Proposal for the establishment of a Task Force
International Lithosphere Program (ILP) for 2021-2025

Global Lithospheric Stress - The World Stress Map in 3D

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I. Introduction

In the early 80s two key advancements triggered the idea of the former ILP president Karl Fuchs to initiate a comprehensive global compilation of data that indicate the orientation of the contemporary maximum horizontal stress orientation (S_{Hmax}) in the Earth's crust. The first was the finding that borehole breakouts are stress indicator and the second was the advent of systematic compilation of earthquake focal mechanisms. Finally, the World Stress Map (WSM) Project was initiated in 1986 as an ILP project to investigate the hypothesis that the intraplate stress pattern is mainly controlled by plate boundary forces. The first public WSM database with over 7300 data records confirmed that the S_{Hmax} orientation is sub-parallel to absolute plate motion (Zoback *et al.,* 1989; Zoback, 1992).

During the second (1996-2008 at the Heidelberg Academy of Sciences and Humanities) and the third phase of the WSM project (since 2009, the WSM is based at the GFZ German Research Centre for Geosciences), the database increased significantly (> 42,000 data records). The resulting higher resolution stress data revealed that plate boundary forces are not enough to fully explain the crustal stress pattern and regional deviations from the plate-wide S_{Hmax} trend e.g. due to density and strength contrast or/and faults can lead to substantial re-orientations resulting in rotations of >50° on spatial scales <100 km (Heidbach *et al.*, 2007; Heidbach *et al.*, 2010; Heidbach *et al.*, 2018; Rajabi *et al.,* 2017; Sperner *et al.,* 2003).

The 3D *in-situ* stress state (stress magnitudes and orientation) is important to several aspects of earth sciences to quantify the processes that drive plate tectonics, to better link the dynamics of the crust to mantle convection models, and to better understand the seismic cycle from an energy conservation perspective (i.e. storage and release of accumulated stresses in terms of total energy loading rates and at smaller scale in application for the management of geo-reservoirs and underground storage sites). However, **there is no systematic compilation of stress magnitude data** and the current WSM database is sparse for the stress magnitudes (Heidbach *et al.,* 2018).

Therefore, **the first major aim of this proposed Task Force is to extend the WSM database with a quality ranked compilation of stress magnitude data**. In addition, the current WSM database only compiles the stress data for the upper 40 km of the Earth's crust to represent the crustal stress. However, most of the global scale geodynamic models need to be calibrated with stress data on the deeper part of the Earth's lithosphere. Therefore, as **the second major aim of this proposed Task Force, we will systematically compile the lithospheric stress data**.

II. Objective

1- *Systematic compilation of a public stress magnitude data:* In the published literature and unpublished (and open-access) industry reports there are massive stress magnitude data. As a part of this Task Force, the proponents as wells as postdocs and PhD students in Germany and Australia will collaborates to systematically compile *in-situ* stress magnitude data. We will also collaborate with international network (see below) to get access to data.

2- *Development of a quality ranking scheme for stress magnitude data*: The current focus of the WSM project is the orientation of S_{Hmax}. The available WSM quality ranking scheme for S_{Hmax} orientation is to a large extent based on standard deviations and often defaults to a mean S_{Hmax} orientation averaged. Considering the mean value over depth is reasonable since the S_{Hmax} orientation in most cases shows variation only within the uncertainty of the observations. As a part of this Task Force, we collaborate with global experts to develop a quality ranking scheme for stress magnitude as the backbone of the database.

3- *Systematic compilation of stress data from the deeper part of the Earth's lithosphere*: The current WSM database only compiles crustal S_{Hmax} orientation at depth < 40km. While the stress information from deeper intervals are required to calibrate global scale geodynamic models. As a part of this Task Force, we will compile earthquake focal mechanism from various catalogue (mainly ISC, Global-CMT and Geofon) to integrate the stresses from the deeper interval into the WSM database.

4- *Use a cluster analysis to automize stress regime assignment for earthquake focal mechanism*: The substantial increase of earthquake focal mechanism data requires a fully automized assessment of the stress regime (style of faulting). As a part of this Task Force, we will use a recently developed tool entitled "ACE" by von Specht *et al.* (2018), which is based on an objective data-driven data selection approach to classify the style of faulting.

III. Cooperation

This WSM extension cannot be handled by a single institution, but needs, as it has been successfully shown in the initial phase of the WSM project, an international collaboration and network of individual scientists, research institutions, service agencies and industry likewise. In the mid-term of the Task Force period we will organize a stress summer school in Australia. In addition, we aim to organise the 4th World Stress Map Conference that will focus on the first results of this new initiative.

