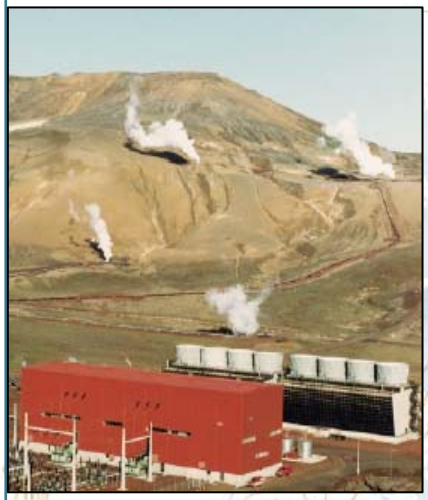

Use of new Sodium/Lithium (Na/Li) geothermometric relationships for HT geothermal fluids from Iceland

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Department of Geothermal Energy (GTH)

HITI final meeting, Athens, Greece, 16-17 September 2010

BRGM's involvements in the HITI STREP (FP6-2004-Energy-3)

> BRGM has participated to the following Work Packages:

- WP2: Well fluid properties (to develop a wire line logging tool measuring temperatures up to 320°C)
- WP3: Reservoir evaluation (to validate the Na-Li chemical geothermometer at high temperatures; to estimate reservoir storativity and fluid flow rate from the tracer tests using organic compounds injected at temperatures of 350°C)
- WP5: Field testing and data analysis (to test the new tools developed in this project in the high temperature geothermal wells)
- WP6: Prospects to 500°C (to examine and develop prospective strategies and new concepts in order to perform geophysical and geochemical measurements at temperatures up to 500°C)
- WP7: Dissemination

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Chemical and isotopic geothermometers

- Since 1965, several chemical and isotopic geothermometers are applied on waters discharged from thermal springs or geothermal wells in order to estimate the fluid temperature in the deep reservoirs:
  - Silica (Quartz, Chalcedony,…)
  - Na/K, Na/K/Ca, K/Mg, Na/K/Ca/Mg…
  - $\delta^{18}O(H_2O\text{-}SO_4)$
- Most of these geothermometers are based on empirical or semi-empirical laws derived from known or unknown chemical equilibrium reactions between water and minerals occurring in the geothermal reservoirs

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Na/Li geothermometer

- Unfortunately, the estimations of temperature using these classical tools are not always concordant (fluid mixing, precipitation/dissolution processes during fluid rising to the surface)
- Given this discordance and from numerous data obtained in several world geothermal and US oil fields, a new auxiliary geothermometer was proposed for thermal and geothermal waters, based on three empirical and statistical Na/Li thermometric relationships (Fouillac and Michard, 1981; Kharaka and Mariner, 1989)
- These relationships seem to be essentially dependant on the fluid salinity and on the reservoir type (crystalline or sedimentary rocks). Due to a low Li reactivity, this geothermometer often gives more reliable deep temperature estimates. Unfortunately, the Na/Li running is badly known and for the moment, this geothermometer has not been tested for very high temperatures (> 350°C)

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Main BRGM objectives in the EU HITI project

- Use, calibrate and validate the Na-Li geothermometer on dilute and saline Icelandic geothermal fluids at very high temperatures in order to develop relevant tools able to estimate the temperatures in supercritical reservoirs located in the Krafla and Reykjanes geothermal areas where deep wells must be drilled in the IDDP framework
- A large variety of Icelandic geothermal waters ranging from low to very high temperatures (supercritical conditions) and from low (Krafla geothermal field) to high salinities (Reykjanes area) was an excellent opportunity to develop this geothermometer and to better understand its behavior

