

Fluid chemistry of the Reykjanes reservoir

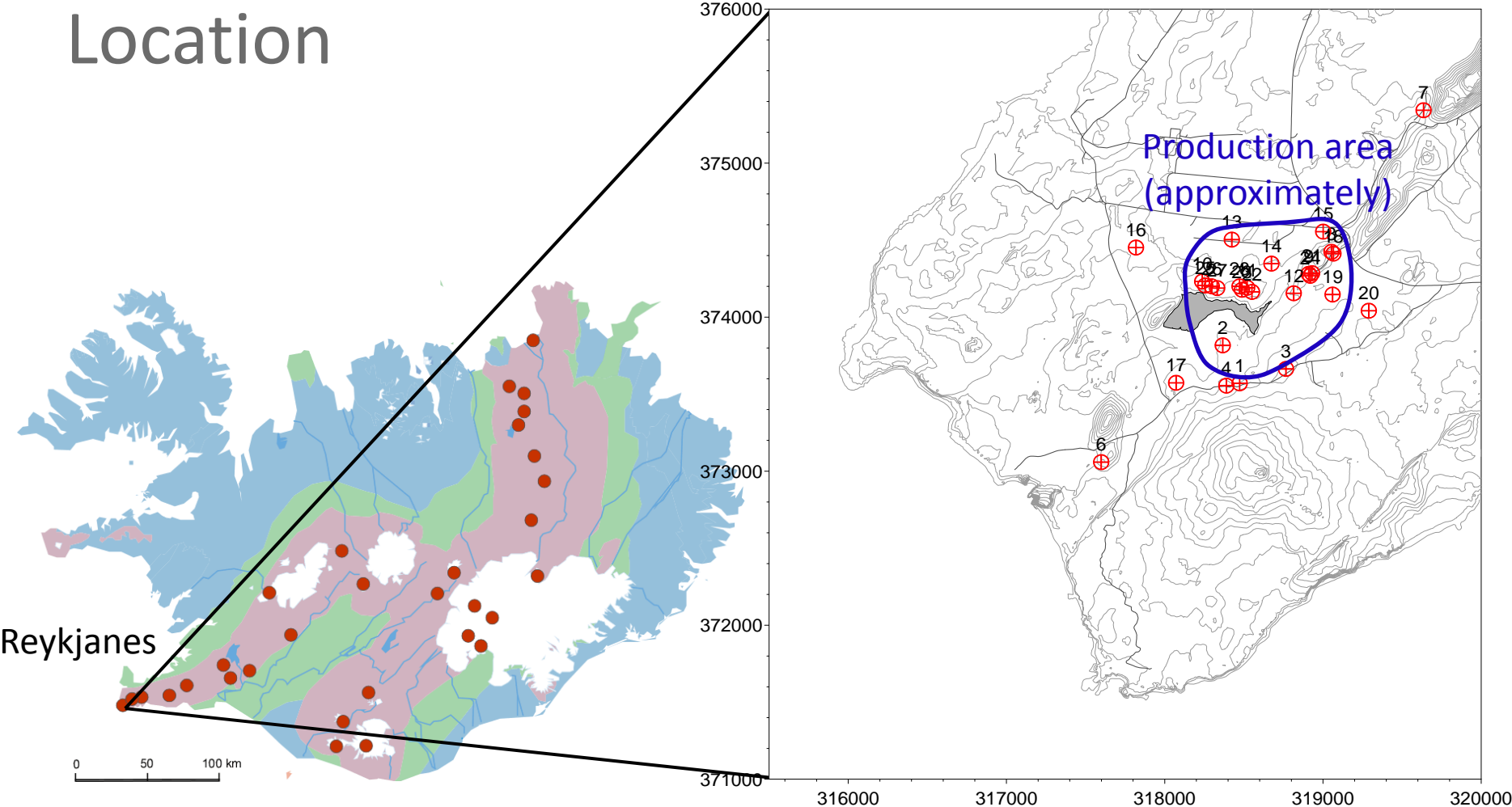
Thráinn Fridriksson

Fluid chemistry of the Reykjanes reservoir:

Outline

- General characteristics
- Processes affecting the fluid chemistry
- Sources of components
- CO₂ budget of the reservoir and implications for heat flow considerations

Location



Reykjanes geothermal fluid compared to seawater

well		RN-19	RN-12	RN-10	Seawater
sample		20060386	20060387	20030679	*
Reference temperature (°C)		275	295	310	
pH at Tref		5.41	5.39	5.33	7.9
Cl ⁻	ppm	19,567	18,740	18,790	19,354
Na ⁺	ppm	9,943	9,502	9,564	10,770
K ⁺	ppm	1,436	1,372	1,445	390
Ca ²⁺	ppm	1,660	1,608	1,537	410
SiO ₂	ppm	586	648	747	6.4
CO ₂	ppm	891	1,710	1,808	102
H ₂ S	ppm	30.9	56.5	80.8	-
SO ₄ ²⁻	ppm	23.7	16.1	10.6	2,712
Mg ²⁺	ppm	0.71	0.66	1.22	1,350

