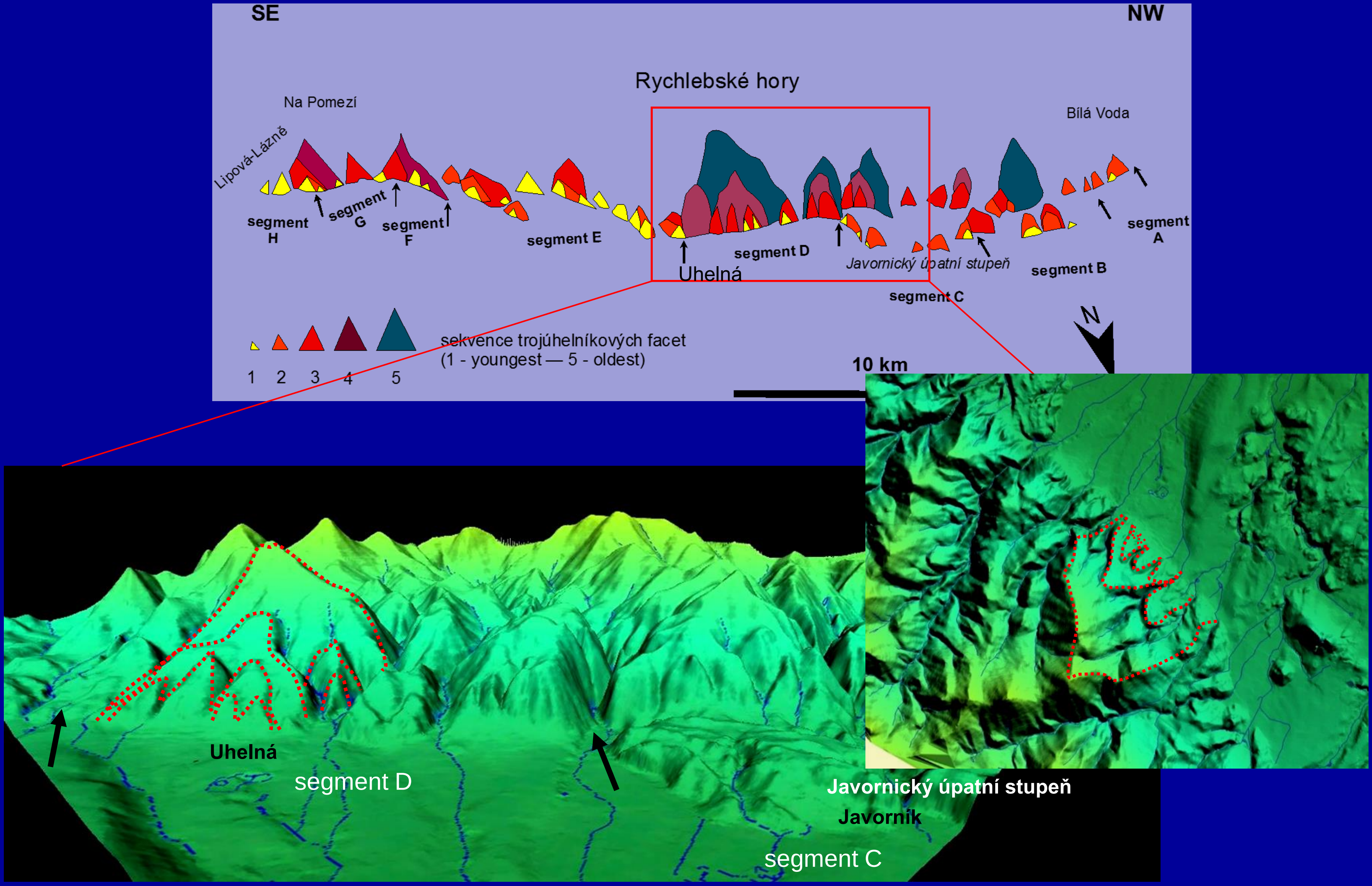
The highest facets (5 generations) – Soví hory Mts and Rychlebské hory Mts (most elevated part of the mountains on the SMF)

Rychlebské hory Mts – near Uhelná village

average height of facetes – 5 tiers – 275m, 173m, 111m, 60m, 28m

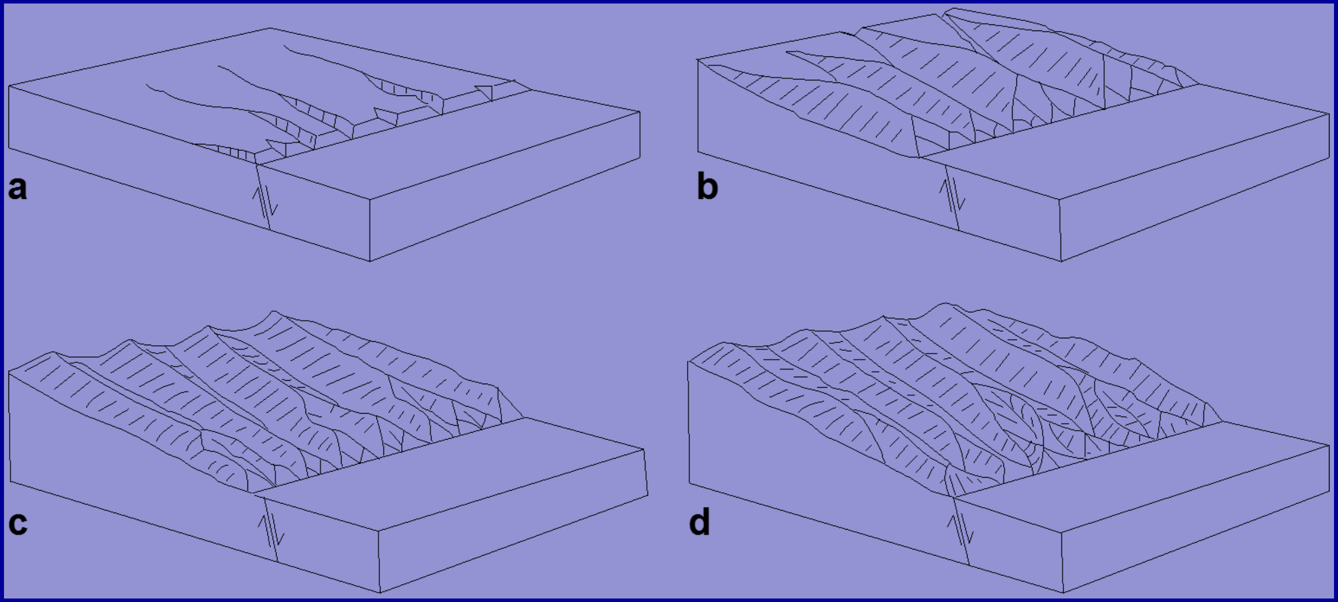
Active mountain front

Facets of the Rychlebské hory Mts



Mountain front – fault scarps, active mountain margins,

Several generation of facets – evolution of compound faceted spurs - mountain front



Anderson (1977)

By repeated episodic movements – origin of:

- n–hundreds meters high fault scarp
- fault-controlled mountain front– 100 km long, up to 1 km high (Stewart, Hancock 1994)

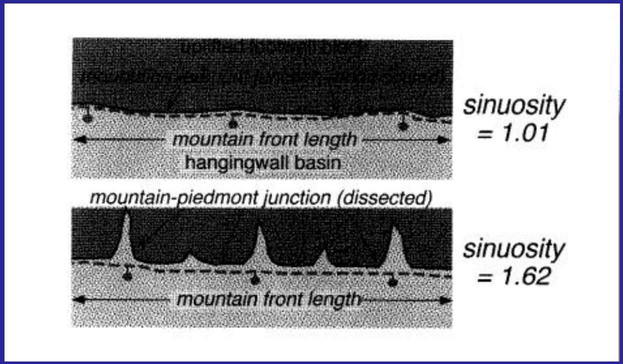
Active mountain front

Mountain front sinuosity index Smf (Bull, McFadden 1977)

$Smf = (L_{mf})/(L_s)$

Lmf – length of mountain front

Ls – straight-line length of mf



- intensity of the dissection of the former linear and straight fault-controlled scarp