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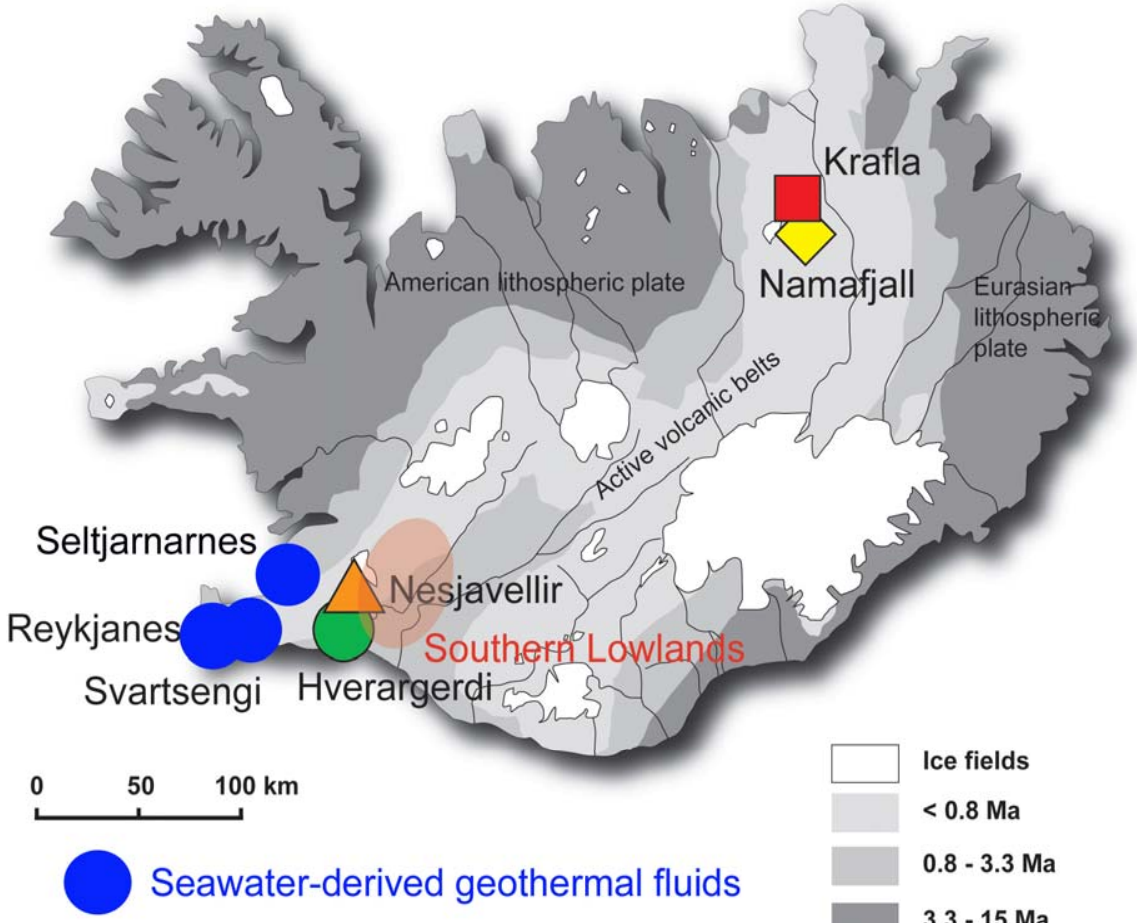
Three campaigns of fluid sampling from HT and BT geothermal wells

- **October 2007 (n=13, HT)**
  - **Reykjanes (256-319°C)**
  - **Svartsengi (244°C)**
  - **Krafla (215-326°C)**
  - **Namafjall (229-334°C)**
  - **Hverargerdi (200°C)**
- **June 2008 (n=14, HT)**
  - **Reykjanes**
  - **Svartsengi**
  - **Nesjavellir (270-309°C)**
  - **Krafla**
- **July 2009 (n=21, BT)**
  - **Seltjarnarnes (114°C)**
  - **Southern Lowlands (55-164°C)**



