Quantifying scour depth in a straightened gravel-bed river with ground-penetrating radar

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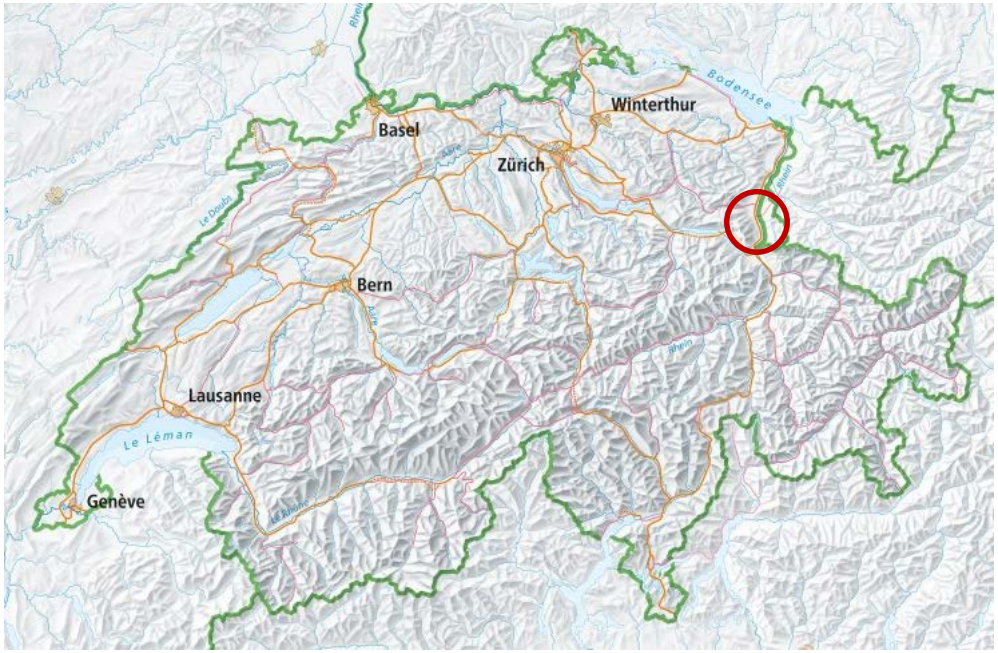
Alpine Rhine River

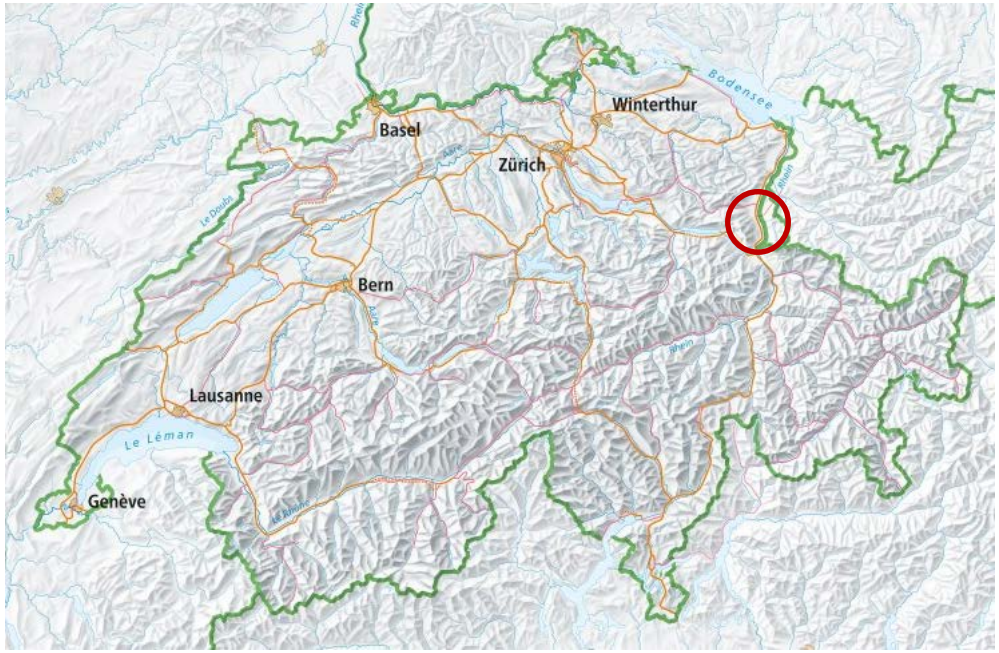
Switzerland



- heavily channelized in the 19th and 20th centuries
- flood protection measures

Alpine Rhine River

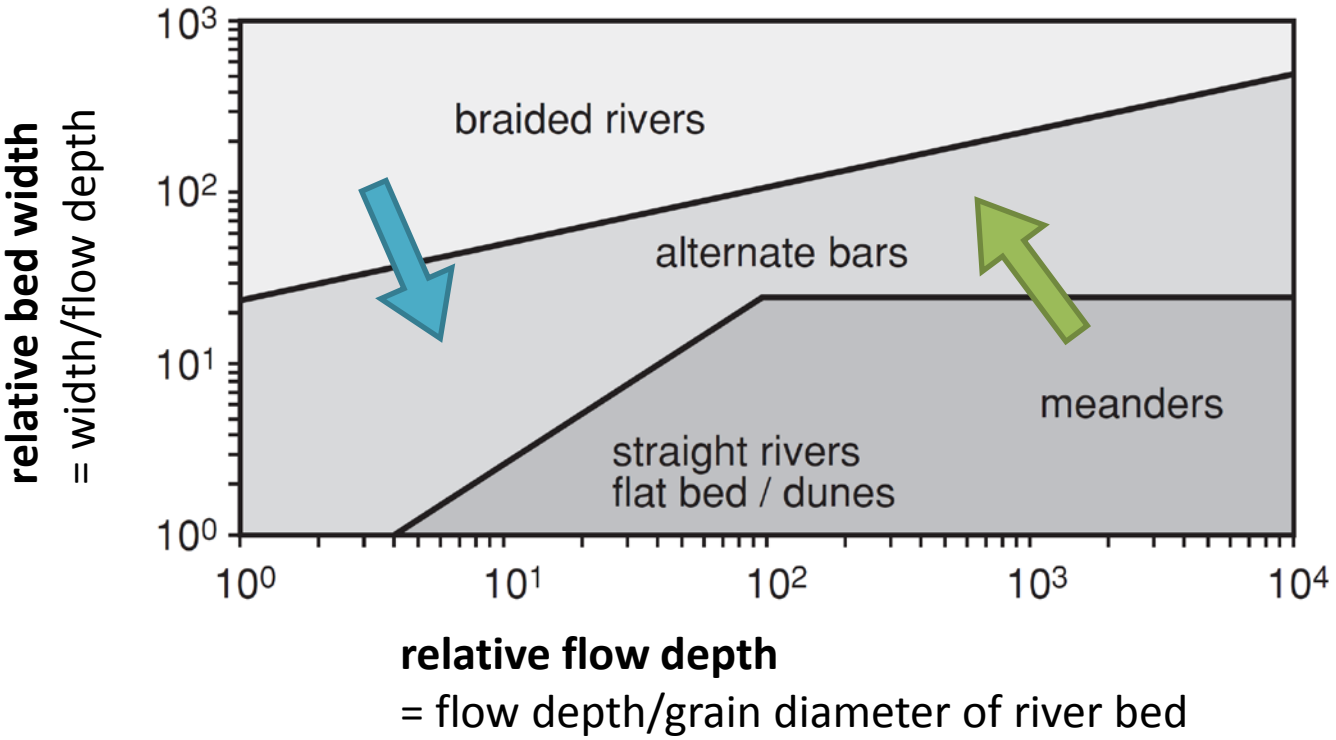
Switzerland



alternate bars →

Alternate bars

- appears under specific conditions



river channelization

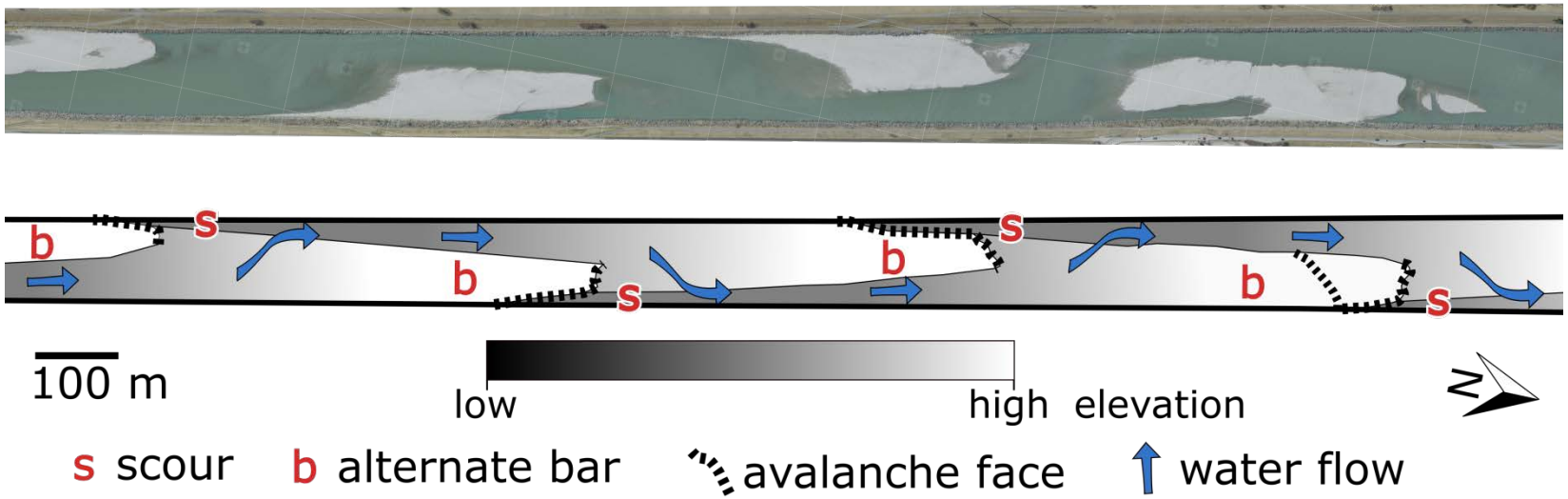
river revitalization

Marti and Bezzola (2009), after da Silva (1991)

