Accelerated uplift of the Rhenish Massif (central Europe) since 700–800 ka revealed by isochron-burial dating of strath terraces

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Photography encouraged

1. Introduction

Strath terraces are key geomorphic markers that help us:

- Quantify rock uplift in tectonically active regions
- Reconstruct river incision histories
- Identify climate-driven changes in river behavior
- Link landscape change to glacial–interglacial cycles

Age control essential for quantifying incision and uplift rates.

Motivation

Critical problems with existing dating techniques used for terrace chronology:

- Paleomagnetic data limitations: shallow thickness of sedimentary deposits (< 10 m; Fromm, 1987).
- Tentative correlations of terrace levels with Quaternary glacial-interglacial cycles – older ages for Main Terraces (Preuss et al. 2015).

Chronological constraints of main terrace levels remain inconclusive

Two competing hypotheses:

HYPOTHESIS A

Uplift and river incision *acceleration* driven by mantle plume below Eifel region at ~700-800 ka

Fuchs et al. 1983; Ritter et al., 2001

HYPOTHESIS B

Steady uplift and progressive river incision due to lithospheric folding since the Pliocene

Demoulin and Hallot, 2009; Preuss et al., 2015

Research question:
When did uplift and incision accelerate — and why?

We provide the first ^{10}Be and ^{26}Al isochron-burial ages for Rhine strath terraces.

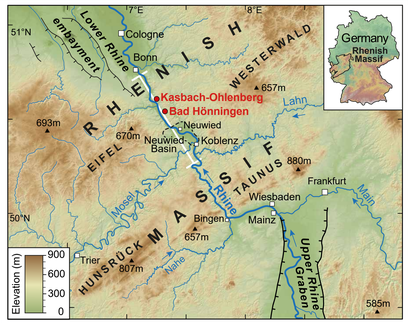


View of the Rhine valley, looking NE (downstream).

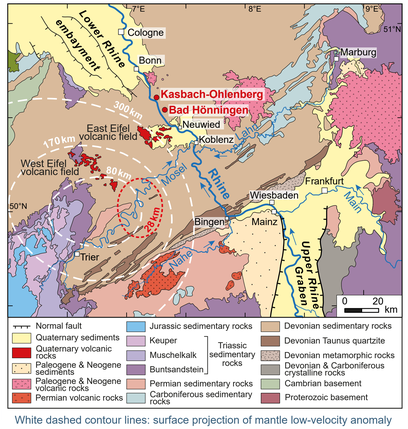
2. Study Area

Two sampling sites, northern Rhenish Massif:

Rhenish Massif

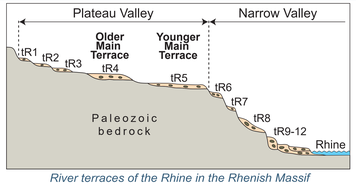


Digital elevation model of the Rhenish Massif



White dashed contour lines: surface projection of mantle low-velocity anomaly (after Ritter et al., 2001; Mertz et al., 2015).
Red dashed line: reduced crustal thickness ~28 km (from Budweg et al., 2006).

Terrace sequence in the Rhine valley



River terraces of the Rhine in the Rhenish Massif (modified from Meyer and Stets, 1998).
Note: break-in-slope separates the Narrow Valley from the Plateau Valley.

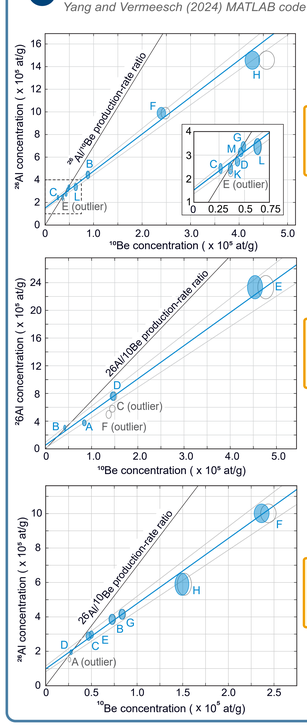
3. Methods & Results

Isochron-burial dating workflow:

1. Quartz-rich clasts collection near bedrock strath from single stratigraphic horizon

	Bedrock strath elevation	Sediment thickness
Kasbach-Ohlenberg		
Older Main Terrace (24D3)	203 m	6.7 m
Younger Main Terrace (19D1)	199 m	10.8 m
Bad Hönningen		
Older Main Terrace (23D1)	218 m	11.4 m

