Autogenic versus allogenic controls on a fluvial megafan/mountainous catchment coupled system: Numerical modelling and comparison with the Lannemezan megafan (Northern Pyrenees, France)

Margaux Mouchené [1,*], Peter van der Beek [1], Sébastien Carretier [2,3], Frédéric Mouthereau [2]

1. Université Grenoble Alpes, CNRS, ISTerre Grenoble F-38058 , France
** now at:* Tulane University New Orleans LA, United States *mmouchene@tulane.edu*
2. GET, OMIP, Université de Toulouse, CNRS, IRD Toulouse , France
3. France / Department of Geology, FCFM, Universidad de Chile Santiago , Chile

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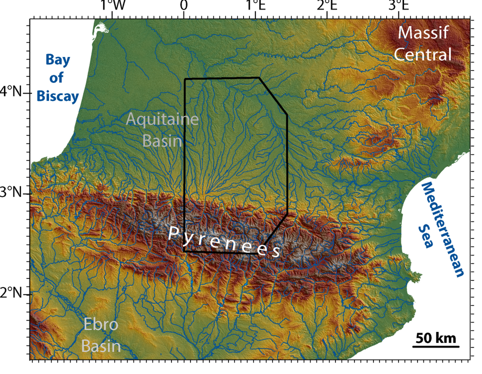
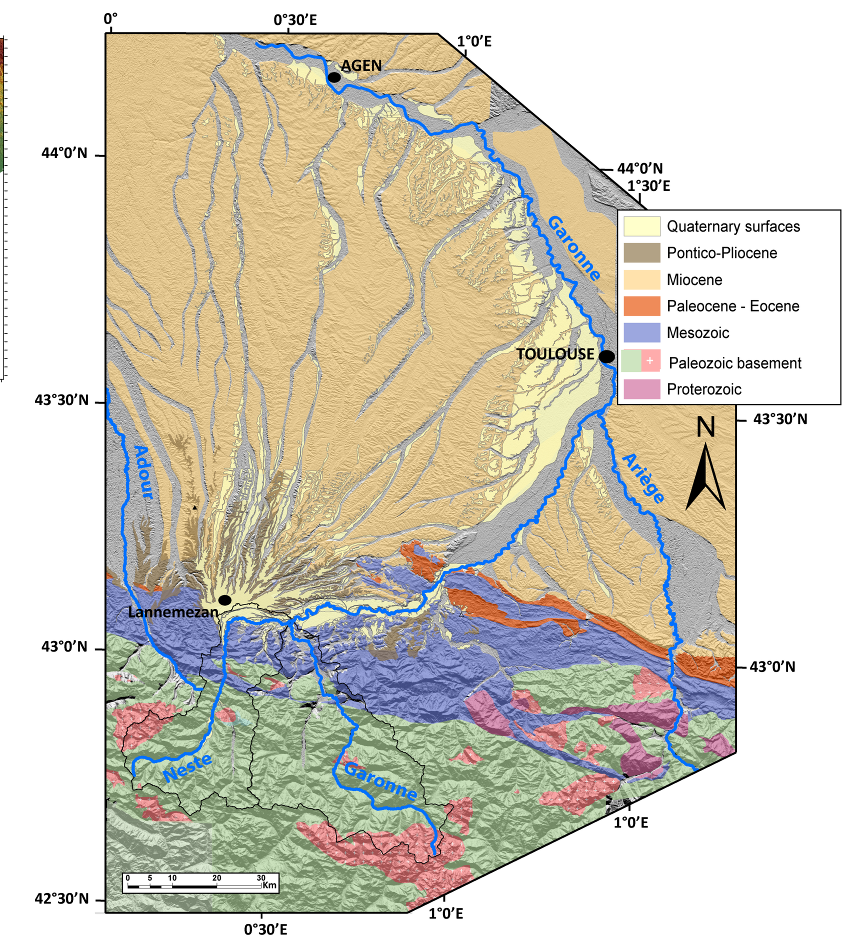
The Lannemezan megafan:

In the northern foreland of the Pyrenees (France), the Lannemezan megafan (13,000 km²) was built during the **Miocene** by the erosional products of the mountainous Neste river catchment, and was abandoned during the **Quaternary** (**onset of incision at ≥ 300 ka,** Mouchené et al., 2017). The Neste turns sharply to the east at the megafan apex and **incises the fan head >100m vertically** before merging with the larger Garonne River at its mountainous outlet; this drainage pattern suggests the **capture of the Neste by the Garonne**. The episodic abandonment **alluvial terraces** along the rivers of the northern foreland during incision may be related to changing fluvial dynamics during shifts between Quaternary cold and warm climatic phases (Mouchené et al., 2017).