higher Smf – lower activity, higher dissection of the foothill

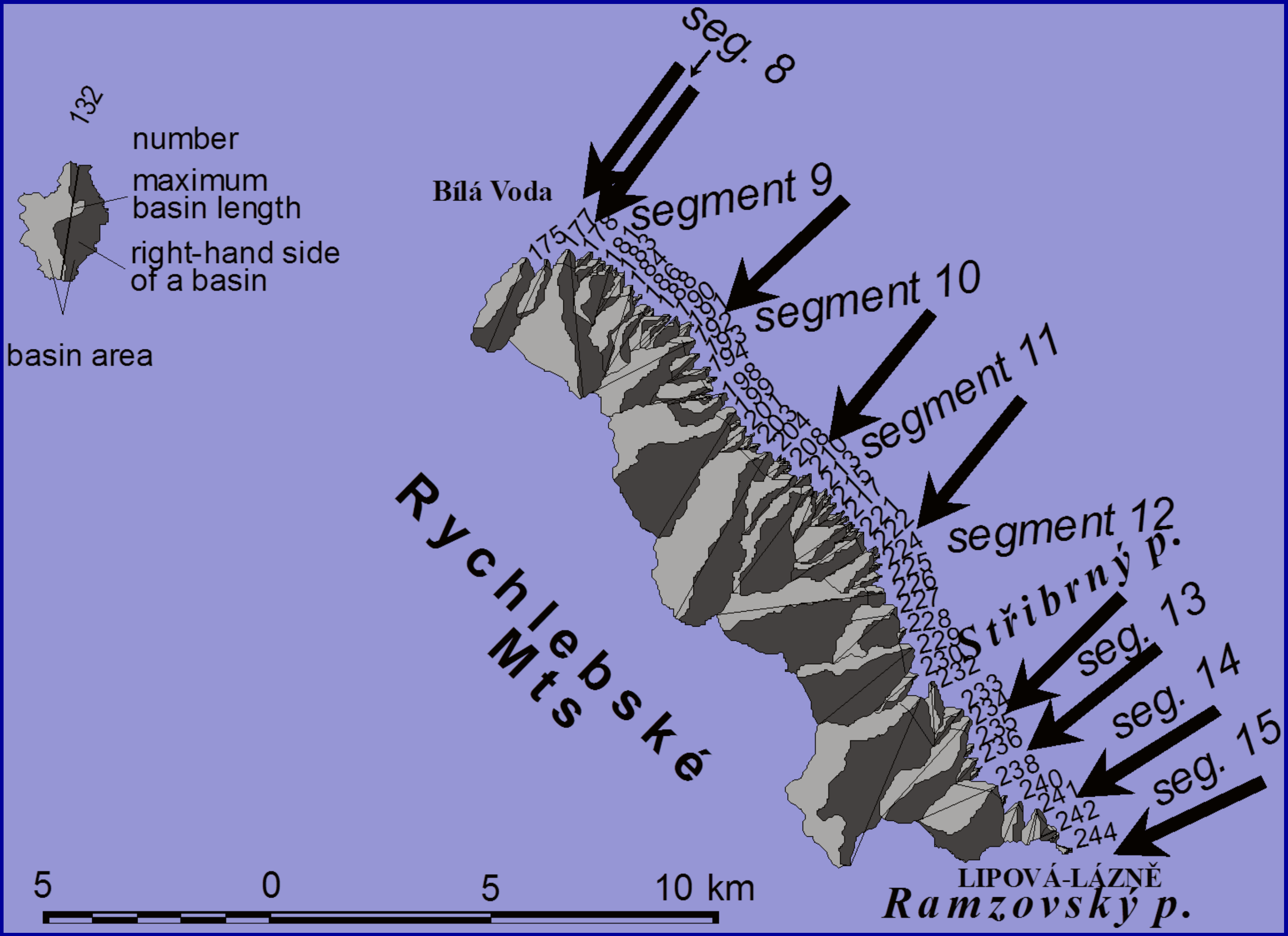
Smf index < 1.4 indicates tectonically active mountain front,

1.4 to 3 reflects lower activity, but still active tectonics

> 3 not active mountain front any more, slope retreated by erosion at minimum 1km from the original position controlled by the fault line (Keller, Pinter 2002)

Smf for the studied segments A – H: 1.013 to 1.11. for the whole fault incl. Polish part average 1.051 which suggests (!) relatively high activity and young uplift (Badura et al. 2007).

Active mountain front



Active mountain front

Parameter -

valley floor width - valley heigth ratio Vf (Bull, McFadden 1977)

$$Vf = 2Vfw / [(Eld - Esc) + (Erd - Esc)]$$

Vfw = valley floor width

Eld, Erd, Esc = the altitudes of the left and right divides and the stream, respectively

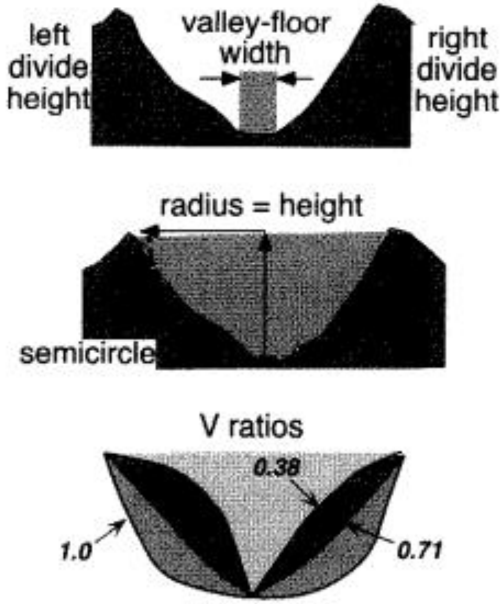
Low values (<1.0) - deep valleys with actively deepening streams

(usually related to the uplift)

In the studied parts of the Sudetic Marginal fault: Vf ranges between 0.06 - 0.97

Active mountain front

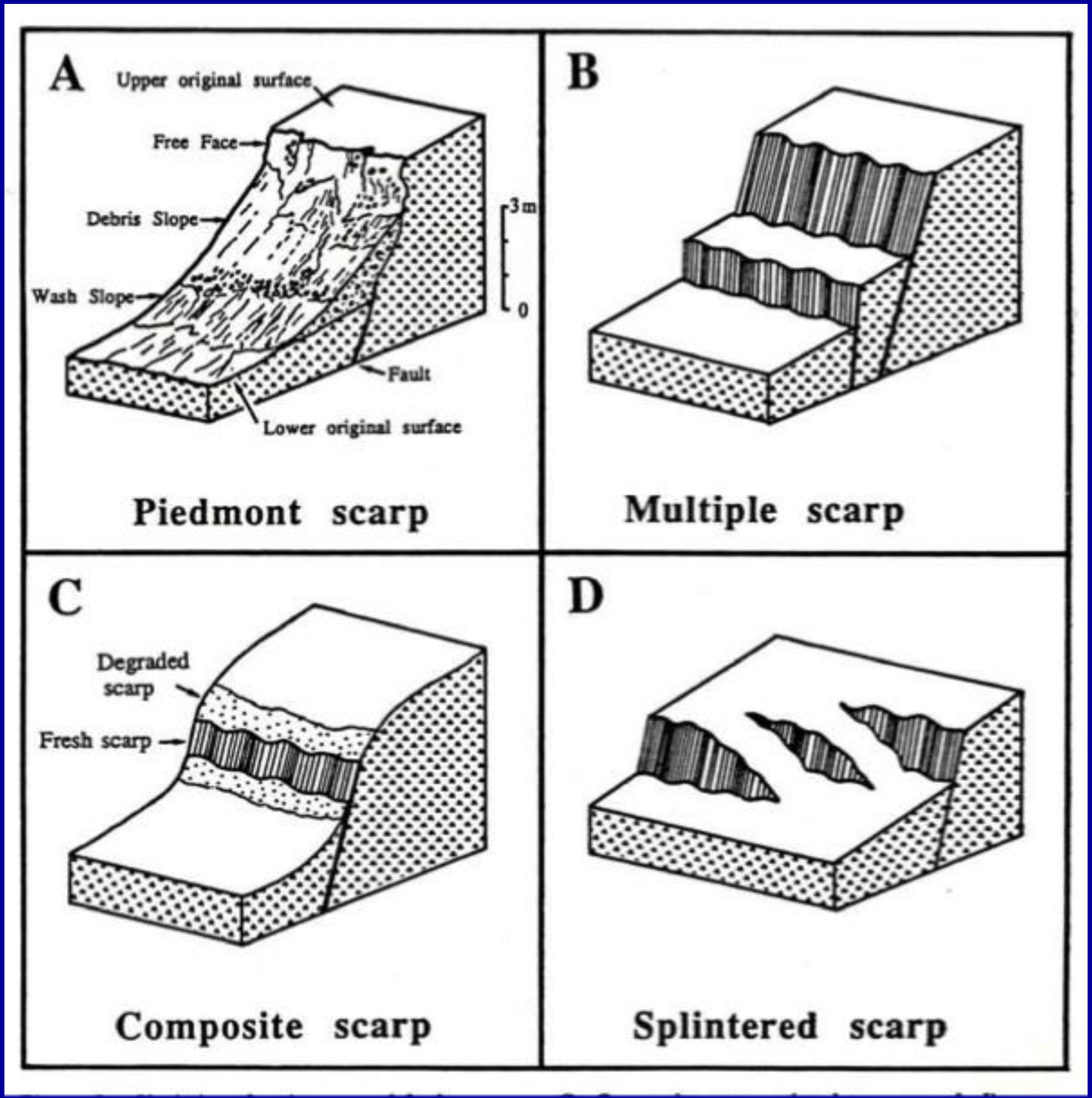
FIGURE 10.6. Measurements of valley shapes in foot-wall blocks



Top: Valley-floor width-to-height ratio. Middle: Parameters for calculating a "V ratio." Bottom: Examples of V ratios for several valley shapes.