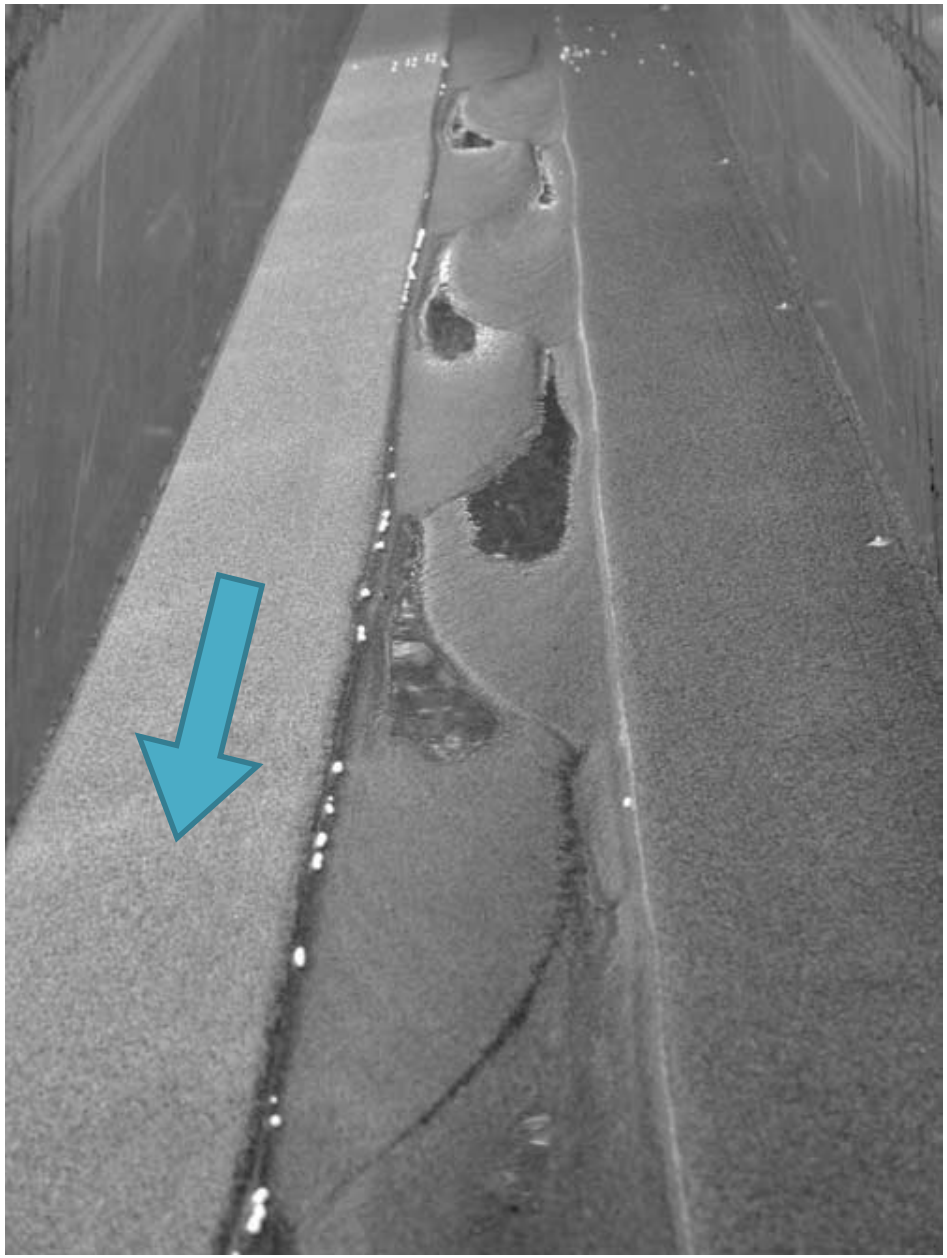
Alternate bars

- appears under specific conditions
- associated with **scours** (pool)

Alpine Rhine River at low discharge



Alternate bars



associated with **scours** (pool)

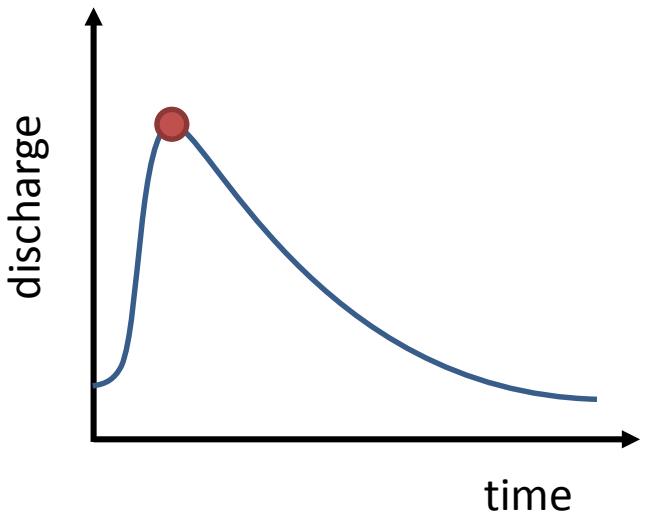
← laboratory experiment

Bertoldi and Tubino (2009)

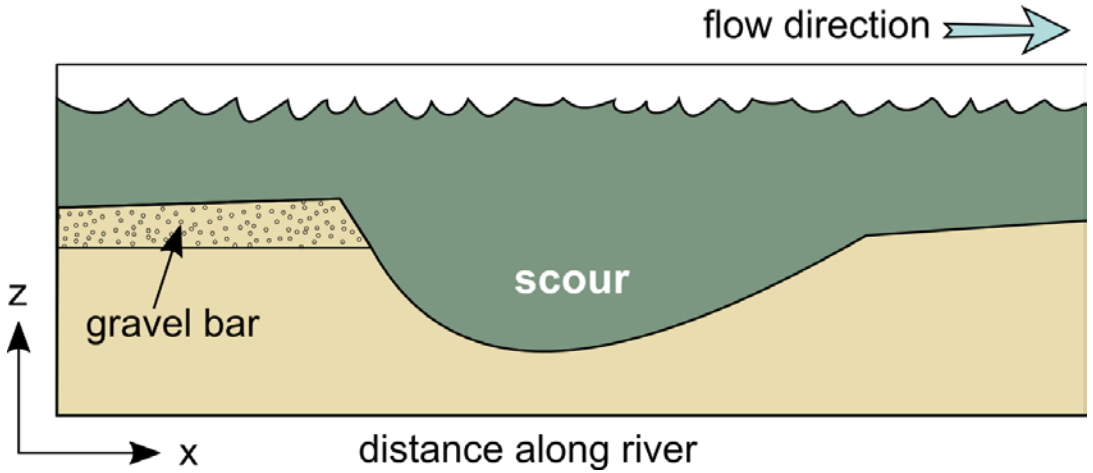
Scours

scour formation (working hypothesis)

hydrograph



longitudinal section



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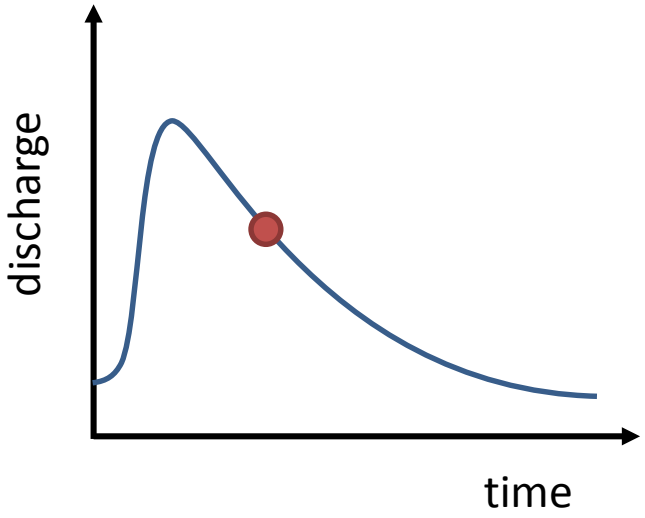

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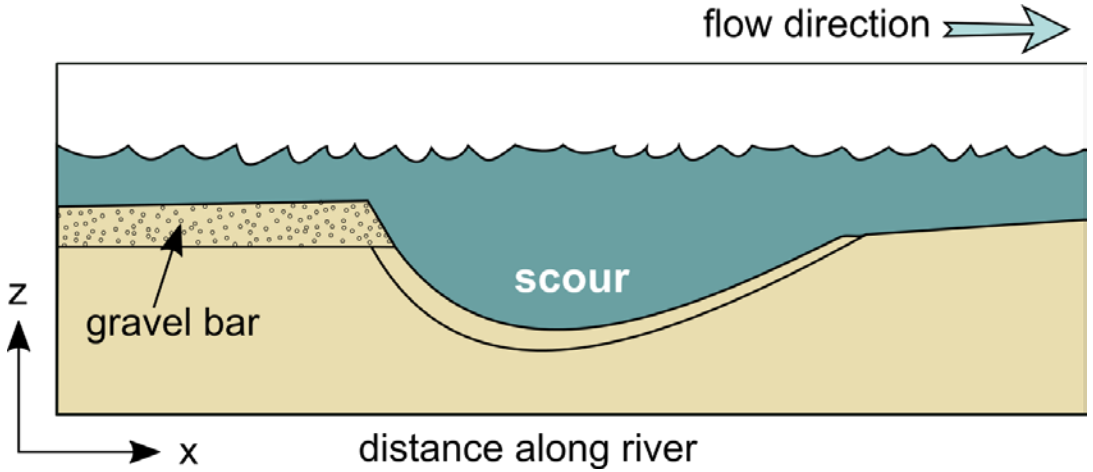