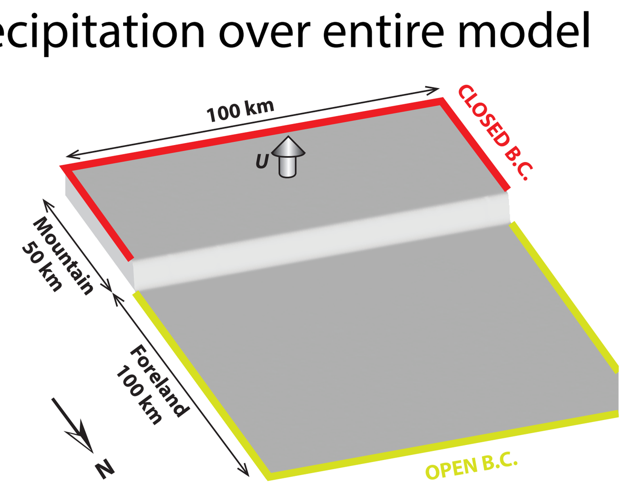


Objective

What processes control the long-term evolution of the Lannemezan megafan?
We test hypotheses on the mechanisms at play in the abandonment and incision of the megafan through numerical modelling. We explore the respective effects of potential forcing factors, including autogenic dynamics, climate change, tectonic tilting, and base level change, on trends and patterns of incision (time and space scales, amplitudes).

The numerical model CIDRE

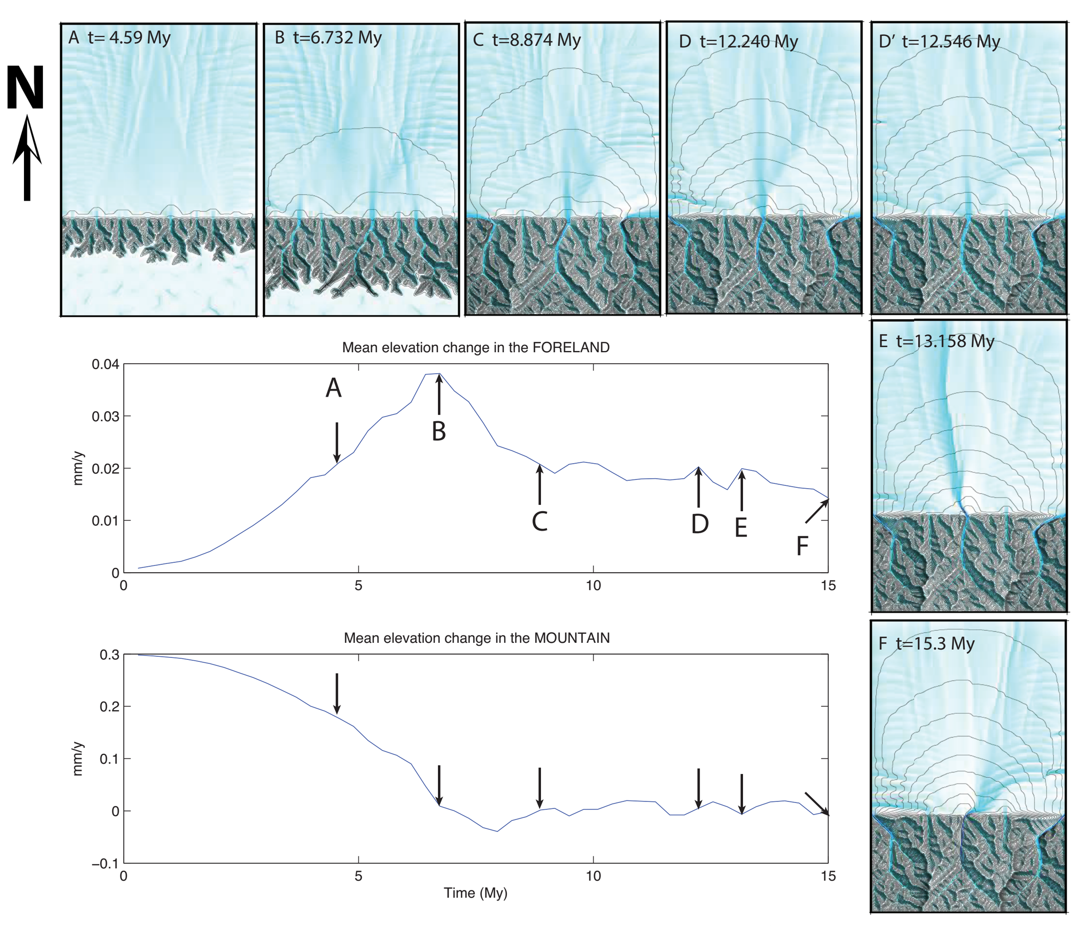
(Carretier et al., 2015)
Fluvial incision and hillslope diffusion after Davy & Lague (2009)
Multiple Flow algorithm
Precipitation over entire model