Fault scarps

Fault scarp – tectonic landform coinciding with fault plane



Stewart, Hancock 1990

Piedmont scarp – formed during one movement in unconsolidated sediments

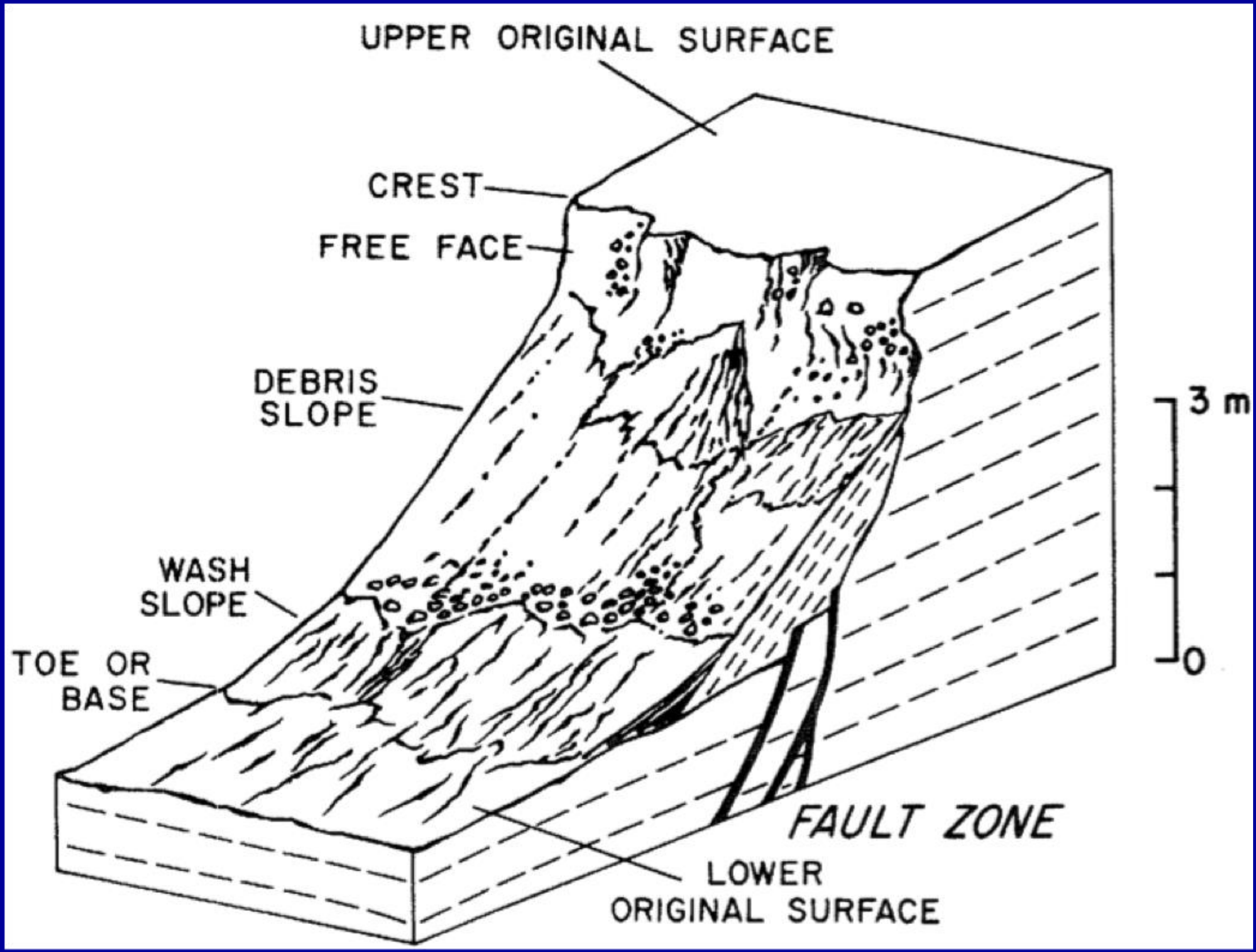
Multiple scarp
- Formed on parallel faults or branches of the fault during one movement

Composite scarp (combined)
- Formed by reactivation and by degradation of the former free face

Splintered scarp – formed - during movement distriuted on en échelon fault segments

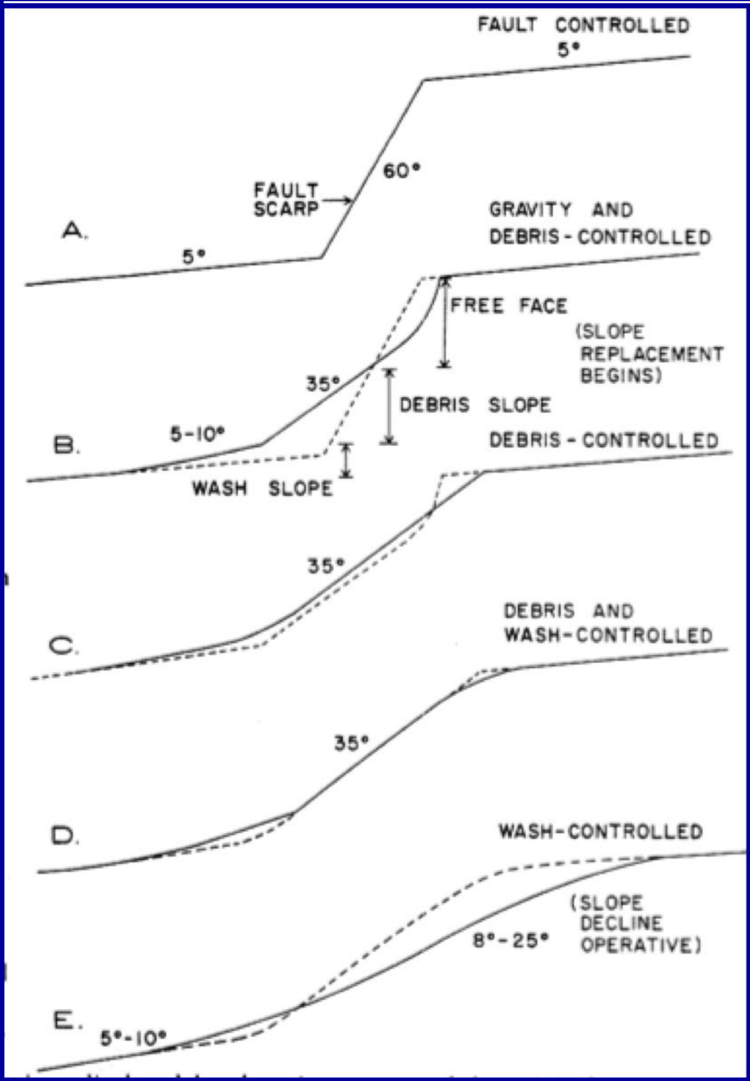
Fault scarp anatomy

- *Toe* a *crest* - horní a spodní hrana zlomového svahu
- *Free face - subvertikální část*, obnažený zpevněný aluviální kužel nebo svahoviny, vytvořená pohybem – může držet tvar – 10-1000 let
- *Debris* slope – osypový kužel akumulovaný pod free face gravitací
- *Wash slope -* část svahu při úpatí řízena fluviální erozí nebo akumulací

