Evaluating the effect of variable lithologies on rates of knickpoint migration in the Wutach catchment, southern Germany

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Key points

- We present a modelling approach that aims to estimate the SPIM-parameter K for variable lithologies by comparison of simulated (LEM-based) and actual stream profiles.
- The approach is tested for a catchment with a well-constrained incision history (the Wutach catchment, southern Germany), by use of an existing geological 3D-model.
- First results indicate threefold variation in K between different lithological units as well as possible effects by deglaciation, which may be revised with further refinement of the analysis.

SPIM: Stream Power Incision Model
K: Bulk parameter of erosional efficiency, largely determined by bedrock erodibility
LEM: (Numerical) landscape evolution model

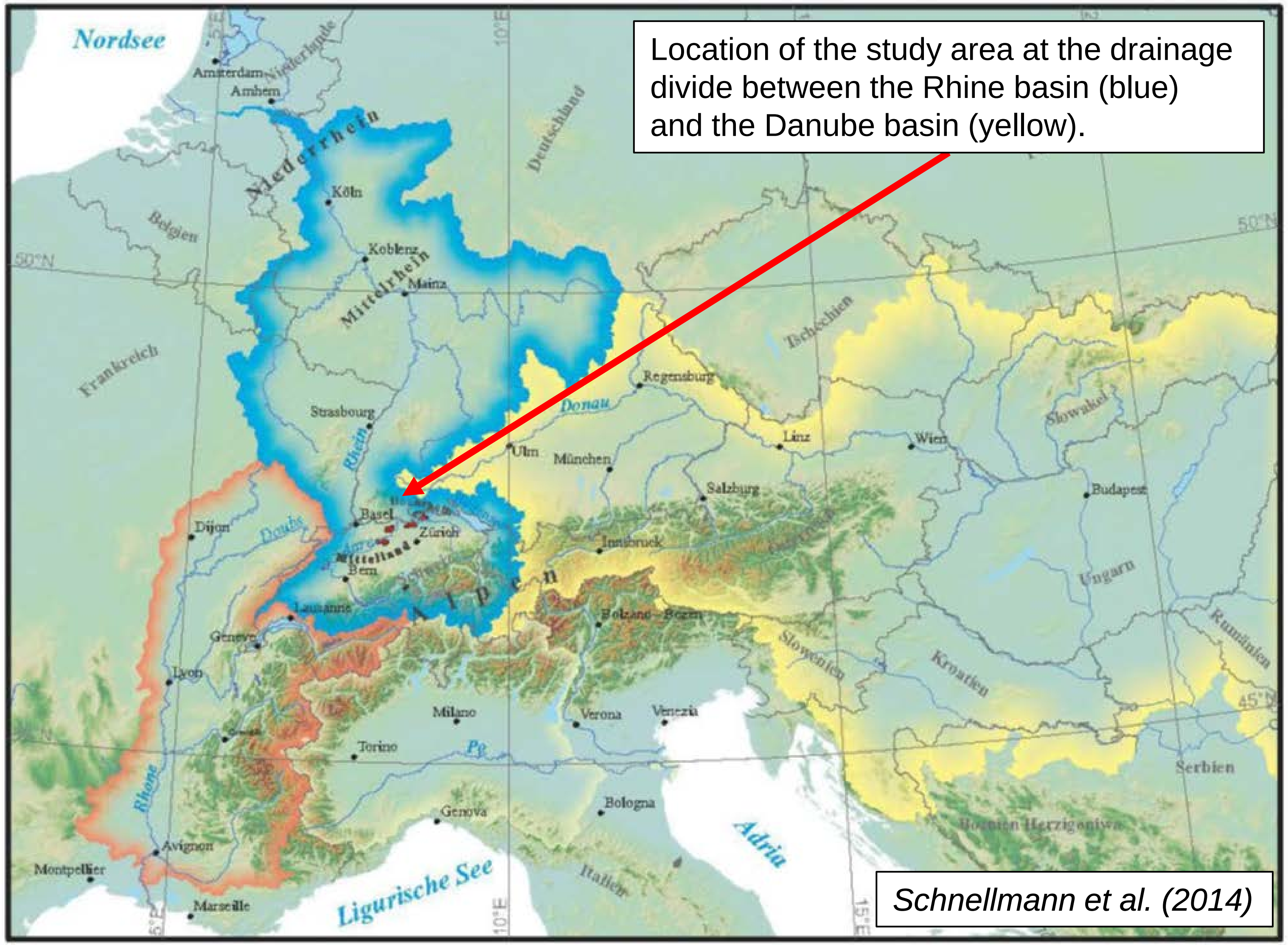
Motivation

- The topographic evolution of landscapes strongly depends on the **resistance of bedrock** to erosion.
- Detachment-limited fluvial landscapes are commonly analyzed and modelled with the **stream power incision model** (SPIM; e.g. Howard & Kerby 1983).