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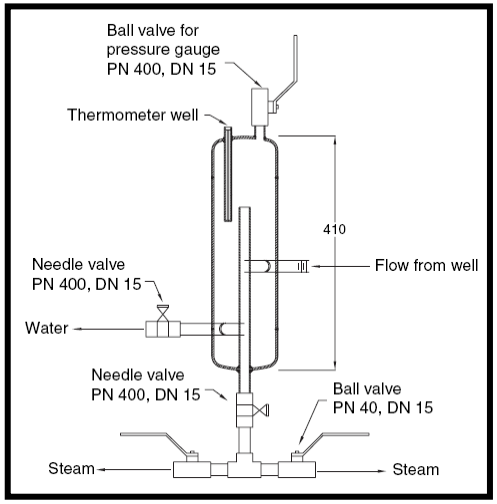
Fluid sampling and on site measurements



Geofluids (2006) 6, 203–216 doi: 10.1111/j.1468-8123.2006.00147.x

Sampling and analysis of geothermal fluids

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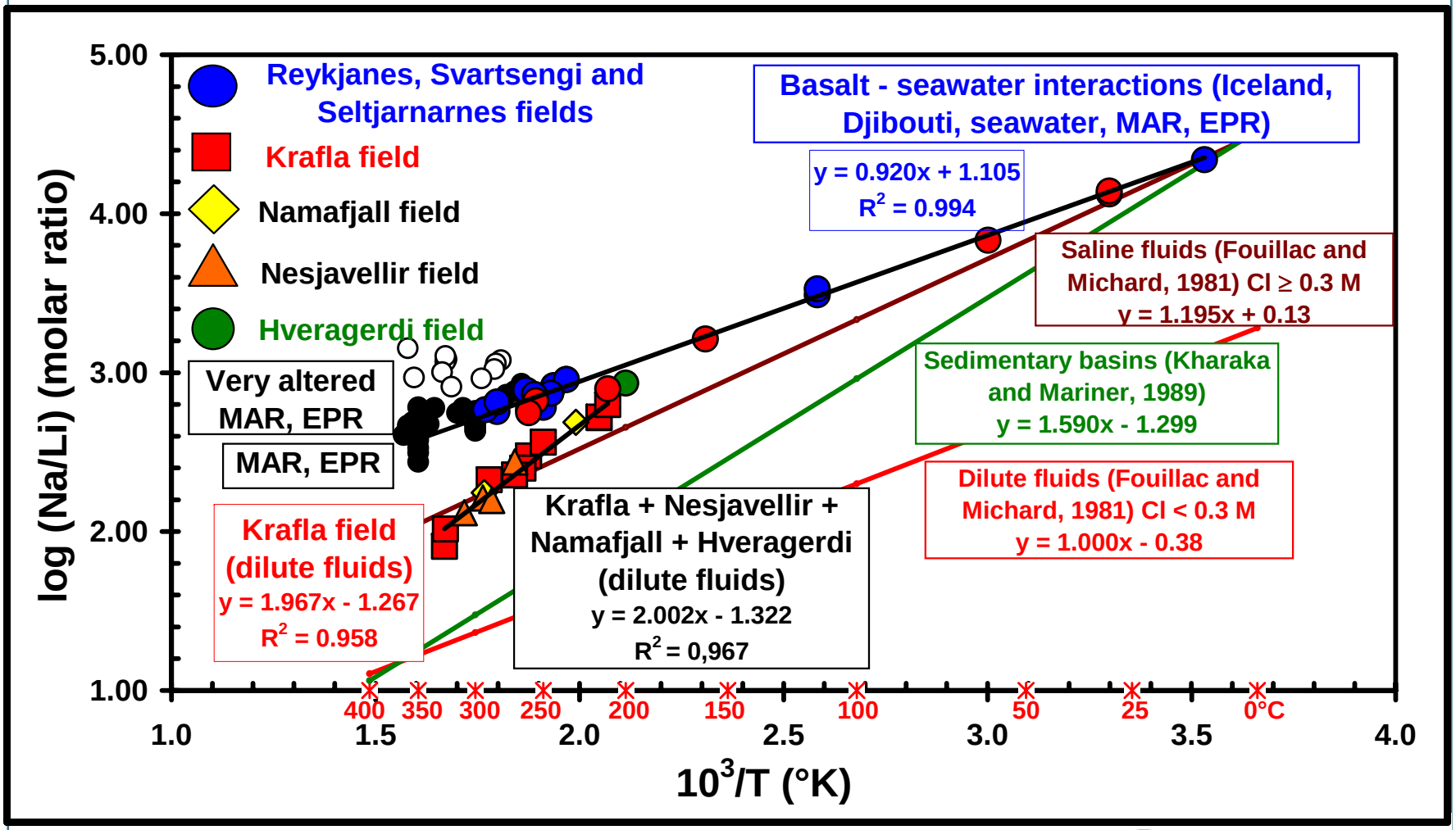
Institute of Earth Sciences, University of Iceland, Reykjavík, Iceland