Building a megafan

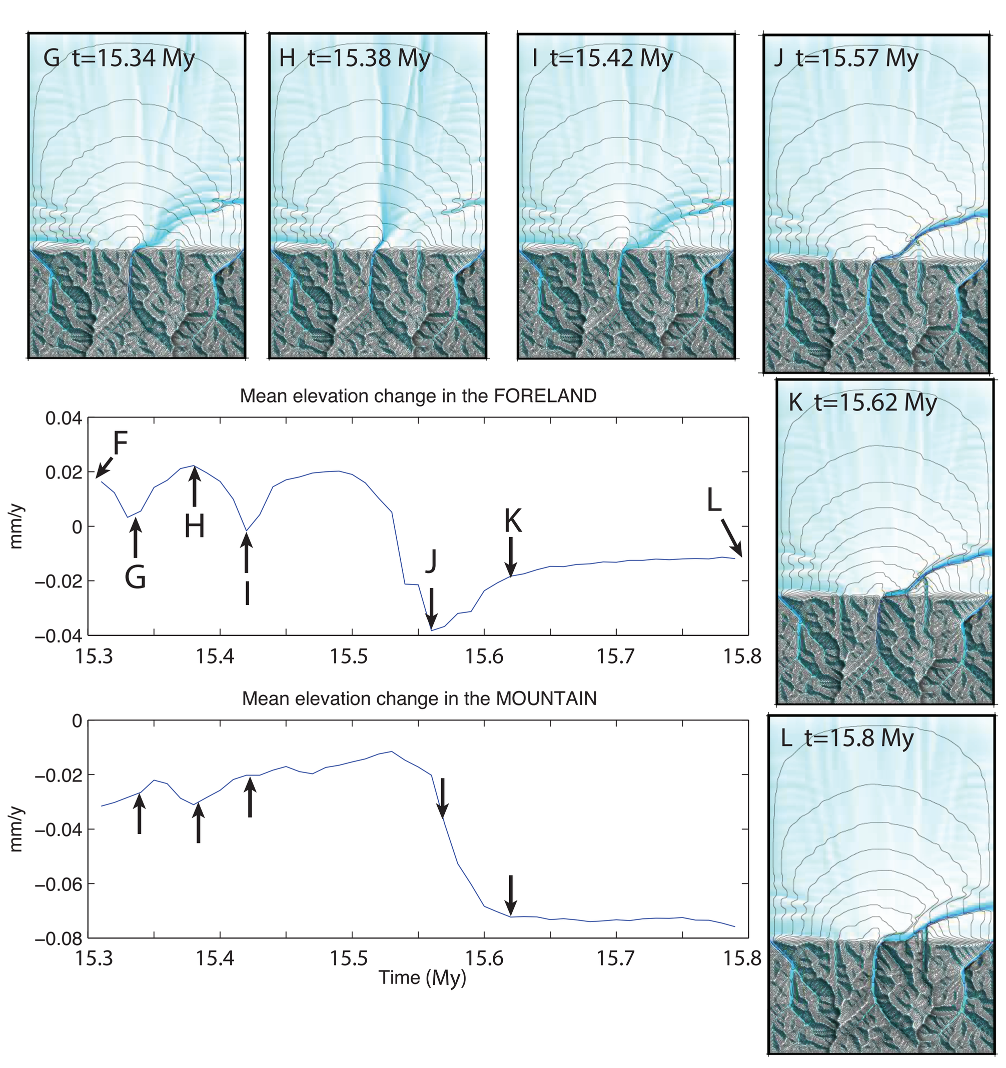
- Development of the river network on the uplifting block
- Aggradation in stable foreland
- Lateral rivers take shortest path towards open boundaries leading central river to provide most of the foreland sediments
- Rapid avulsion alternating with sheet-like flow allows for large, conical sediment accumulation