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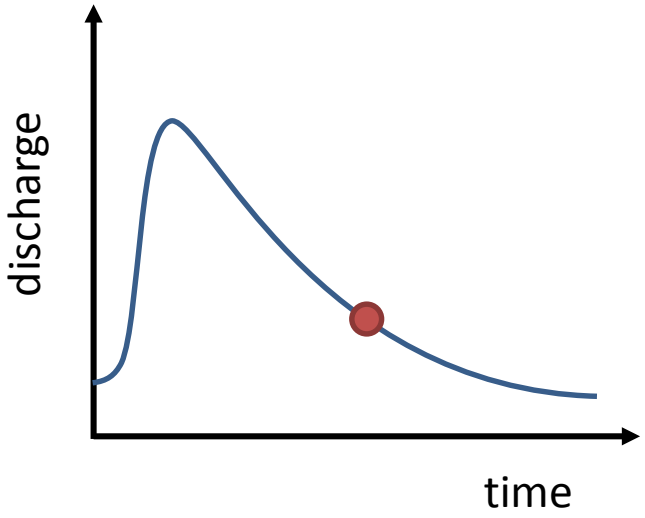

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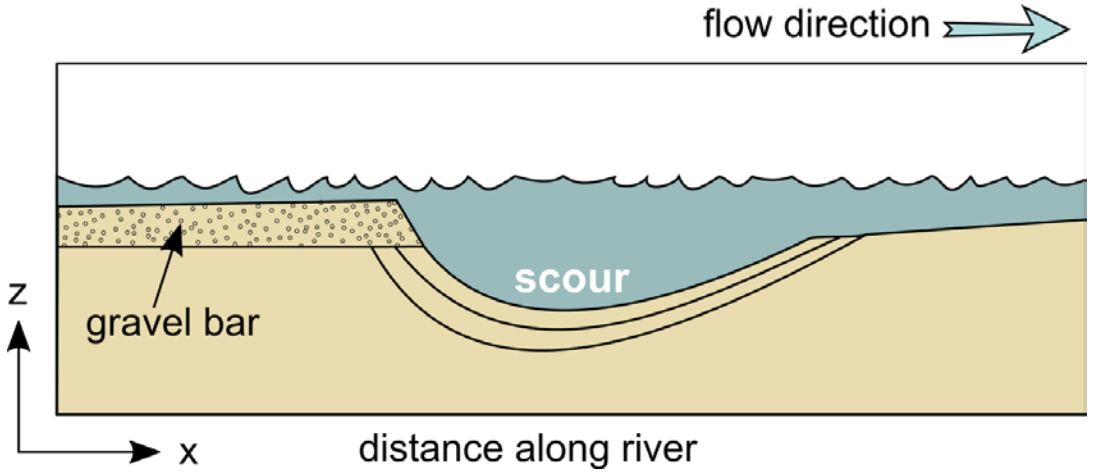

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scour formation (working hypothesis)

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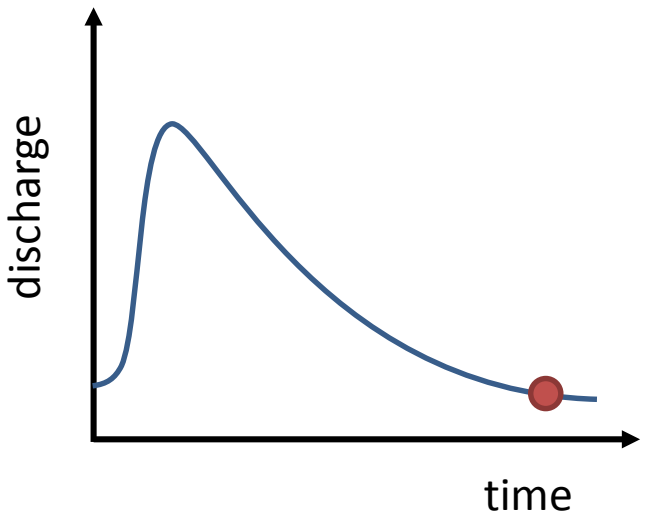

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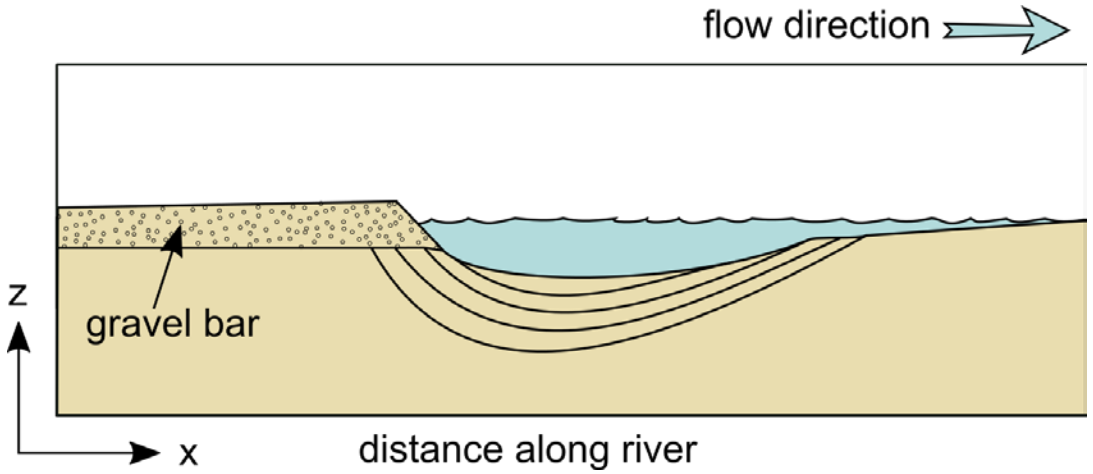

Scours

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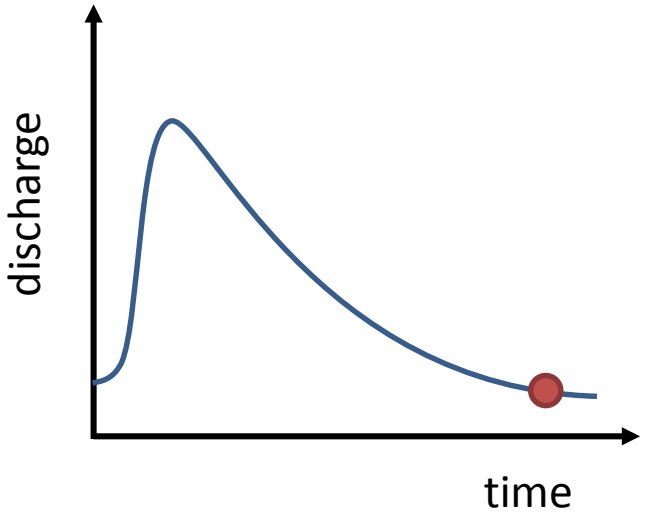

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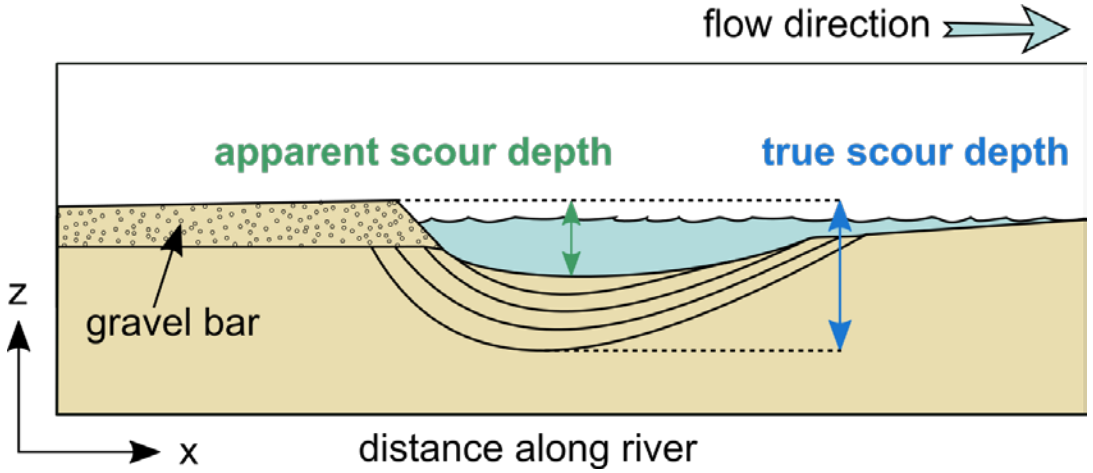


- bathymetric surveys may underestimate scour depth
- bar and scour migrate downstream