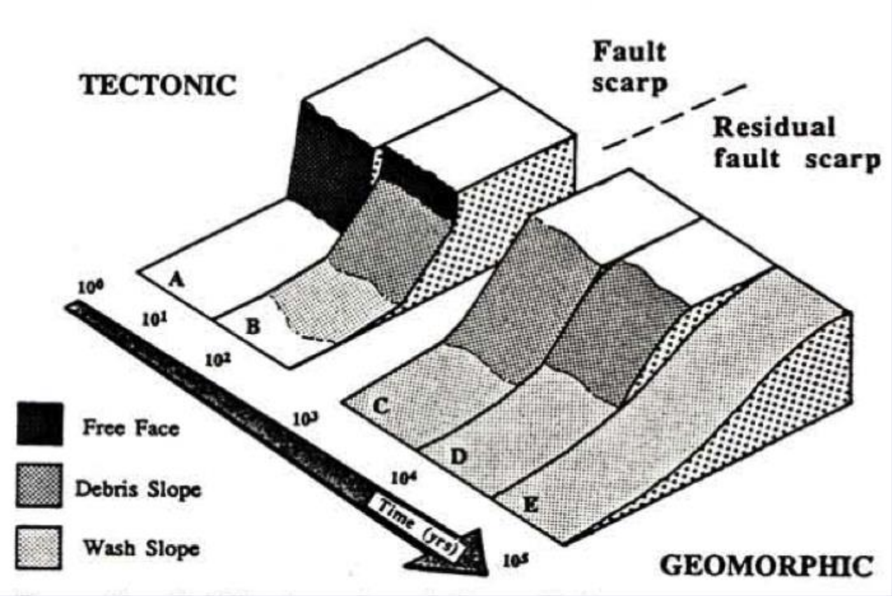


Wallace 1977

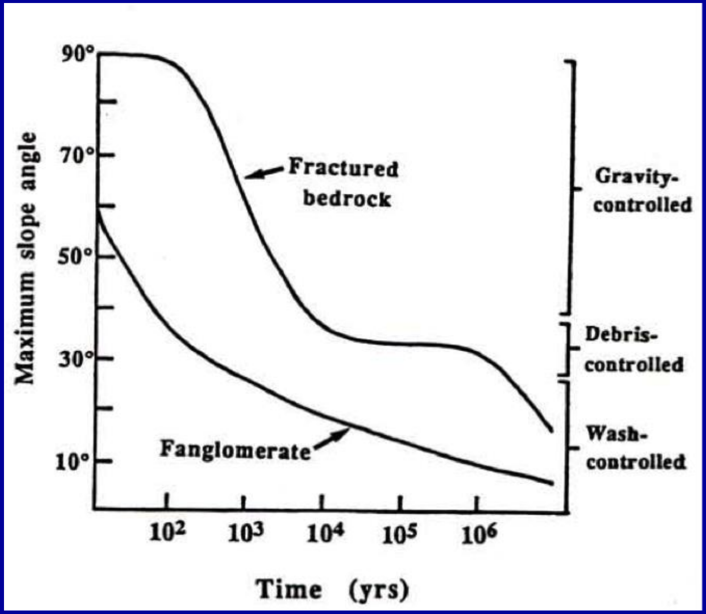
Fault scarp degradation



Wallace, 1977

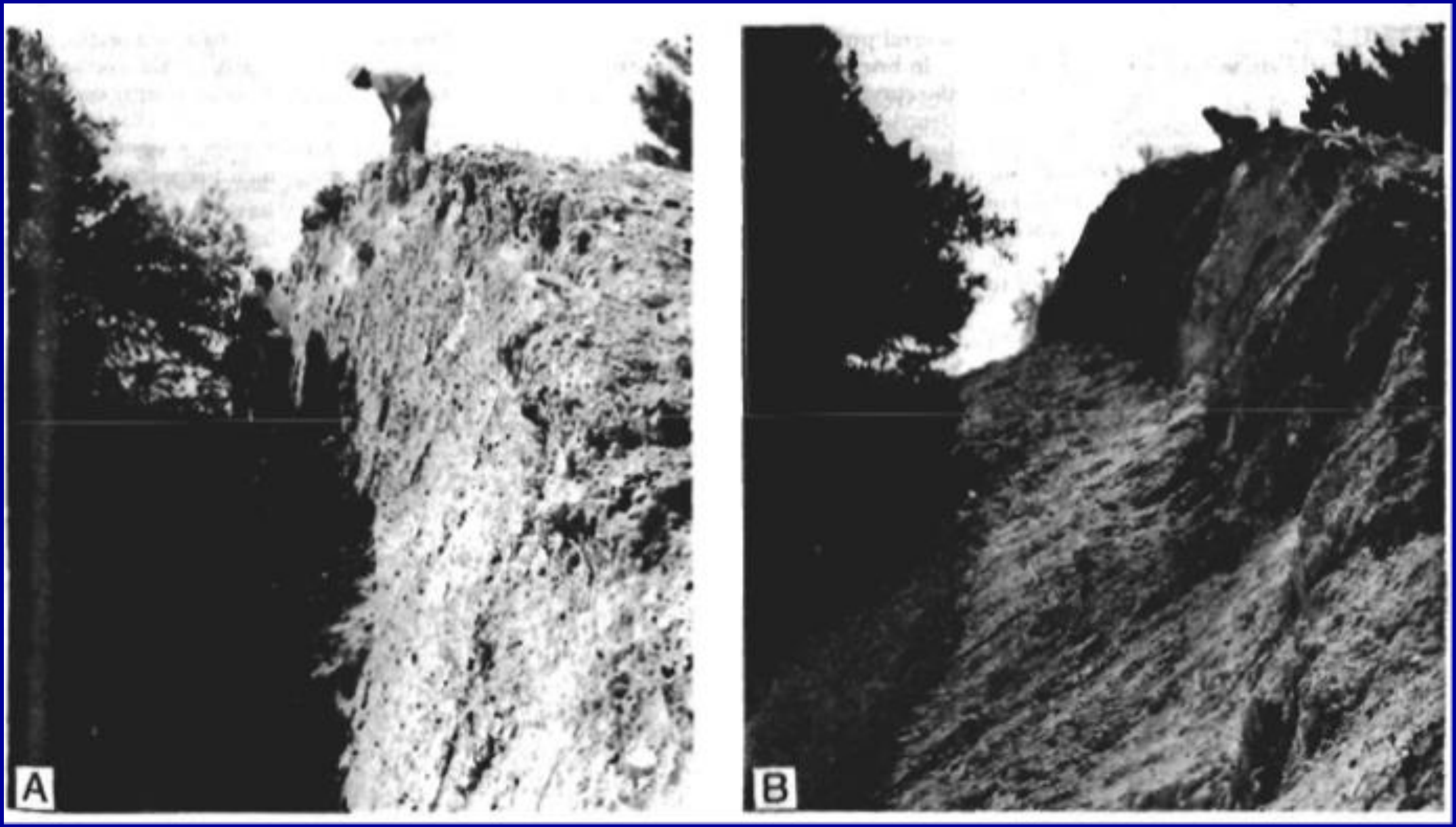


Stewart, Hancock, 1990



Wallace, 1977

Fallon-Stillwater earthquake, July 6th, 1954 M 6.6



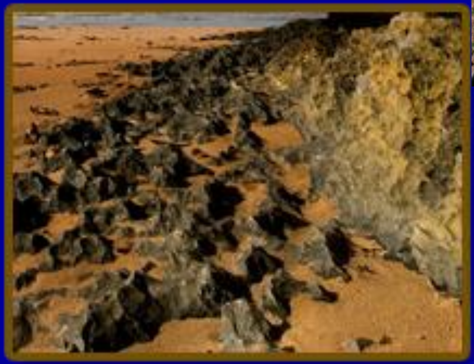
Wallace, 1977

Pictures taken from 1954 and 1974 show several meters of retreat from the free face, forming a debris-slope.

Factors that influence rate of degradation.


Hirschfeld

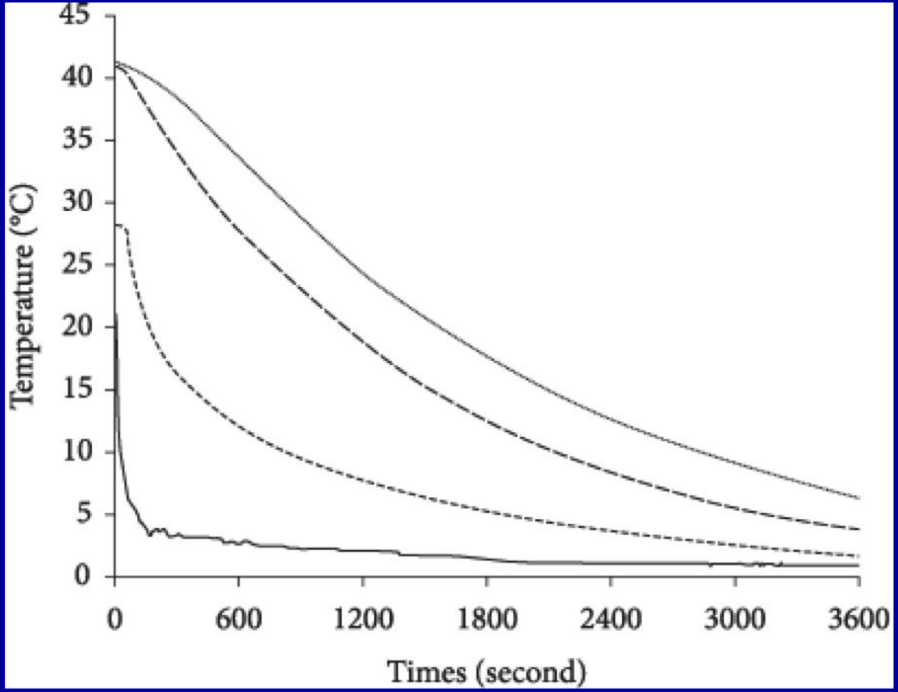

Cunningham



- Climate
- Scarp height
- Topography (steepness of slope)
- Lithology
- Vegetation
- Dust (wind)

Diffusion model definition

- Movement of a medium from an area of higher concentration to an area of lower concentration. Diffusion is a result of the kinetic properties of particles of matter. The particles will mix until they are evenly distributed.



Carciofi, Laurindo, 2010

Zandbergen international meat

How does this model apply to scarp morphology

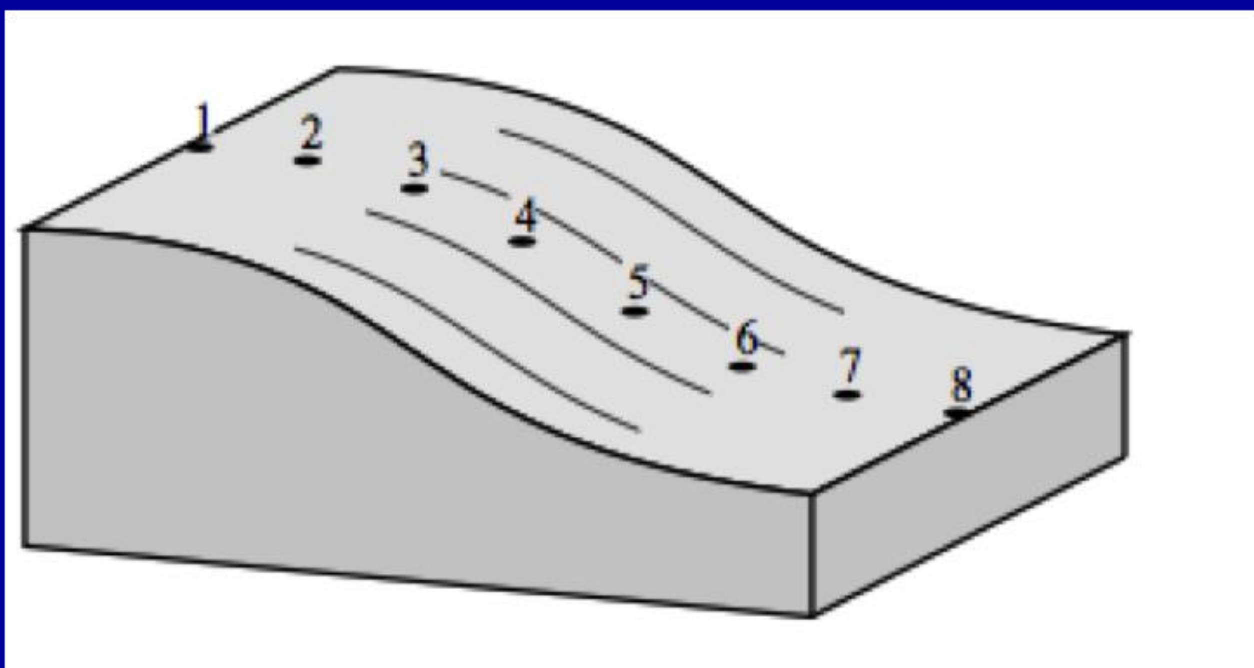
-Is useful in areas with little mineral or organic material that can be used for radiometric dating.