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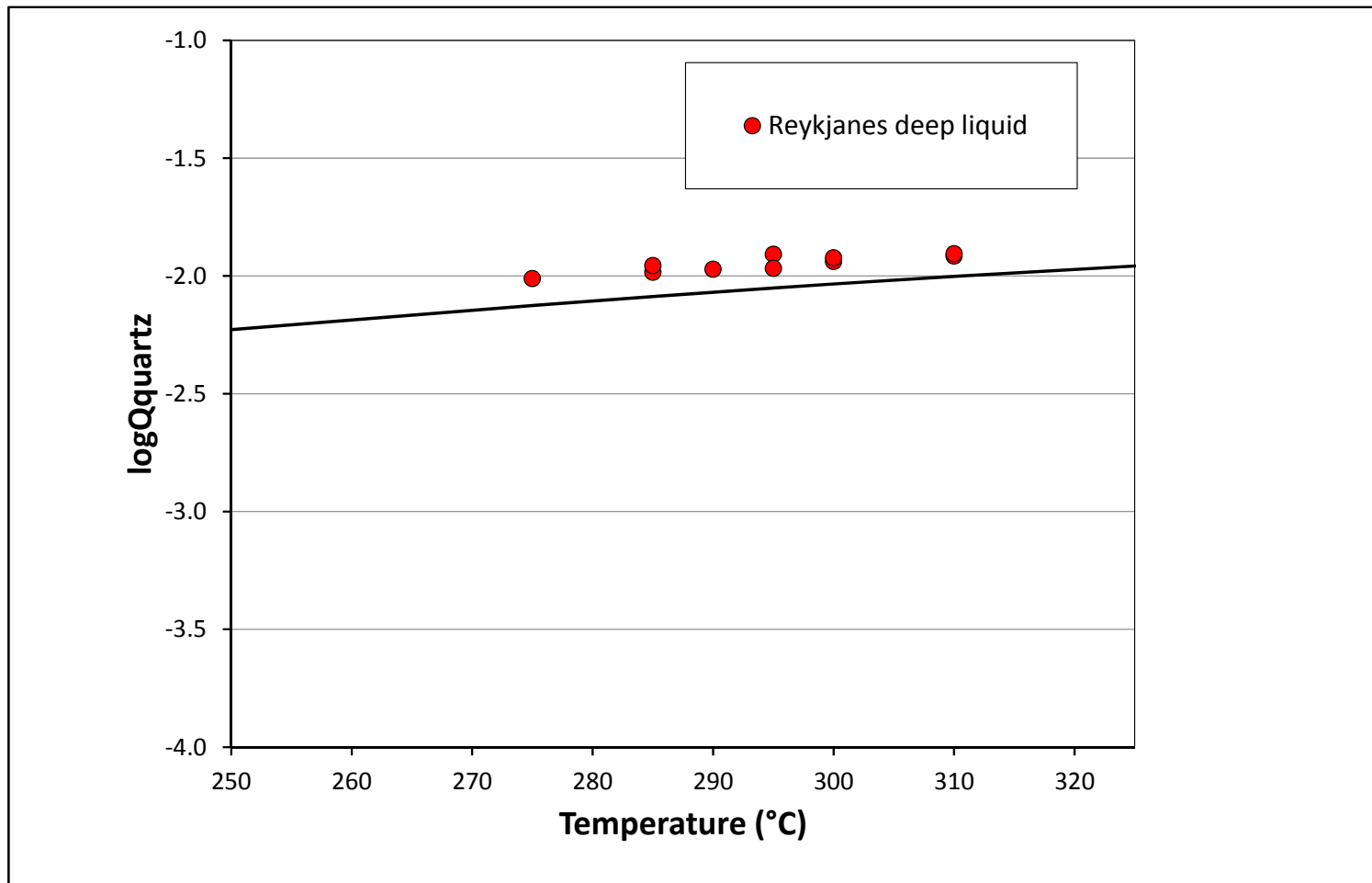
Processes affecting the Reykjanes geothermal solutions and component sources

- Seawater recharge after glaciation
- Water-rock interaction at elevated temperatures
 - Common sense and mineral saturation state considerations (*e.g. Björnsson et al., 1971 and Arnórsson, 1978*)
 - Physical experiments (*e.g. Mottl and Holland, 1978*)
 - Reaction path modeling (*Padilla, 2011; and this study*)
- “Magmatic” gases
 - (*Padilla, 2011; and this study*)

