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Building a Monitoring Network for Studying Hydrological changes in Relation to Earthquakes

Helga Rakel Guðrúnardóttir[1]

[1]*Stockholm University, Sweden (helga.rakel.gudrunardottir@gmail.com)*

Hydrological changes in relation to earthquakes have been documented for centuries (*Wang at al.* 2010). These include water-level or flow, temperature and chemical composition changes. It is not surprising that large earthquakes can affect groundwater near the epicentre but what is surprising is how far from the earthquake epicentres these changes can be seen. Co-seismic changes have been seen in wells that are hundreds or even over a thousand kilometres away from earthquake epicentres (*Matsumoto at al.* 2011; *Wakita* 1996; *Wang at al.* 2010). One example is the 1994 Hokkaido-toho-oki (M 8.1) earthquake where the water level fluctuated rapidly over 2 m in a well located 1200 km from the earthquake epicentre (*Wakita* 1996).

Hydrological changes are also seen before earthquakes. These pre-seismic changes have given hope that they can be used to predict earthquakes. Pre-seismic hydrological changes were used together with other observations in the successful prediction of the 1975 Haicheng (M 7.3) earthquake in northern China, saving the lives of up to 100,000 people (*Wang at al.* 2010; *Stefánsson* 2011). Other successful predictions, based on hydrological data, have yet to be achieved (*Wang at al.* 2010) despite efforts in several places. The underlying physics of these pre-seismic hydrological changes is still not fully understood. Unravelling the mysteries behind these phenomena is a prerequisite for using them to successfully predict earthquakes.

Hydrological changes in relation to earthquakes have been studied in Iceland. Radon concentration in groundwater was regularly measured in the South Icelandic Seismic Zone (SISZ) from 1977-1993(*Einarsson et al.* 2008). Data series are available from nine different stations and changes were seen before and after the 2000 earthquakes in the SISZ.

In the years 2000 to 2001, water-level was monitored in a number of low-temperature geothermal boreholes on the Tjörnes Fracture Zone (TFZ) in northern Iceland with promising results (*Björnsson* 2000; *Björnsson at al.* 2000). After the 17 of June 2000 (M 6.6) earthquake in the SISZ, Björnsson monitored the water level in boreholes in that area, and saw changes in water-level for the following 21 of June (M 6,6) earthquake and then the recovery of the whole area in the weeks following (*Jónsson et al.* 2003). Interestingly 24 hours before the 17 of June earthquake the water-level dropped by over 5 m, for a period of a few minutes, in a low-temperature geothermal borehole at Flúðir, 10 km north of the fault plane (*Björnsson at al.* 2001). However this was not seen as an earthquake precursory phenomenon until after the earthquake struck (*Stefánsson at al.* 2003). Unfortunately these monitoring programs were discontinued due to organizational changes.

Stockholm University (SU) has run a geochemical monitoring program on the TFZ since 2002 (*Claesson et al.* 2004). In this project changes in groundwater chemistry were seen 5-10 weeks prior to an earthquake (M 5.8) in September 2002 (*Claesson et al.* 2004; *Claesson et al.* 2007) where the monitoring site was approximately 90 km from the epicentre (*Claesson et al.* 2007). Chemical changes were also seen before the M 5.6 earthquake in October 2012 and the M