-Gives a quick and approximate preliminary observation of a seismically active area.

Diffusion modelin

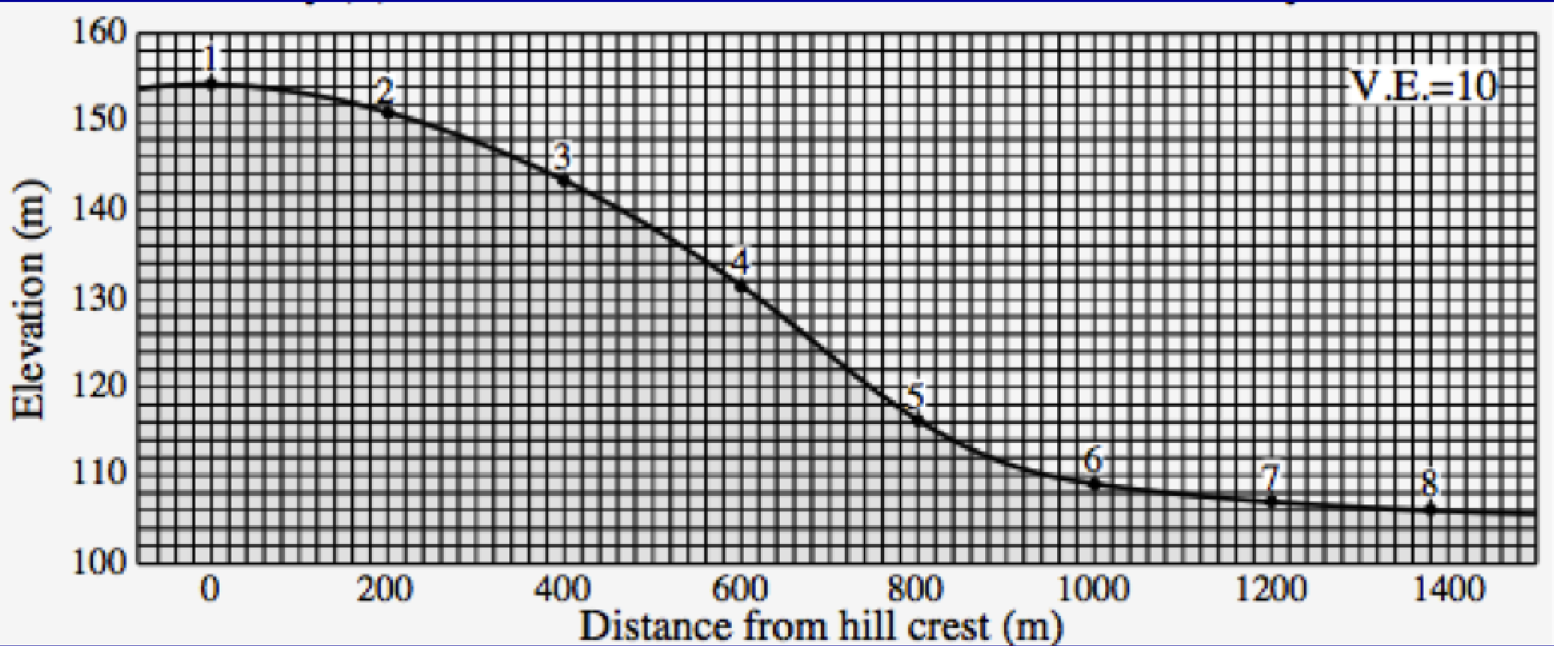
Parameter	Explanation	Units
z	elevation	meters
t	time	years
R	sediment flux rate	m^2/ yr
x	horizontal position	meters
$\delta z/\delta t$	elevation change over time	m / yr
$\delta R/\delta x$	change in transport rate	m^2/ yr^2
κ	diffusivity	m^2/ yr
$\delta z/\delta x$	slope gradient	none

- Series of elevation points are measured in a line perpendicular to the scarp.



- Those heights and the distances between them are used to construct a cross section.

Modeling slope evolution: *How will this slope change over 1000 years with a diffusivity constant of* ***50 m^2/yr***



	1	2	3	4	5	6	7	8
Distance (m) = x =	0	200	400	600	800	1000	1200	1400
Elevation (m) = z =	154.0	151.0	144.0	131.0	116.0	109.0	107.0	106.0

	1–2	2–3	3–4	4–5	5–6	6–7	7–8
Gradient = $\frac{\delta z}{\delta x}$	0.015	0.035	0.065	0.075	0.035	0.010	0.005

Gradient = height/time (m/yr)

Sediment flux rate

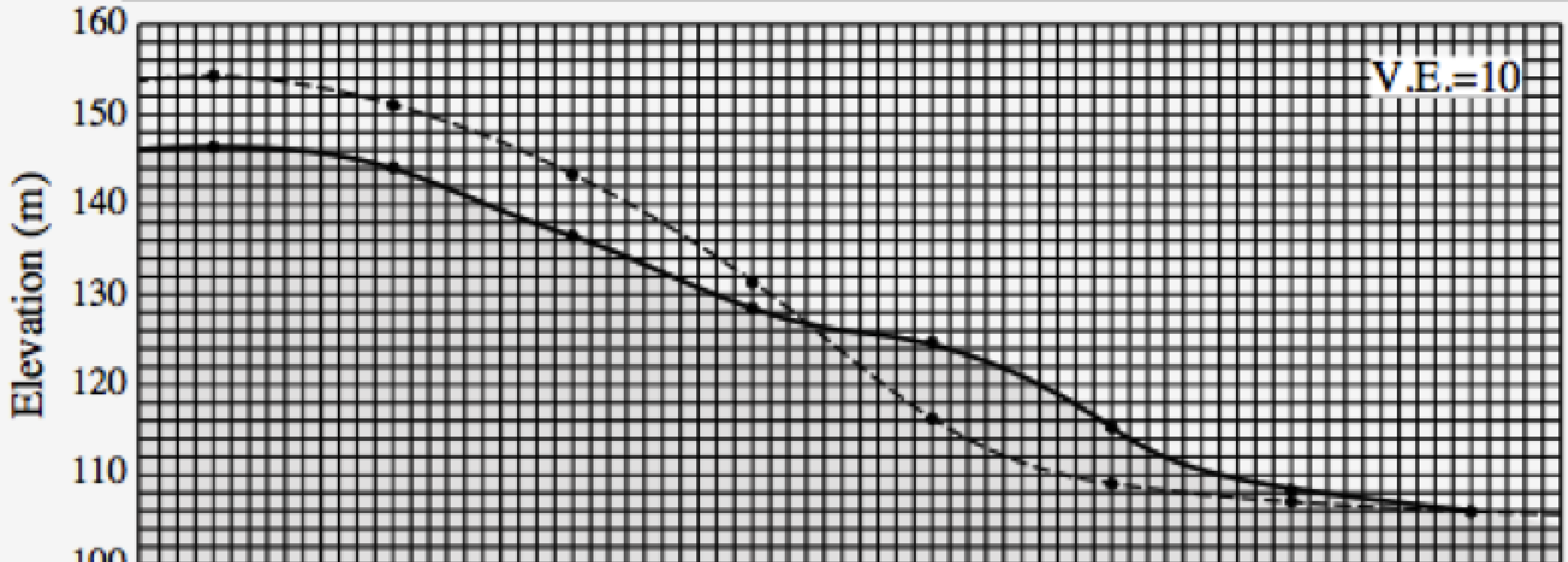
$$R = K \times \frac{\partial z}{\partial x}.$$

	1–2	2–3	3–4	4–5	5–6	6–7	7–8
d. transport rate = R = (m^2/yr)	0.75	1.75	3.25	3.75	1.75	0.5	0.25

