Newsletter No. 01/ July 2017

WSM newsletter and new project website

by Oliver Heidbach (GFZ Potsdam)

The key purpose of the re-launch of the WSM newsletter is to inform researchers and users of the WSM database on the progress of the project. We will present here our advancements and results on research dedicated to the contemporary in-situ stress state of the Earth's crust, software development, job announcements and key publications from WSM team members, our international collaborators, but also from your research. We will also announce here new project activities and invite you to participate actively in the further development of the WSM to share visions and ideas with us.

The newsletter will appear two or three times per year and reaches currently more than 3,000 subscribers from academia and industry. The website links, e-mails and doi's in the WSM newsletter text are interactive links that bring you with a mouse click to the related website in order to access articles and further detailed information. You are invited to contribute to the WSM newsletter to announce your key research results, opinions or comments with short articles. The editorial deadline for the next newsletter to be send in early December is November 15th.

Along with the launch of the new WSM newsletter format we also completely revised the design and content of the WSM project website at www.world-stress-map.org. The service CASMO (Create a Stress Map Online) to produce a user-defined stress has not changed, but the stress map generation has been accelerated and the service is now using the new WSM database release 2016.

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New WSM website

The new WSM website with a new design and revised structure. Latest news and the WSM newsletter can be found under News.

The new WSM database release 2016

by the WSM Team

Since 1986 the World Stress Map (WSM) project compiles systematically information on the present-day tectonic stress in the Earth‘s crust. For the 30th anniversary of the project the new WSM database release 2016 has been compiled with the double amount of data records (n=42,870). Focus of this new compilation was to fill areas with sparse stress information and to resolve the stress pattern on different spatial scales. About 4,000 of the approximately 22,000 new data records were derived from borehole logs (Heidbach et al., 2016). In particular we fully integrated new or updated national stress compilations from Australia, Canada, China, Germany, Iceland, Italy, New Zealand and Switzerland. With this significantly higher data density in some regions we can now resolve stress pattern heterogeneities on regional and local scale as well as with depth.

