Geochemical modelling of aquifer water from Húsavík, northern Iceland and hydrochemical responses to earthquakes

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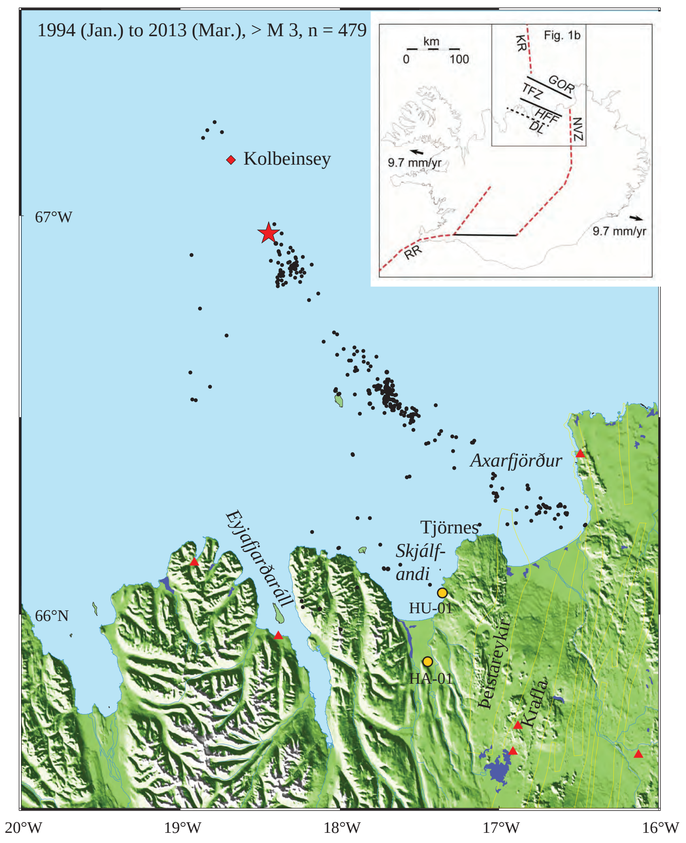
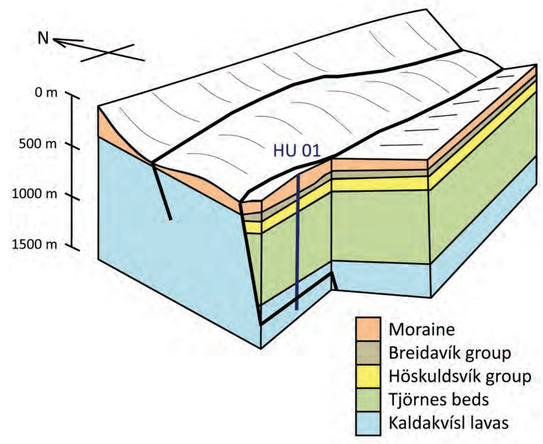
Introduction



The Húsavík area is located in northern Iceland on a transform fault system called the Tjörnes Fracture Zone (TFZ). This zone, which connects the Northern Volcanic Zone to the Kolbeinsey ridge, is part of the mid-Atlantic spreading ridge system and subject to a constant crustal stress build-up with a frequent number of earthquakes above M > 4. Stockholm University has monitored water chemistry from two wells in the Húsavík area: one in Húsavík (HU-01) for more than 10 years and one in Hafralækur (HA-01) since 2008. A large M 5.8 earthquake in 2002 and several M 4-5 earthquakes in 2008 and 2012-2013 occurred within the TFZ and the connecting Kolbeinsey ridge system. This has provided a unique opportunity to study water chemistry changes in response to stress build-up and subsequent earthquakes.



Block diagram showing the geological sequence on the Tjörnes peninsula, which are displaced by the Húsavík Flatey Fault (HFF). The location of borehole HU-01 is shown. Note that this borehole might cross the HFF fault zone close at an approximate depth of 1200 meters. This implies that the main aquifer is located within the fault-damaged rocks.

Water sampling and chemistry

Water is sampled on a weekly basis from wells HU-01 and HA-01 and shipped to Stockholm University for cation, anion and isotope analysis (δ18O and δD). Alkalinity and pH measurements are done both onsite and in Stockholm later on. Average water chemical composition of HU-01 and HA-01 is listed below.

Borehole	Húsavík, HU-01	Hafralækur, HA-01
Depth (m)	~1500	~100
Temp. (°C)	~94	~73
pH (23 °C)	9.1	10.2
Alkalinity (meq/kg)	0.31	1.773
Conductivity (µS/cm)	~16500	264
Major ions (mmol/kg):		
Si	1.47	1.43
Al	0.001	0.003
Ca	5.99	0.08
Mg	0.0006	0.0003
Fe	0.0002	0.0001
Na	36.18	3.00
K	0.84	0.03
Cl	46.43	0.28
SO_4^{2-}	0.88	0.25