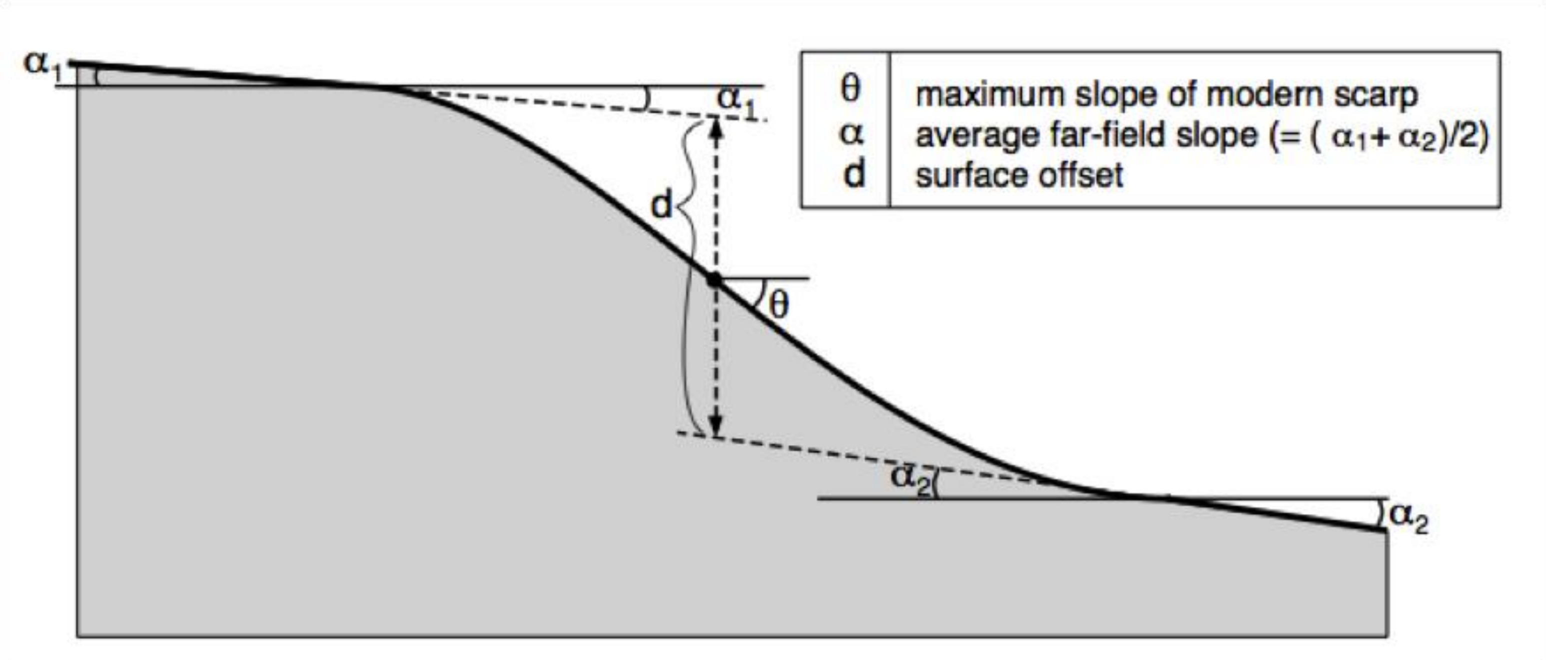
	1–2	2–3	3–4	4–5	5–6	6–7	7–8
Sed. flux = R∗1000 yrs = (m ^{2})	750	1750	3250	3750	1750	500	250

	1	2	3	4	5	6	7
Sed. gained − sed. lost = (m ^{2})	- 1500*	- 1000	- 1500	- 500	+2000	+1250	+250
Elevation change (m) =	-7.5	-5.0	-7.5	-2.5	+10.0	+6.25	+1.25

	1	2	3	4	5	6	7	8
NEW elevation (m) =	146.5	146.0	136.5	128.5	126.0	115.25	108.25	106.0



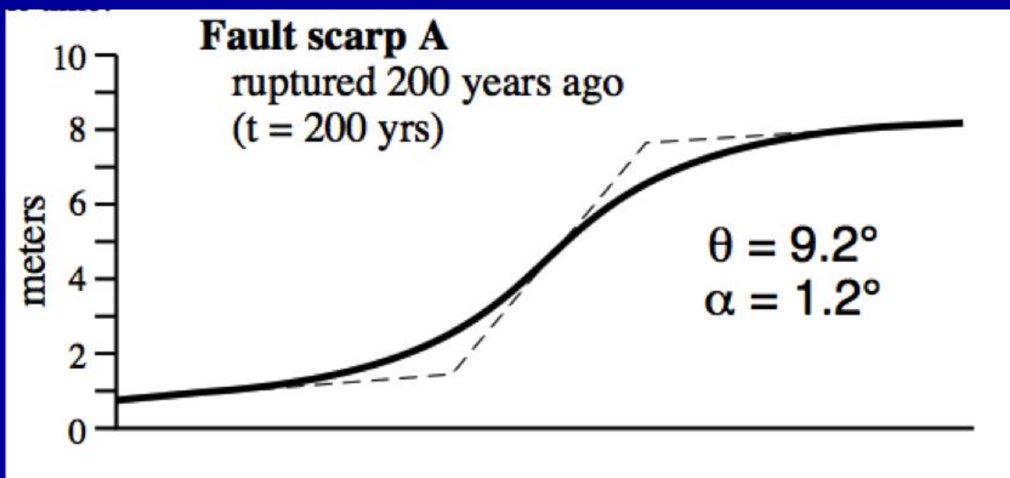
Diffusion model



$$\kappa t = \frac{d^2}{4\pi} \frac{1}{(\tan\theta - \tan\alpha)^2},$$

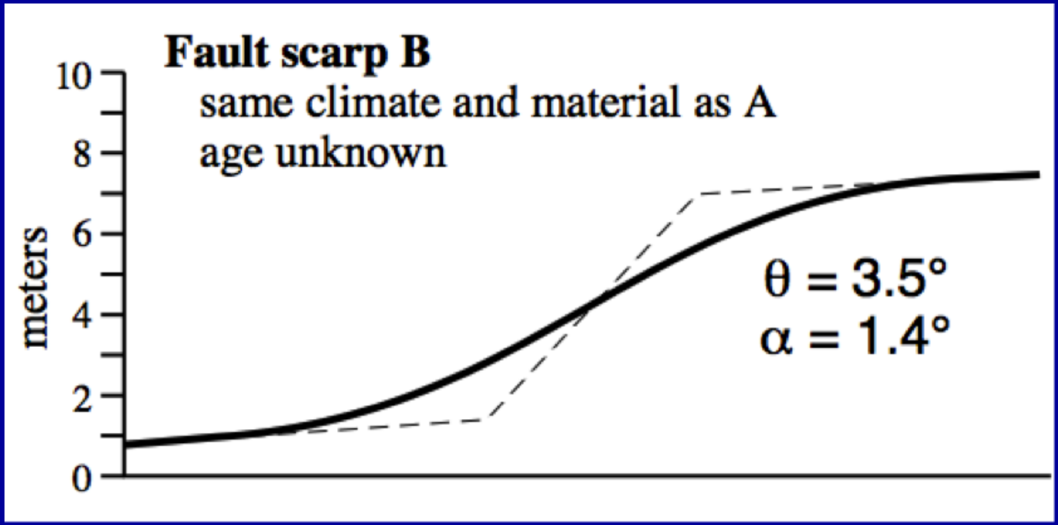
Parameter	Explanation	Units
d	vertical displacement on a scarp	meters
π	pi = 3.14159	none
θ	maximum scarp slope angle	degrees
α	average far-field slope angle	degrees

$$\kappa t = \frac{d^2}{4\pi} \frac{1}{(\tan\theta - \tan\alpha)^2},$$



- $K = [(6^2/4\pi) \times 1/(\tan 9.2 - \tan 1.2)^2] / 200$
  - $[(28.27) \times 50.29] / 200$
    - K = 7.12

$$\kappa t = \frac{d^2}{4\pi} \frac{1}{(\tan\theta - \tan\alpha)^2},$$



- $t = [(6^2/4\pi) \times 1/(\tan 3.5 - \tan 1.4)^2] / 7.12$
  - $t = [(28.27) \times 741.5] / 7.12$
    - <u>t = 2,944 yrs</u>