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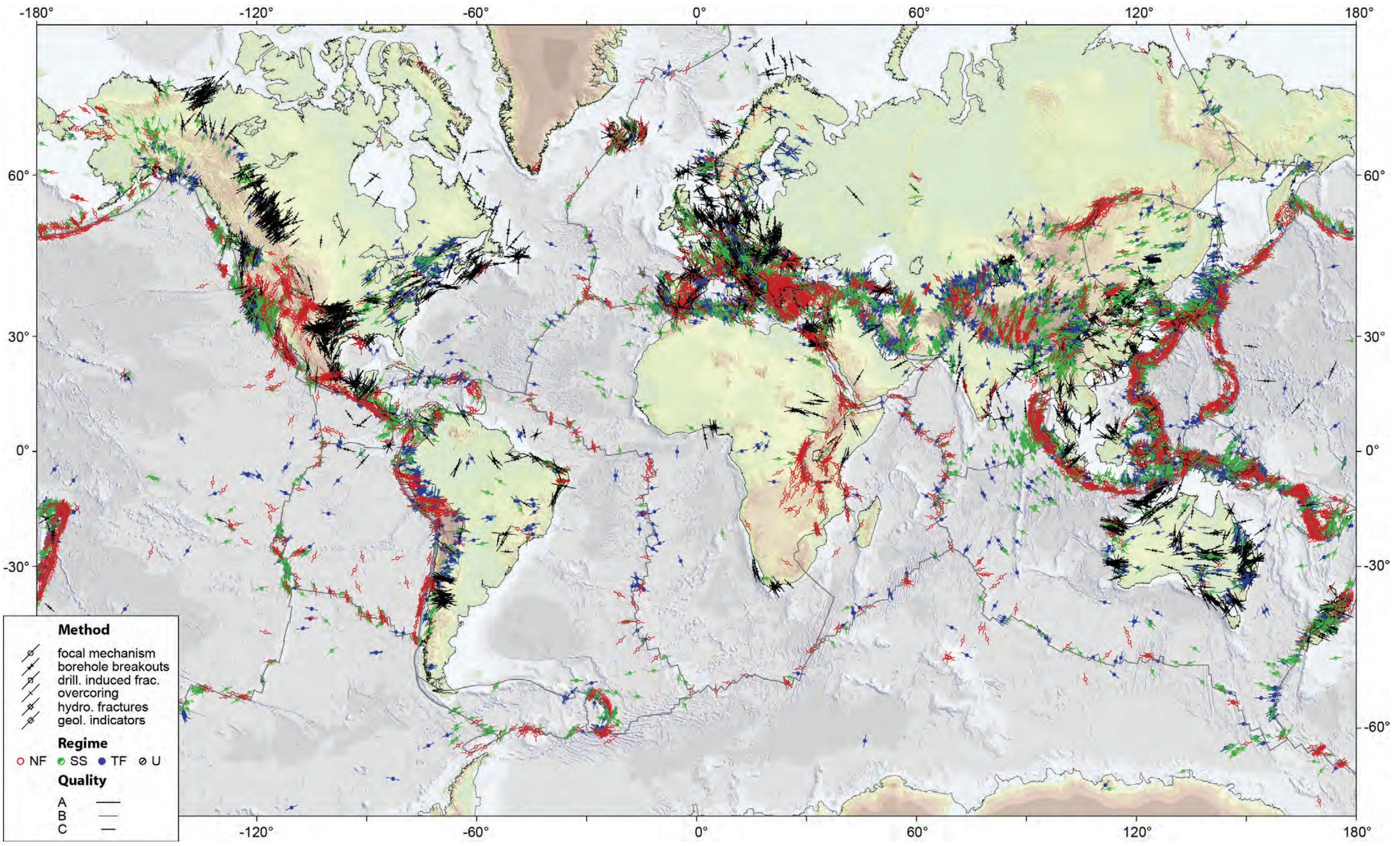

World Stress Map 2016

Map displays the contemporary crustal stress in the upper 40 km based on the World Stress Map (WSM) database release 2016 (Heidbach et al., 2016). Lines show the orientation of maximum horizontal stress (S_{Hmax}) from different stress indicators; line length is proportional to data quality. Displayed are the 20,757 data records with A-C quality according to the WSM quality ranking scheme except those that are labelled as possible plate boundary events (Heidbach et al., 2010). Colours of the symbols and lines indicate the tectonic stress regime with red for normal faulting (NF), green for strike-slip (SS), blue for thrust faulting (TF) and black for unknown (U) tectonic stress regime.

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30 Years and beyond - WSM project phase IV 2017-2023

by Oliver Heidbach (GFZ Potsdam)
and Mojtaba Rajabi (Univ. Adelaide)

The 30 year history of the WSM project can be divided into three phases. It started with the initiation in 1986 as a project of the International Lithosphere Program under the leadership of Mary-Lou Zoback. The first comprehensive global compilation of information of the contemporary crustal intra-plate stress published by Zoback et al. (1989) had 3,574 data records. At the end of this phase in 1992 approximately 7,700 data records were compiled (Zoback, 1992) and d the research results are summarized in special issue of the Journal of Geophysical Research (1992, Vol. 98/B8).

The second phase of the WSM project lasted from 1996-2008 as a research project of the Heidelberg Academy of Sciences and Humanities, Germany headed by Karl Fuchs and Friedemann Wenzel. During this phase the project intensified the compilation from borehole data, started to include stress information from plate boundary zones and provided an easy-to-use access of the WSM database via the online service CASMO to produce user-defined stress maps. The resulting WSM database release 2008 had 21,750 data records (Heidbach et al., 2010) and the key research results were published in a special issue of Tectonophysics (2010, Vol. 492).