Model successfully reproduces first-order metrics and timescale of the Lannemezan megafan



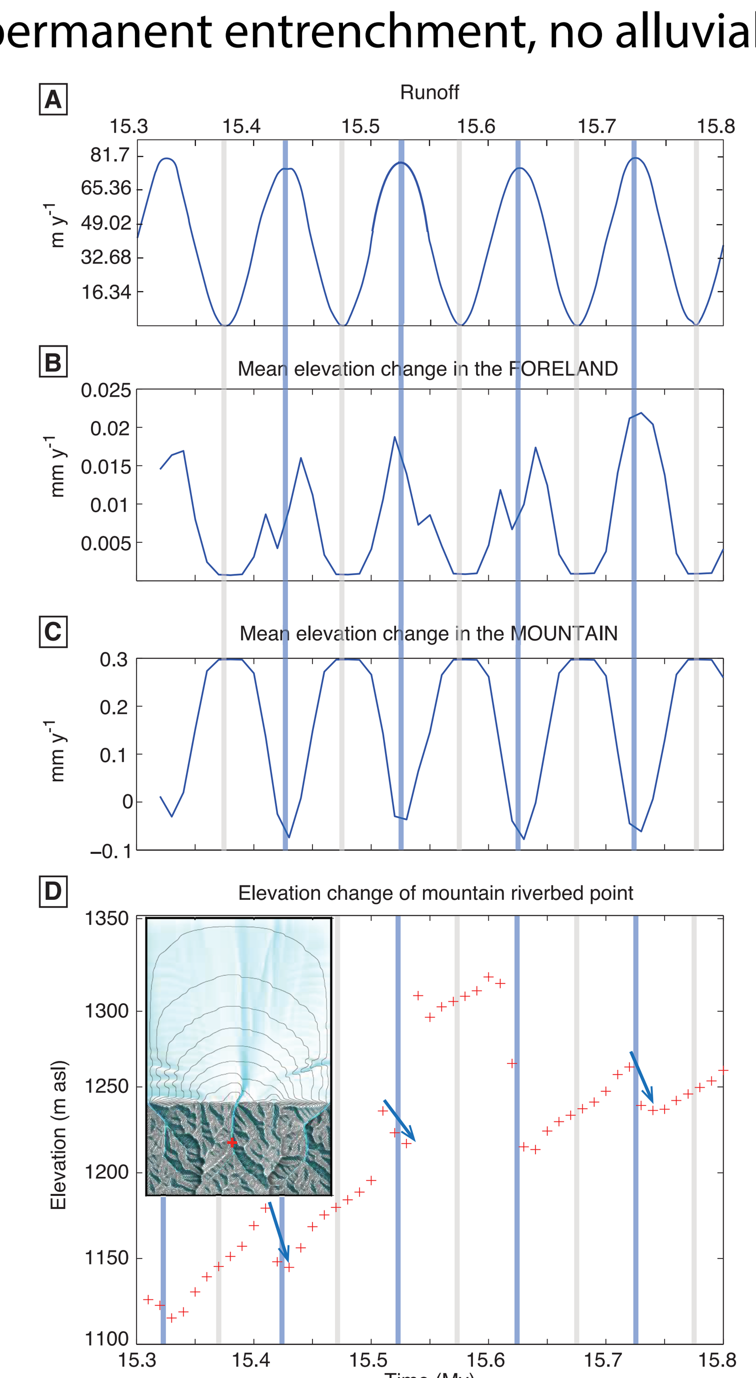
Autogenic evolution

- Headward incising lateral stream ends up capturing the main central stream, near the apex
- At the time of capture, they both incise rapidly into the megafan sediments, >100 m vertically
- The incision is permantent, the megafan is abandoned