Scours

riverbank erosion/collapse during flood events

Alpine Rhine River, 1927

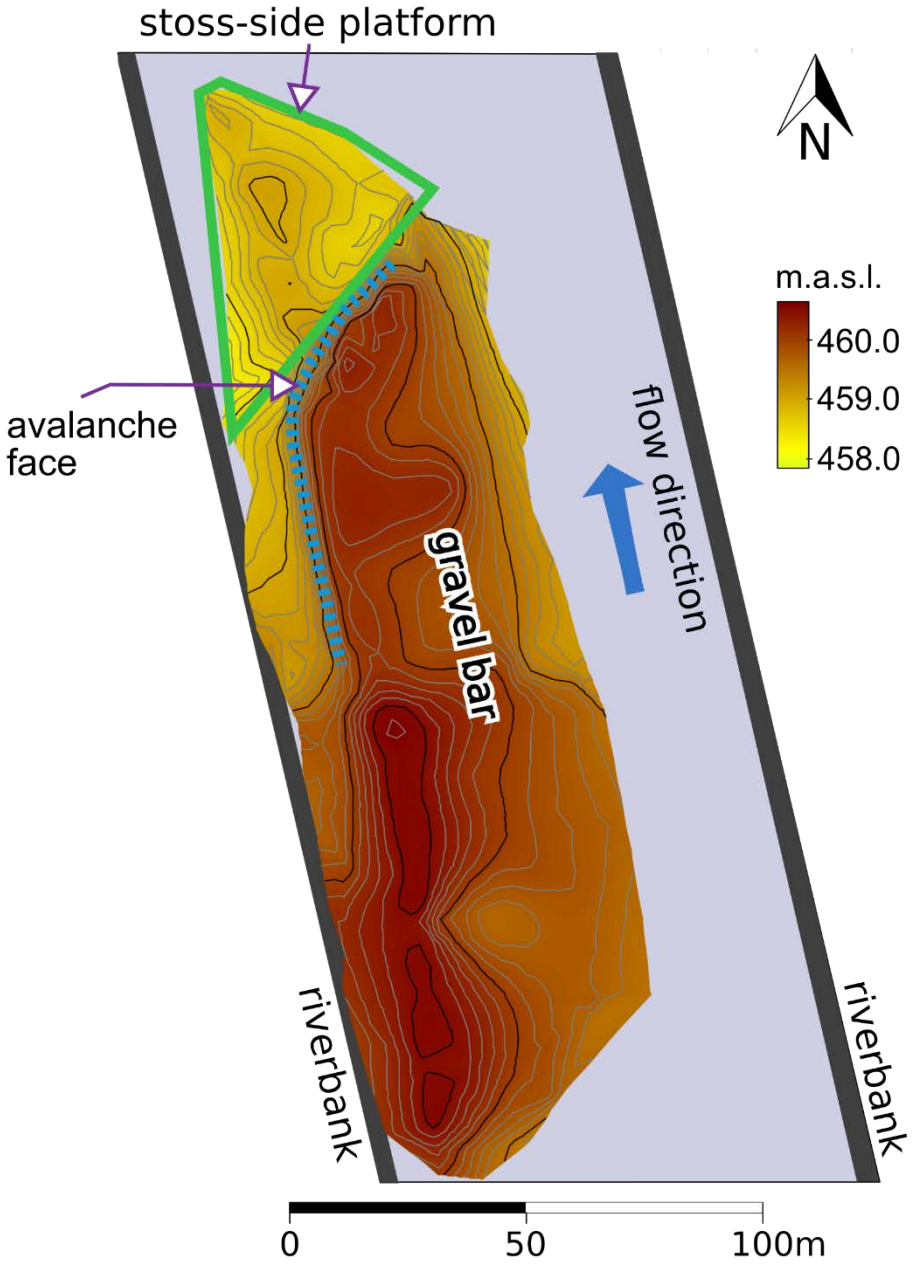
Alpine Rhine River, 1987

maximal scour depth
= critical parameter for flood embankment design

Research questions

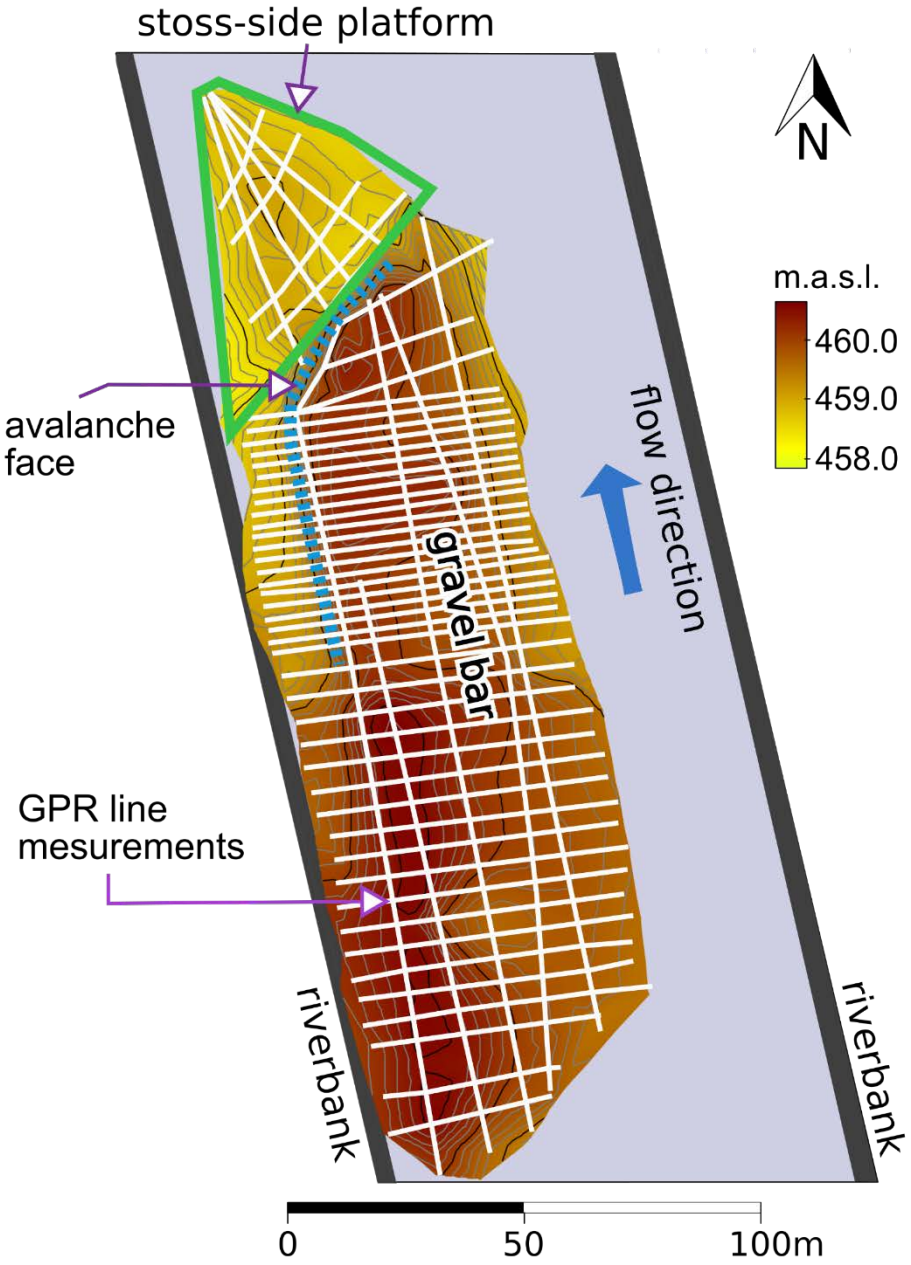
1. scour below scour?
2. scours location?
3. maximal scour depth?

Preliminary experiment



- topographic survey (Total Station)

Preliminary experiment



- topographic survey (Total Station)
- GPR survey (100 MHz antennas, PulseEkko Pro)
- CMP

Processing & Interpretation

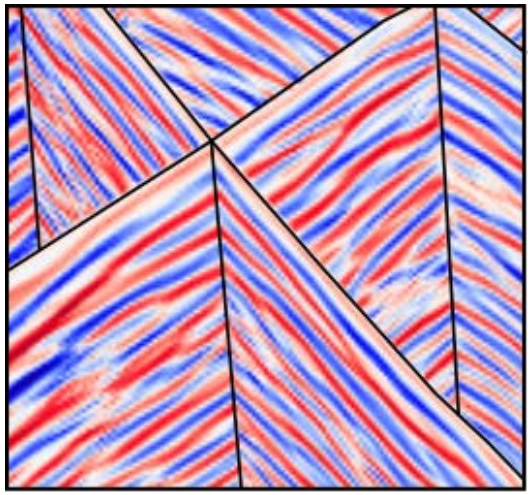
- GPR processing

TABLE I. GPR PROCESSING STEPS

Processing step	Description/literature
DC-shift removal	Remove constant amplitude shift.
First-breaks picking and time-zero adjustment	E.g., [16].
Constant offset correction	Compensate for the 1-m-offset between transmitter and receiver antennae (the acquisition time of the traces is converted into the corresponding acquisition time for a mono-static antenna GPR).
Low-frequency trend removal (dewow)	Low-frequency trend estimated with a Hampel filter (e.g., [17]).
Band-pass frequency filtering	Remove the low and high noisy frequencies (corner frequencies: 5, 25, 150, 250 MHz).
Spherical and exponential amplitude corrections	Compensate for geometric spreading and attenuation of the GPR signal (e.g., [18-19]).
2D median filtering	Applied over a 3-by-3 neighborhood to remove high-frequency noise.
Topographic Kirchhoff migration	Topographic Kirchhoff migration [20-21] with constant GPR wave velocity (0.1 m/ns) that leads to results that are accurate enough for the purpose of the study.
Automatic Gain Control	Adaptative amplitude correction (e.g., [22]).

