Inversion of the Rhenohercynian rift shoulder (Middle European Variscides): Implications for the strain and the metamorphism from numerical modelling

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The Rhenohercynian zone of Belgium and Germany represents the northern fold-and-thrust belt of the central European Variscides. The rocks which underwent the shortening at the end of Carboniferous consist of mainly (meta-) sediments of the Lower Palaeozoic and the Devonian-Carboniferous. In the northern part of the fold-and-thrust belt (Ardenne Anticlinorium), the Lower Palaeozoic rocks are exposed as a series of inliers such as the Rocroi and the Stavelot-Venn Massifs. These are surrounded by Lower Devonian detrital sediments which show a considerably thickening toward the south. This variation is due to steep-dipping normal synsedimentary faults during a rifting event (Oncken et al. 1999). During the Variscan Orogeny (Carboniferous), this zone induced a preferential strain localisation and a strong exhumation above a major ramp. In the eastern Stavelot-Venn Massif, the synsedimentary fault was inverted into a transpressive shear zone (Fielitz 1992), the so-called the Monshau shear zone. It is located between a series of south-dipping thrusts (Venn, Soiron, Aachen thrusts) in the North and the north-dipping Troisviersges–Malsbenden backthrust in the South. The southern limb of the Ardenne Anticlinorium shows mainly green-schist facies metamorphic aureoles in Lower Palaeozoic and Lower Devonian metasediments. The paragenesis and the fluid inclusions indicate that maximal P and T values of 400 MPa and 500 °C, while the paleo-geothermal gradient ranged between 30 °C/km and 60 °C/km.

We used the 2D thermomechanical finite element “DLR” software (Batt and Braun 1997) to study the strain partitioning, the exhumation and the PTt paths during the inversion of a steep-dipping normal synsedimentary fault. Different models have been applied to compare the influence of the competence contrast between the footwall and the hangingwall. The results show that without the presence of a low cohesion level along the fault and whatever the competence contrast is, the footwall is cut by a shear band which decreases the synsedimentary fault dip. The models applying a weak level show (1) in the ductile field, the strain growths along the synsedimentary fault and (2) the footwall is only cut at the brittle-ductile transition. The results of the numerical models are consistent with structures of eastern Stavelot-Venn Massif and the available PT data of the Ardenne Anticlinorium.


Dynamical evolution of orogenic wedges and continental plateaux: Insights from thermal-mechanical modelling of convergent orogens

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Orogenic belts are zones of thickened continental crust that form as a result of convergence between lithospheric plates. Deformation of the crustal layer typically comprises a phase of
crustal thickening followed by a phase of widen-
ing of the zone of thick crust associated with the
development of a continental plateau. Crustal
thickening perturbs density interfaces such as
the surface and the base of the crust (the Moho)
and hence introduces lateral variations of grav-
itation potential energy. Thickening of the con-
tinental crust also redistributes radioactive
heat-producing material. In the case of prolonged
thickening, thermal relaxation and radio-
active heat production cause temperatures to rise
in the interior of the orogenic belt. Accordingly,
the dynamic evolution of an orogenic belt is con-
trolled by the thermal and mechanical evolution
of the zone of thickened crust and by the inter-
play between buoyancy, horizontal compression,
and basal traction.

We investigate the dynamical evolution of con-
vergent orogens assuming a physical model in
which lithospheric subduction occurs beneath the
region of crustal thickening. Under these condi-
tions, orogenic evolution is controlled by the com-
petition between tectonic and gravity forces com-
combined with the role of temperature on the
rheologic evolution of the crust. We test the abil-
ity of this physical model to reproduce first-order
features of orogenic belts (thermal structure,
geometry and dynamics of orogenic wedge, con-
tinental plateau, etc.), using a fully coupled ther-
mal-mechanical numerical model based on the
finite element method.

The following conclusions can be drawn from
this study:
• The formation of a model orogenic wedge by
accretion of heat-producing radioactive mate-
rial is an efficient mechanism to generate high
temperatures in the orogenic core, even while
subduction and related cooling are active be-
neath the orogen.
• Deformation of crustal layers with constant
rheologic behaviour (frictional-plastic or con-
stant viscous) leads to the growth of
back-to-back wedges with no limit in crustal
thickness.
• A limited decrease in viscosity as a function of
depth or temperature causes a decrease in the
surface slope of the wedge. With lower values
of viscosity at the base of the deformed crust
the surface slope tends to zero and at this
stage mechanical decoupling occurs. Further
convergence is accommodated by the widening
of the zone of thick crust leading to the forma-
tion of a plateau.

Numerical modelling of coupled orogenic processes using
the distinct element method

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The distinct element method is applied to study
the interaction of deformation, erosion and iso-
tasy in numerical models of continental collision
zones.

The 2D plane-strain model consists of up to
20,000 cylindrical disks interacting only at con-
tacts. The contact laws and the properties of the
disks define the bulk rheology of the model. For
this study a noncohesive Mohr Coulomb material
was defined by assigning only surface friction,
normal stiffness, shear stiffness and density to
the disks. These models using only material with-
out cohesion exhibit scale independent behav-
ior. The same parameters except density were
chosen for the bounding walls.

In the model a rectangular array of disks repres-
sents a vertical section through a continental col-
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ossional zone. Prior to the onset of deformation the
 disks are allowed to settle for some time to pro-
c
duce a gravitationally equilibrated starting
model. Deformation is then induced by moving
the left half of the lower boundary to the right.
This results in deformation and uplift in the cen-
tre of the model were the moving lower boundary
slides under the other. Progressive movement of
the bounding walls leads to the formation of dou-
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bly vergent thick-skinned orogens. During deforma-
tion the lower boundary of the model is kept in
isostatic equilibrium which is calculated using a
flexural isostatic compensation. Deletion of par-
ticles at the surface according to preset rates simu-
lates erosion of the orogen.

The modelling results include the kinematic
evolution of the model, the stress history of par-
ticles and regions, the work performed by the
bounding walls, by frictional sliding of the disks
and the energy stored by elastic deformation.

The present study shows a range of models
with varying crustal strengths and erosion rates
as well as different elastic parameters of the litho-
sphere and shows the influence of these varia-
tions on the evolution of the orogen, its foreland
basins, on the particle paths and the energy bal-
ance of the system.