# Differential Strain Rate as a Mechanism for the Formation of Detachment-Fault Corrugations: A Case Study from Western Norway

Scott Johnston, Brad Hacker; University of California, Santa Barbara

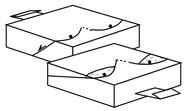

## Abstract

Transport-parallel corrugations on normal-sense detachment faults are described in extensional tectonic settings at the range through orogen scale. The mechanisms by which these corrugations form have implications for the original shape of the detachment fault, pre-existing basement structures, the formation and architecture of supra-detachment basins, and the overall tectonic setting of the orogenic event. Western Norway provides an ideal setting to investigate the formation of detachment-fault corrugations. There, the normal-sense Nordfjord-Sogn Detachment Zone--thought to be one of the primary structures responsible for exhuming the high- and ultrahigh-pressure rocks of the Western Gneiss Complex--is corrugated by a series of extension-parallel folds that deform footwall rocks, hanging-wall rocks, and muscovite chrontours. The largest of these corrugations displays a minimum fold amplitude of tectonostratigraphic layers of 5 km, and exposes muscovite cooling ages in the core of the antiform that are 10--15 Myr younger than the immediately adjacent synformal structures. Here, we suggest that the limbs of these corrugations represent transfer faults/shear zones between regions of differential exhumation that were localized by the density-driven ascent of the ultrahigh-pressure Western Gneiss Complex.

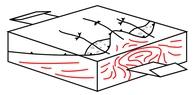
The viability of this hypothesis was tested through a series of 2-D kinematic/finite-difference thermal models. Subducted lithosphere with an initially cold geotherm was allowed to exhume via a combination of pure-shear thinning and simple-shear removal of upper crust along a broad detachment zone, followed by conductive relaxation. The models indicate that even modest differences in exhumation rate (less than even 20 percent) create fold amplitudes within the tectonostratigraphy of up to 7 km, and produce 2--5 km offsets of the 400° isotherm (muscovite closure to Ar). These results are consistent with outcrop patterns and 10--15 Myr differences in muscovite cooling ages observed in Western Norway. This work has important implications for the geology of Western Norway, suggesting that the corrugations on the Nordfjord Sogn Detachment Zone may be the result of differential exhumation rather than orogen-scale constriction and transtension, and indicates that transfer faults/shear zones should be considered a viable mechanism for corrugated detachments in extensional settings worldwide.


## Existing Models for Detachment Fault Corrugations

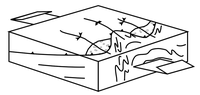
Originally scalloped range front devel-ops fault corrugations during contin-ued extensional and block rotation.



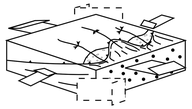
Lower crustal instabilities lead to exag-gerated exhumation above rising diapirs.



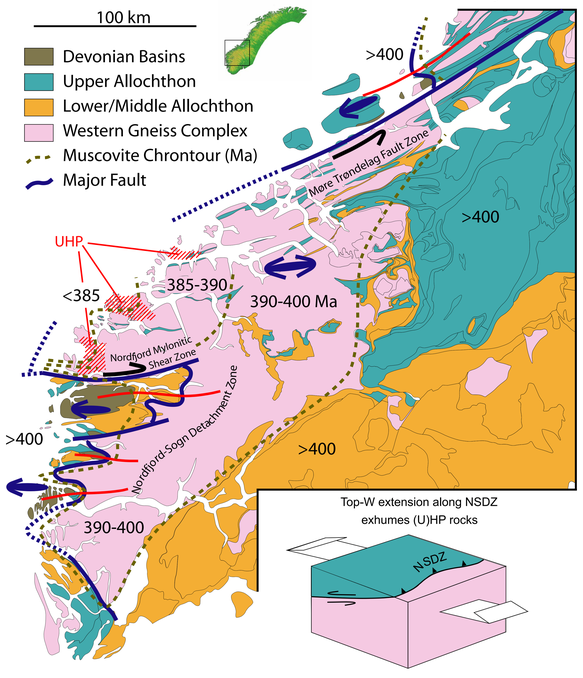
Pre-existing footwall structure defines the shape of the detachment surface.



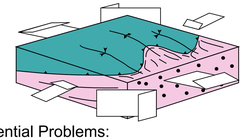
Constrictional strain fields (can be set up via transtension) progressively fold the detachment surface during deformation.



