Microearthquakes, stresses, crustal stability, and earthquake warnings.

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Microearthquakes and stresses.

A new seismic network in Iceland was presented in the Blue Book 1986. One of the main aims was to create a seismic network allowing analysis of very small microearthquakes. The results of the microearthquake analysis at the FOA network in Sweden 1979-1982 had shown that each earthquake give the same amount of information independent of size, at least in the magnitude range -1 to 5. The number of microearthquakes (giving crustal information) increases with a factor of 8 if the magnitude threshold is reduced one unit.

Sigurdur Th. Rögnvaldsson, to which this seminar is dedicated, was early to realize the power of microearthquake analysis and his excellent work was much too early interrupted.

From the beginning the automatic microearthquake analysis that was implemented into the SIL network included location, extraction of signal parameters, estimation of source parameters including seismic moment and fault radius, and fault plane solutions. It turned out that statistical methods including foreshock activity rate worked rather well as earthquake warnings before the larger Hengill earthquakes 1997 and 1998. However, the June 17 2000 EQ was not proceeded by high foreshock activity. This indicated that a more physical approach was motivated.

The early paper by McKenzie 1969 stated that microearthquake source mechanisms could only put weak constraints on the stress tensor causing the slip. That conclusion is true only if the volume around the EQ contains just one fracture. All microearthquake analysis (both FPS and high accuracy locations) show that the crust is very fractured. If McKenzie's conclusion is wrong it is possible to rely on Coulomb's criterion instead of the weaker Bott's criterion when estimating crustal stresses. By relating the water pressure to the stress tensor it turned out that the absolute in situ stress tensor causing a microearthquake could be estimated. The results of such stress estimates has been shown in a number of presentations here in Iceland and in different European scientific meetings. The results show that the place of the June 17 2000 EQ was seen in the stress mapping years before and the later studies (the SAFER project) show that there were clear indications during the last weeks and days before the EQ.

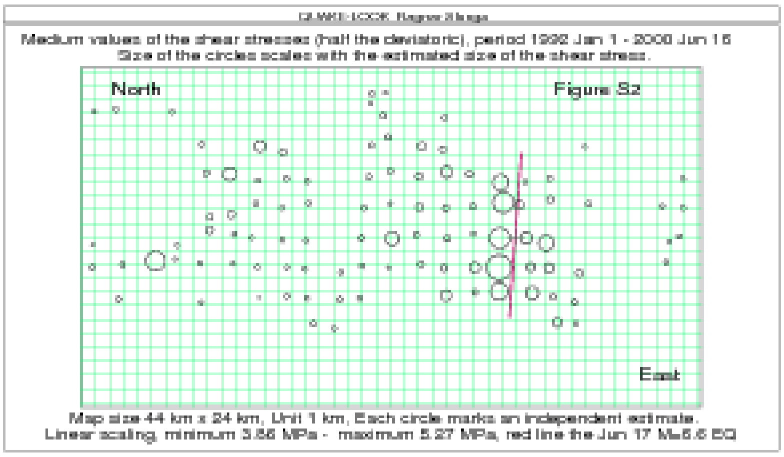
In conclusion the extremely promising results of the estimation of the absolute crustal stress tensor field by use of microearthquakes show how correct the early ideas of the Blue Book were, earthquake warnings require in situ information and microearthquake analysis is the key.

The stress pictures before the major earthquakes along SIL 1998-2008.

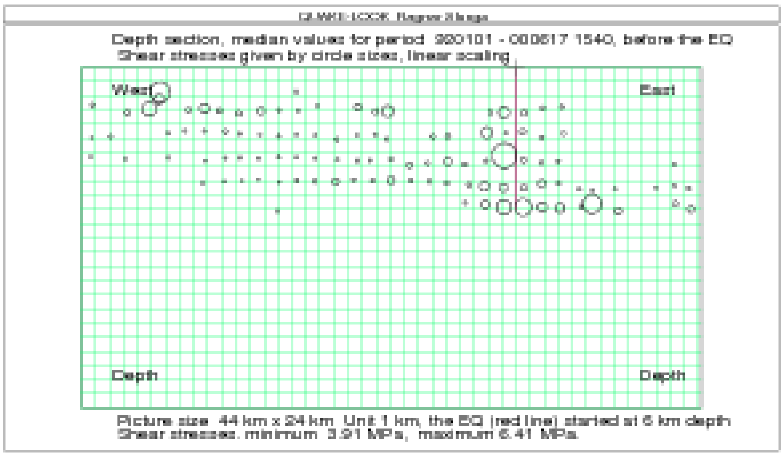
The stress field is a tensor field which is hard to illustrate. In the following scalar parameters given by the stress tensor estimates will be shown. One simple scalar is the size of the deviatoric field which in terms of shear stress is given by $(\sigma_1 - \sigma_2)/2$