The third phase of the WSM project started in 2009 with the transfer to the Helmholtz Centre Potsdam, German Research Centre for Geosciences GFZ where it is maintained and further developed in the GFZ section 2.6 „Seismic Hazard and Stress Field". In the past eight years we intensified the international collaboration and fully integrated new or updated national stress compilations from Australia, Canada, China, Germany, Iceland, Italy, New Zealand and Switzerland. The resulting new WSM compilation has 42,870 data records (Heidbach et al., 2016) with almost 4,000 new data records from deep boreholes.

The next phase IV of the WSM project will last from 2017-2023. In these six years we will continue to compile stress data with focus on areas that are not well represented. Due to the increasing and frequent influx of new data we intend to change our release policy to a more frequent updates of the public WSM database, e.g. every half year or more often if necessary. To facilitated the update of the database we will transfer the database to professional database software, fully integrate the literature and reference database and revise a number of data record fields to modern standards. In particular we will facilitate the submission of new data records with an online user interface. We also envision to revise, update and extend the stress data analysis guidelines for the individual stress indicator. However, our key vision for the next years is to extend our stress data compilation with stress magnitude data.

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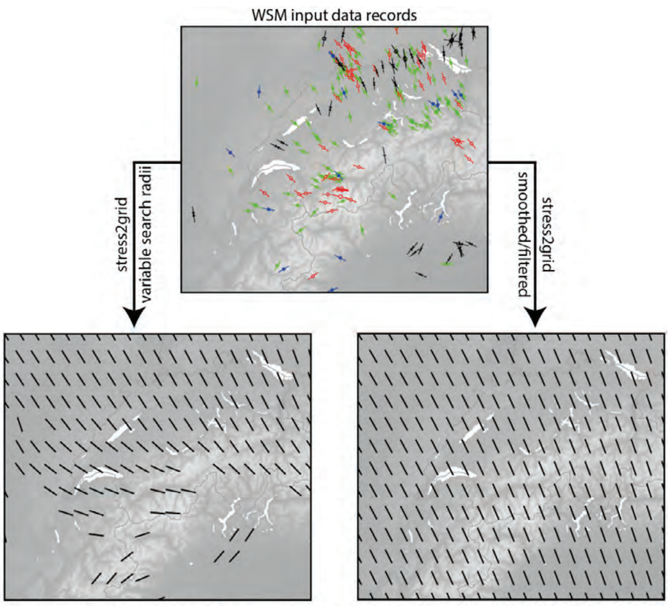
Mean S_{Hmax} orientations on user-defined grids: Release of the Matlab script *Stress2grid*

by Moritz Ziegler (GFZ Potsdam)

The distribution of data records for the maximum horizontal stress orientation S_{Hmax} in the Earth's crust is sparse and very unequally. To analyse the stress pattern and its wavelength or to predict the mean S_{Hmax} orientation on a regular grid, statistical interpolation as conducted e.g. by Coblentz and Richardson (1995), Müller et al. (2003), Heidbach and Höhne (2008), Heidbach et al. (2010) or Reiter et al. (2014) is necessary. Based on their work we wrote the Matlab® script Stress2Grid that provides several features to analyse the mean S_{Hmax} pattern. The script facilitates and speeds up this analysis and extends the functionality compared to the publications mentioned before.



The script provides two different concepts to calculate the mean S_{Hmax} orientation on a regular grid. The first is using a fixed search radius around the grid point and computes the mean S_{Hmax} orientation if sufficient data records are within the search radius. The larger the search radius the larger is the filtered wavelength of the stress pattern. The second approach is using variable search radii and determines the search radius for which the variance of the mean S_{Hmax} orientation is below a given threshold. This approach delivers mean S_{Hmax} orientations with a user-defined degree of reliability. It resolves local stress perturbations and is not available in areas with conflicting information that result in a large variance. Furthermore, the script can also estimate the deviation between plate motion direction and the mean S_{Hmax} orientation. The script, the accompanying manual and several input files are provided by Ziegler and Heidbach (2017).