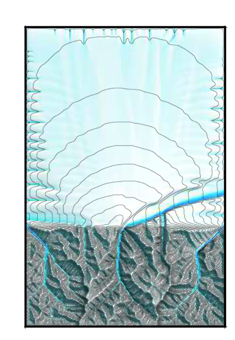


Cyclic precipitation pattern

- Alternating phases of erosion in range + deposition in foreland / no erosion or deposition
- No permanent entrenchment, no alluvial terraces

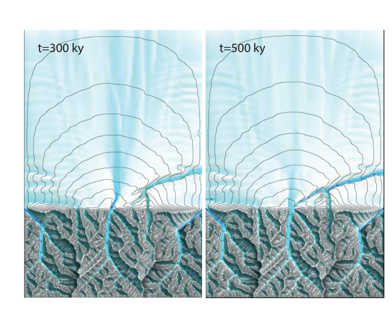


Other scenarios tested



Base-level drop

- Headward incision of streams on the sides of megafan
- Rapid capture of the main stream and entrenchment

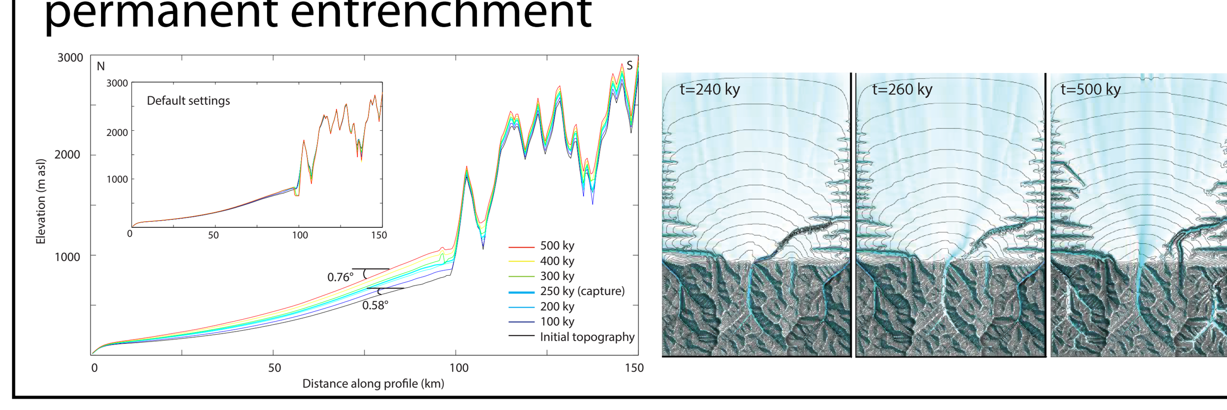


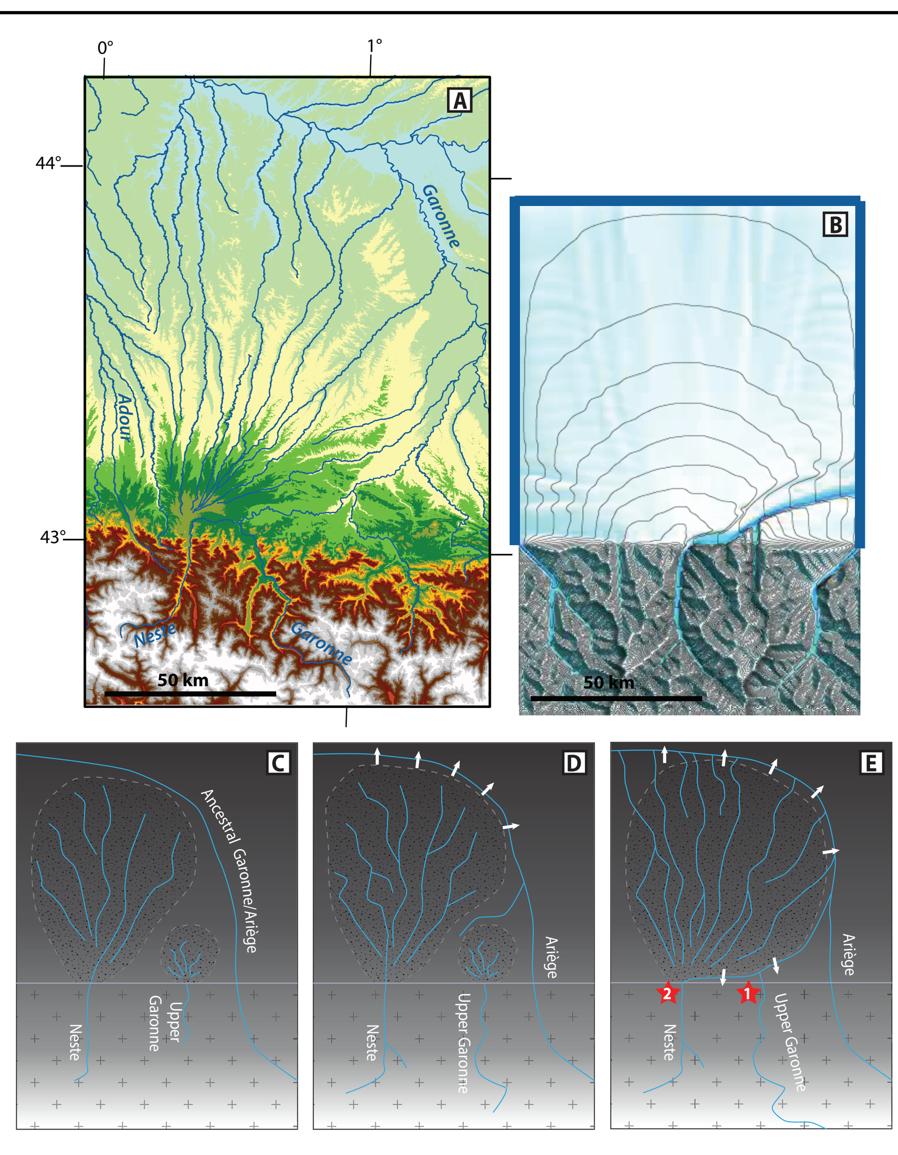
Change in uplift rate

- Headward-incising stream from the eastern border captures a secondary river before connecting to the main central channel

Tilting

- We seek to reproduce the effect of isostatic rebound: we use a scaling law between fan area and fan slope to estimate the initial depositional slope of the megafan and subsequent tilting
- Tilting increases megafan slope but prevents permanent entrenchment





Conclusions

Numerical modelling has provided (i) new insight into the building and incision of a foreland MF and (ii) key elements to infer the evolution of the Lannemezan MF and its mountainous catchment in the northwestern Pyrenees.
The role of **preexisting transverse rivers** across the foreland (Adour, Garonne–Ariège) seems to be critical in the building and incision of the MF: their spacing controls the size of the fan, limit its extension and efficiently evacuate water and sediments out of the MF. The MF grows in response to the **autogenic oscillations between sheet-flow and channelized flow.**

Autogenic processes seem to be sufficient to explain the permanent entrenchment of the river network and abandonment of the Lannemezan MF through: (i) **progressive headward incision** of a stream from the foot of the fan and (ii) **capture** of the feeding river at its mountainous outlet, (iii) rapid entrenchment of the apex and **abandonment** of the MF. **No external forcing** is needed to induce long-term entrenchment but external factors cannot be ruled out. In particular, on a **shorter timescale**, incision may have been influenced by **Quaternary climatic variations** as suggested by the abandonment of **alluvial terraces** along the foreland rivers. In contrast, **base-level changes, tectonic activity in the mountain range or tilting** of the foreland through flexural isostatic rebound appear to be **unimportant** factors in the abandonment of the MF.

References
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Davy, P. and Lague, D.: The erosion / transport equation of landscape evolution models revisited, J. Geophys. Res.-Earth, 114, F03007, doi:10.1029/2008JF001146, 2009.
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Université Grenoble Alpes
ISTerre
GET Géosciences Environnement Toulouse
PYRAMID