IV. Outreach

This Task Force will provide a platform and a network for early career scientists to present and discuss their findings on lithospheric stresses and their applications in various spatial scales. Several PhD students are already involved in the previous studies leading to this proposal. The aim of the Task Force is to continue attracting early career researchers as well as experienced experts that are willing to share their expertise in lithospheric stresses, analysis of stress magnitude and geomechanical modelling in order to jointly improve our knowledge of geodynamic processes.

V. Key partners within this planned Task Force

In this proposed Task Force, we plan to closely collaborate with the following researchers and institutions all of which are already long-standing partners of the proponents:

1- Maria Ask (Luela University of Technology, Sweden)
2- Marcelo Assumpcao (University Sao Paulo, Brasil)
3- David Coblentz (Los Alamos National Laboratory, USA)
4- Francois Cornet (University Strasbourg, France)
5- Xiaofeng Cui (Inst. of Crustal Dynamics, China)
6- Damien Delvaux (Royal Museum of Central Africa, Belgium)
7- Susana Custodio (University Lissabon, Portugal)
8- Thomas Finkbeiner (KAUST, Saudi Arabia)
9- Cecilia Guzman (University of Buenas Aires, Argentina)
10- Richard Hillis (University of Adelaide, Australia)
11- Andrew Kingdon (British Geological Survey, UK)
12- Jens Lund-Snee (Stanford University, USA)
13- Kuo-Fong Ma (National Central University, Taiwan)
14- Marcos Moreno (University of Santiago, Chile)
15- Paola Montone (INGV, Italy)
16- Birgit Müller (Karlsruhe Institute of Technology, Germany)
17- Karsten Reiter (TU Darmstadt, Germany)
18- Bernhard Seinberger (GFZ Potsdam, Germany)
19- Mark Tingay (Petronas, Malaysia)
20- John Townend (GNS, New Zealand)
21- Douglas Schmitt (Purdue University, USA)
22- Martin Schoenball (Lawrence Berkeley National Laboratory, USA)
23- Duvvury Subrahmanyam (National Institute of Rock Mechanics, India)
24- Furen Xie (Institute of Crustal Dynamics, China)
25- Moritz Ziegler (GFZ Potsdam, Germany)
26- Günter Zimmermann (GFZ Potsdam, Germany)
27- Mark Zoback (Stanford University, USA)

VI. References

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Rajabi, M., Tingay, M., Heidbach, O., Hillis, R., Reynolds, S. (2017). The present-day stress field of Australia. Earth-Science Review 168, 165-189.

Sperner, B., Müller, B., Heidbach, O., Delvaux, D., Reinecker, J., Fuchs, K. (2003). Tectonic stress in the Earth's crust: advances in the World Stress Map project. Geological Society, London, Special Publications 212, 101-116.

von Specht, S., O. Heidbach, F. Cotton, and A. Zang (2018), Uncertainty reduction of stress tensor inversion with data-driven catalogue selection, Geophys. J. Int., 214(3), 2250–2263.

Zoback, M.L., Zoback, M.D., Adams, J., Assumpcao, M., Bell, S., Bergman, E.A., Blumling, P., Brereton, N.R., Denham, D., Ding, J., Fuchs, K., Gay, N., Gregersen, S., Gupta, H.K., Gvishiani, A., Jacob, K., Klein, R., Knoll, P., Magee, M., Mercier, J.L., Muller, B.C., Paquin, C., Rajendran, K., Stephansson, O., Suarez, G., Suter, M., Udias, A., Xu, Z.H., Zhizhin, M. (1989). Global patterns of tectonic stress. Nature 341, 291-298.

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Curriculum vitae Dr. Mojtaba Rajabi

Current Positions: Research Officer, School of Earth and Environmental Sciences
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I am a geoscientist with demonstrated experience in crustal stress and wellbore geomechanics. I have over 12 years of extensive research experience in academia and industry. Since 2010, I have worked on the stress analyses of **>30 sedimentary basins from across the world**. In particular, **I have led the Australian Stress Map Project**, since 2012. I was one of the key driving scientists in compiling the 2016 release of the World Stress Map and am the **Deputy-Head of the World Stress Map Project**. I have received **18 prestigious awards and prizes** for my research including the *Early Achievement Award of Australian Society of Exploration Geophysicists* for significant contributions to geophysics in Australia by a scientist under the age of 36, the *Flinn-Hart Award of International Lithosphere Program* for my extensive work on the global tectonic stresses, and the *EAGE Louis Cagniard Award*.

