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# Geochemical Monitoring of the Reykjanes Geothermal Reservoir 2003 to 2013

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## ABSTRACT

This paper presents data collected for chemical monitoring of the geothermal reservoir in Reykjanes, Iceland from before the commissioning of the 100 MWe Reykjanes Geothermal Power Plant in 2006 to present. This includes the concentrations of dissolved minerals and gases and stable isotope composition of the deep liquid, as well as $CO_2$, $H_2S$ and $CH_4$ emissions from the production wells. The most notable chemical changes in the Reykjanes reservoir fluid is that several wells, in particular the directional wells producing from the reservoir south of the SW-part of the production field have exhibited gradual increase in the concentrations of the most abundant dissolved solids (Cl, Na, K, and Ca) since the commissioning of the power plant in 2006, most likely indicating progressive boiling in the reservoir. Other wells do not exhibit this trend. Lately the concentrations of dissolved solids in the deep geothermal solutions has levelled off to some degree and even showed some decrease. The concentrations of $CO_2$ and $H_2S$ in the deep liquid remain more or less constant with time. The concentrations of $N_2$ and Ar have decreased gradually since 2006. This is clear from the $CO_2/N_2$ and $H_2S/N_2$ ratios in the deep liquid which decreased gradually in 2006–2010 but has since levelled off, perhaps indicating that the influence of progressive boiling is becoming less significant.

## 1. INTRODUCTION

The Reykjanes geothermal system is located on the SW-tip of the Reykjanes Peninsula in SW-Iceland (see Figure 1). To date 37 wells have been drilled into the system. The productive reservoir is at about 800 to 2300 m depth, and the reservoir temperatures range from about 270 to 310°C. The areal extent of surface manifestations is of the order of 2 km$^2$ (Pálmason et al., 1985) and extensive drilling seems to indicate that the productive part of the geothermal system is not significantly larger. The geothermal surface manifestations at Reykjanes include altered rocks, steam vents, mud pits and warm ground (Fridriksson et al., 2006). The reservoir fluid in the Reykjanes system is hydrothermally modified seawater with some addition of magmatic gases (Arnórsson, 1978; Freedman et al., 2009; Hardardóttir et al., 2009; Óskarsson et al., 2015).