## Case Study: Geology of Western Norway




Constrictional Model:

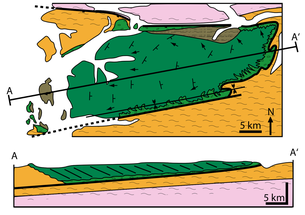


Potential Problems:

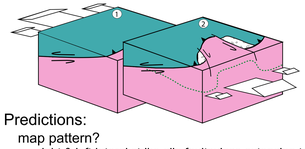
- map pattern
  - right-lateral faults do not match left-lateral orogen
- basin stratigraphy
  - the Hornelen formed adjacent to a strike-slip fault
- constrictional fabrics
  - are constrictional fabrics dominant?
- mechanics of faulting
  - can detachment faults remain active during progressive folding?

Primary Support:

- E-W trending fold axes
- Constrictional lower plate fabrics



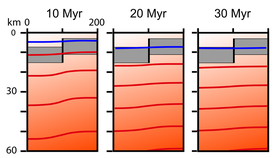

New Alternative Model: Differential Strain



Predictions:

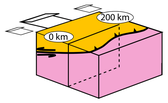
- map pattern?
  - right & left-lateral strike-slip faults; less extension to north and south
- L=S fabrics
  - local variation, but average fabric suggest plane strain
- basin stratigraphy?
  - strike-slip/pull-apart basin stratigraphy
- thermal signature?
  - muscovite cooling ages

## Testing the Hypothesis: Thermal Modeling




Slow: 1.85 km/Myr Vs. Fast: 2.3 km/Myr

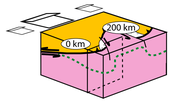
Initial conditions:




Assume a cold geotherm due to slab subduction (constrained by thermobarometry and supra-Barrovian overprint)

$T_{moho}$ allows for lower crustal flow

10 Myr of Exhumation:

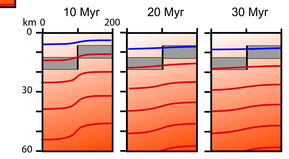



Along-strike variation in strain rate (constrained by geochron, PT & mapping)

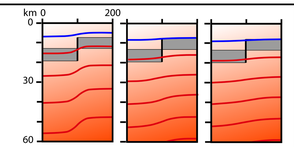
Pure shear thinning (finite stretch / 10 Myr)

Simple shear removal and vertical throw (km/Myr)

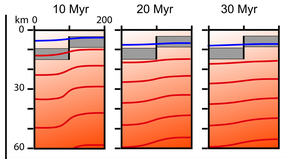
Simple Shear Removal/Excision



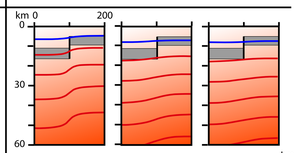

Slow: 0.8 Vs. Fast: 1.2




Slow: 0.7 Vs. Fast: 1.1

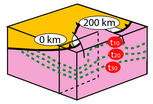



Slow: 0.8 Vs. Fast: 0.7

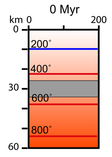



Slow: 0.7 Vs. Fast: 0.6

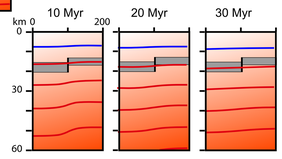
2X 10 Myr Thermal Relaxation:




Geotherm relaxes toward slightly elevated, post-contratctional geotherm (thinned radiogenic layer but higher Qm)

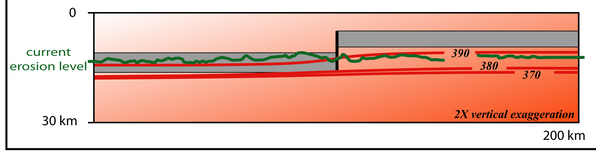


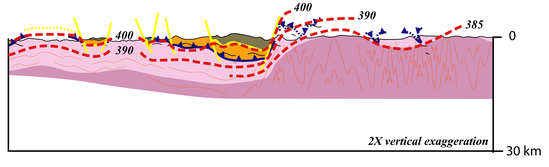

Pure Shear Thinning




Slow: 0.6/ 10 Myr Vs. Fast: 0.5/ 10 Myr

## Model Comparison with Western Norway




## Conclusions

The map patterns, tectonostratigraphy, and structural data in western Norway suggest along-strike variations in post-orogenic exhumation.

Thermal models of localized along-strike strain variations predict 2-4 km offsets on the 400° isotherm and 10-15 Myr differences in muscovite cooling ages.

## Potential Implications

Along-strike strain variations should be considered as an alternative to transtension for the exhumation of the (U)HP rocks of western Norway.

Transfer faults may play an important role in the formation of extension parallel basins.

Variable exhumation should be considered when investigating corrugated detachment faults.

## Future Work

Western Norway

- Regional survey and mapping of Caledonian strain markers

Can along-strike variations in strain become localized?

- 3-D modelling of diapiric ascent - with and without the presence of melt

Do variable exhumation models work in other extensional settings?

- other UHP orogens
- smaller-scale core complexes and gneiss domes