Processing & Interpretation

- GPR processing
- interpretation
  - continuity of the dominant reflections



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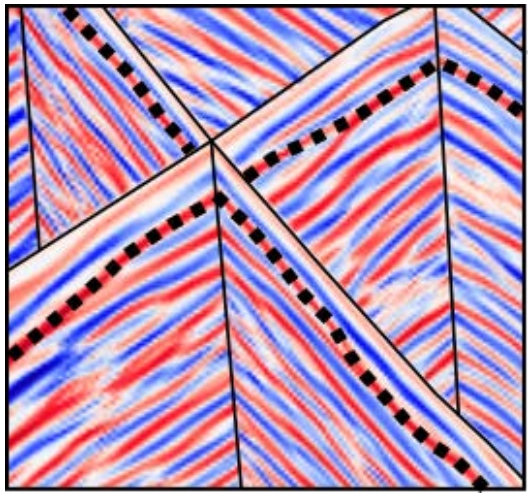
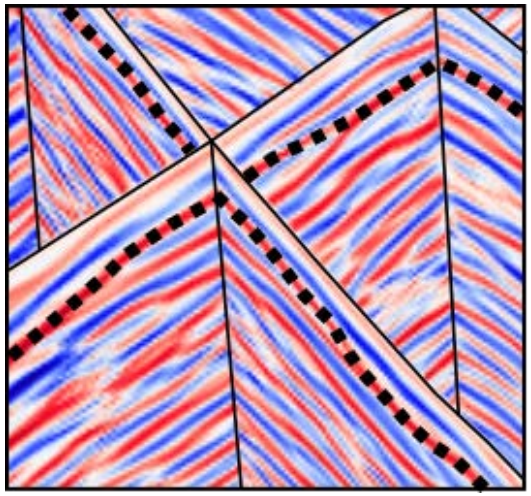
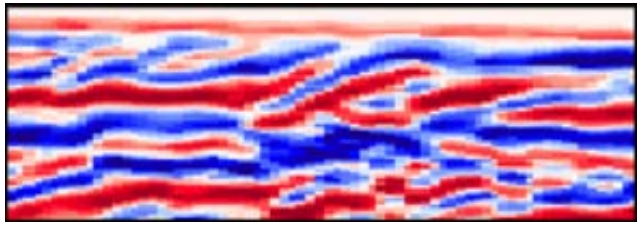


Processing & Interpretation

- GPR processing
- interpretation
  - continuity of the dominant reflections
  - angular unconformity





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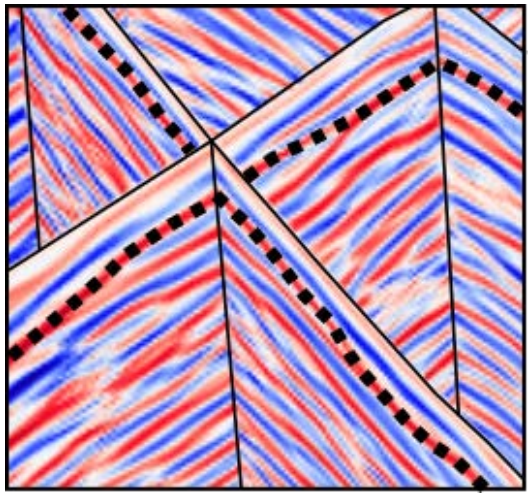

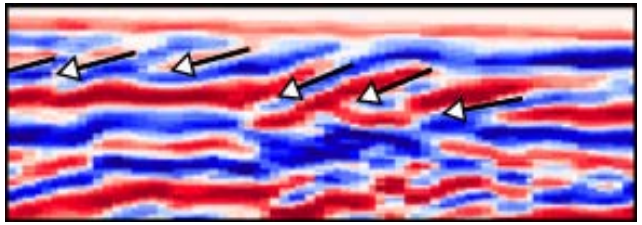

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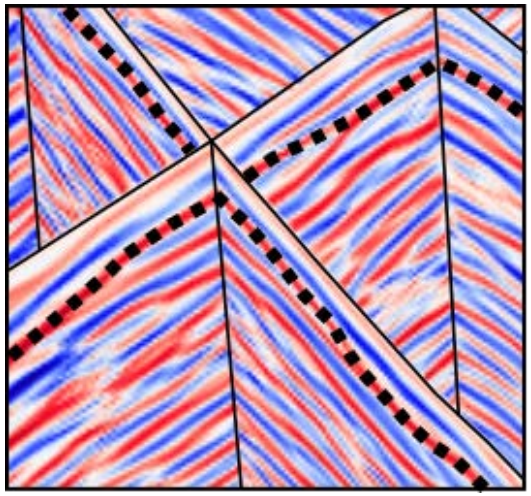
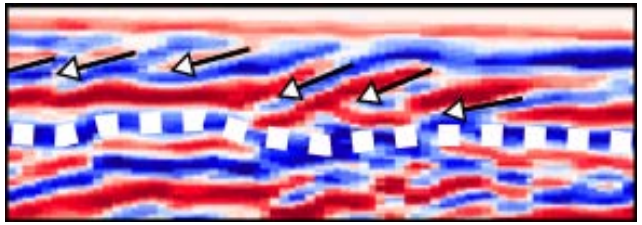
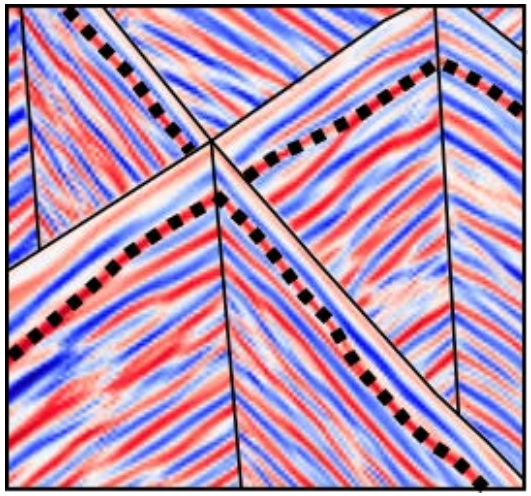
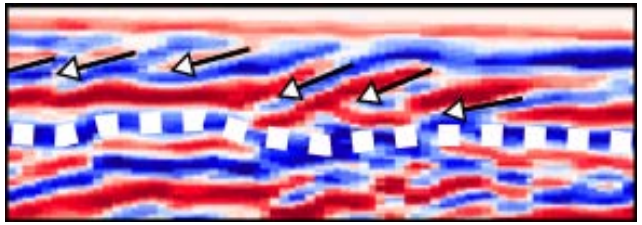




Processing & Interpretation

- GPR processing
- interpretation
  - continuity of the dominant reflections
  - angular unconformity
  - only non-ambiguous structures