- SPIM parametrizes **erosional efficiency** by the **bulk parameter K** whose value is largely determined by bedrock erodibility.
- K is often poorly constrained and difficult to relate to field or laboratory data.
- Here, we present a numerical modelling approach to resolve values of K for different lithological units, in a catchment with a well-constrained incision history (Wutach catchment).

Study area

- The Wutach (southern Germany) is a prominent example of **river piracy** that occurred **~ 18 ka ago** as response to headward erosion of a tributary to the Rhine at the expense of the Danube basin *(Einsele & Ricken 1995)*.

- Large elevation difference between the local base levels of the Danube and Rhine basins resulted in strong landscape response.



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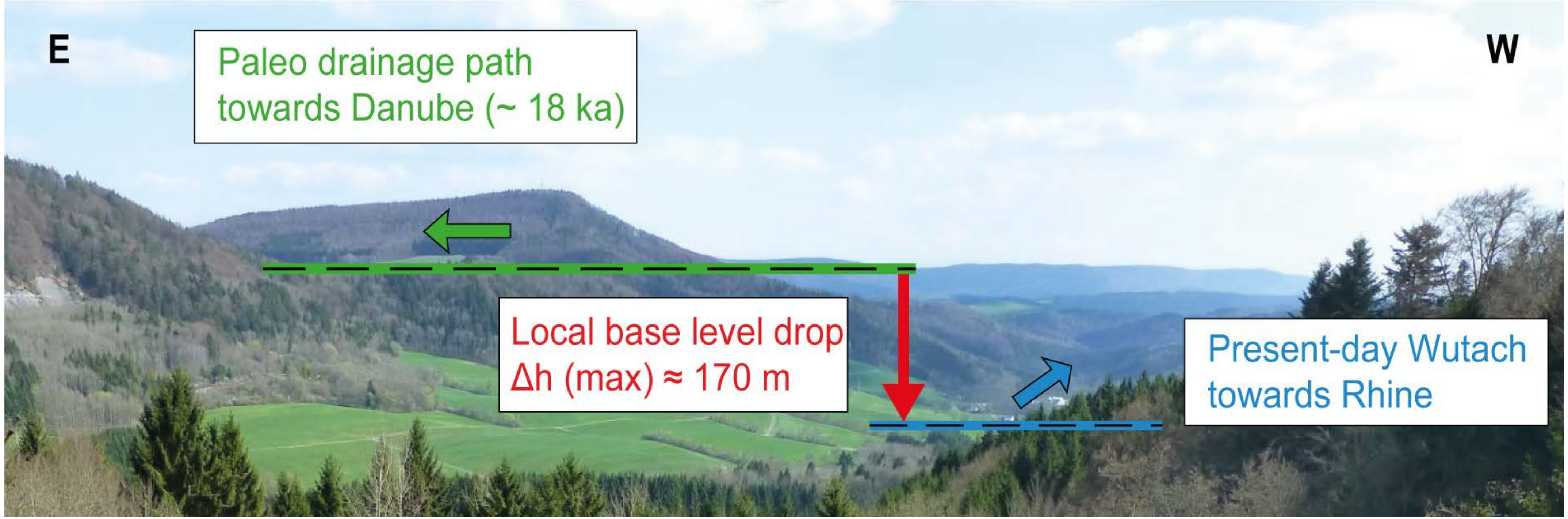
Study area / landscape response

- **Local base level drop of up to 170 m** following the capture event **~18 ka** triggered a wave of upstream migrating knickpoints along the Wutach main trunk stream and its tributaries, that represent markers for the transient response of the landscape.