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Smoothed stress maps

From stress data records to mean S_{Hmax} orientation on a regular grid. Top: Stress map with data records from the Western Alps. Bottom: The Stress2Grid script derives a smoothed mean S_{Hmax} orientation with a fixed search radius of 500 km (right) and a mean S_{Hmax} orienation using different search radii and variance threshold of < 25°.

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Impact of earthquakes and glacial loads on a nuclear waste repository

by Jeoung-Seok Yoon (GFZ Potsdam)

To assess the long-term safety of a repository for disposal of radioactive waste it is required to consider all possible loads that could affect the geomechanical integrity of the barriers. Two of the natural loads are earthquakes occurring at nearby faults and glacial loads. In our paper (Yoon et al., 2016) we investigate the combined impact for different scenarios for the repository in Forsmark, Sweden.

We use a commercial 2D Particle Flow Code which is a discrete element based geomechanical simulator. This tool enables the representation of geological discontinuities in various scales (fractures, joints, faults) in a heterogeneous way. Furthermore, we extended the code with dynamic fault rupture (see Yoon et al., 2015). The remote earthquake at a fault is simulated by instantaneous release of the strain energy stored along the fault after build-up of the rock stresses. This strain release produces earthquakes and the seismic waves propagate and attenuate through the model. The earthquakes are simulated under different present day in situ stress conditions and under estimated future glacial cycles of Weichselian type.

The modelling results demonstrate that glacial ice cover has an effect on the fault activation magnitude. They show that in the complex geologic setting of Forsmark, activation of a fault may trigger displacement of other faults in particular at their tips and intersection areas. Furthermore, the model results show that the magnitudes and the stress drops of the induced seismic events associated with fracture slip tend to be the largest under stress condition with high anisotropy, i.e. where the ratio of the maximum and the minimum horizontal stresses is large. Among the seven tested in situ stress conditions, the occurrence of an earthquake under the stress condition at the time of forebulge in front of the ice cover is found to produce the largest induced moment magnitude (~M_w 3). These results indicate that more scenario simulations are needed to better understand the impact of natural stress changing processes on a repository and we currently work on more advanced 3D simulations.

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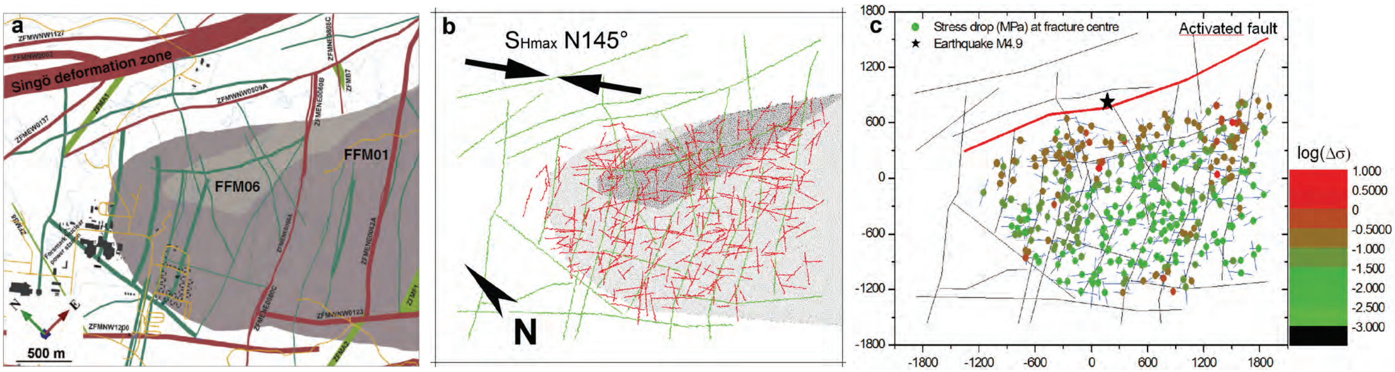

Model geometry and results

a. Integrated geological repository model. **b.** Discrete element based geological model, containing the faults (green) and the discrete fracture network (red). **c.** Dynamic fault rupture simulation show earthquake load (red trace, hypocenter by star) and distribution of stress drop associated with coseismic slip.