Assumptions

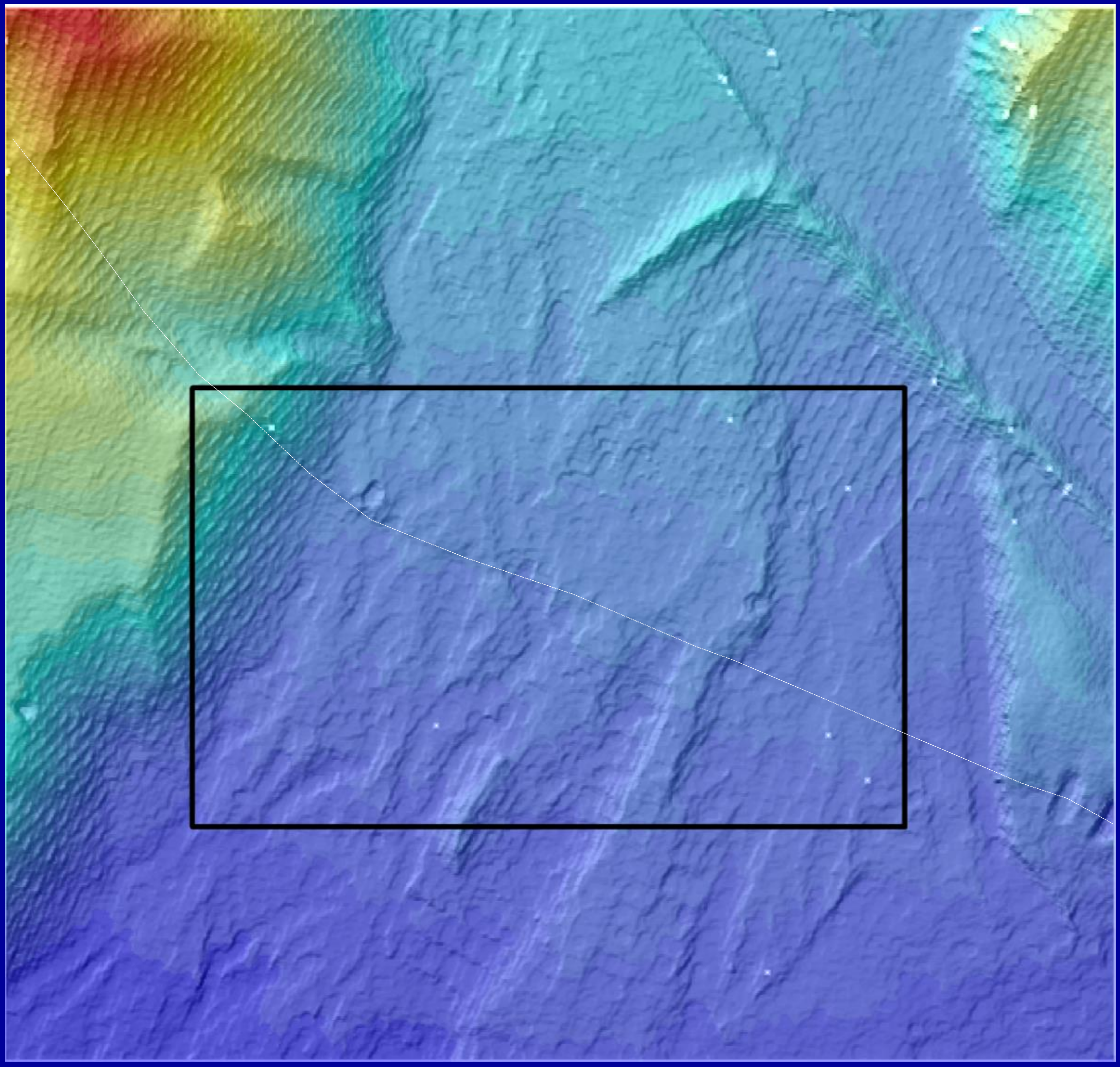
- Rate of sedimentation transport is limited by the strength of the transporting process, and not by the availability of material.
- The rate of sediment transport is only a function of scarp slope, and not a position of the scarp.

  - Why is this model important

Is useful in areas with little mineral or organic material that can be used for radiometric dating.

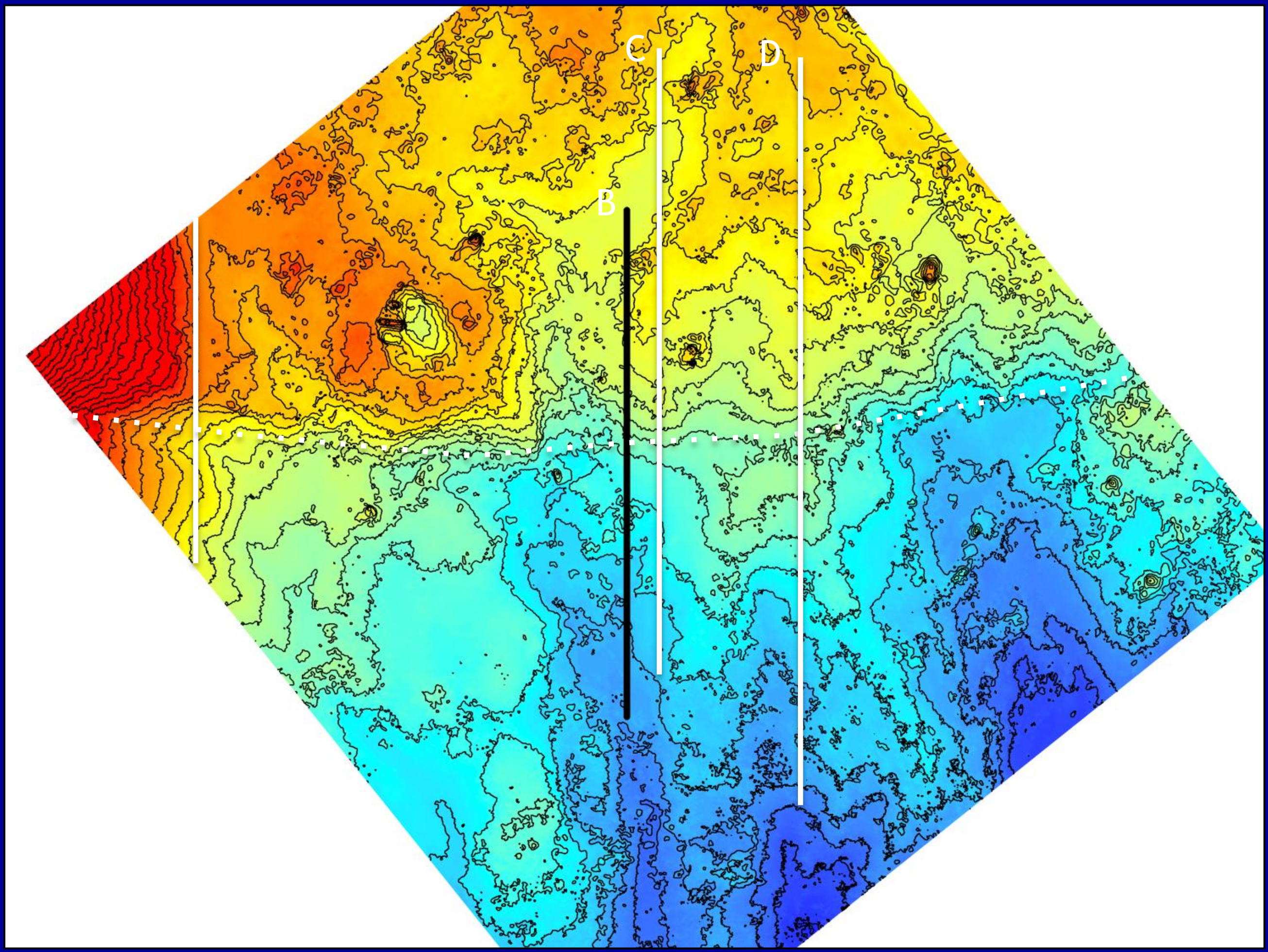
Gives a quick and approximate preliminary observation of a seismically active area.