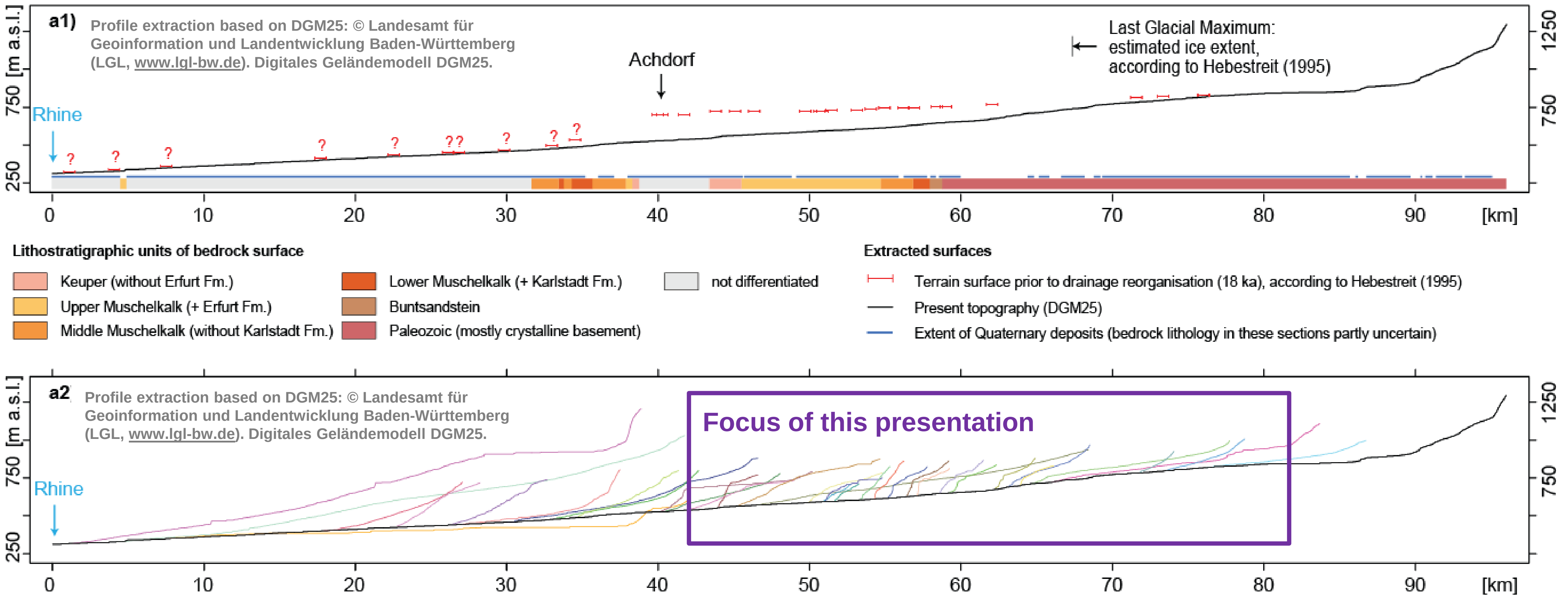


Present-day landscape at the location of the former stream capture (village of Achdorf).

Study area / landscape response

- Local base level drop of up to 170 m following the capture event ~18 ka triggered a wave of **upstream migrating knickpoints along the Wutach main trunk stream and its tributaries**, that represent markers for the transient response of the landscape.

Longitudinal profile Wutach trunk stream (vertical axis x 10): a1) stream profile with bedrock lithology and former terrain surface; a2) stream profile with tributary streams



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Data and methods

1. Observations

- Onset of incision (following stream capture) at ~ 18 ka
- Spatially variable lithology
- Spatially variable incision along main trunk stream and tributaries

2. Data

- Digital elevation model of Baden-Württemberg DHM25, 25m resolution (LGL 2010)
- Geological 3D-model ISONG Baden-Württemberg (LGRB 2015)

3. Initial conditions

- PaleoDEM reconstruction
- Lithostratigraphical reconstruction with three main erodilibity classes (EC)

4. Landscape Evolution Model (LEM)

- Modified version of TTLEM (TopoToolbox Landscape Evolution Model) (Campforts et al. 2017)
- Incorporates variable lithologies