2. Quartz purification - HCl + HF/HNO_3
3. ICP-OES check + Be/Al carrier spiking
4. AMS at CologneAMS - ^{10}Be + ^{26}Al ratios
5. Isochron regression - burial age
   Yang and Vermeesch (2024) MATLAB code



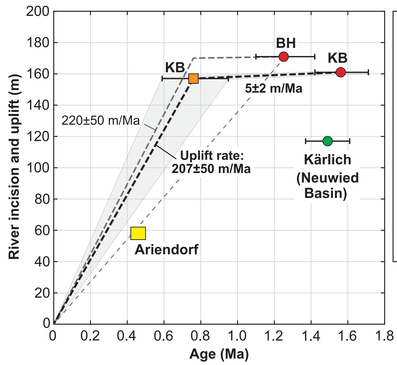
Kasbach-Ohlenberg: sample 24D3
1.56 (+0.15/-0.14) Ma

Kasbach-Ohlenberg: sample 19D1
0.76 (+0.19/-0.17) Ma

Bad Hönningen: sample 23D1
1.25 (+0.16/-0.15) Ma

4. Discussion - Uplift History

Uplift vs. Time



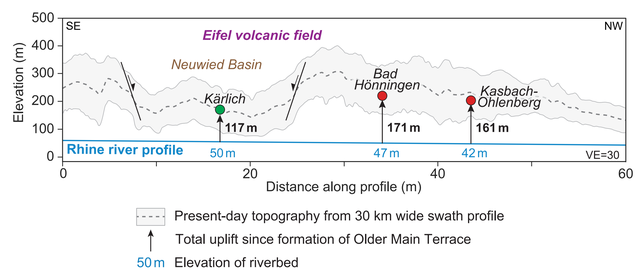
Burial ages
- Older Main Terrace (tR 4)
- Younger Main Terrace (tR 5)
- KB = Kasbach-Ohlenberg
- BH = Bad Hönningen

this study

ESR age
- Older Main Terrace (Neuwied Basin) — Bartz et al. (2024)

^{40}Ar/^{39}Ar ages from volcanic tuffs
- Terrace tR 8 — Lippolt et al. (1986)

Uplift accelerated from ~5 to ~200 m/Ma at ~700-800 ka

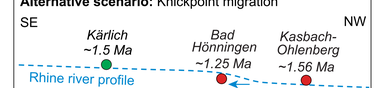


Formation of Older Main Terrace (~1.6 - 1.2 Ma)

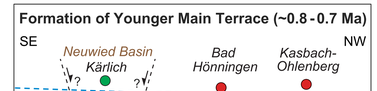
Preferred scenario:
Graded river and differential uplift after ~0.8 Ma



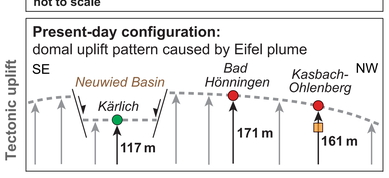
Alternative scenario: Knickpoint migration



Formation of Younger Main Terrace (~0.8 - 0.7 Ma)



Present-day configuration:
domal uplift pattern caused by Eifel plume



KEY FINDINGS

- **Terrace Ages:** The Older Main Terrace formed at **~1.56 Ma** and **~1.25 Ma** at two sites, while the Younger Main Terrace dates to ~760 ka.
- **Uplift rate:** A long period of minimal incision (~5 m/Ma) was followed by rapid uplift starting around 700-800 ka at rates of ~200 m/Ma.
- **Spatial variation:** Uplift increases southeastward along the Rhine, with maximum uplift of >250 m near the Eifel volcanic field.

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5. Conclusions

1. First isochron-burial ages for strath terraces in the Rhenish Massif:
   Older Main Terrace: ~1.56 & ~1.25 Ma
   Younger Main Terrace: ~760 ka
2. A phase of rapid river incision and rock uplift starts at ~700–800 ka.
3. The onset coincides with Eifel volcanism and a low-velocity mantle anomaly, pointing to a mantle plume.
4. Since ~700–800 ka, the Rhine has incised at an average rate of 0.2 mm/yr.

***Future work:** extend isochron-burial dating to additional Rhine terrace sites.*

Acknowledgements:
Schmitz Wiedmuhle GmbH for sampling access. C. Bode (WSA Rhein) for bathymetric data.
LGB Rheinland-Pfalz for LiDAR terrain models. Dr. E. Voronina for sample processing (Cologne Cosmo Lab). L. Schlottbohm and L. von Zitzewitz for lab support.

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

Session GM2.4 / EGU26
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