Proposal for the establishment of a Task Force of the International Lithosphere Program (ILP) for 2010-2014 in the theme Contemporary Dynamics and Deep Processes
Numerical Geomechanical Modelling

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I. Introduction

Data compilations of the lithosphere and crustal structure, their physical properties as well as details of the contemporary temperature, stress and strain field have increased significantly over the past decade (e.g. Cloetingh *et al.*, 2006; Tesauro *et al.*, 2008; Heidbach *et al.*, 2008; Kreemer *et al.*, 2003). For some natural laboratories such as the Marmara Sea region, the San Andreas fault or the Chilean subduction zone data density and quality is high enough to resolve 3D details (e.g. Carena *et al.*, 2004, Laigle *et al.*, 2008; Bécel *et al.*, 2009; Zoback and Boness, 2006; Hardebeck and Michael, 2004; Oncken *et al.*, 2003). This increase of knowledge is a result of e.g. active and passive seismic experiments, the increase of regional seismological broadband arrays and the development of new data analysis tools such as the analysis of seismological receiver functions. Furthermore with the advent of modern space geodesy the number of sites with high precision time series is steadily increasing and new tools like PS-InSAR provide unforeseen spatial coverage of precise observations of the Earth's surface deformations.

These recent achievements enable us to study in 3D the processes that deform the lithosphere and shape the Earth's surface, to interpolate between known parameters and field values as well as to predict the deformation in time and space. The numerical tools and concepts that are needed to quantify the contemporary processes of stress and strain accumulation and release through time and space in three dimensions have just begun to arise (e.g. Buchmann and Connolly, 2007; Chéry *et al.*, 2004; Henk, 2008; Hergert, 2009; Masterlark and Hughes, 2008; Kurfeß and Heidbach, 2009). Furthermore, the computational power is nowadays not a limit anymore. Even large-scale numerical models with coupled field equations and several million discretization points can be solved without extensive technical effort. However, despite the increase of input data and availability of numerical tools and computing power, there are still three major challenges that must be addressed: (1) Integration of structural and physical data sets and rock properties from various sources into 3D models. (2) Calibration of the model results by using appropriate model-independent kinematic and dynamic constraints from a wide range of geodisciplines such as structural geology, paleoseismology, satellite geodesy and geophysics. (3) Quantification of the impact of model assumptions and uncertainties of the model parameters on the model results.

These technical issues are of key importance to further enhance our knowledge of the geodynamic processes. To accomplish these challenges a network of experts is needed in order to communicate the state-of the art of technical concepts, pitfalls and to discuss and present the results of case studies of selected natural laboratories where the concepts can be tested.

II. Objective

The overall goal of this network is to identify, assess and quantify the geodynamic processes that deform the Earth's crust and lithosphere by means of 3D geomechanical models. The collaborative project aims at the installation of a network of geoscientists with expertise in 3D geomechanical modelling. Furthermore, the Task Force aims at linking the modellers with the researchers that observe the geodynamic processes in order to foster the communication between them. The linkage of these groups is of great importance since they are often separated to large extend. As a consequence numerical model results are often in contradiction with field observations, or model assumptions are invalid. Vice versa the usage of model results by field geoscientists is sometimes inappropriate and overestimates the validity of the model results. It is expected that the link will produce synergies such as faster exchange and better understanding of the model input and the observations needed for model calibration. Vice versa the field geoscientists will have deeper insight on the limits of model results.

The following three key topics are addressed with the proposed Task Force:

1. Simulation of deformation processes by means of 3D geomechanical models:

- What are the key ingredients for the next generation of numerical models that describe the complete stress tensor and its changes in space and time?
- What is the cause of the systematic deviation between GPS-derived fault slip rates and the ones from paleoseismological and geological fault slip rates?
- How can we analyse the various parts of the deformation signal that is mixed time series from satellite geodetic observations (man-made, groundwater changes, co-, inter- and post-seismic, poro-elastic, aftershock, viscous relaxation)?
- What is the impact of the initial stress field for geodynamic processes such as postseismic relaxation and how do we define the initial stress?
- What is the impact of mass redistribution due to erosion and sedimentation on the tectonic processes at depth?
- To what extend are the co-seismic slip rates that result from joint inversion of InSAR, GPS and seismic wave forms reliable?
- Are models that result in the quantification of change of Coulomb Failure Stress (ΔCFS) appropriate for seismic hazard assessment?
- Is the systematic deviation of geological fault slip rates and the ones that are derived via geomechanical models from GPS observations reality or an artefact of oversimplification of model assumptions?
- What is the link between observed strain rates and stresses?
- Is the magnitude deviation of stress and strain tensor observed in seismic active regions a proxy for the maturity of a fault segment in terms failure by an earthquake?