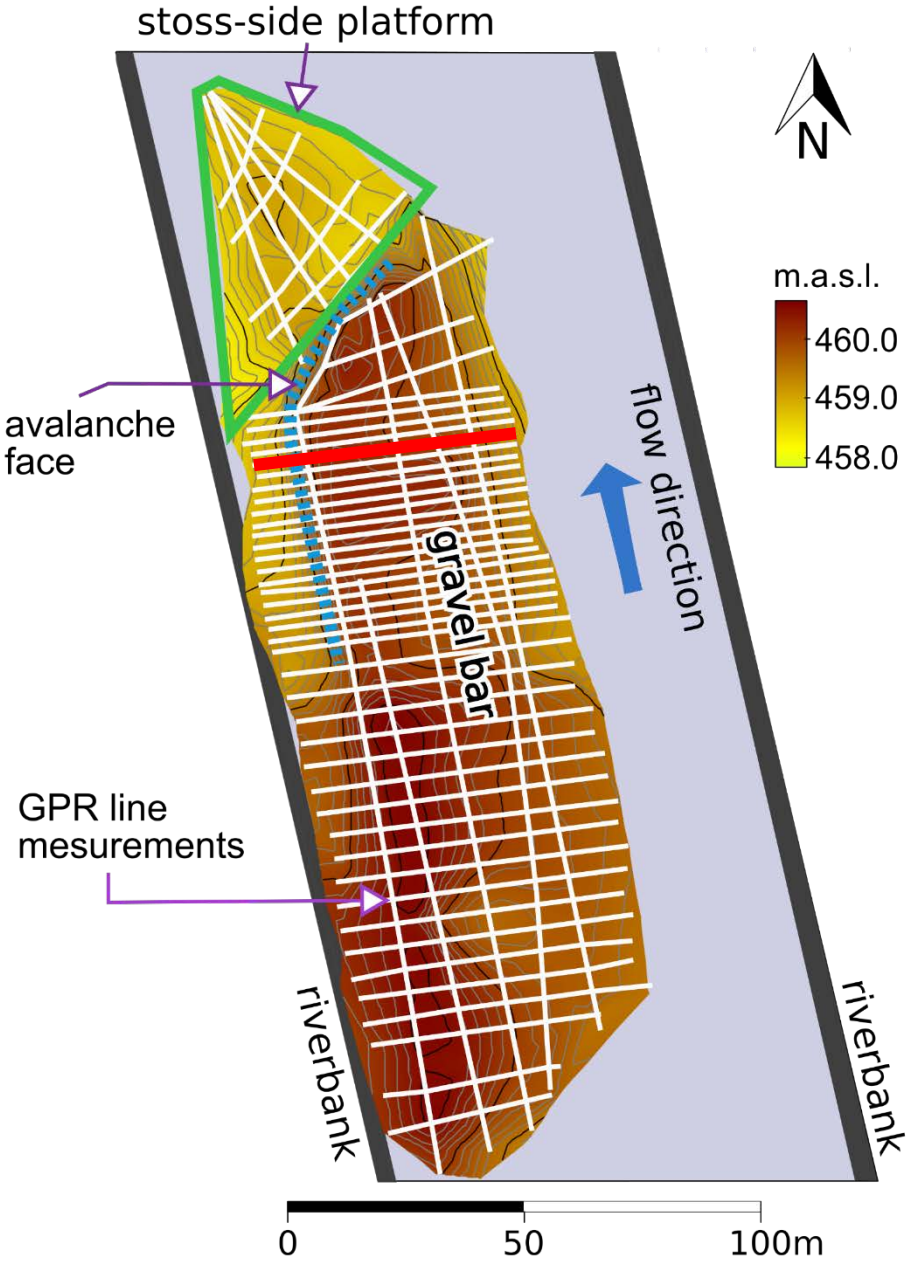




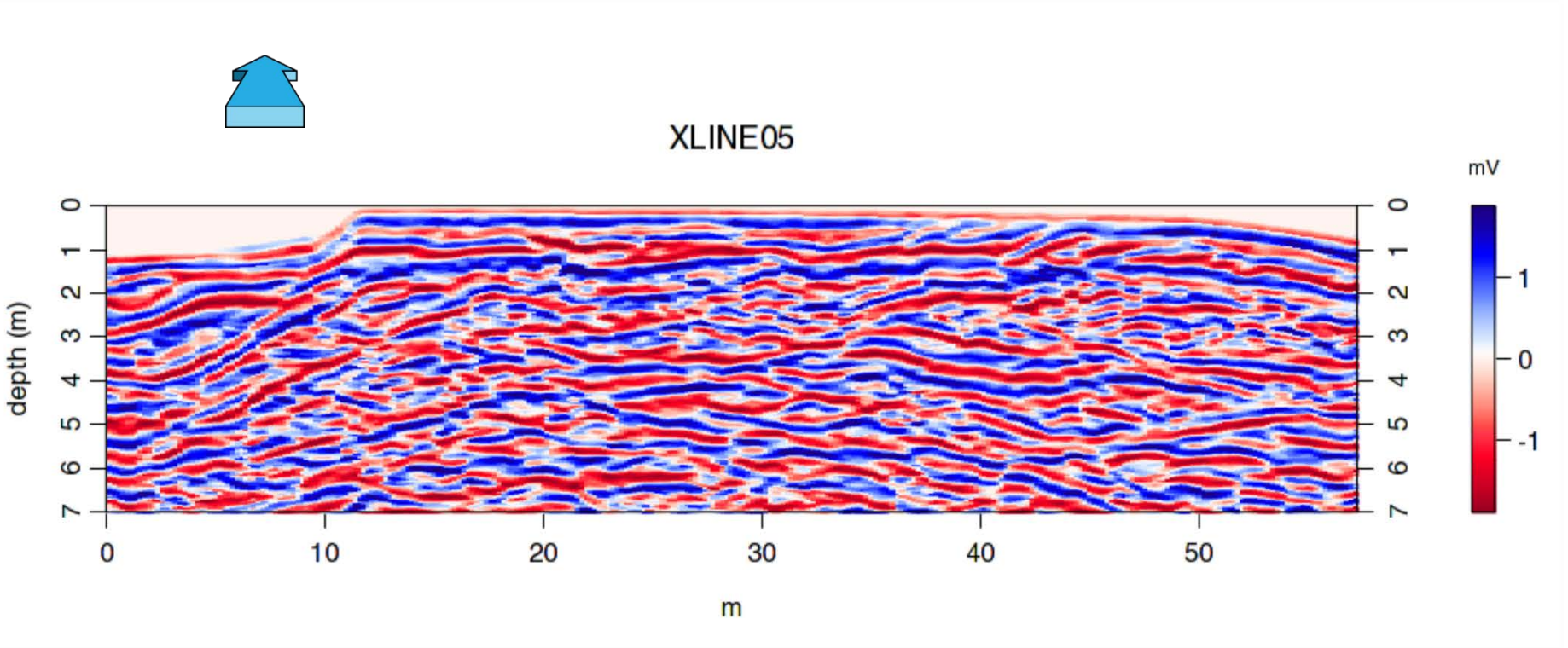
Processing & Interpretation

- GPR processing
- interpretation
  - continuity of the dominant reflections
  - angular unconformity
  - only non-ambiguous structures
- surface interpolation in GOCAD

Results - bar


stoss-side platform
N
m.a.s.l.
460.0
459.0
458.0
avalanche face
flow direction
gravel bar
GPR line mesurements
riverbank
riverbank
0
50
100m

Results - bar



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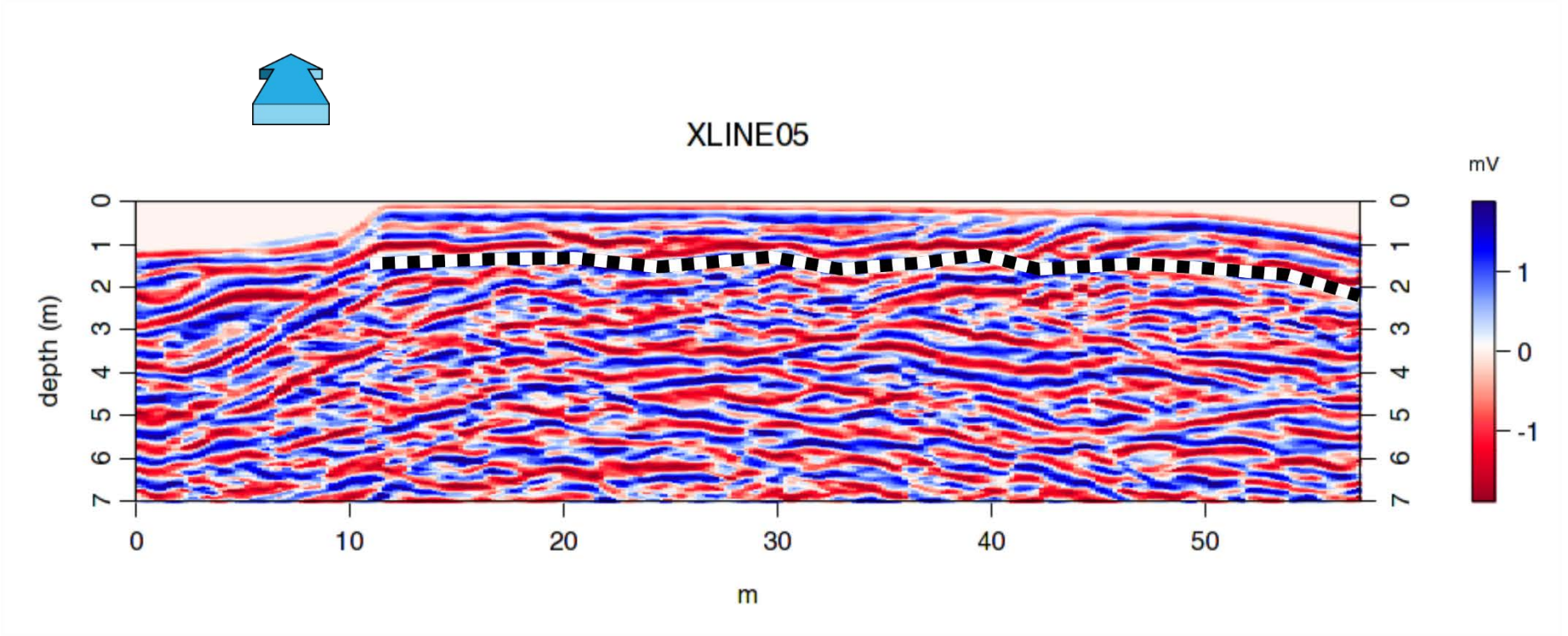

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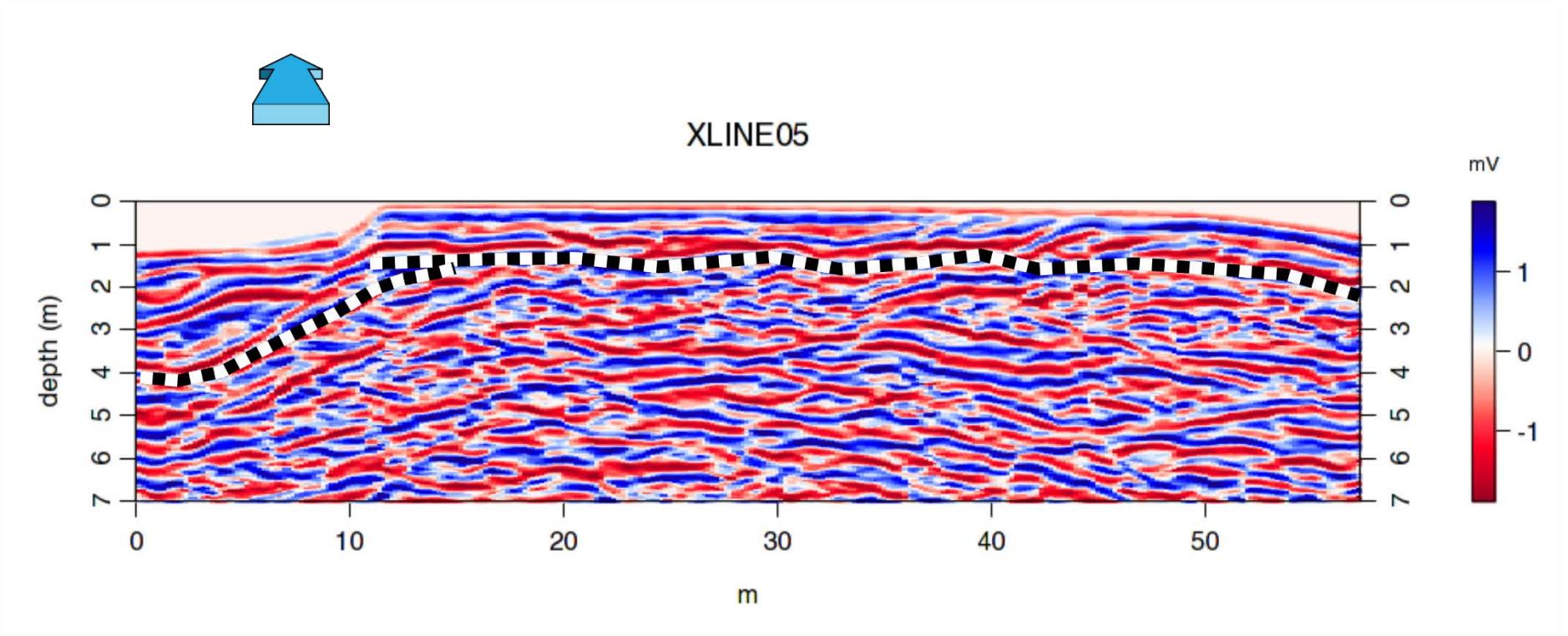