Elsinore fault, Alverson canyon, Coyote mountains

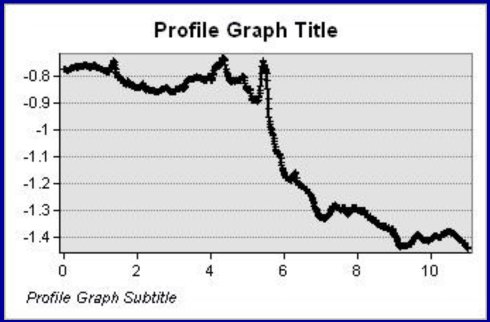


Barrett

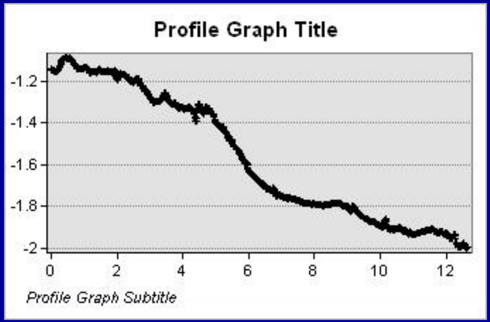
Elsinore fault



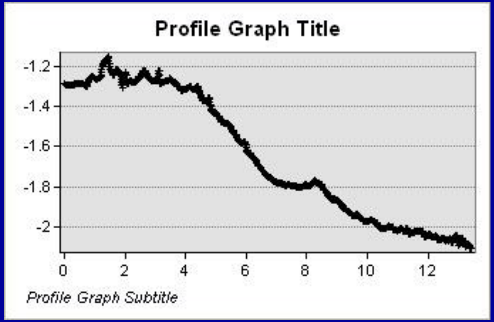
A



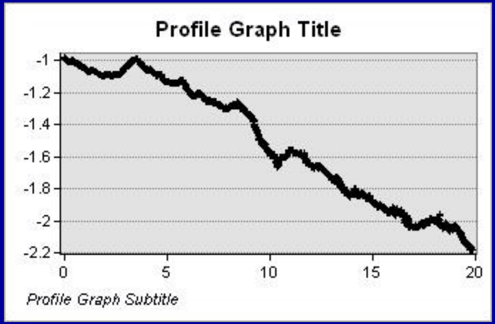
B



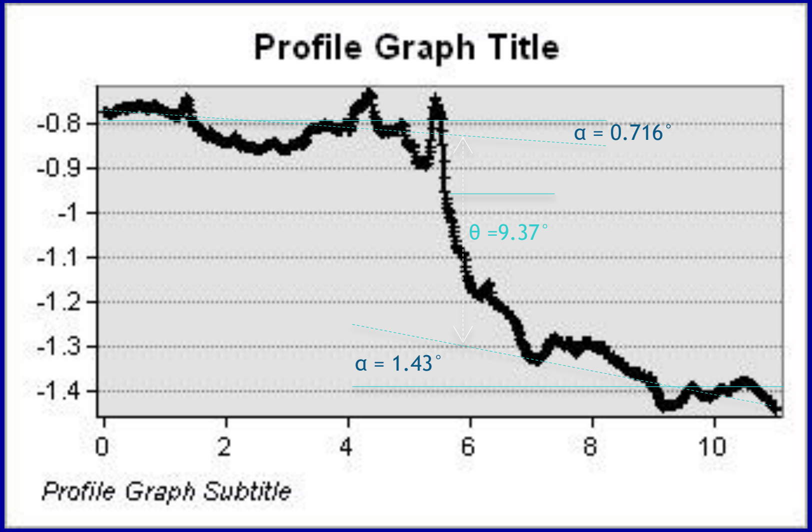
C

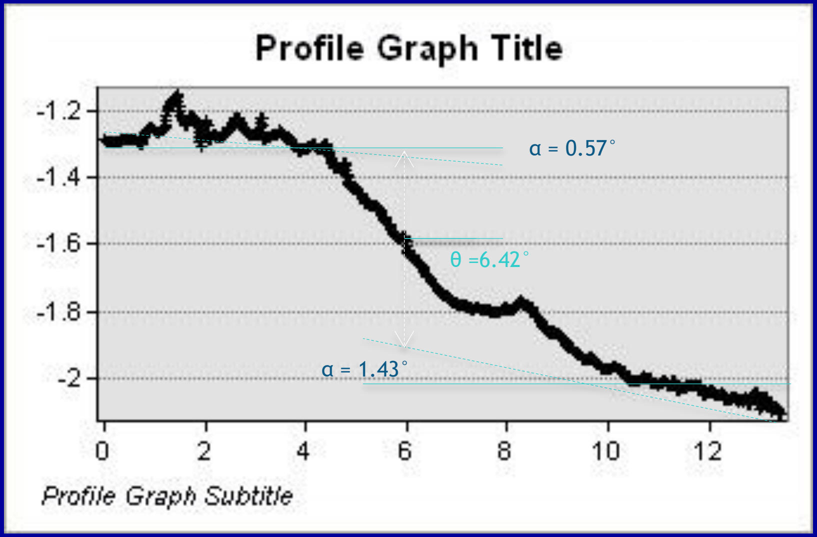


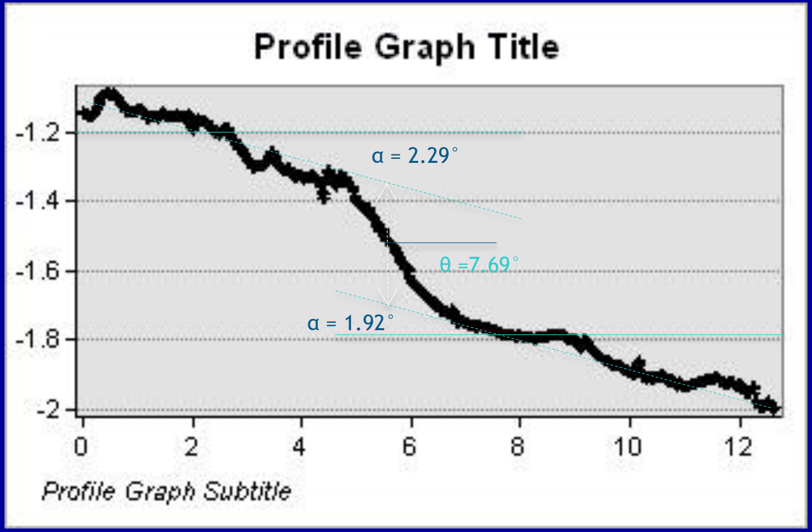
D

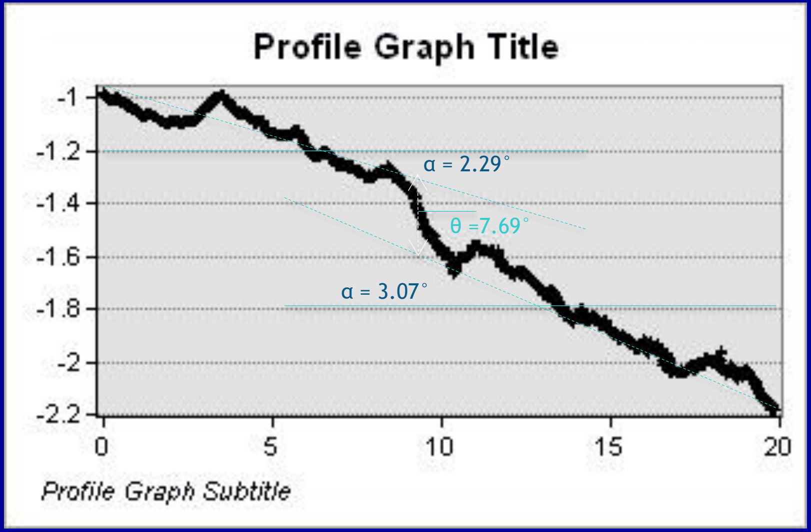


Barrett


Profile Graph Title
-0.8
-0.9
-1
-1.1
-1.2
-1.3
-1.4
0
2
4
6
8
10
α = 0.716°
θ =9.37°
α = 1.43°
Profile Graph Subtitle


Profile Graph Title
-1.2
-1.4
-1.6
-1.8
-2
0
2
4
6
8
10
12
α = 0.57°
θ =6.42°
α = 1.43°
Profile Graph Subtitle


Profile Graph Title
-1.2
-1.4
-1.6
-1.8
-2
0
2
4
6
8
10
12
α = 2.29°
θ =7.69°
α = 1.92°
Profile Graph Subtitle


Profile Graph Title
-1
-1.2
-1.4
-1.6
-1.8
-2
-2.2
0
5
10
15
20
α = 2.29°
θ =7.69°
α = 3.07°
Profile Graph Subtitle

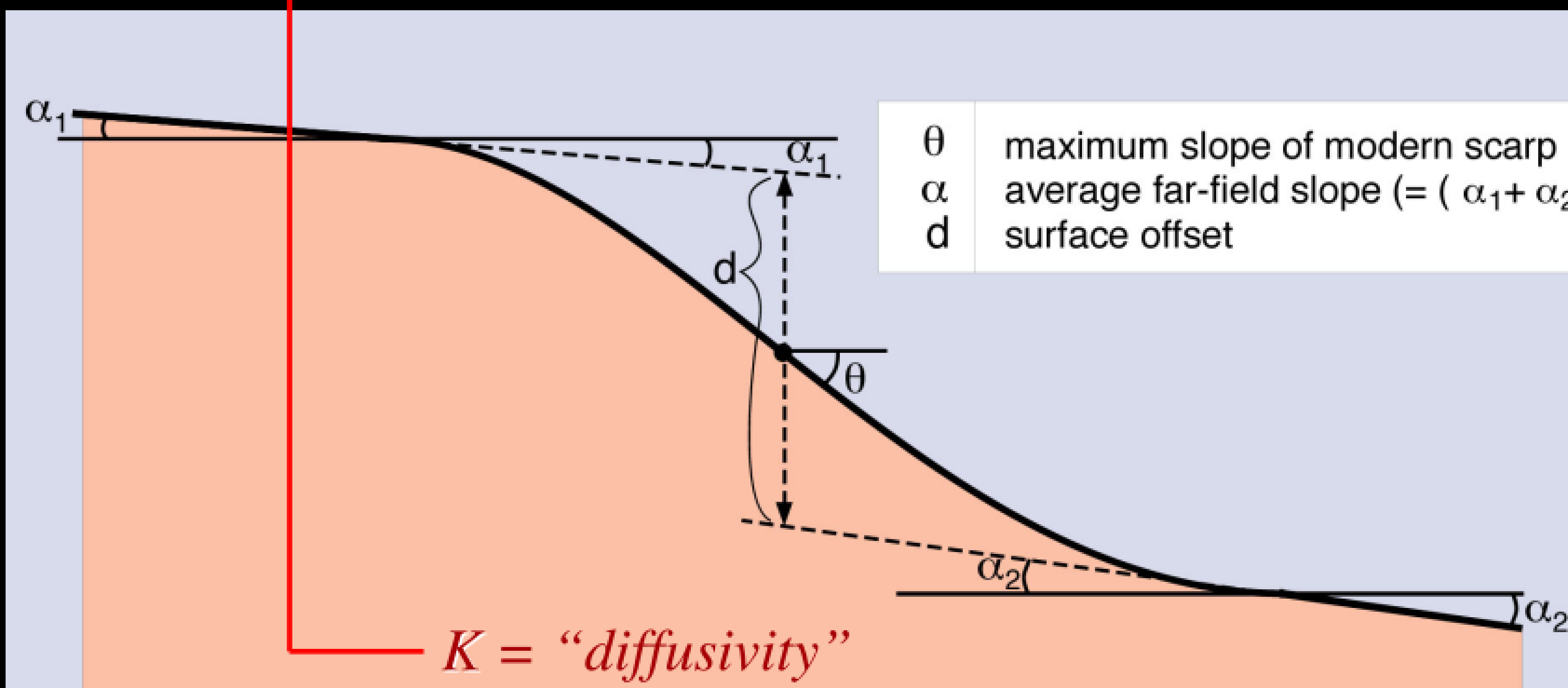
Scarp Degradation Exercise

Solution to diffusive scarp degradation (just one example):

$$\kappa t = \frac{d^2}{4\pi} \frac{1}{(\tan\theta - \tan\alpha)^2}$$

Scarp Degradation Exercise

$$\kappa t = \frac{d^2}{4\pi} \frac{1}{(\tan \theta - \tan \alpha)^2}$$



Scarp Degradation Exercise

Estimating diffusivity:The 2-scarp prob