Changes in groundwater chemistry preceding consecutive earthquake swarms in northern Iceland

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Introduction

Changes in groundwater chemistry have been reported before earthquakes. These changes have been attributed to fracturing induced by pre-seismic dilation. However, most studies of such precursory phenomena lack sufficient data to rule out other explanations unrelated to earthquakes. For example, reproducibility has not been shown. Here we show similar changes in groundwater chemistry preceding consecutive earthquake swarms in northern Iceland.

Methods

Samples of pre-Holocene groundwater were collected on a weekly basis from a borehole at Hafralækur, northern Iceland (65.8725°N 17.4525°W) since October 2008 and analyzed for δ^2H, $\delta^{18}O$ and cation concentrations.

Results

Figure 1 compares δ^2H and $\delta^{18}O$ of groundwater samples from Hafralækur with the world meteoric water line (WMWL) . This figure shows that the borehole receives groundwater from four sources (1-4). Each source is seen as a cluster of data elongated parallel to WMWL suggesting mixing between pre-Holocene and Holocene groundwater components. Separation of these clusters indicates differing degrees of rock buffering.

Figure 2 shows time series for (a) deviation of δ^2H from its average value (-127 ± 2 ‰) recording mixing of Holocene and pre-Holocene groundwater components, (b) deviation of $\delta^{18}O$ from WMWL recording rock buffering, and (c) Na and Si concentrations.

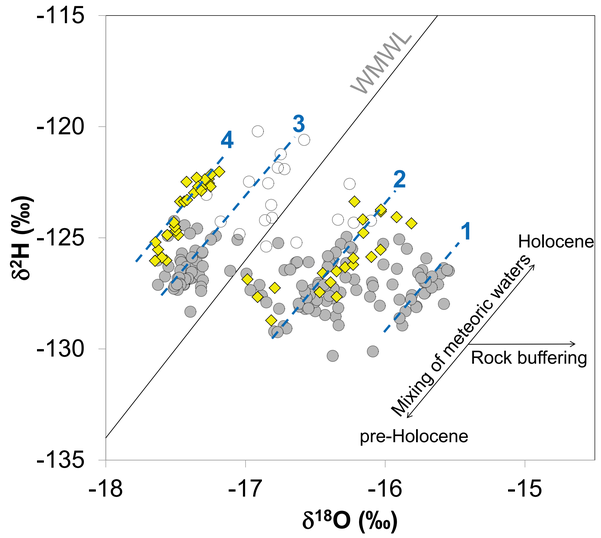

Figure 1: $\delta^{18}O$ – δ^2H plot for groundwater samples from Hafralækur. Samples collected between October 2008 and April 2012 are shown as dark grey circles. Samples collected before each earthquake swarm are shown as yellow triangles. Samples collected at other times are shown as open circles. Sources 1-4 are shown. Isotopic shifts caused by mixing between meteoric waters and rock buffering are shown.

Discussion

From October 2008 to April 2012 (3.5 years), multiple abrupt changes of $\delta^{18}O$ accompanied by a steady decrease of the concentrations of Si and Na record an overall trend of successive sealing off of more extensively rock buffered groundwater sources.

During a period of 4-6 months before each earthquake swarm, a gradual increase of δ^2H towards heavier values was followed by a gradual return towards lighter values beginning 3-4 weeks before each swarm. These changes can be explained by a gradual influx of Holocene groundwater followed by its dilution with pre-Holocene groundwater. We argue that this occurred in response to pre-seismic dilation.

Each earthquake swarm was followed by an abrupt change of $\delta^{18}O$. We attribute these changes to switching between groundwater sources.