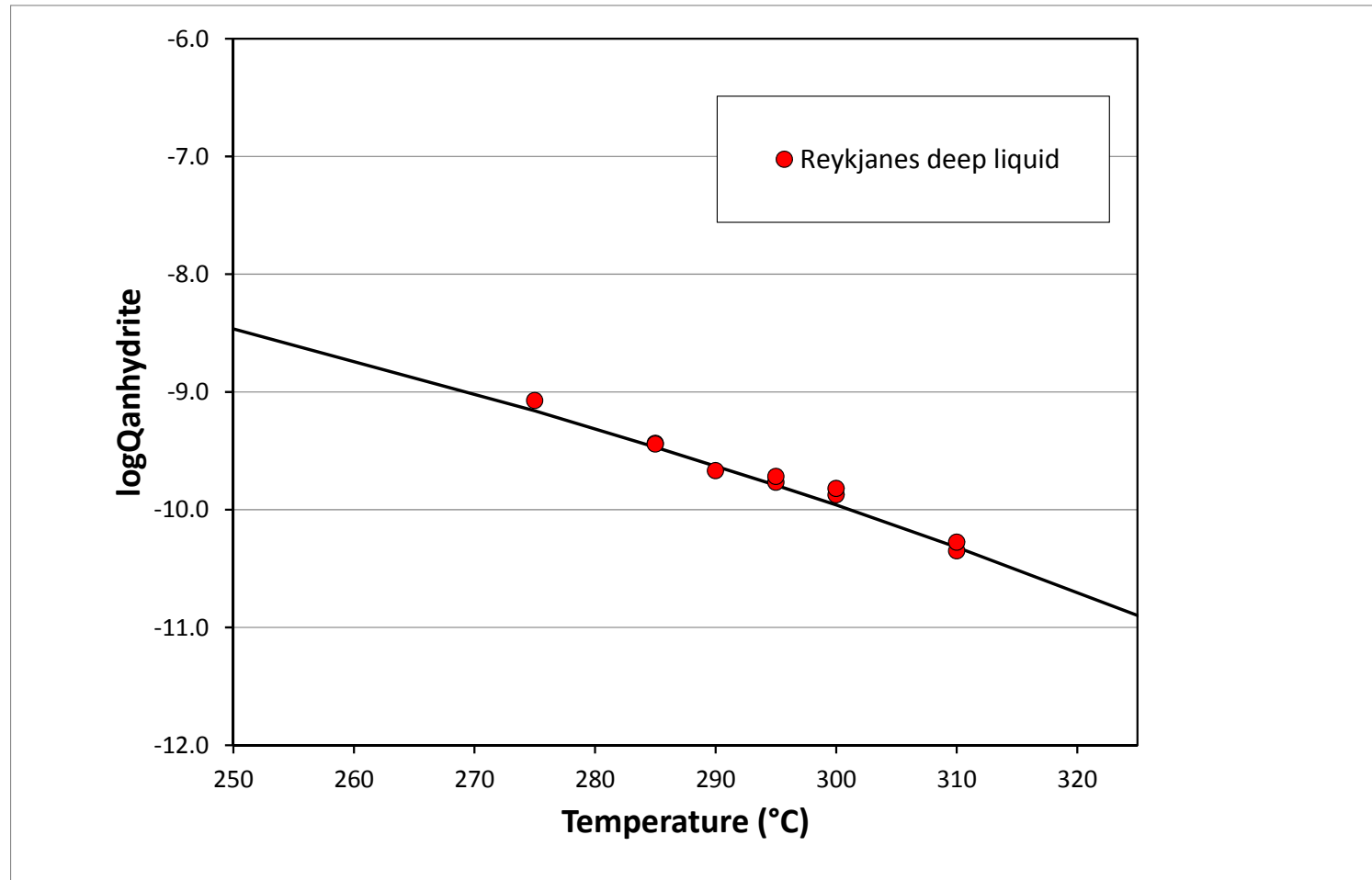
Mineral saturation

- Deep liquid reconstructed and speciated using *solveq* and *chim-xpt* (formerly *chiller*) and the *slop98* data base
- The most common hydrothermal minerals observed in the drill cuttings are close to equilibrium with the geothermal fluid at reservoir conditions
- e.g. quartz, anhydrite, wairakite, albite, microcline...
- Calcite is consistently undersaturated