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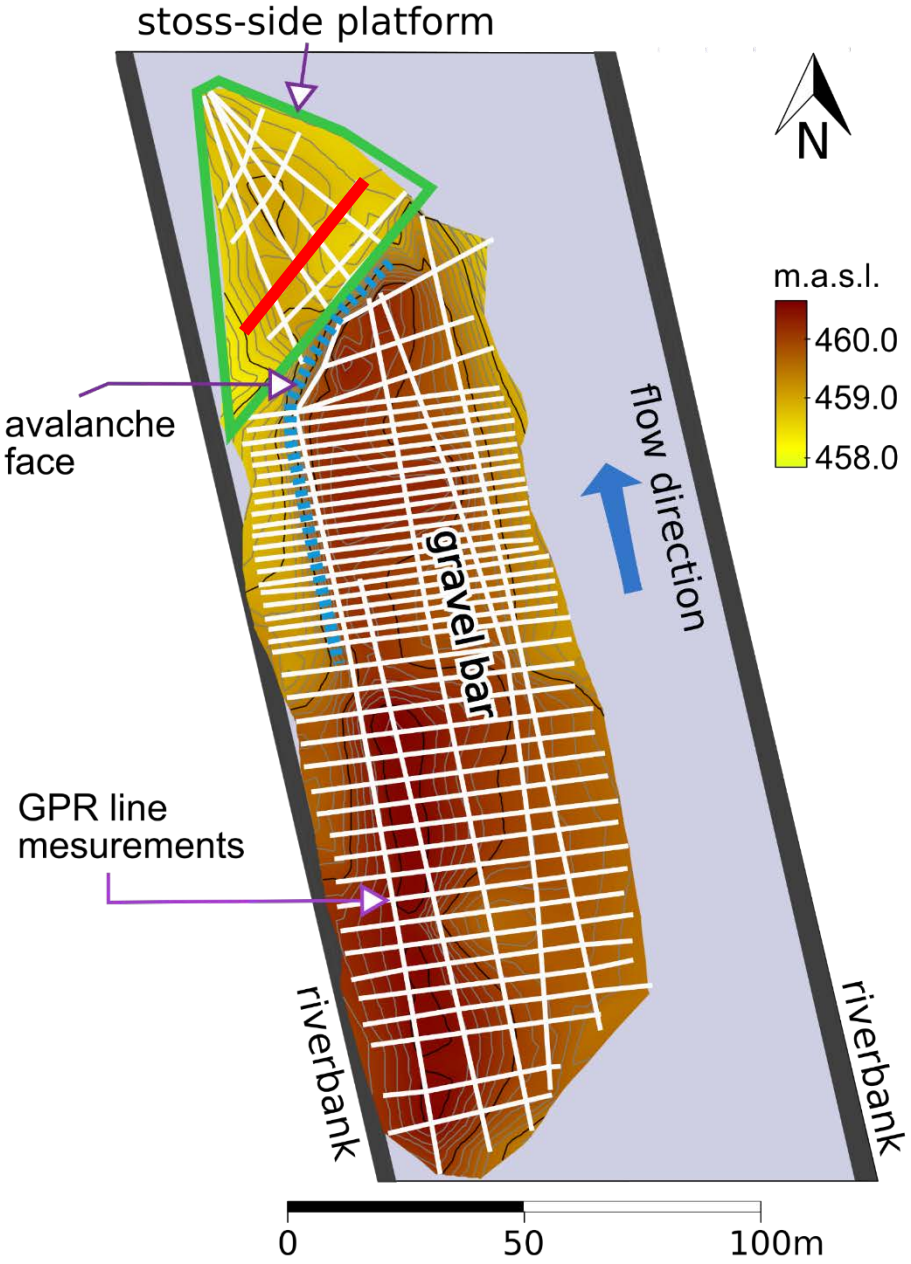
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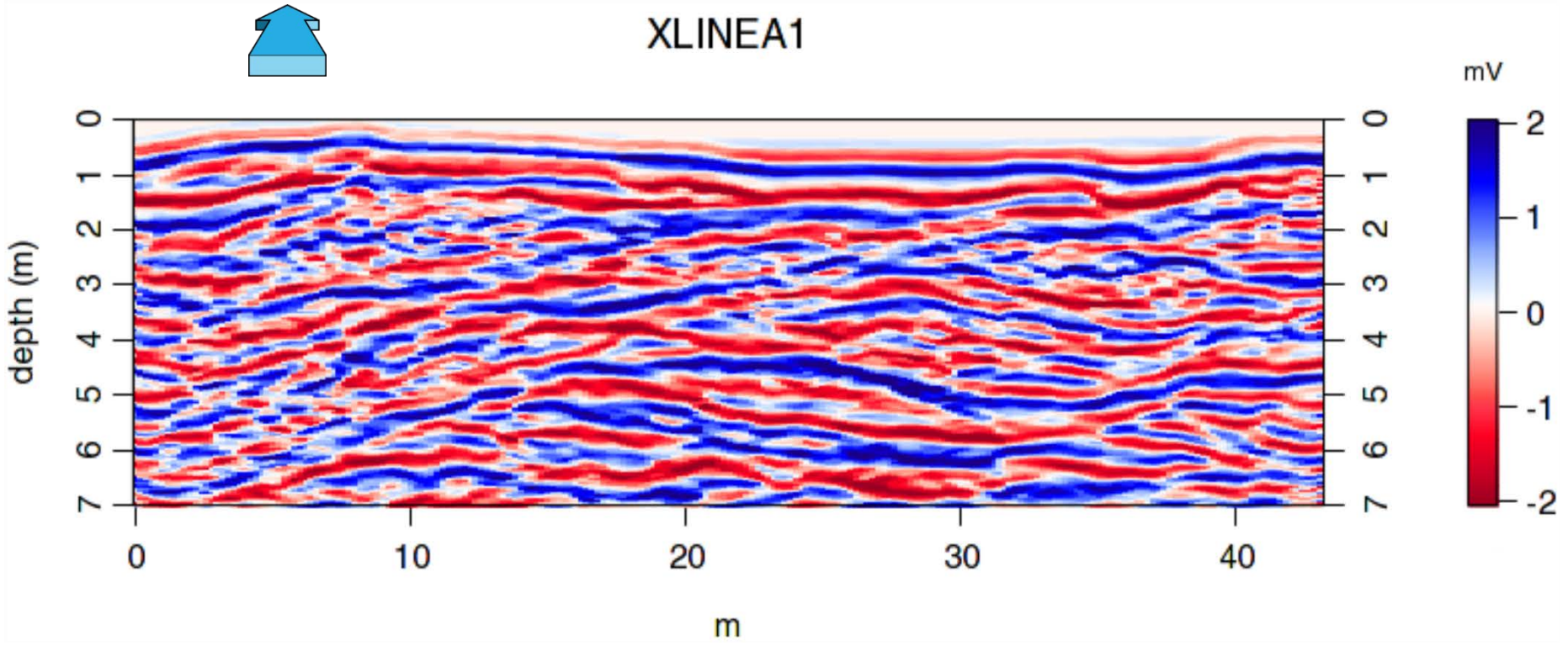
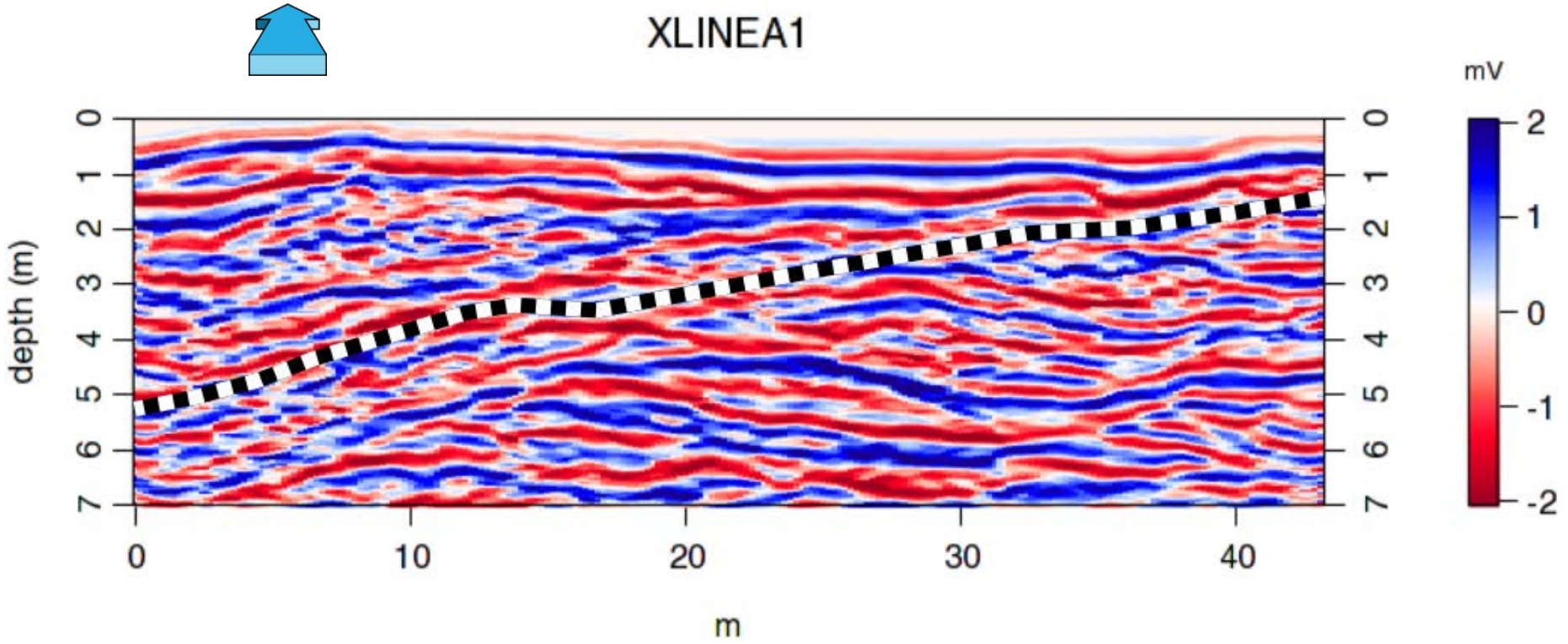
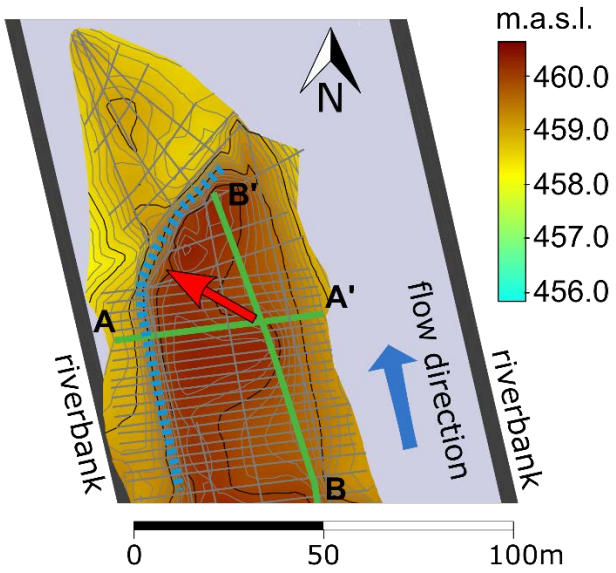