The two new Na/Li geothermometer relationships



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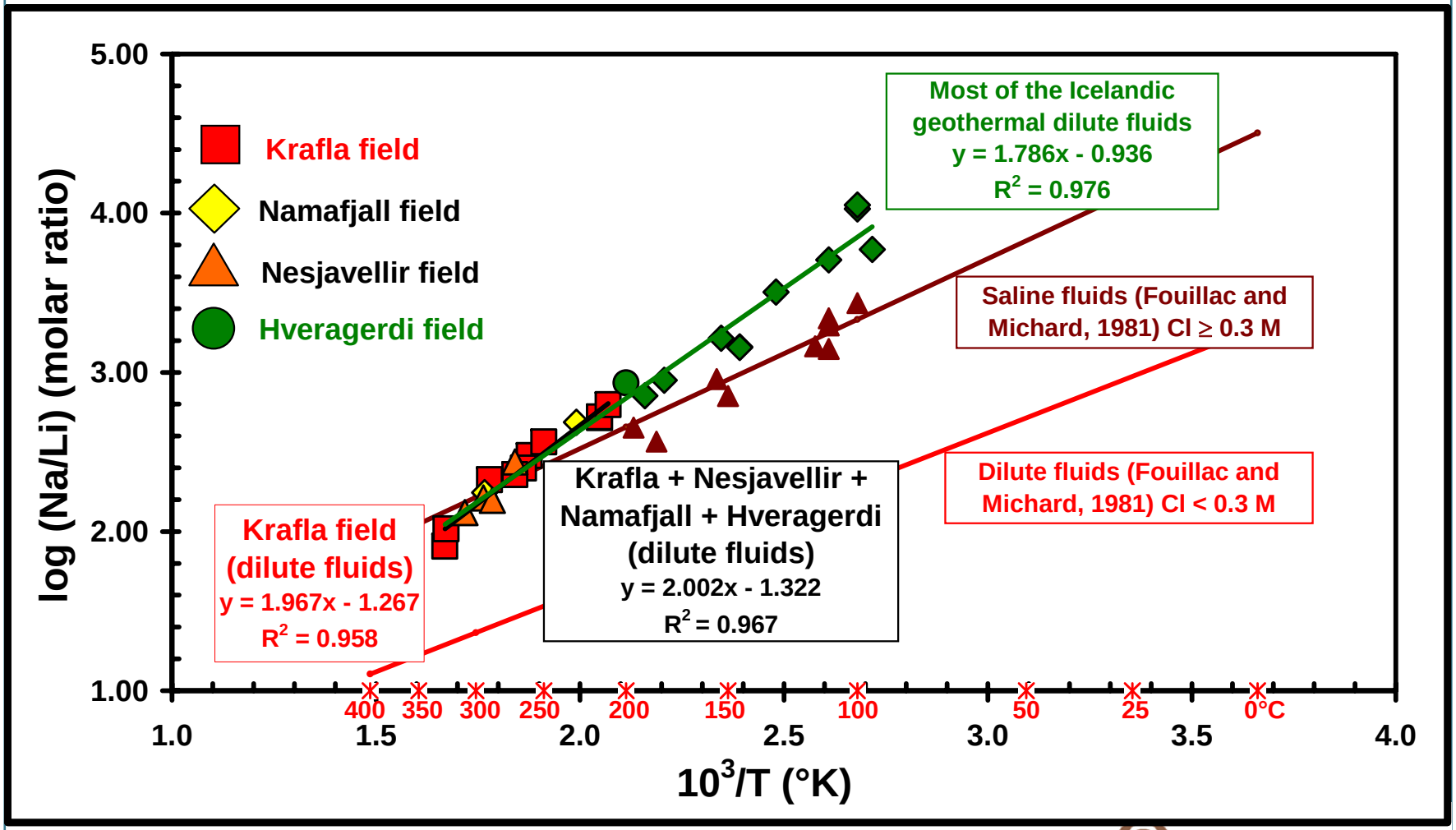
The new Na/Li geothermometer relationships for dilute geothermal fluids from Iceland



