Mapping and monitoring the crustal stresses and fault stabilities north of Iceland by use of QuakeLook's stress inversion algorithm.

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Extended abstract.

The crustal stresses are causing all deformations and fracture slips. Still very little efforts are normally made to estimate the crustal stress tensor field because it was long accepted that the earthquake mechanism puts only weak constraints on the stresses causing the slip. But, this is not true if the crust contains not one but many fractures having different orientations. The rock masses contain numerous fractures of “all” orientations. The assumption of having only one single fracture within the earthquake volume is not reasonable for microEQs. All fractures have negative CFS (Coulomb Failure Stress) when not slipping. T*he old single fracture analysis faild to add the very strong constraint that all other fractures are stable, only the slipping fracture has nonnegative CFS.* The QuakeLook method includes these missing constraints.

The QuakeLook stress inversion method is based on a number of most reasonable and well motivated assumptions. It is assumed that the earthquakes occurs when the maximum Coulomb failure stress (CFS) for the sliding fracture has grown to 0.0 MPa.

To get all six parameters more assumptions are needed. The vertical stress is assumed to equal the lithostatic stress (the pressure of the overburden). The rock mass is assumed to contain a large number of different fracture orientations (typically for seismically active volumes). Thus it is assumed that Coulomb's failure criterion can be used instead of the weaker Bolt's criterion. Coulomb's criterion gives 4 constraints and the vertical stress requirement gives one more. The required sixth requirement (the stress field is in every point described by 6 components) is normally achieved by requiring that the deviatoric deformation energy is smallest possible (the nature avoids overkill, compare soap bubbles). In the same way the water pressure (needed in the Coulomb's failure criterion) is assumed to be smallest possible and also that the stress field is quite varying when going to smaller scales as supported by direct stress measurements. I*f these assumptions are reasonable approximations, the complete stress tensor at the hypocenter that caused the earthquake slip can be determined*. Thus, each observed microearthquake will give one in situ stress tensor observation.

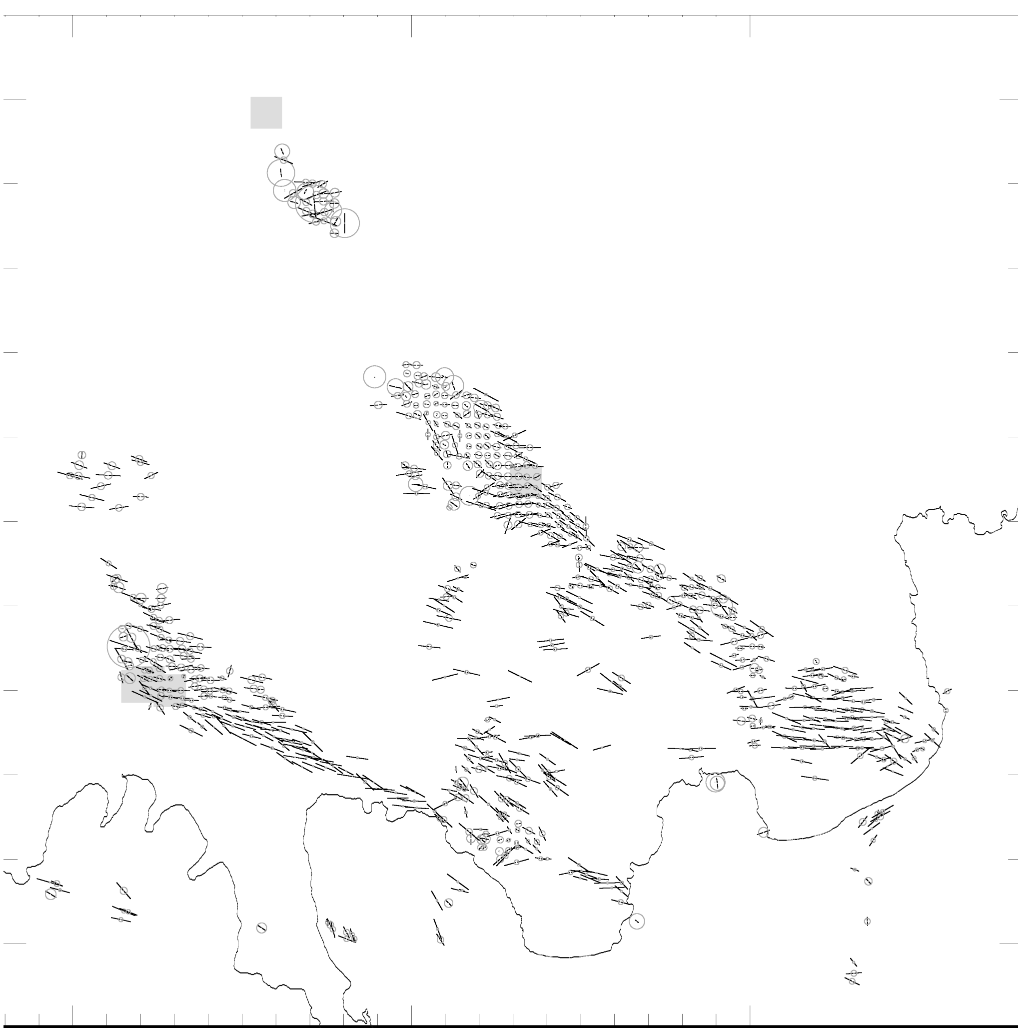
The stress tensor field is actually composed of six scalar fields. It is not easy to visualize a six parameter field. In the following stress maps only a few different interesting aspects of the stress field and of the crustal stability are shown.

