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Lithosphere dynamics and sedimentary basins: from the deep Earth to the surface

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Satellite derived gravity anomalies







Intraplate deformation: plumes

Plumes in the upper mantle resolved from seismic tomography (in the Northern Atlantic, depth slice between 100 – 200 km)





Rickers et al., 2013. Earth Planet. Sci. Lett.





Global strength, effective elastic thickness of the lithosphere



Tesauro, Cloetingh et al. 2012. G3



Intraplate stresses



Some general features

- Most of the Earth is under compression
- Most of the times, compressions are perpendicular to the oceanic ridges
- Tension is typically limited to the areas with high topography (mountains)

World Stress Map Rel. 2003 Heidelberg Academy of Sciences and Humanities Geophysical Institute, University of Karlsruhe

- Normal faults
- Strike-slip faults
- Thrust faults
- Unknown regime





Rheological strength maps

Correlation of weak and strong zones using seismicity







Intraplate seismicity and vertical movements



Societal impact of geohazards: the European continent









Research Infrastructure and E-science for Data and Observatories on Earthquakes, Volcanoes, Surface Dynamics And Tectonics





ESFRI









Earth Simulation Lab (2017)

An integrated multi-scale experimental & modelling facility



- (Un)conventional gas
- Geothermal energy
- Induced earthquakes
- Subsidence & geological storage
- River and estuarine morphodynamics
- Experimental sedimentology



- EPOS: European Plate Observation System 500 M€
 - UU coordinates thematic core service multi-scale experimental facilities
- Macro micro nano scales



Integrated multiscale experimental facilities



REVIEW SUMMARY

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Inherited landscapes and sea level change

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Sierd Cloetingh, Se<mark>an Willett</mark> & TOPO-EUROPE t<mark>eam</mark>

TOPO-EUROPE

Fundamental Premise

- Continental topography is the product of the interaction between processes operating deep in the Earth, on its surface and in the atmosphere
- It's understanding requir<mark>es a multidisciplinary approach</mark>
- > 23 participating countries
- > 14.5 M Euro funding
- > 60 new positions for young researchers



INTERNATIONAL LITHOSPHERE PROGRAM







SUBITOP - ETN

Topographic expressions of subduction zones

Coordinator: Niels Hovius (GFZ)



Universiteit Utrecht

H-2020

European Commission

- Participants; GFZ, Oslo, ETH, CSIC, UniRoma3, Durham, Utrecht, Edinburgh, Montpellier and Rennes
- •15 industry partners
- EU funding for 15 PhD positions



Extensional basin formation and deformation in a continental back-arc setting

(Horvath and Cloetingh, 1996, Tectonophysics)



Coupled physical analogue and numerical modelling







Crust-mantle decoupling of the upper and lower plates









Alps – Carpathians – Dinarides – Pannonian Basin

On the surface expression of laterally changing subduction polarity







Alps – Carpathians – Dinarides – Pannonian Basin

From Source to Sink



Cloetingh et al., 2007. Global and Planetary Change, 58.



Matenco and Andriessen, 2013. Global and Planetary Change 103.





Carpathians: a dynamic foredeep in the bend zone



Cloetingh et al., 2004. EPSL



Stretching model McKenzie (1978)

1-D kinematic model for instantaneous, uniform extension of continental lithosphere



Syn-rift subsidence caused by isostasy is instantaneous Post-rift subsidence caused by cooling is gradual: $W_t \propto \sqrt{t}$





Crustal stretching distribution in the Pannonian basin





Universiteit Utrecht

Lenkey et al., 2002



A. Balázs, L. Matenco, I. Magyar, F. Horváth, and S. Cloetingh, 2016, Tectonics





A. Balázs, L. Matenco, I. Magyar, F. Horváth, and S. Cloetingh, 2016, Tectonics



Heterogeneous structure of Europe's lithosphere

Crustal thickness map



Tesauro et al. 2008 (GRL)

Regional component of residual mantle gravity anomaly



Tesauro et al., 2007, EPSL



Lithosphere rheology

Heterogeneous structure of Europe's lithosphere: T_e distribution (km)



Tesauro et al., 2009. Geophys. Res. Lett., 36.



Dynamic topography Mediterranean region

Residual topography after correcting for isostatic adjustment (Boschi, Faccenna, Becker, 2010 GRL)





Iberian peninsula

GPS derived present-day vertical motions (Serpelloni et al., 2013, JGR)





Intraplate deformation: plumes and folding

Coupling between deep Earth and surface topography



Guillou-Frottier et al., 2007. Global Planet. Change 58.



Intraplate deformation: folding



Cloetingh et al., 2013. Gondwana Research







Heterogeneous structure of Europe's lithosphere

Ratio of crustal and lithospheric strength



Tesauro et al. 2009 (GRL) Cloetingh et al. 2011 (Tectonophysics)

Plume-lithosphere interactions



Burov & Cloetingh, 2009 (Geophys. J. Int.)



East African Rift system





Gabriel D. Mulibo, Andrew A. Nyblade, Geochemistry, Geophysics, Geosystems (2013) Silas M. Simiyu, G. Randy Keller, Tectonophysics (1997)



Model design



The strength envelope and thermal gradient of the lithosphere are shown on the right side. Grey arrows show the velocity boundary conditions, applied in a direction perpendicular to the model domain. The initial radius of the plume is 200 km.







From: Lavecchia A., Thieulot C., Beekman F., Cloetingh S., and Clark S., Lithosphere erosion and continental breakup: interaction of extension, plume upwelling and melting. Earth and Planetary Science Letters, 2017

From: Lavecchia A., Thieulot C., Beekman F., Cloetingh S., and Clark S., Lithosphere erosion and continental breakup: interaction of extension, plume upwelling and melting. Earth and Planetary Science Letters, 2017



TOPO-EUROPE's science base for energy resources

The energy transition is a challenge for solid Earth science in Europe:

- Geothermal energy
- Natural gas
- Subsurface storage

Research aspects:

- Thermal regime
- Stress fields
- Flow in porous media



Cloetingh et al., 2010, Earth Science Reviews









Data compilation and heat flow extrapolation





Limberger et al., GtES (2014)







Joint European Programme on Geothermal Energy



Conclusions

- Europe through its excellent natural laboratories, its high level of integrated solid earth science and its links to other science fields has a strong potential to be at the forefront of connecting frontier science with societal relevance.
- This applies both to geo-energy and natural hazards.
- The science base is now rapidly developing to bring geothermal energy into power in plate interiors, significantly enhancing its contribution to the global energy transition.



Thanks for your attention!



Group picture in Tectonics Laboratory, Utrecht