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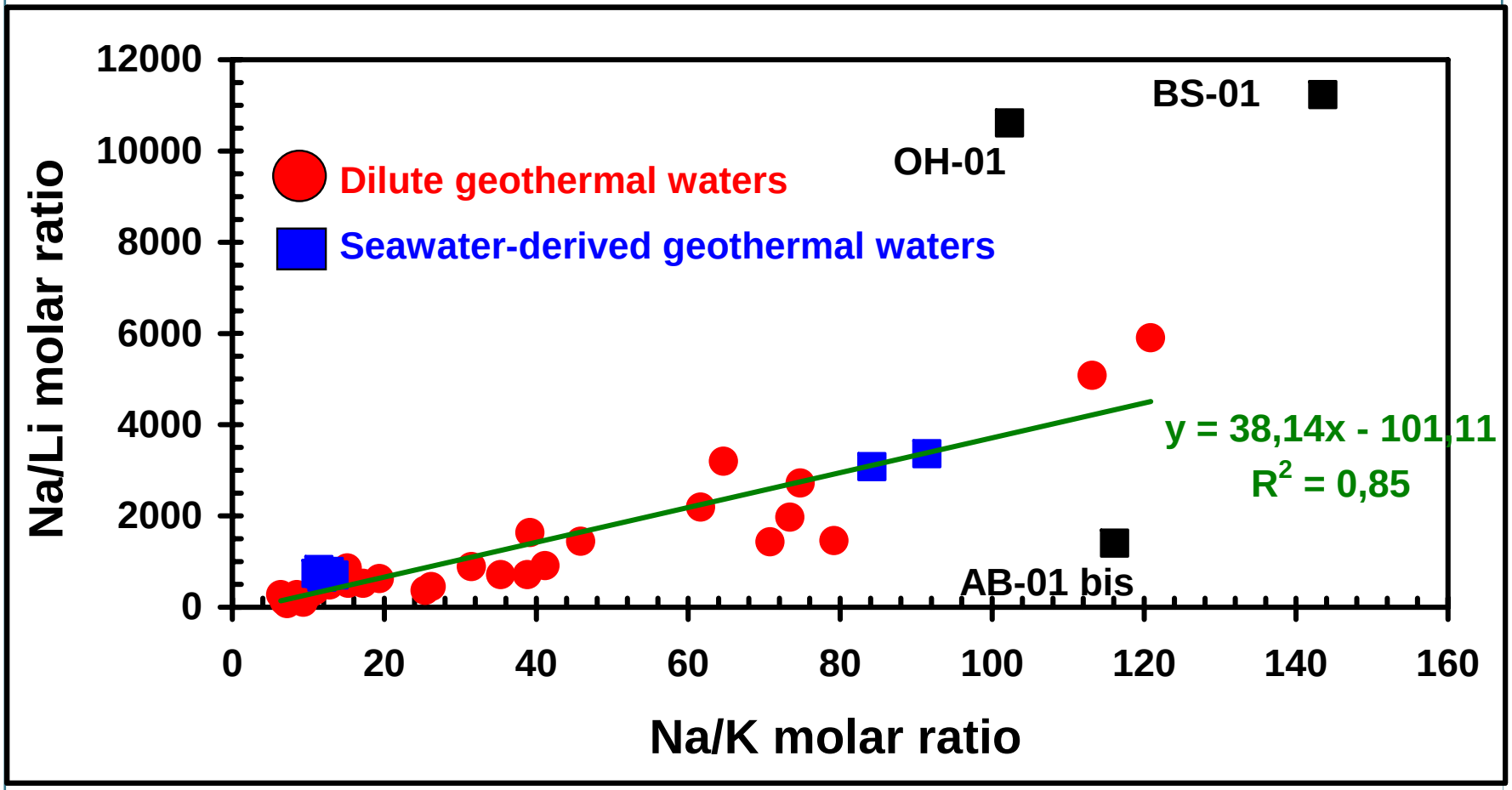
Correlation between the Na/K and Na/Li ratios