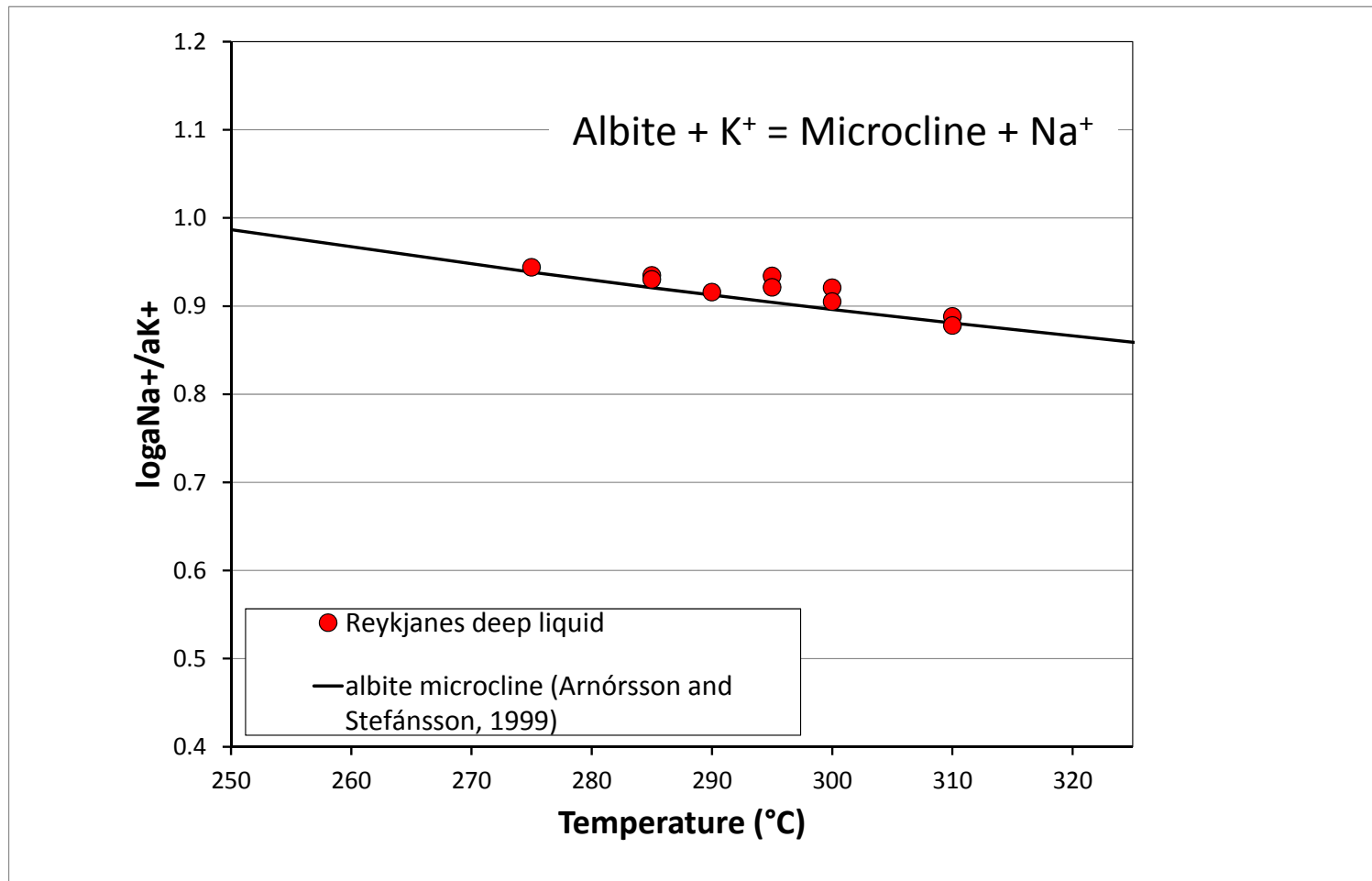
Examples of mineral saturation: Quartz



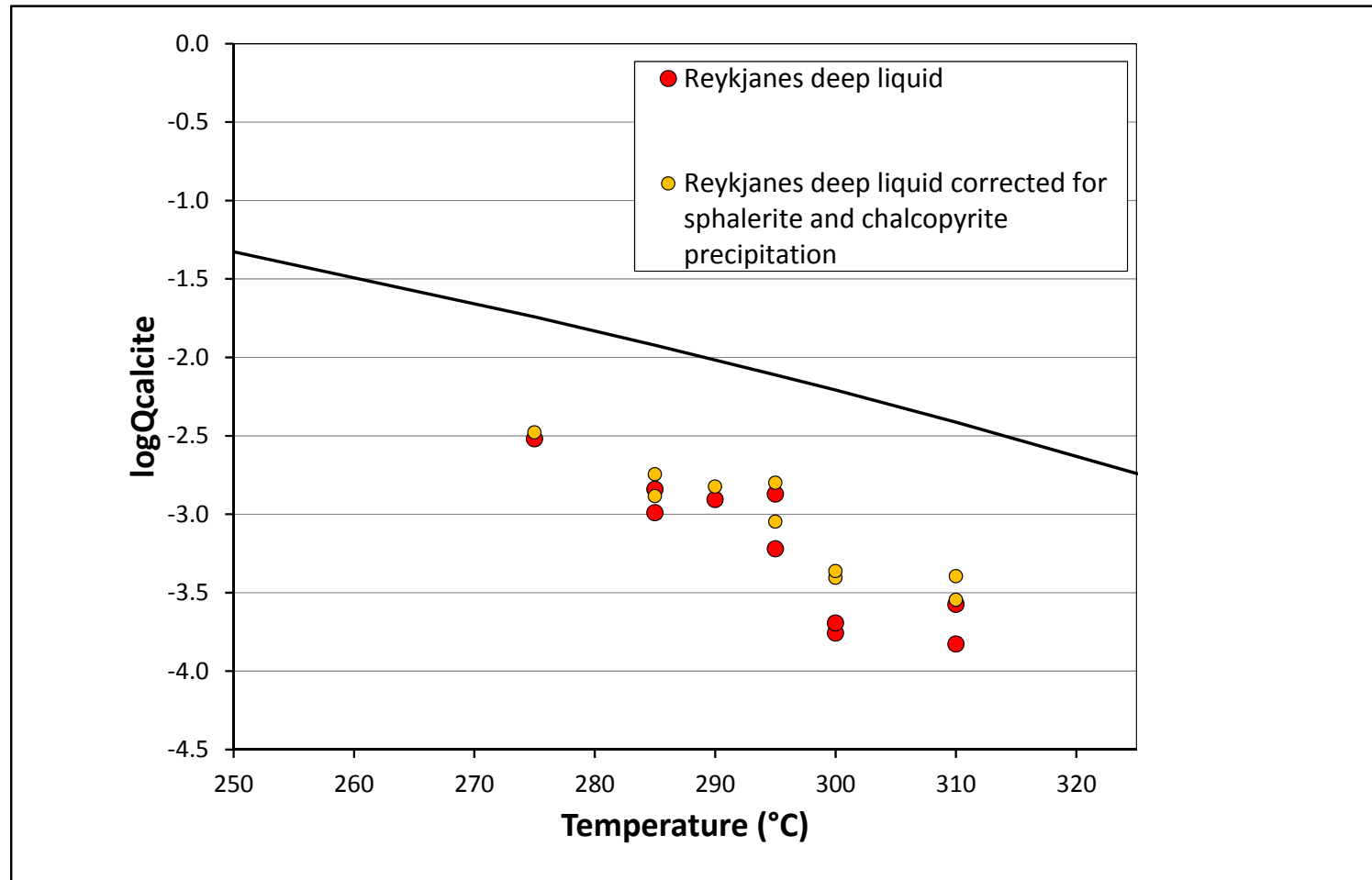
Examples of mineral saturation: Anhydrite