5. Optimization of lithology-dependent K values

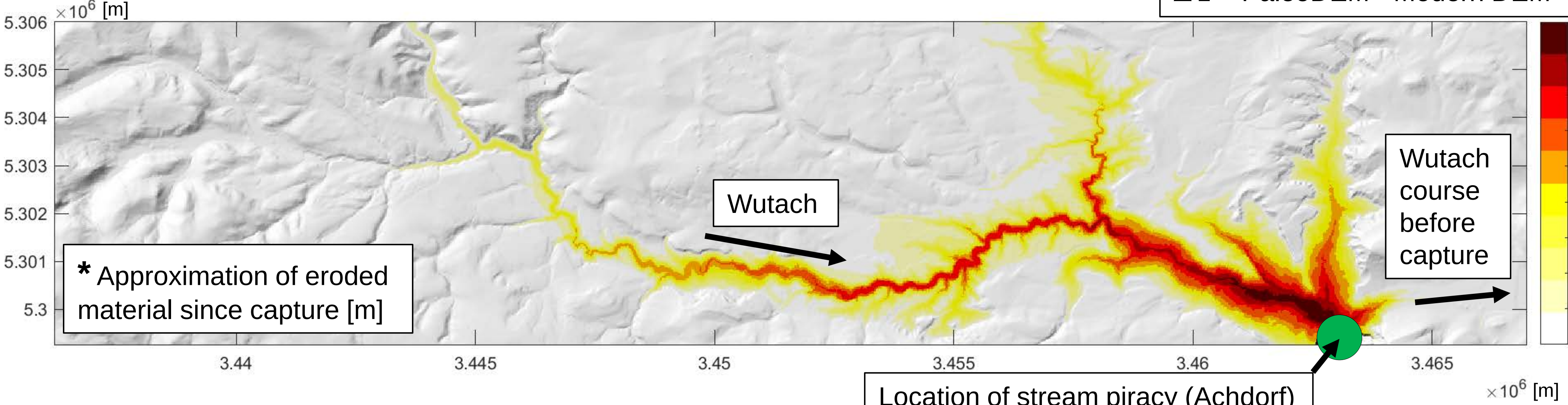
- Comparison of simulated and actual topography
- Surrogate optimization (global optimization for expensive problems)

Reconstruction of initial conditions for LEM

PaleoDEM (1)

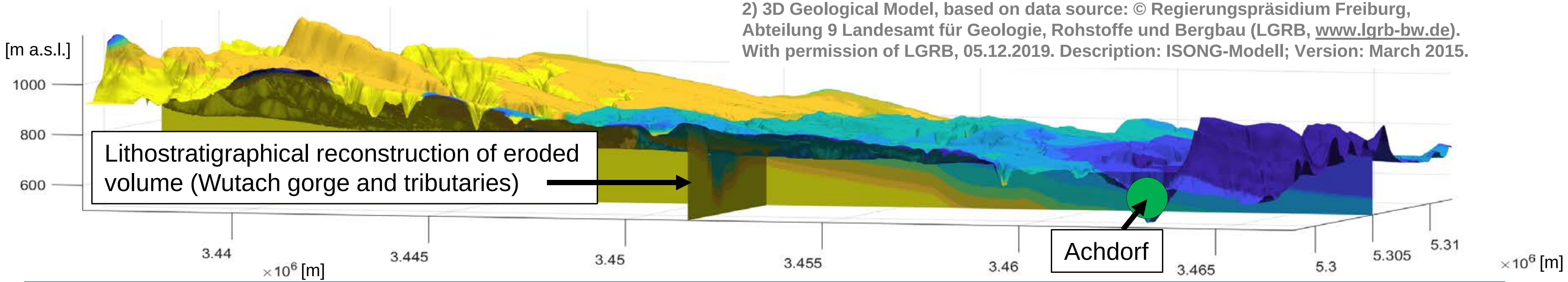
1) Digital Elevation Model, based on data source:
© Landesamt für Geoinformation und Landentwicklung Baden-Württemberg (LGL, www.lgl-bw.de). Digitales Geländemodell DGM25; Purchased: March 2010.

Colour scale: elevation difference [m]:
Δz = PaleoDEM - Modern DEM *



Paleo 3D Geology (2)

2) 3D Geological Model, based on data source: © Regierungspräsidium Freiburg, Abteilung 9 Landesamt für Geologie, Rohstoffe und Bergbau (LGRB, www.lgrb-bw.de). With permission of LGRB, 05.12.2019. Description: ISONG-Modell; Version: March 2015.