2. Discussion, evaluation and dissemination of new numerical concepts that can be used to address these key questions.

3. Development of a general assessment scheme for 3D numerical model results with model-independent constraints in order to test the validity of the model results.

III. Scientific Impact

1. Understanding geodynamic processes in general:
   The number of processes that explain essentially the same observations is still unacceptable high and reflects our still limited knowledge which geodynamic process as the source of our stress and strain observations. This reflects both; insufficient input data that constrain the model in order to rule out processes as well as inappropriate model assumptions and boundary conditions. The Task Force will contribute to the discussion whether the discrepancy is an artefact of model setup or if our process understanding is still not sufficient to result in unique answers. The Task Force will foster the exchange of data in order to guarantee that the model input is state of the art.
2. Contribution to seismic hazard assessment:
   A key ingredient of seismic hazard assessment is the contemporary fault slip rate and locking depth. However, so far numerical model estimates that incorporate GPS data deviate substantial from geological fault slip rates. Furthermore, locking depth is so far a rather insensitive model parameter. Both issues are to large extend a conceptual problem of the model approach, a lack of incorporation of further constraints and inappropriate a priori model assumptions. The Task Force envisions to participate into that controversial discussion by assessing the role of model assumptions and uncertainties.
3. Model concepts:
   3D geomechanical model are a major challenge in terms of model validation. The Task Force will foster the communication and exchange of knowledge amongst the widely separated groups of field geoscientists and numerical modellers. This link will contribute to the establishment of the next generation of 3D geomechanical model and concepts to calibrate and validate the model results.

IV. Outreach

In particular this Task Force will provide a platform and a network for young scientists to present and discuss their model concepts. The aim of the Task Force is to attract young researchers as well as experienced experts that are willing to share their expertise in geomechanical modelling in order to jointly improve our knowledge of geodynamic processes.

V. Work plan

- Organisation of a kick-off meeting/workshop at the GFZ Potsdam to setup a network
- Organisation of EGU sessions in Vienna (2011) and Barcelona (2012 onwards)
- Organisation of a 3rd International Geoqus workshop
- Link of the Task Force to the yearly US/Canada expert meeting of the modellers in Boulder, Colorado (geodynamic.org workshops)
- Link to industry related 3D geomechanical reservoir modellers
- Editing of a special issue in an international peer-reviewed journal on the *Achievement of the next generation of geomechanical models*

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Curriculum vitae

Name:	**Oliver Heidbach, Ph.D.**
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Education & Training

Tertiary Education

HSC (Abitur) 1986, 1986 - 1995: Student of Geophysics and Meteorology at the Ludwig-Maximilians University of Munich, Germany and University of Reading, England.

Topic of the 'Diploma' thesis: *Modelling of crustal deformation in the Mediterranean with the finite element method*. Academic degree: Dipl.-Geophys. (Master of Geophysics)

Postgraduate education and degrees

2000 Dissertation at the Faculty of Physics of the Ludwig-Maximilians University of Munich; title of doctoral thesis: *The Mediterranean - 3D Numerical modelling of crustal deformation in comparison with results from satellite geodesy*; Academic degree: Dr. rer. nat. (Ph.D.)

2009 Habilitation at the Faculty of Physics of the University Karlsruhe, Germany; title of habiliation thesis: *Spatial and temporal variability of the contemporary crustal stress pattern of the Earth*; Academic degree: Dr. habil. (Adj. Prof.)

Previous appointments

1994-1995	Research assistant at the Institute of Geophysics, University Munich, Germany in the continental deep drilling project
1995-2000	Researcher at the German Geodetic Research Institute (DGFI) in Munich in the DFG projects *Mediterranean Geodynamics* and *Jordan Rift Dynamics*
2000-2003	Post-Doc at the Heidelberg Academy of Sciences and Humanities in the *World Stress Map Project*
2003-2008	Assistant Professor at the Geophysical Institute, Karlsruhe Universität, Germany
since 2009	Senior Scientist at the GFZ German Research Centre for Geosciences, Germany
since 2009	Adj. Professor at the University Karlsruhe, Germany (Priv.-Doz., Dr. habil.)

Responsibilities

Supervision of 10 diploma thesis and three Ph.D. thesis

Since 2009 head of the World Stress Map Project

Since 2005 chair of the International Lithosphere Program Task Force VII *Temporal and Spatial Changes of Stress and Strain*

2003-2008 Head of the *Tectonic Stress Group,* Geophysical Institute, Karlsruhe University,

2003-2008 Associate head of the World Stress Map Project

2003-2008 Coordinator of the sub-project *Geodynamics and Tectonic Stress* A6 of the Collaborative Research Center 461 *Strong Earthquakes - A Challenge for Geosciences and Civil Engineering* at Karlsruhe University;

2004-2008 Leader of the project *Numerical stress field modelling of the Istanbul Region* of the CEDIM Megacities Project Istanbul

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