The mapped area is divided into squares, each microearthquake within a square means one stress tensor observation. For each square with a required number of such observations their median value is chosen as the stress observation of the square. The position of the observation is given by the median values of the microearthquake locations. In this way the stress maps are produced.

One stress component which is chosen to be mapped here is **the shear stress** which is half the deviatoric stress (the difference between largest and smallest principal stress). Large deviatoric stress is expected to be seen close to locked fault parts (asperities). Many of the M>4 EQs in the Hengill area plus the June 17 2000 M=6.6 SIL EQ occurred at places showing large shear stresses.

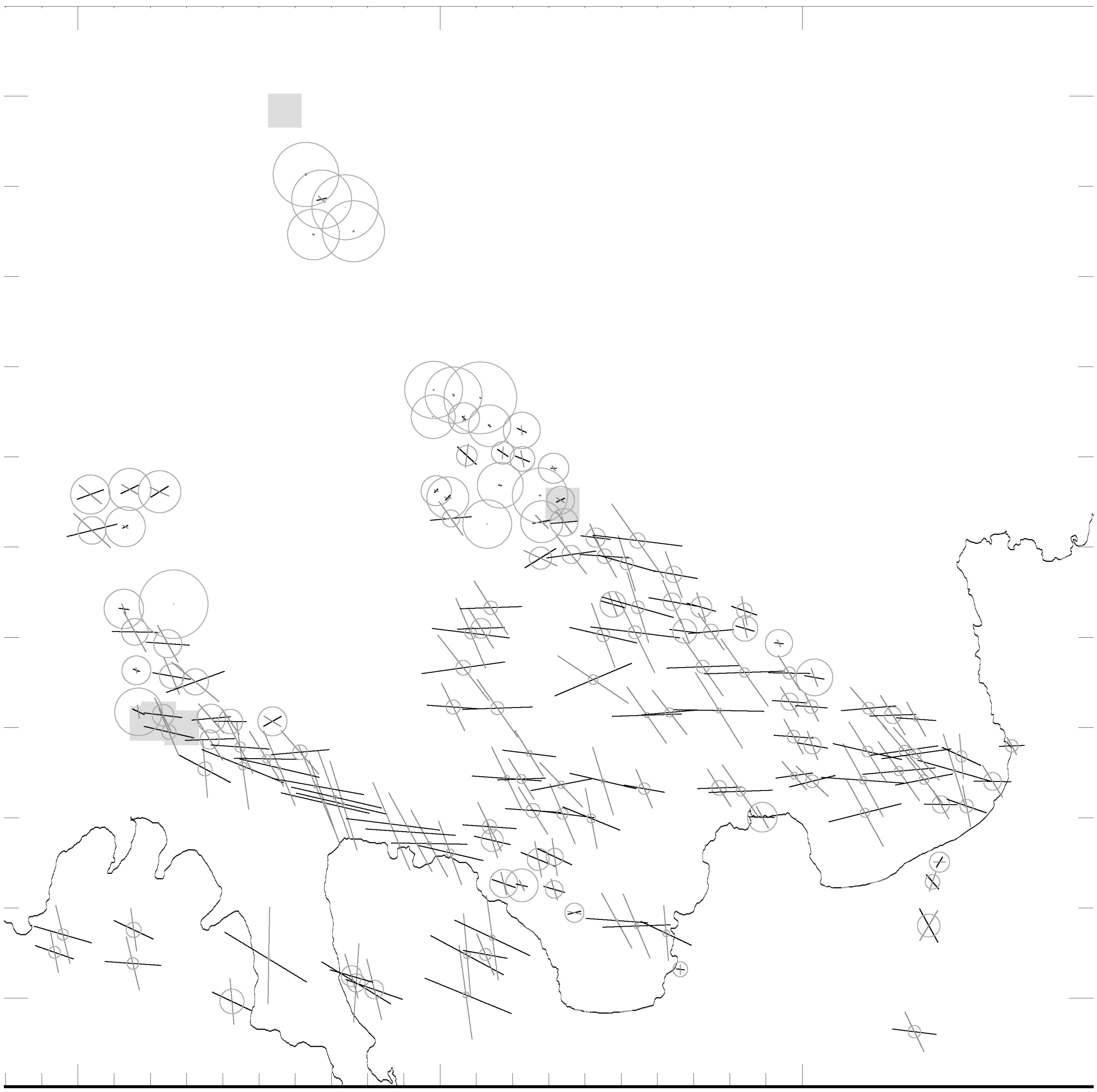
The **directions of the largest horizontal compression**, SH, are mapped as they together with the fault orientation determine the source mechanism (SH along the fault gives a normal faulting component while SH perpendicular to the fault may give reverse faulting component). In the maps they are scaled with the horizontal deviatoric stress, SH-Sh, as this shows the significance of the directions.