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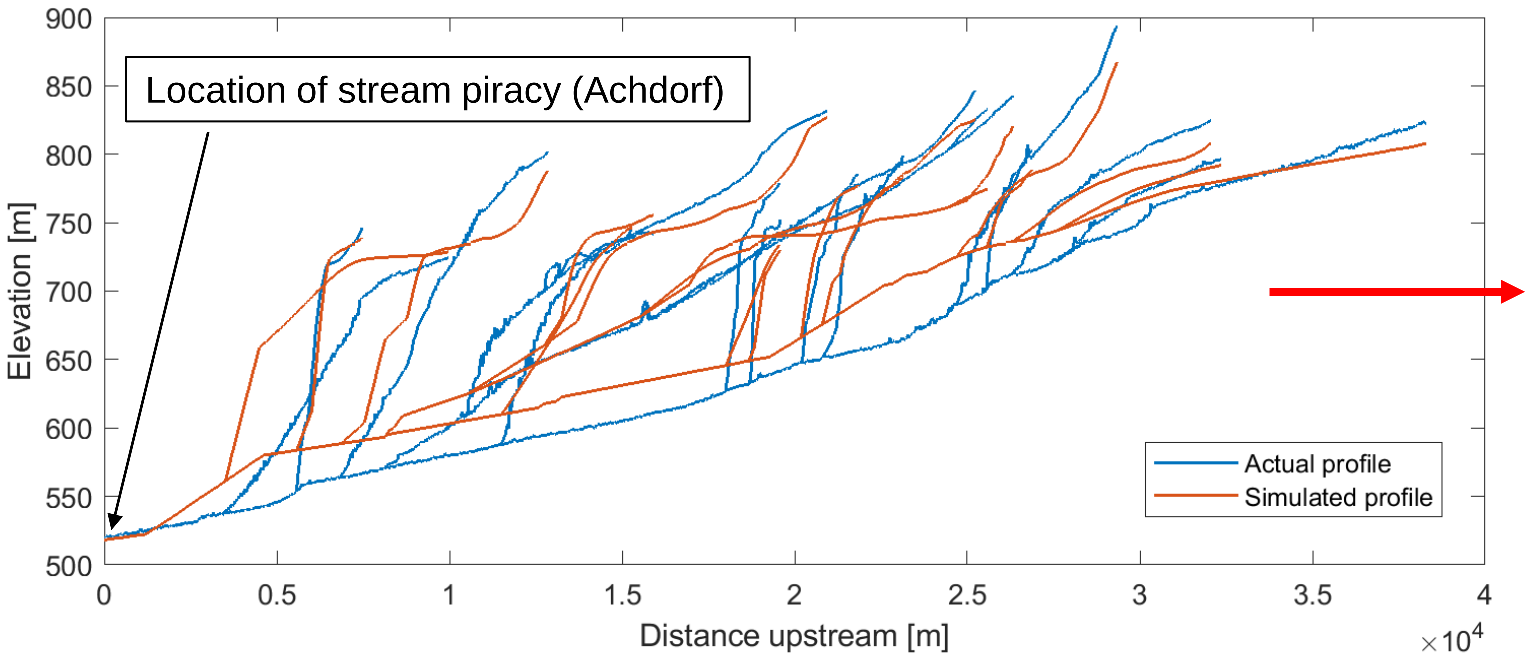
Optimization of lithology-dependent K values

- K-values for 3 main erodibility classes (EC) are optimized by comparing simulated (LEM-based) and actual profiles.
- Optimization utilizes objective function that minimizes sum of squared residuals between simulated and actual profiles.