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How heterogeneous is the tectonic stress at different scales?

by Martin Schoenball (Stanford University)

Regional and global data sets show that tectonic stress varies smoothly and continuously, revealing coherent domains of stress. However, resolving stress on a scale of core to boreholes shows strong heterogeneities, often larger than on a regional scale. It is assumed that small scale heterogeneities result from contrasting rheology and elastic parameters or active faults and fractures.
In our recent paper (Schoenball and Davatzes, 2017), we continue the discussion of how to describe stress heterogeneity. We analyze more than 4 km of image data from two boreholes drilled from the same well pad in a vertical and deviated trajectory, respectively. We observe strong heterogeneities with stress rotations as large as 60° over wavelengths from less than a meter to more than 100 m along each borehole. For both boreholes, the mean and the standard deviation of stress orientation indicators (borehole breakouts, drilling-induced fractures and petal-centerline fractures) agree to the limit of the resolution of our method although measurements at specific depths may not.

We then test the bias on determining stress orientations if only shorter intervals of image logs are available. For both boreholes, we observe an increase of the standard deviation with increasing logged interval. For intervals longer than 600 m, the obtained stress orientations and standard deviations converge towards the same values for both boreholes. Similar behavior is found for global data from the new WSM database release 2016. This demonstrates that stress heterogeneity is a site characteristic and that stress measurements over intervals >1 km are necessary to reliably characterize that heterogeneity.

We would like to encourage more research to better characterize the heterogeneity of the tectonic stress field. Better understanding of the scales of stress heterogeneity has major implications for subsurface engineering applications, specifically on hazard estimates near faults with known orientation. Furthermore, the pattern of the stress heterogeneity is a major ingredient for dynamic earthquake rupture models and has links to the magnitude-frequency relation.

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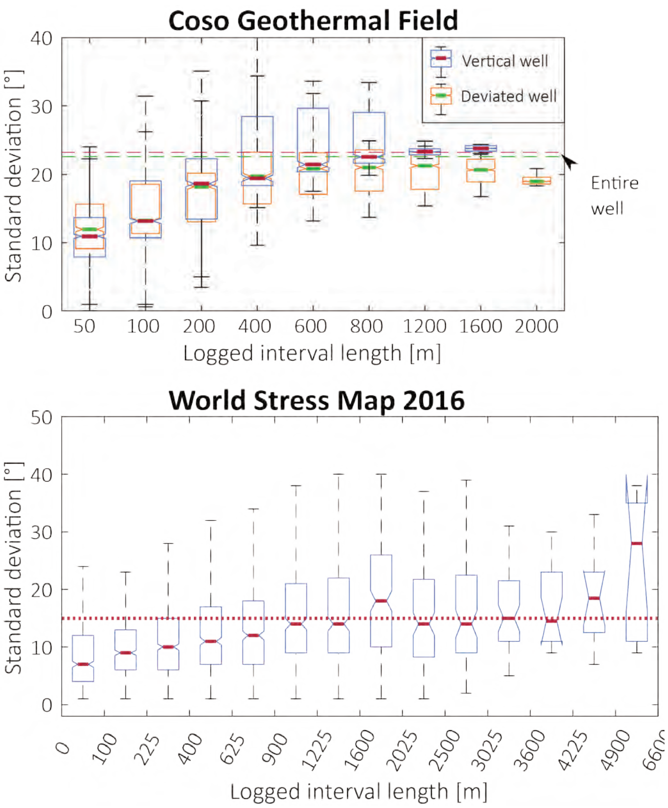

Standard deviation vs. log length

Estimated from data restricted to given logged interval length. Top: Data from two boreholes in the Coso Geothermal Field masked to synthetic logged interval lengths. Bottom: Data from the 2016 WSM. For both data sets we obtain a saturation of standard deviation at a length scale of about 1 km.