where σ_1 is the largest principal stress (compression positive) and σ_3 is the smallest principal stress. Large shear stresses means large elastic energy and can be expected at locked parts to which stress may build up. In the following maps and/or depth sections the area/section has been divided into squares and the median of the observations at each square (with more than 10 observations) have been computed. The scalar stress is shown by marks (mostly circles) with mostly linear scaling. Note that all marked estimations are statistically independent of each other as they are based on different microearthquakes. No smoothing is made.

The following picture shows the shear stresses in the SIL area estimated from more than 8000 microearthquakes in the area between 1992 and 2000. Note that 5 of the 6 largest shear stress estimates are situated along the fault of the coming June 17 2000 EQ. The stress estimates are also shown in a depth section.



The shear stress map.

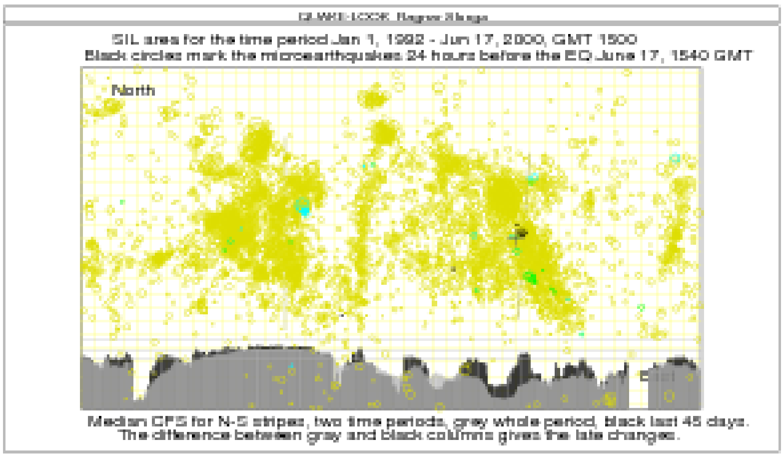


Depth section.

Note that the largest estimated shear stresses are found close to the fault and at about 6 km depth which is close to the hypocenter. High stresses are also found close to the epicenter of the two 1998 EQs, June 4 and Nov 13. The June 21 EQ 3.5 days after the June 17 EQ was also well predicted by its closeness to failure at the time of the June 17 EQ.

Shortterm warnings

It is obvious that large Coulomb Failure Stress, CFS, which is expected before an EQ. However, if the coming EQ is at an asperity, a locked part, large shear stresses are the expected long term indication as seen above. However, the size of the CFS shows how close a fault is to rupture. For short term warnings the closeness to failure is a key parameter. Monitoring the CFS for expected earthquakes is the most direct way to achieve short term EQ warnings. In the following map showing the microearthquakes the gray columns at the bottom shows the median CFS within N-S stripes for the whole 8 year period. The black columns show the median CFS for the last 45 days only. The period ends just before the June 17 2000 EQ. The largest increase in CFS, difference between the black and gray columns, occurs exactly at the fault of the coming June 17 EQ. The black event marks show the foreshocks during the last 24 hours befor the EQ.



Results like this is very typical before coming earthquakes, also the late May 29 2008 M=6.3 EQ was clearly indicated by monitoring CFS. As the stress information is independent of the conventional statistical EQ warning algorithms the value is great and even may improve deterministic EQ warnings based on absolute CFS, not only ΔCFS.

Conclusions

The inclusion of stress estimates which are totally independent of the statistical parameters so far used in EQ warning algorithms means a significant improvement of the quality of the warnings. The very promising results also indicate that for short term warnings the situation will be highly improved.