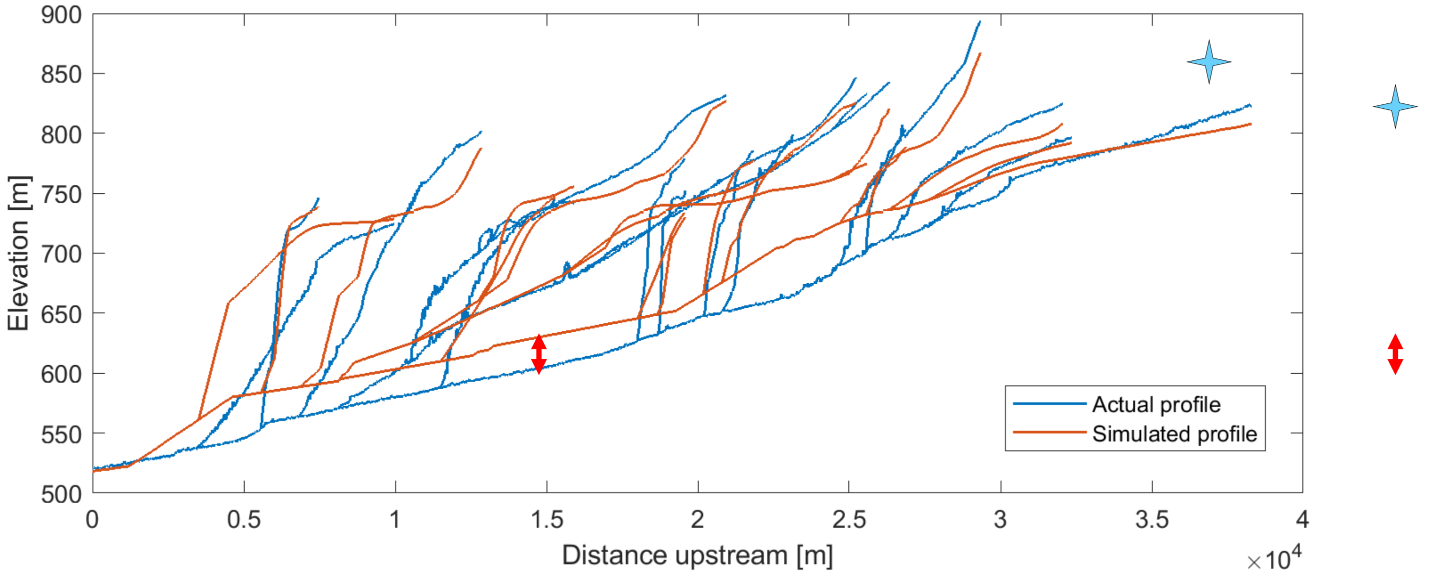


Optimization results (prelim.):

Erodibility Class	K-value (m/n = 0.5)
EC1 (e.g.claystone, marl)	1.37 10^{-4}
EC2 (e.g.sandstone, calcareous marl)	3.45 10^{-5}
EC3 (e.g.limestone, crystalline units)	4.55 10^{-5}

Discussion of preliminary results

- Preliminary results indicate threefold variation in K between different erodibility classes.
- Highest K-value, and thus erosional efficiency, is found for weak rock types of EC1. Lowest K is found for EC2, instead of EC3 (which would have been expected from field observations). This may be due to a small spatial extent of EC2, turning it more sensitive to local anomalies.
- Offset between simulated and actual profile may indicate enhanced erosional efficiency due to glacial meltwater and tool supply along the main trunk in the early phase after stream capture.



Headwater region of Wutach main trunk, glaciated at time of stream capture (as opposed to most tributaries)

Vertical offset along Wutach main trunk

Conclusion & Outlook

- We have presented a modelling approach that aims to estimate the SPIM-parameter K for variable lithologies by comparison of simulated (LEM-based) and actual stream profiles.
- The approach has been tested for a catchment with a well-constrained incision history (the Wutach catchment), by use of an existing geological 3D-model.
- First results indicate threefold variation in K between different lithological units as well as possible effects by deglaciation.
- These findings may be revised with further refinement of the analysis
  - time-variable boundary conditions
  - alternative erodibility classes

Acknowledgment

- The *Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg (LGRB)* and the *Landesamt für Geoinformation und Landentwicklung Baden-Württemberg (LGL)* are thanked for their permission to use their data as part of this presentation.

References

- Campforts, B., Schwanghart, W. & Govers, G. (2017): Accurate simulation of transient landscape evolution by eliminating numerical diffusion: the TTLEM 1.0 model. Earth Surface Dynamics 5(1), 47–66.
- Einsele, G. & Ricken, W. (1995): The Wutach gorge in SW Germany: late Würmian (periglacial) downcutting versus Holocene processes. Zeitschrift für Geomorphologie, NF Supplement-Band 100, 65-87.
- Hebestreit, C. (1995): Zur jungpleistozänen und holozänen Entwicklung der Wutach (SW-Deutschland). Tübinger Geowissenschaftliche Arbeiten, Reihe C, 25, Dissertation Geowissenschaftliche Fakultät Universität Tübingen.
- Howard, A.D. & Kerby, G. (1983): Channel changes in badlands. Geological Society of America Bulletin 94(6), 739–752.
- LGL (2010): Digitales Geländemodell DGM25 (25m grid size). Landesamt für Geoinformation und Landentwicklung Baden-Württemberg.
- LGRB (2015): Geologisches 3D-Modell ISONG. Regierungspräsidium Freiburg, Landesamt für Geologie, Rohstoffe und Bergbau Baden-Württemberg.
- Schnellmann, M., Fischer, U., Heuberger, S. & Kober, F. (2014): Erosion und Landschaftsentwicklung der Nordschweiz. Zusammenfassung der Grundlagen im Hinblick auf die Beurteilung der Langzeitstabilität eines geologischen Tiefenlagers (SGT Etappe 2). Nagra Arbeitsber. NAB 14-25.

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