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Schoenball, M., and Davatzes, N. C. (2017). Quantifying the heterogeneity of the tectonic stress field using borehole data, J. Geophys. Res. Solid Earth, 122, http://doi.org/10.1002/2017JB014370

Mojtaba Rajabi received the **Flinn-Hart Award** of the International Lithosphere Program

by Oliver Heidbach (GFZ Potsdam)

We are proud to announce that Mojtaba Rajabi from the University of Adelaide, Australia, was awarded the Flinn-Hart Award by the International Lithosphere Program. The award is presented to outstanding young scientist for contributions to the solid earth sciences covered by the International Lithosphere Program. During the past five years Mojtaba Rajabi published 13 peer-reviewed papers and finished his PhD in October 2016 with great success.

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His research project developed the most comprehensive understanding of the present-day stress state in Australia to date. He has personally more than doubled the amount of stress orientation data that have been collected for the Australian Continent, including developing stress maps for 14 new geological provinces in Australia, as well as the first maps for most Coal Seam Gas basins in Australia. The key paper of his research is an invited contribution to the journal Earth Science Reviews (Rajabi et al., 2017) on the "The present-day stress field of Australia". Mojtaba made a remarkable contribution to the WSM database release 2016, personally analysing over 1000 wells in Iceland, Australiaand New Zealand, which is probably more than any other individual in the WSM history. He was one of the key driving scientists in compiling the new WSM database 2016 and has been recently elected by the WSM team as the deputy head of the WSM for the next phase of the project from 2017-2023.

Rajabi, M., Tingay, M., Heidbach, O., Hillis, R., and S. Reynolds (2017). The present-day stress field of Australia. Earth Science Reviews, 168, 165-189, http://doi.org/10.1016/j.earscirev.2017.04.003

Job announcements

by Fabrice Cotton and Oliver Heidbach (GFZ Potsdam)

The Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences is the national research centre for Earth sciences in Germany. With approx. 1280 employees, the GFZ is conducting interdisciplinary research on the "System Earth" and the influence of humans on the planet. As a member of the Helmholtz Association, it is part of Germany's largest science organization. Section 2.6 "Seismic Hazard and Stress Field" invites applications for the following three positions:

1.) Research scientist position on physics-based ground-motion modeling and seismic hazard evaluation
2.) PhD position on stress and strain accumulation in stable part of Western Europe
3.) PhD position on Marmara Sea earthquake simulation model

Further information on these positions, requirements and application details are given at: www.gfz-potsdam.de/en/career/job-offers. You can also visit our section website to learn more about our team and the current project we are working on.

AGU 2017 Session T021 In Situ Stress Field: Observations, Uncertainties, and Modeling

Natalia Zakharova from the Columbia University and her colleges Chandong Chang (Chungnam National University, Republic of Korea) and Hiroki Sone (GFZ Potsdam, Germany) are organizing a session on in situ stress. Note that the deadline for abstract submission is August 2nd 2017.

Session description: The knowledge of in situ stresses is important for a variety of applied and fundamental problems in geosciences, including large-scale tectonics, fault mechanics, reservoir geomechanics, and stability of engineering structures. In recent years, significant improvements in the stress field analysis have been driven by the need to address seismic hazards, both natural and human-induced, but in situ stress information remains sparse, especially offshore. While stress is known to vary consistently at regional scale, local variations are often observed, and remain challenging to predict and quantify. In addition, temporal evolution of in situ stresses needs to be better understood for accurate assessment of seismic hazard and deformation processes. We invite results on recent in situ stress observations, as well as experimental and modeling studies, which advance our understanding of stress patterns and heterogeneity in the shallow crust, and advance our capability to evaluate and predict in situ stresses.

Publications related to research on crustal stress

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