Examples of mineral saturation: albite-microcline equilibria



Examples of mineral saturation: Calcite



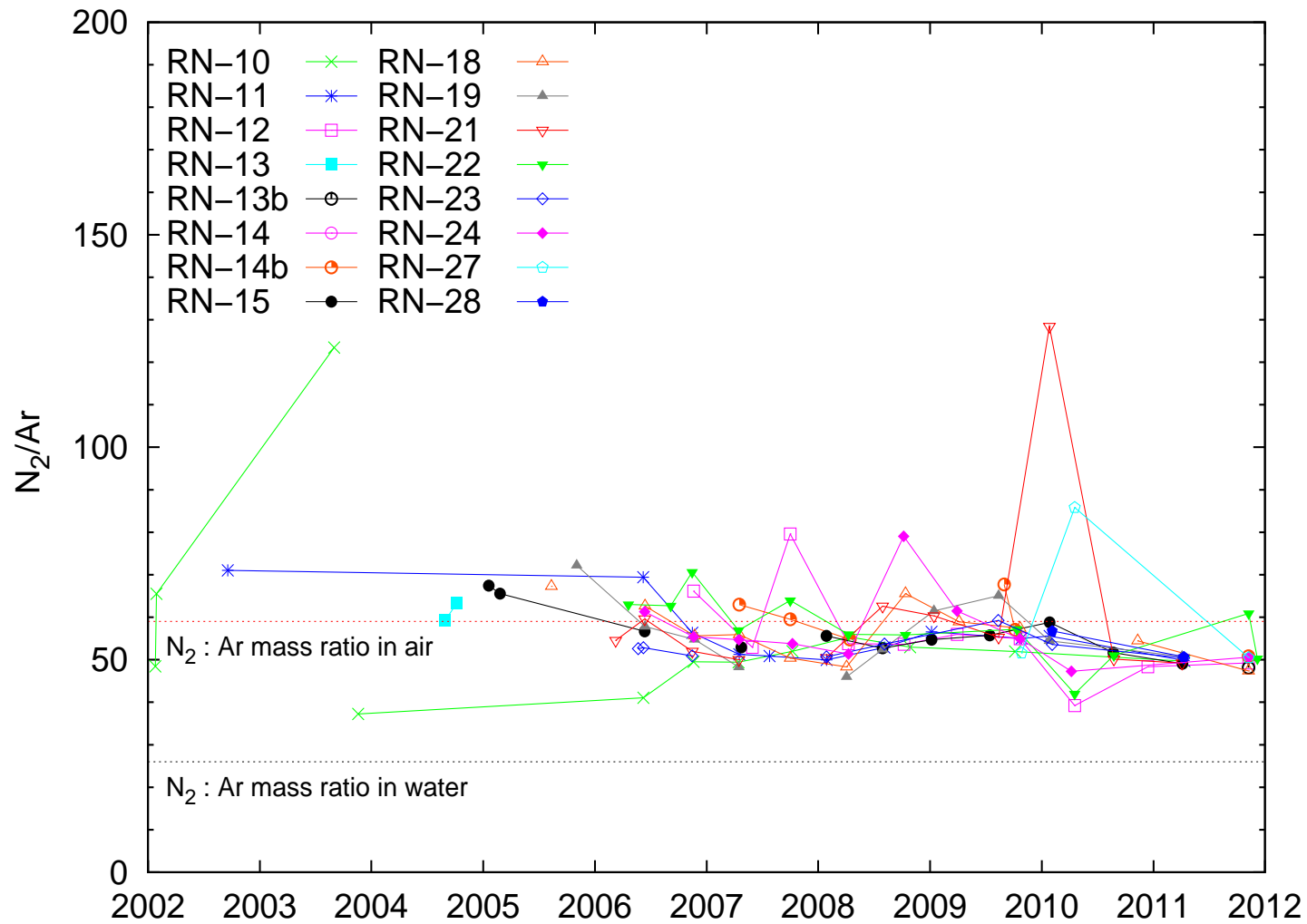
Reaction path modeling of seawater-basalt interactions at 300 °C