Results - bar



Results - bar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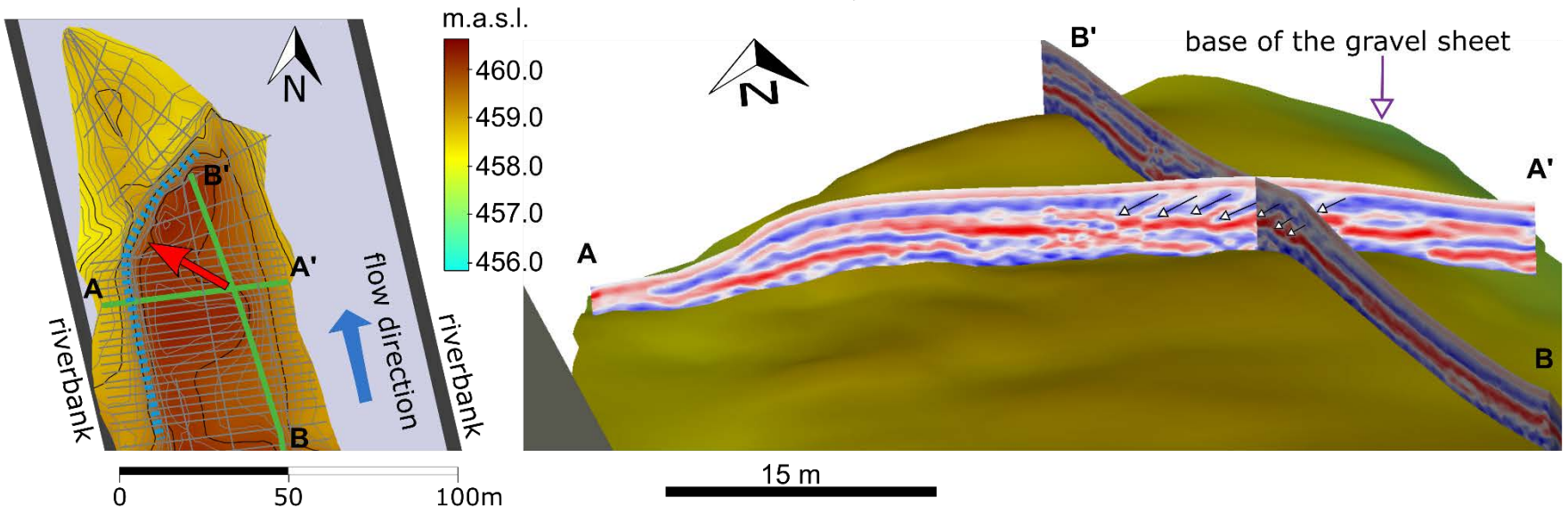
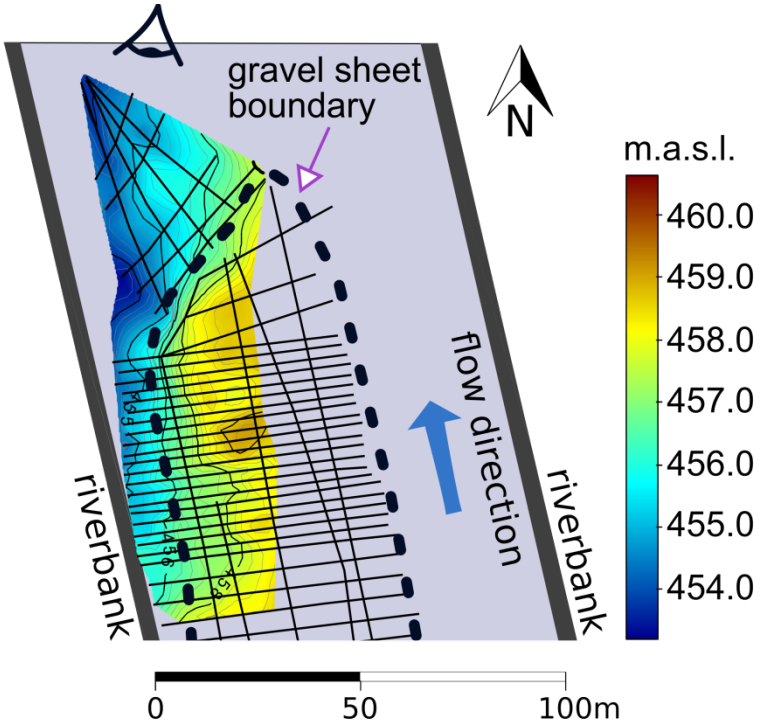
Results - bar



- up to 2 m thick
- foreset → migration direction
- base = armour layer
- two superimposed bar?

Results - scour



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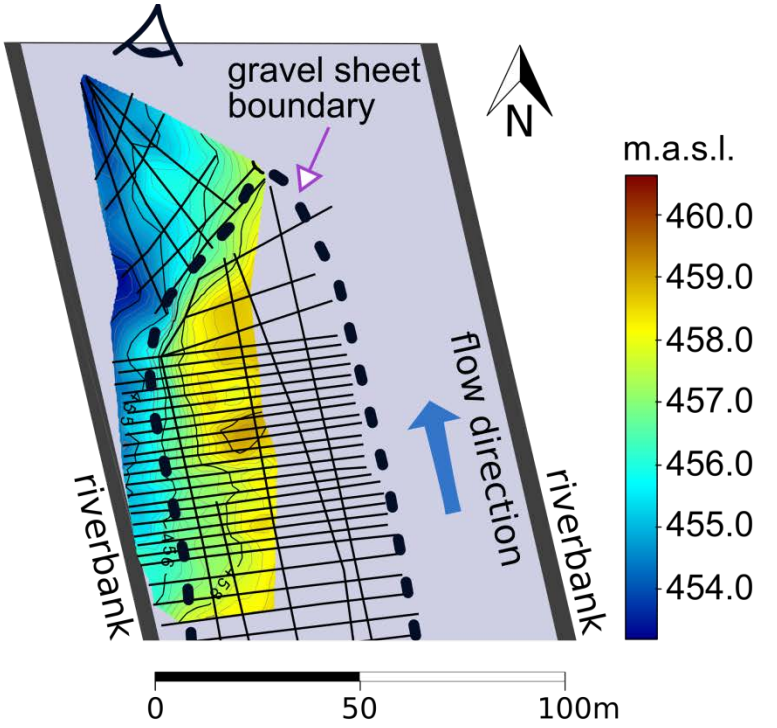

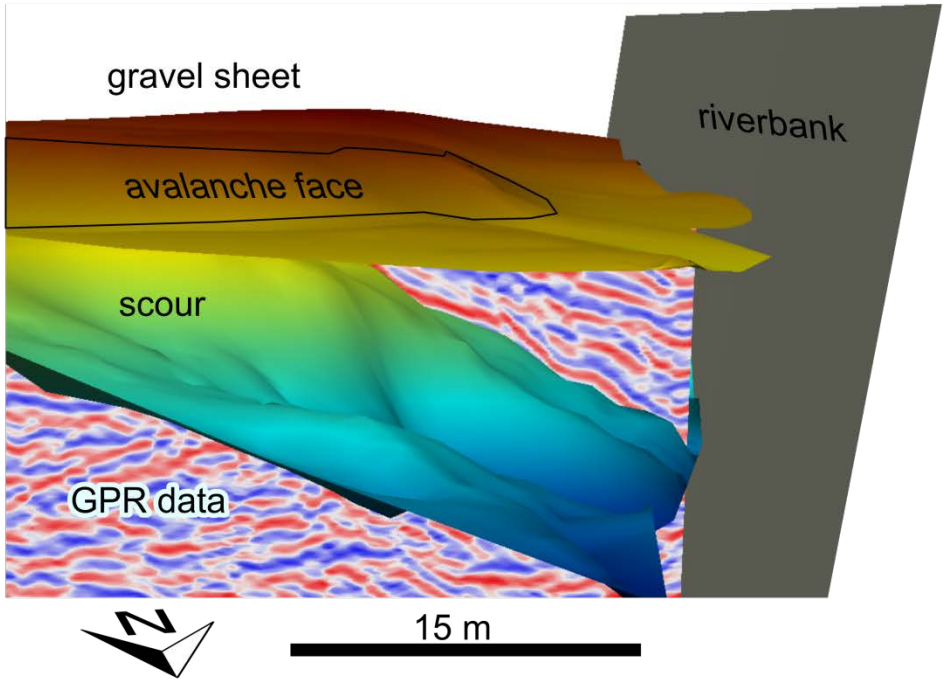

- partially imaged (100 m × 30 m × 4.5 m)
- river bed elevation difference = 7.5 m
  (vs. 2.5 – 4 m from bathymetric surveys)
- erosion surface starts 10 – 15 m upstream the bar
- oinon-like internal structure

Conclusion

- do ″less″ to get more
- surface morphology vs. sedimentology
- scour partially imaged
- scour depth > 4.5 m

- Future research:
  - full imaging (GPR bathymetry)
  - statistical significance
  - capture the dynamics of scour formation (link discharge – scour size)
  - impact scour on subsurface flow and biology

Literature

Bertoldi, W., and M. Tubino (2005), Bed and bank evolution of bifurcating channels, Water Resour. Res., 41, W07001, doi:10.1029/2004WR003333

Marti, C. and Bezzola, G. R. (2009). Braided Gravel-Bed Rivers with a Limited Width: Preliminary Results of a Hydraulic Model Study. In Fluvial Sedimentology VII (eds I. Jarvis, M. D. Blum, S. B. Marriott and S. F. Leclair). doi:10.1002/9781444304350.ch8