Impact of deglaciation on geodetic uplift and active faulting in the Alps: A rheological control?

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Present-day uplift of western Alps

IGN leveling

GPS RENAG

Surrection
1-2 mm/yr

J.M. Nocquet et al., ongoing work
Source of present-day uplift?

Flexural isostatic adjustment to:

1/ Present-day denudation (Champagnac et al. 2006)
   Elastic plate 10 km

2/ Post Wurm (LGM) deglaciation (Stocchi et al. 2005)
   Visco-élastique mantle $10^{20}$ Pas

Current models do not explain geodetic observations

Idea: test the effect of alpine rheology on post-deglaciation uplift

4 rheological models of the Alps
Relation between deglaciation, rheology and geodetic uplift?

Ice thickness at 18,000 BP (Late Glacial Maximum - LGM)

Figure 1. Contour lines showing the thickness of the ALPS1 model for the Alpine deglaciation at the LGM (e.g. 18,000 BP). The crosses show the extent of the ice limit, the contour lines correspond to the given thickness intervals. The map has a geographic extent of 8°-12° East longitude and 44°-48° North latitude. The ice thickness is indicated by the contour lines as follows: 1000 m, 500 m, and 250 m.
Distributed post-glacial uplift, completed at present-day

Model I

Elastic crust (Te=30km)
Visco-elastic mantle (10^{20} Pas)

Input load: 500 m deglaciation between -20 000 et -10 000 yrs over a 150km width area
Model II:

Elastic crust (Te=30km)
Low viscosity crustal root (10^{20} Pas)
Visco-elastic mantle (10^{20} Pas)

Localized post-glacial uplift, 1mm/an at present-day

A viscosity of 10^{20} Pas … how this behaves on the long term?
Topographic impact of $10^{20}$ Pas root on strain?

Model III

= model II + topography without glacial unloading
... gravitational collapse of the lower crust

Model III

Fast collapse:
several cm/yr, 5% strain après 0.04 Ma
→ flat Moho after 1Myr
How to reconcile

1/ post-glacial rebound
   (0.01 ka - $10^{20}$ Pas)

2/ stable 3km topography over 10 Ma
   (needs large stress $\rightarrow$ viscosity $> 10^{23}$ Pas)

? 

… back to Alpine geophysics
Swiss Alps seismicity

Foreland: 20-30 km elastic thickness

High topography: 5-12 km elastic thickness

Subcrustal mantle = weak elastic plate

Deichmann, 2003
Model II adapted to the Alps ($\rho_c = \rho_m$)

déglaciation entre -20 et -10 kans

**croute inf. = 10**20 Pas

**manteau supérieur viscoélastique 10**20 Pas
Model II adapted to the Alps \((\rho_c=\rho_m)\)

Model IV = CRUSTAL ASTHENOSPHERE + THIN ELASTIC PLATE
Model IV: The 3 effects of the (half) thin plate

1/ Deflect the crustal flow

2/ Maintain the crustal root

3/ Allow for post-glacial rebound

Max: +17 mm/an
Today: +1.5 mm/an
Conclusions

- Present-day geodetic uplift of the Alps may correspond to the coda of a post-glacial rebound controlled by a low viscosity crustal body

- A thin subcrustal elastic plate is then needed for preventing mountain root collapse

Perspectives

- Document Holocene tectonic activity (e.g. Hyppolite et al. 2009)
- Correlate geodetic uplift and LGM ice thickness
- Build a 3D rheological model integrating geological and geophysical data (e.g. Lardeaux et al. 2006, Diehl et al. 2009)