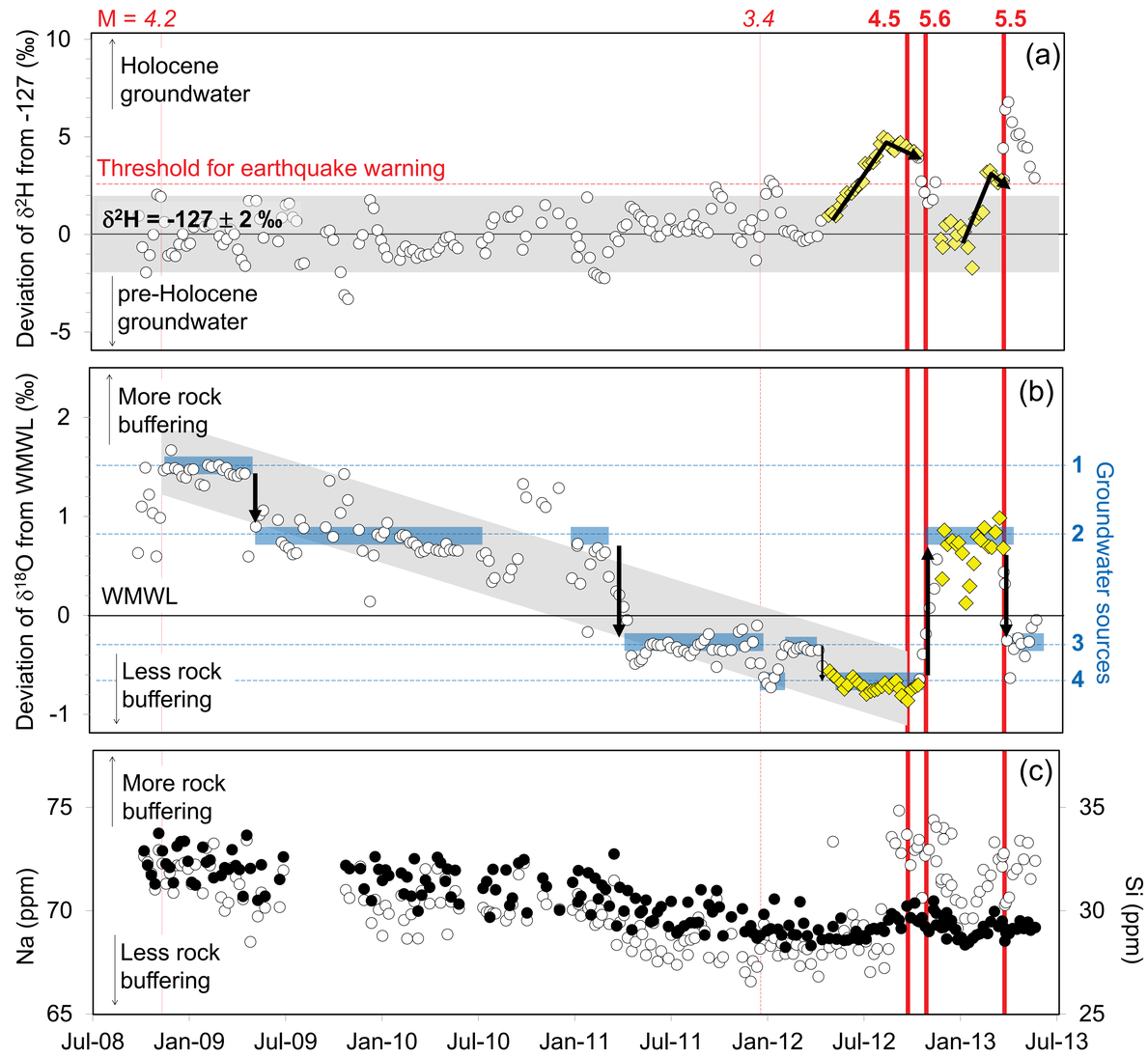

Figure 2: Time series for (a) deviation of δ^2H from -127 ± 2 ‰ (2 standard deviations), representing the average value of δ^2H before the earthquake swarms, (b) deviation of $\delta^{18}O$ from WMWL, calculated as: $8 \times \delta^{18}O + 10)/\delta^2H$, and (c) Na and Si concentrations. Earthquakes for which Hafralækur is within the strain radius ($r = 10^{0.45M}$) are shown as red lines. Precursors to the onsets of the earthquake swarms are shown. These are 1) increase of δ^2H from -127 ± 2 ‰ towards heavier (less negative) values (light yellow shading), and 2) return of δ^2H towards lighter (more negative) values accompanied by increasing concentrations of Na and Si. The threshold deviation of δ^2H on the basis of which a warning could have been issued before the onsets of each earthquake swarm is shown

Conclusion

Gradual changes of δ^2H preceded both earthquake swarms. A threshold shift could have been set that would have allowed for a warning to have been issued before both earthquake swarms..