- Main results: minerals
 - Most of the more common alteration minerals “precipitated” after dissolution of 25 to 50 g of rock in kg of seawater
 - quartz, anhydrite, epidote, wairakite, sphalerite, Cu-sulfides
 - Other common alteration minerals need more rock dissolution or 100 to 1000 g of rock per kg seawater:
 - albite, microcline, pyroxene (hedenbergite)
 - Calcite was not predicted to form
 - Most significant discrepancy between model and reality:
 - prehnite and actinolite were not predicted to form but do occur

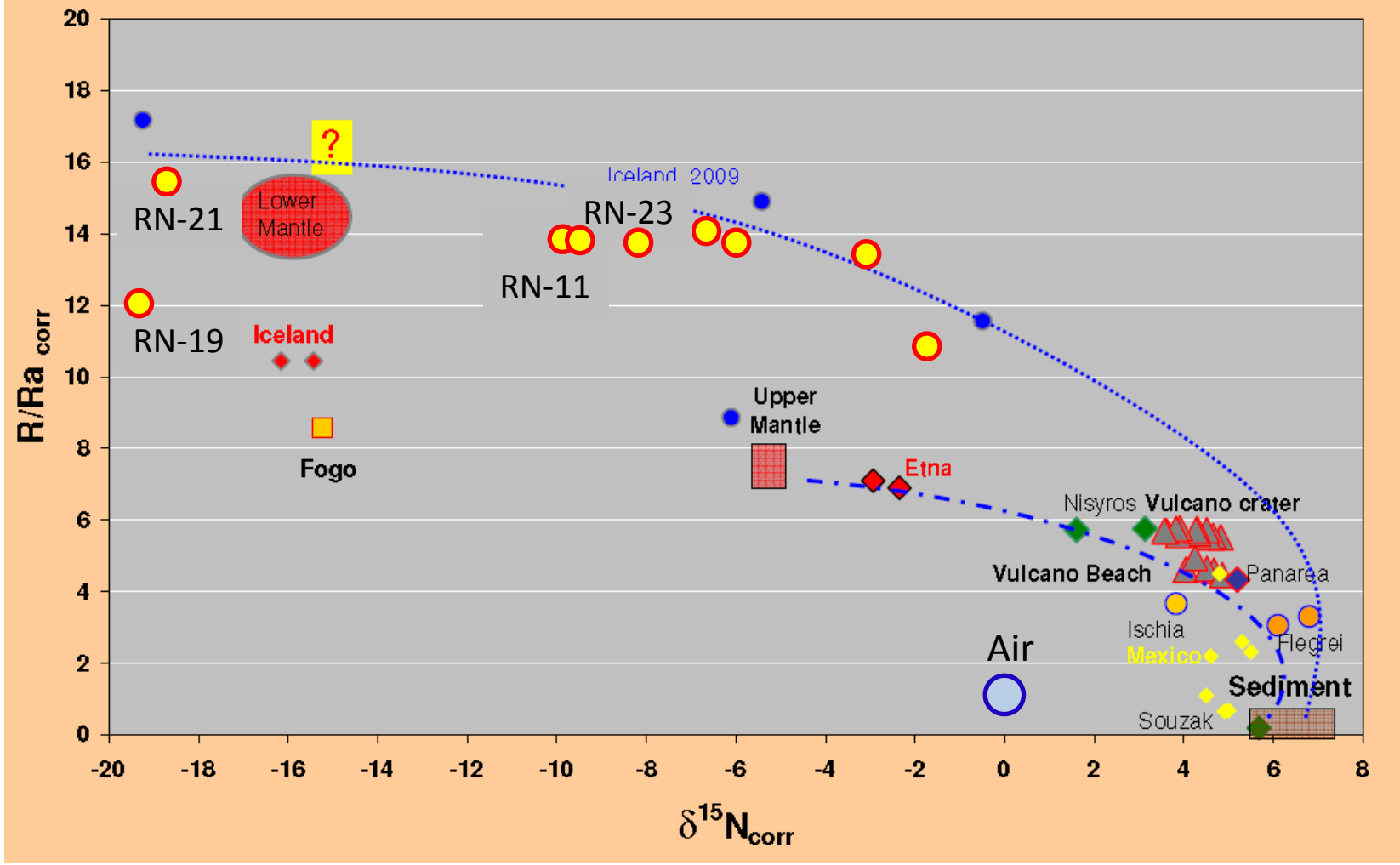
Reaction path modeling of seawater-basalt interactions at 300 °C