The fault stability (Coulomb Failure Stress, CFS) is of course of main importance.The largest EQs in Iceland seem to be mostly strike-slip events on subvertical faults. The Coulomb failure stress for vertical strike slip faults is therefore also mapped. For each square the fault strike having largest CFS-value (SS-events) is given by a line and the length of the line is scaled according to its CFS-value. This is done both for right-lateral (RL) and left-lateral (LL) strike-slip. Note that they are often very similar in size but with some 60 degrees strike difference. **The size of the shear stresses** are determined by the rock friction (assumed to be 0.6) and by the strength of the fractures when the effective normal pressure is zero (assumed to be 1 MPa). Together with the assumed rock strength the maximum shear stress within the Icelandic crust will be 17 MPa. The static stress drop of a strike-slip EQ will be some 6 to 7 MPa. It is in agreement with the SS M=6.6 EQ June 21 2000 where no clear asperity was involved. **The size of the principal stresses** are mostly determined by the depth of the hypocenter (the vertical stress, SV, is assumed to equal the lithostatic stress). The horizontal principal stresses are in the range SV-11.3 MPa to SV+31.2 MPa (with the assumed parameter values). **The following map** gives the shear stresses by scaled circles (smallest 5.5 MPa and largest 8.1 MPa). In addition the directions of the maximum horizontal compression are shown and scaled with the horizontal deviatoric stress (SH-Sh). It is based on the seismicity Jan 1 1997 to Aug 31 2014 and the map gives 777 independent observations. The centrum of the map is 66.5N, 17.7W, and the size is 133x133 sqkm. The number of observations within each square (every mark in the map pertains to its own square) is 6-606, the square size is 1.4x1.4 sqkm. Note the areas of large shear stresses. Note also that the maximum horizontal compression in many cases have a very dominating direction along the faults which indicates a normal faulting component in addition to the strike-slip mechanism. Note also the high similarity with the stress directions within blocks. The gray squares mark the positions of the largest EQs from 2002 to 2013 within the map.



All these stress estimates are independent (no stress observation is used twice).

It is interesting to note the very varying stresses, in a fractured crust the stresses must be very complex at any scale.



The fault stability is illustrated in the map beabove.The circles again gives the shear stress as in the previous map but the lines now shows the strike and size of the maximum CFS for strike-slip on vertical faults. The black lines pertain to right-lateral (RL) vertical strike-slip (SS) mechanisms, and the gray to left-lateral (LL). In both cases the strikes for the most unstable orientations are shown. Again the time period is Jan 1 1997 to Aug 31 2014. The square sizes are 4.4x4.4 sqkm and the required minimum number of observations within each square is 20 (maximum is 2352). Note again that all values are independent (based on different stress observations (events)). The shear stresses vary between 5.8 to 9.2 MPa, the CFS values (the length of the lines) are in the range -10.6 MPa to -1.1 MPa (the longest lines). Note that in general the RL and LL assumptions give similar stabilities with some 60 degrees difference.

The **short term warnings** (increasing instability days and hours before the earthquakes) work rather well in the SIL and Hengill areas where the median ML is about 0.35 before the 1997-2000 EQs. North of Iceland the median ML is one magnitude larger before the 2002, 2012, and 2013 earthquakes. This means that one cannot expect to get as good short term warnings. The stress maps before the three EQs will still be included in the presentation.