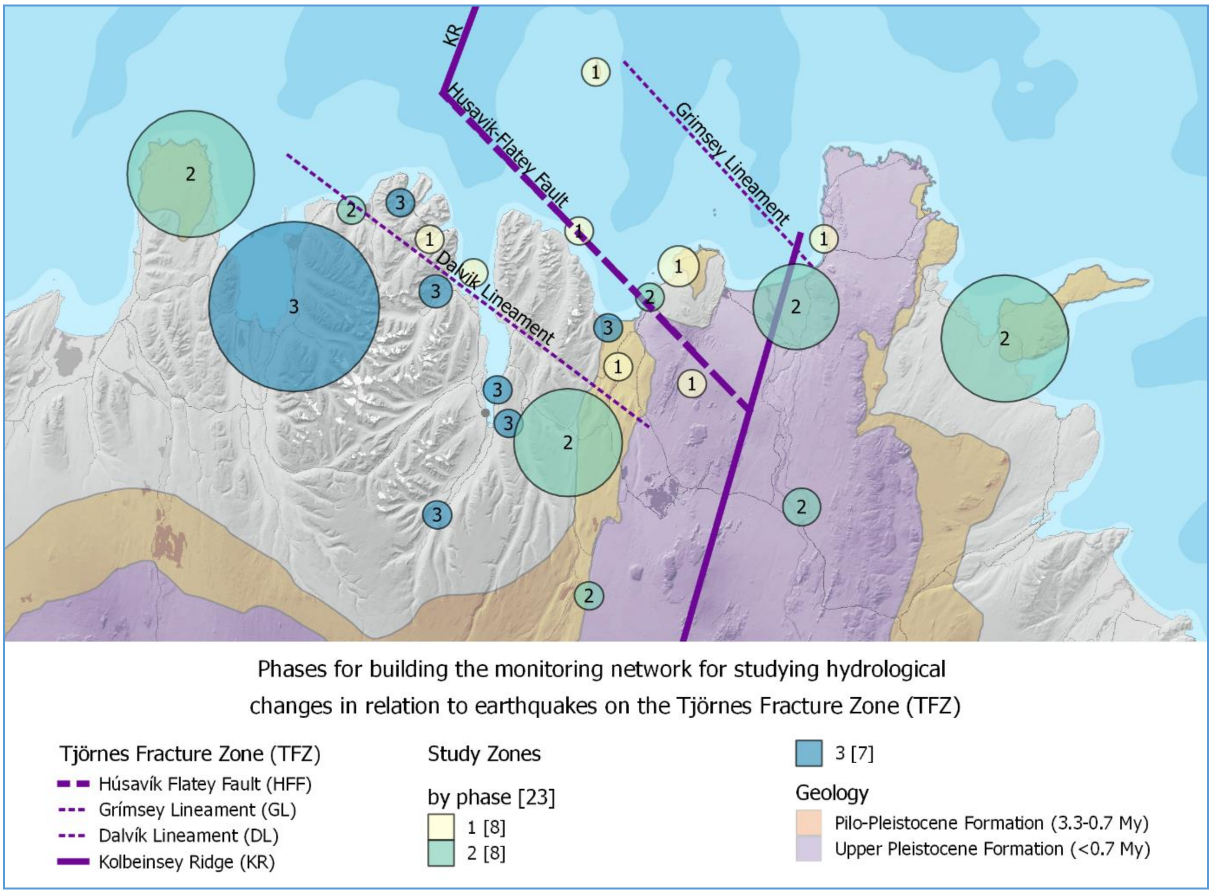
5.5 earthquake in April 2013. Both earthquakes had an epicentre distance of 77 km (*Skelton et al.* 2014). This hydrochemical monitoring program consists of taking manual water samples once a week and sending them to a laboratory for analysis. Data on precursory phenomena can therefore not be used in a predictive capacity.

The question presents itself: how do we best construct a network of monitoring stations to automatically collect reliable data on hydrological changes in relation to earthquakes in the TFZ for the purpose of studying the underlying physics and possibly, as a result of this study, use the data in earthquake hazard assessments?

Hydrological changes have and are being studied around the globe. For example in the US, Russia, Turkey, Taiwan and Japan. The Japanese earthquake prediction program was started in 1962 (*Hirata* 2004) and in 1978 hydrological and geochemical monitoring was formally added to the program (*Wakita* 1996; *Matsumoto at al.* 2011). Today Japan has one of the most sophisticated monitoring network for study hydrological changes in relation to earthquakes (*Itaba et al.* 2010).

The network is composed of 40 observatory stations. All stations monitor water level or flow rate and most stations also measure water temperature and borehole strain. Some stations are also equipped with seismometers, GPS and radon measurement equipment. The stations built after 2006 are of a different design. Each station has three purposely drilled boreholes at different depths, 30 m, 200 m and 600 m (*Itaba et al.* 2010). At the bottom of the boreholes are seismometers and in the water column are temperature and water level sensors. Borehole strainmeters and GPS are in some wells and data is transferred in real time.

It seems logical to try to learn from the Japanese design when designing a monitoring network for Iceland. But I propose, to begin with, that we use existing boreholes rather than drilling specially for hydrological monitoring. In Iceland there are already over 8000 boreholes and in the TFZ area there are over a thousand.



Phases for building the monitoring network for studying hydrological changes in relation to earthquakes on the Tjörnes Fracture Zone (TFZ)

I propose 23 study zones in the TFZ where each study zone consists of one or more boreholes. I also propose three phases for building the monitoring network (Fig. 1).

In the first phase emphasis is on study zones close to or on the three main fault lines and where after initial inspection there is a high likelihood of finding suitable boreholes for monitoring. In the second phase are study zones where the borehole selection depends on the selections in the first phase or where there are many unknowns at this moment. In the third phase are study zones that would enhance the completeness of the network but have many unknown factors and require more work than the first two study zones. Two study zones in phase three, Siglufjörður and Dalvík, could however be added much sooner to the system by utilizing data that the geothermal district heating companies in these places are already gathering.

To survive this project needs to have stable and long term financing. A small department within the IMO or the University of Iceland would give this project the stability it needs to be successful. It would also remove the risk of the project dying with changes in personnel. One scientist in 50-100% job with access to a technician would be sufficient to run this project. However while setting up the monitoring stations more help might be needed.

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