Education and professional experience

PhD, Earth Sciences 2012-2016: Australian School of Petroleum, University of Adelaide, Australia. Topic of the PhD thesis: *Present-day crustal stress pattern across spatial scales - analysis and interpretation from plate-wide to local-scales*

MSc, Geology 2006-2009: University of Tehran, Iran. Topic of MSc thesis: *Fracture analysis and petrophysical evaluation using well log data in one of the Iranian southwestern oil reservoirs*

BSc, Geology, 2001-2006: Azad University of Shiraz, Iran

Responsibilities

Since 2019	Research Officer in Mine Geomechanics, University of Queensland, Australia.
2016-2019	Research Associate at the University of Adelaide. Worked on the geomechanics and petrophysics of eastern Australian sedimentary basins.
2012-2016	Led the Australian Stress Map project at the University of Adelaide. My research resulted in the development of the most comprehensive stress map of Australia.
2013-2015	Consultant Geoscientist at the Ikon Geomechanics, Adelaide, Australia. Worked on the structural geology and wellbore geomechanics based on client projects.
2011-2012	Project Geoscientist in consulting companies in Iran to investigate different aspects of structural geology and petrophysics.
2003-2005	Research and Teaching Associate at the Azad University of Shiraz.

5 recent key publications by the proponent relating to the proposed TF

Heidbach, O., **Rajabi, M.**, Cui, X., Fuchs, K., Müller, B., Reinecker, J., Reiter, K., Tingay, M., Wenzel, F., Xie, F., Ziegler, M.O., Zoback, M.-L., Zoback, M., (2018). The World Stress Map database release 2016: Crustal stress pattern across scales. Tectonophysics 744, 484-498.

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Curriculum vitae Dr. Sebastian von Specht

Current Positions: Researcher, National Central University, TAIWAN
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Education and professional experience

PhD, Earth Sciences 2015-2019: Research Training Group "Natural hazards and risks in a changing world" at University of Potsdam, Germany. Topic of the PhD thesis: *Likelihood-based optimization in strong-motion seismology,* Academic degree: Dr. rer. nat. (Ph.D.)

MSc, Earth Science (focus: geophysics) 2011-2014: University of Potsdam, Germany. Topic of MSc thesis: *Spatiotemporal variations of the seismic wavefield at The Geyers geothermal area (California) from ambient noise cross-correlations*

BSc, Geology, 2007-2011: University of Potsdam, Germany

Responsibilities

2015-2016 Research and Teaching Associate at the University of Potsdam.

5 recent key publications by the proponent relating to the proposed TF

von Specht,S., O. Heidbach, F. Cotton, A. Zang (2018). Uncertainty reduction of stress tensor inversion with data-driven catalogue selection. Geophys. J. Int. 214, 2250–2263.

G. Kwiatek, P. Martínez-Garzón, K. Plenkers, M. Leonhardt, A. Zang, **S. von Specht**, G. Dresen, M. Bohnhoff (2018). Insights Into Complex Subdecimeter Fracturing Processes Occurring During a Water Injection Experiment at Depth in Äspö Hard Rock Laboratory, Sweden. Journal of Geophysical Research: Solid Earth, 123, 6616–6635.

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A. Zang, O. Stephansson, L. Stenberg, K. Plenkers, **S. Specht**, C. Milkereit, E. Schill, G. Kwiatek, G. Dresen, G. Zimmermann, T. Dahm, M. Weber (2017). Hydraulic fracture monitoring in hard rock at 410 m depth with an advanced fluid-injection protocol and extensive sensor array. Geophys. J. Int. 208, 790–813

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Current Positions: Senior Scientist, Helmholtz-Centre Potsdam
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Education and professional experience

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.)

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.)

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

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

Key responsibilities

Since 2009	Head of the World Stress Map Project
Since 2012	Head of the working group *Analysis and Modelling of Crustal Stress*
2005-2014	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 project *Geodynamics and Tectonic Stress* A6 of the Collaborative Research Center 461 *Strong Earthquakes- A Challenge for Geosciences and Civil Engineering at Karlsruhe University.*

5 recent key publications by the proponent relating to the proposed TF

Heidbach, O., **Rajabi, M.**, Cui, X., Fuchs, K., Müller, B., Reinecker, J., Reiter, K., Tingay, M., Wenzel, F., Xie, F., Ziegler, M.O., Zoback, M.-L., Zoback, M. (2018). The World Stress Map database release 2016: Crustal stress pattern across scales. Tectonophysics 744, 484-498.

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