- Main results: fluid
 - Most fluid components had predicted concentrations very close to observed concentrations after 25 to 50 g of rock dissolution per kg of seawater
 - Cl, SiO₂, Na, Ca, Fe²⁺, SO₄²⁻, H₂S, Mg, Al, and pH
 - Observed K concentrations were not reached until ~1 kg of basalt had been dissolved in 1 kg of seawater
 - Unrealistically low K concentration in basalt used for modeling?
 - Observed CO₂ concentrations were not reached until 1-3 kg of rock had been dissolved in 1 kg of seawater
 - Another source of CO₂?

Source of nitrogen



Nitrogen and helium isotopes



He concentration in Reykjanes fluid

- He concentrations steam from wells and fumaroles in Reykjanes range from 20 to 44 ppmV (dry gas)
- Computed deep liquid He concentrations are ~4 ppb
- The deep liquid He concentration is more than 400 times in excess of air saturated water
- This suggests a magmatic source of He

CO₂ budget of the Reykjanes reservoir and heat flow considerations

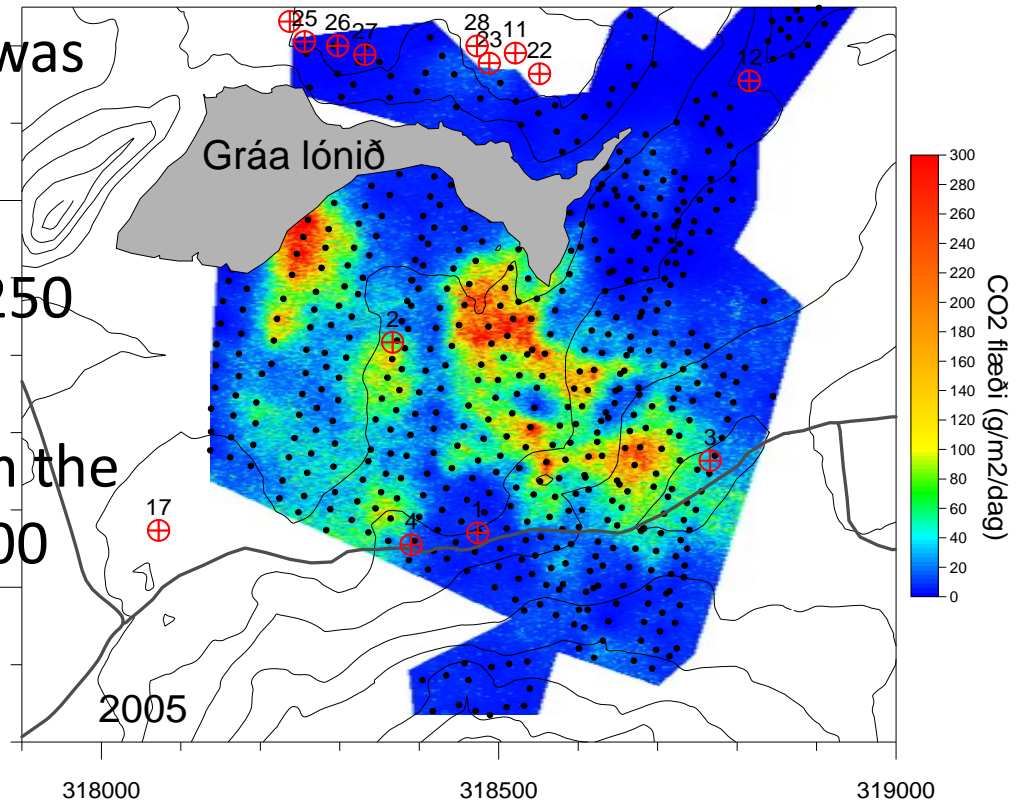
- The Reykjanes geothermal reservoir was boiling in the natural state
- The amount of steam formed by boiling is directly proportional to the natural heat flow into and out of the reservoir
- CO₂ is transported with steam from the reservoir
- The CO₂ concentration in steam from the reservoir is known
- If we can quantify the flux of CO₂ out of the system we can constrain the heat flow from the system in the natural state