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Thermodynamic considerations

Na/Li linear relationship for the Icelandic HT dilute geothermal waters → $\Delta H°_R \approx -38.3$ KJ.mol^{-1} and $\Delta G°_R \approx -30.8$ KJ.mol^{-1}

$2\ NaAlSi_3O_8$ (Albite) + $KAl_3Si_3O_{10}(OH)_2$ (Muscovite) + $Al_2Si_2O_5(OH)_4$ (Kaolinite) + Li^+ =

$KAlSi_3O_8$ (K-Feldspar) + $NaAl_3Si_3O_{10}(OH)_2$ (Na-Mica) + $LiAl_3Si_3O_{10}(OH)_2$ (Li-Mica) + 2 SiO_2 (Quartz) + H_2O + Na^+

$$\Delta G°_R = \Sigma\ n_i\ \Delta G°_{f\ (right\ compounds)} - \Sigma\ n_i\ \Delta G°_{f\ (left\ compounds)} = -30.4\ KJ.mol^{-1}$$

$$\Delta H°R = \Sigma\ n_i\ \Delta H°_{f\ (right\ compounds)} - \Sigma\ n_i\ \Delta H°_{f\ (left\ compounds)} = -37.0\ KJ.mol^{-1}$$

Thermodynamic data0.com.R2 base of the EQ3/6 code (Wolery, 1995) and SUPCRT92 consistent data base (Johnson *et al.*, 1992)

Consequently, the Li concentrations could be well controlled by illitic and mica alteration at high temperature, as observed by Shaw and Sturchio (1992) in different geothermal areas from USA