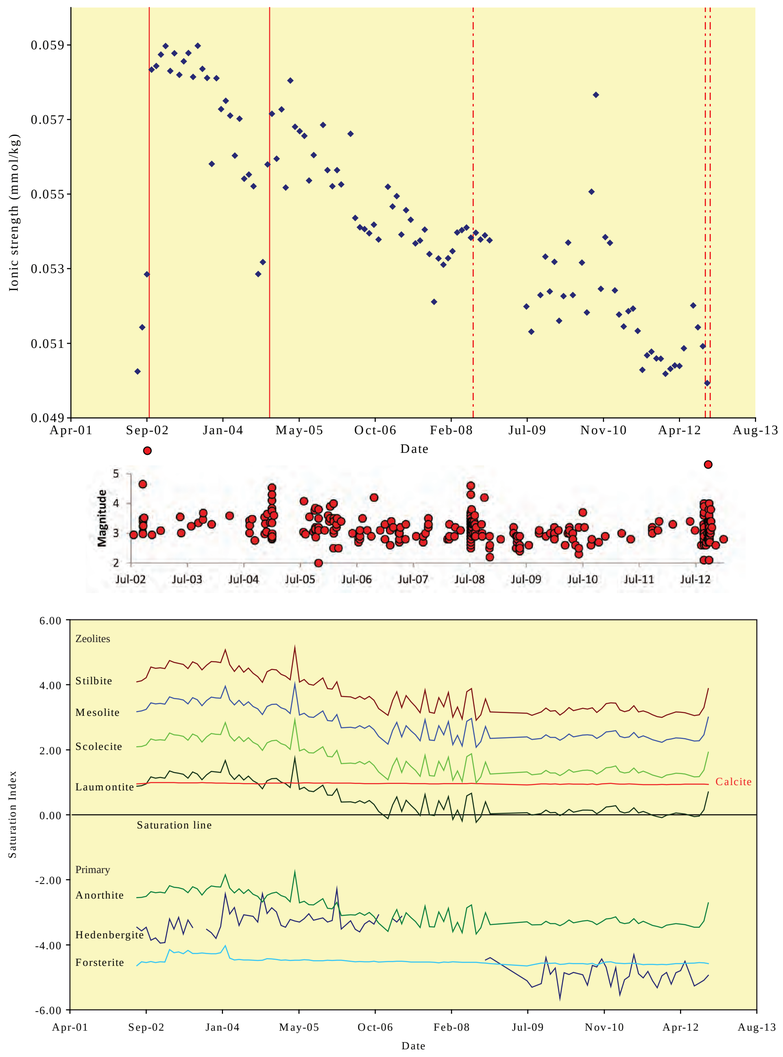
Margareta Andrén at well HU-01

Alasdair Skelton inspecting well HA-01 in Hafralækur

The borehole HU-01 in Húsavík was originally drilled for commercial use, but is now maintained for scientific purposes and to sustain a bathing facility. The borehole is a non-flowing artesian well with an ambient water level of 20 m below the ground surface. A pump maintains a constant flow of ~0.5 l/s into the bath and brings groundwater the remaining 20 m to the surface. HA-01 is a free-flowing artesian borehole, which penetrates young basalt (Laxá) and basalt-derived sediments.

PHREEQC modelling

Results from Húsavík, HU-01 from July 2002 to Oct. 2012

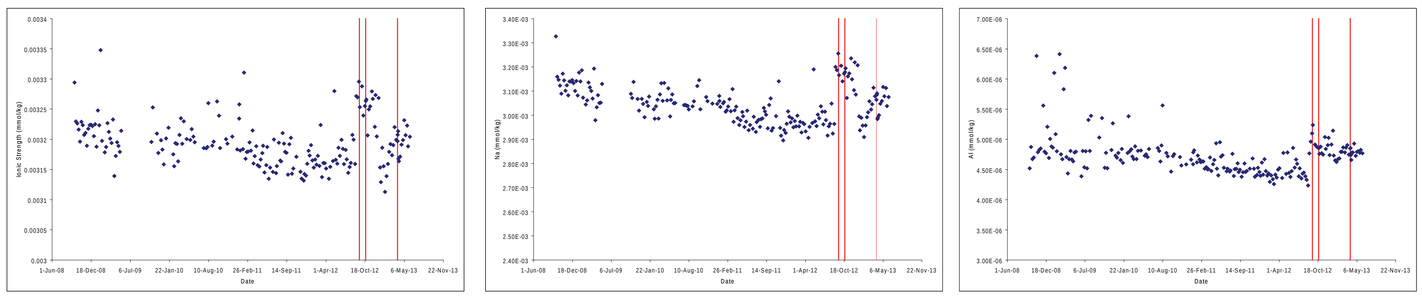


The M 5.8 earthquake, which occurred on September 16, 2002 within the Tjörnes Fracture Zone caused rupturing of a hydrological barrier resulting in an influx of groundwater from a second aquifer, which was recorded by 15-20% concentration increases for some cations and anions as reflected by the ionic strength. This was followed by hydrochemical recovery, which was periodically interrupted by re-fracturing events. Despite re-fracturing, hydrochemical recovery reached completion 8-10 years after the earthquake.

Earthquake activity during the 10-year monitoring period in Húsavík based on data from the Icelandic Meteorological Office.

All primary basaltic minerals are undersaturated, whereas several zeolite minerals, clays and calcite are saturated. This is in accordance with what is observed in nature and reported in the drilling report by Orkustofnun (1969).

Results from Hafralælur, HA-01 from July 2008 to July 2013



The red solid lines mark the earthquakes M 4.5 on Sept. 19, 2012; M 5.6 on Oct. 21, 2012 and M 5.5 on April 2, 2013, respectively. Sodium (Na) concentrations are showing the largest changes of the major cations in response to stress build-up and earthquakes.

Conclusions

Hydrochemical monitoring records fault healing after an earthquake.
The timescale of fault healing is 8-10 years.
In Hafralækur, certain ions (e.g. Na) give precursor signals prior to earthquakes. However, stable isotopes are the more effective precursors (see Margareta Andrén's poster).

References

[1] Claesson L., Skelton A., Graham C., Dietl C., Mörth M., Torssander P., Kockum I., 2004. Hydrogeochemical changes before and after a major earthquake. Geology 32, 641-644.
[2] Tómasson, J., 1969. Jarðlaganið. Jarðhiti vid Húsavík. Orkustofnun, 46 pp.