CO₂ budget of the Reykjanes reservoir and heat flow considerations

- Three possible sinks of CO₂
 - Emission to the atmosphere
 - Precipitation of carbonate minerals (calcite)
 - Dissolution in groundwater
- Natural emission of CO₂ from the Reykjanes reservoir has been measured
- The amount of carbonate precipitated in the bed-rock above the reservoir has been estimated
- Dissolution in groundwater is not known

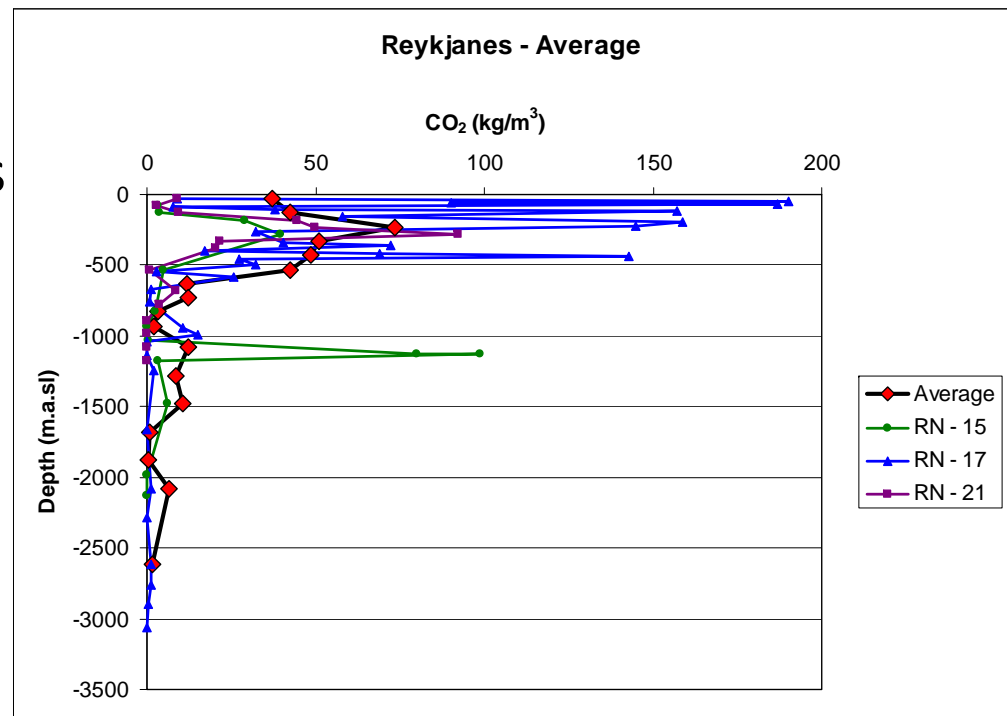
CO₂ budget of the Reykjanes reservoir: Atmospheric emissions

- CO₂ flux through soil and fumaroles in natural state was ~13 t/day
- We assume deep liquid concentration of CO₂ of 1,250 mg/kg
- The observed CO₂ flux from the system corresponds to 4,200 t/day of steam
- **Or 130 MW_t**



CO₂ budget of the Reykjanes reservoir: Carbonate precipitation

- CO₂ concentration of 235 drill cutting samples from 14 Reykjanes wells has been measured
- Elevated CO₂ concentrations observed in the uppermost 500 m, i.e. above the geothermal reservoir
- This represents CO₂ transported with steam and fixed in the bed-rock above the reservoir



CO₂ budget of the Reykjanes reservoir: Carbonate precipitation

- The estimated total amount of CO₂ fixed in the bedrock of the Reykjanes system amounts to 56 Mt
 - This is assuming that the size of the area is 2 km²
- The estimated age of the system is between 10,000 and 100,000 years
- Assuming that the CO₂ has accumulated continuously this corresponds to a daily CO₂ accumulation rate of 15.3 and 1.5 t/day, respectively
- This corresponds to heat flow of the order of **150 to 15 MW_t**

Conclusions

- The Reykjanes geothermal fluid is originally seawater that has been modified by:
 - Dissolution of basalt at elevated temperatures
 - Precipitation of secondary minerals
 - Addition of magmatic gases (at least CO₂, He, and N₂)
- Concentrations of major components in the geothermal fluid are controlled by close approach to equilibrium with secondary minerals
 - Except Cl and probably CO₂
- CO₂ emissions and CO₂ fixed in the bedrock above the reservoir constrain the minimum natural heat flow from the Reykjanes reservoir to about 150 to 300 MW_t