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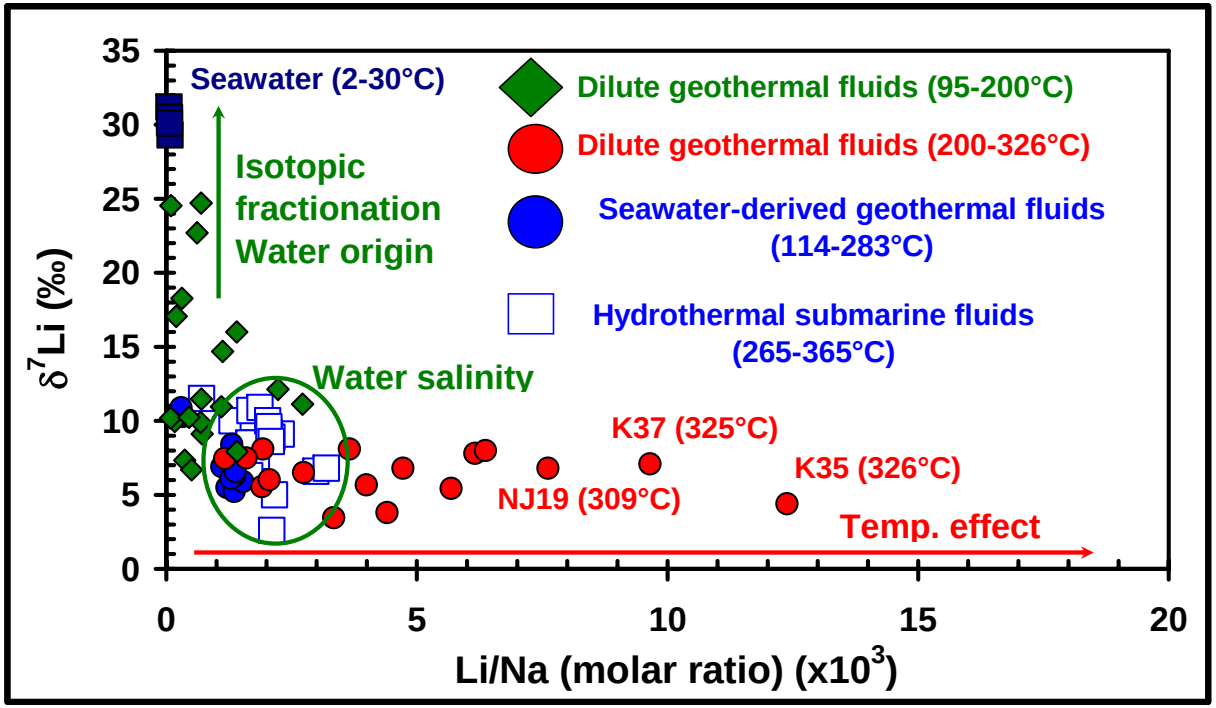
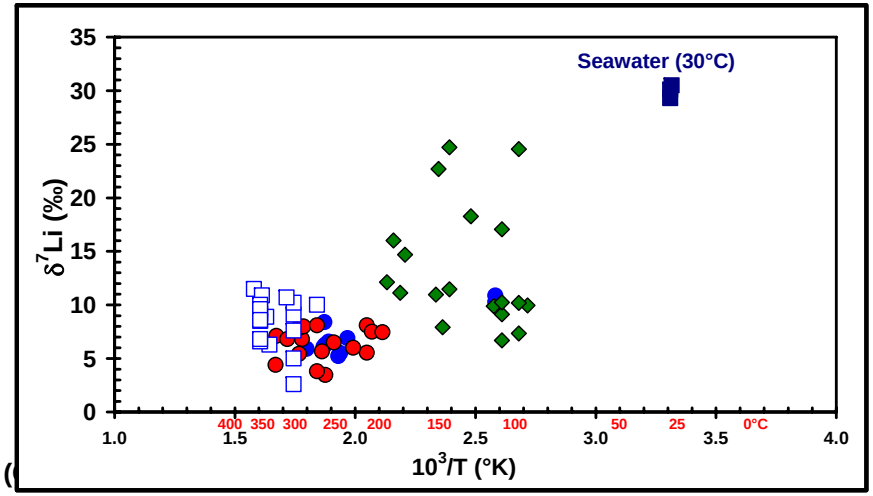
Li isotopes determined in the geothermal fluids





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Conclusions

- **New Na/Li thermometric relationships were found for the Icelandic geothermal waters up to 365°C. Thermodynamic calculations and some case studies suggest that these relationships could be mainly controlled by clay alteration reactions involving minerals such as illite, Li-mica…**
- **The Na/Li relationships found for the Icelandic dilute geothermal fluids are very different from that existing for the worldwide dilute geothermal fluids and from that determined for the seawater-derived geothermal fluids which react with basalts (Reykjanes, Svartsengi and Seltjarnarnes areas…). Isotopic Lithium can be used as a qualitative indicator of temperature.**
- **We can conclude that it is essential to well define the environment in which Na/Li is applied before its use (water salinity, nature and alteration degree of the rocks, etc.). Additional developments in different environments and regions are necessary**