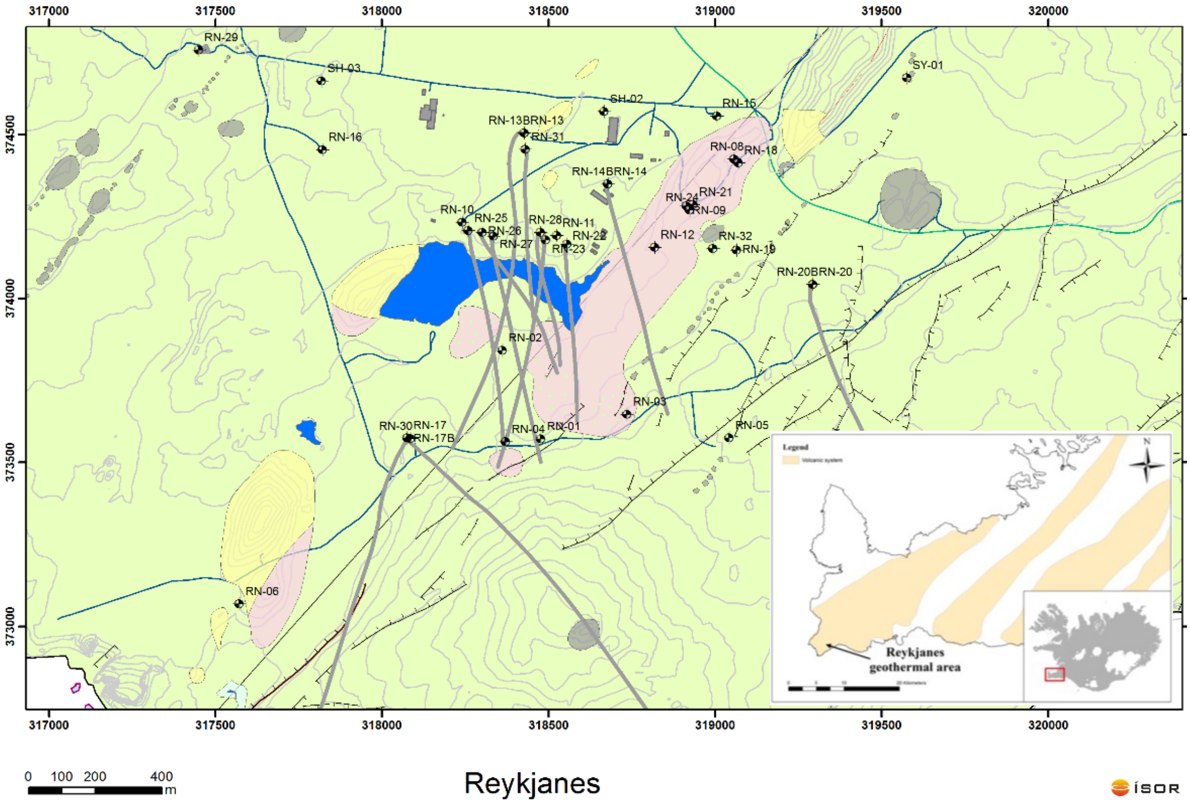

**Figure 1: Well head locations and well paths in the Reykjanes geothermal field. Recent alteration on the surface is indicated by pink, and yellow indicates fossil alteration. Location of the Reykjanes field is shown on the insert maps in the lower right hand corner.**

The first exploration well in Reykjanes was drilled in 1956 and the first proper production well, RN-8, was drilled in late 1969 and started production in 1970. In the years 1970–2006, the annual production rate was of the order of 1.25 to 2.50 million ton/year, excluding the years 1975–1978, in which there was no production. In the first years, RN-8 was the only well in production, but in 1983, well RN-9 was added. Production from RN-9 was discontinued in 2003 and RN-12 taken into production. The steam produced from 1970 to 2006 was used for a small back pressure turbine and the brine was used as a source fluid for a salt processing plant that was operated for a part of the period.

In May 2006 the 100 MW Reykjanes power plant was commissioned, dramatically increasing the production from the system. The peak production was 23.2 million tonnes in 2007, but gross production in 2013 was 16.3 million tonnes (Verkfræðistofan Vatnaskil, 2014). This increase in production resulted in a sharp pressure drop in the reservoir amounting to about 30 bar in the production zone in the first three years and by another 10 bar from 2009 to 2013 (see Figure 2).

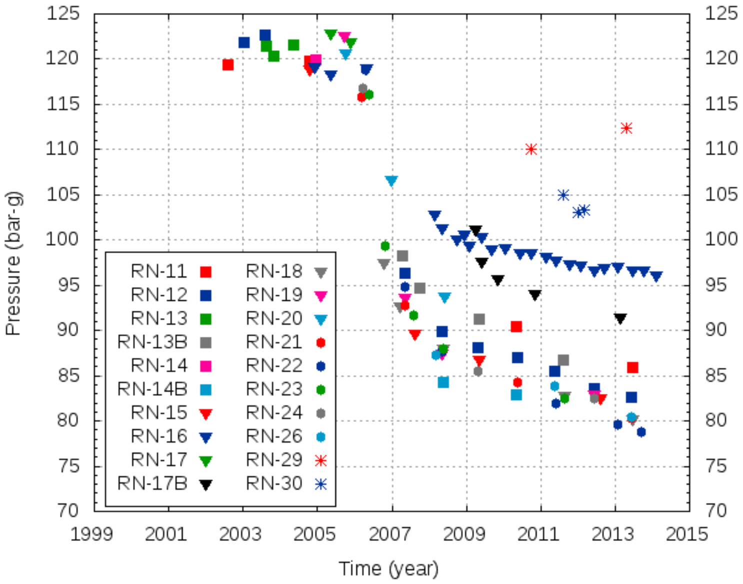

**Figure 2: Reservoir pressure at 1500 m b.s.l. from 2003 to 2013 in the Reykjanes field. The wells that exhibit less pressure decline (RN-16, 17B, 29, and 30) are located outside the production zone (Gylfadóttir, 2014).**

## 2. CHEMICAL MONITORING PROGRAM

The objective of chemical monitoring of geothermal fields under production is to observe changes in the chemical and isotopic composition of the reservoir fluid. Such changes can be due to natural processes although they are more commonly related to the effects of the production. The most common production effects include incursion of colder water or inflow of reinjection fluid and changes due to progressive boiling of the fluid.

Chemical monitoring of the Reykjanes field started in 1970 when RN-8 was discharged and taken into production but became more systematic in 1992 when Hitaveita Suðurnesja hf (later HS Orka) took over the field. Since 2006 the monitoring program has involved sampling from all the production wells. Samples were collected twice a year from each production well since the commission of the Reykjanes power plant in 2006 until 2010, but since 2011 only one sample per year has been collected from each well. Samples are collected using a portable Webre separator which is connected to the well heads and used to collect liquid and vapour separately. Liquid samples are collected through a stainless steel cooling spiral and the sample fractions treated in different ways depending on the components that are to be analysed for; pH, $CO_2$, $H_2S$ and $NH_3$ are determined from untreated samples, samples for analysis of $SiO_2$ are diluted 1:10 upon collection, samples for determination of F, Cl, Br, B, TDS and stable isotopes are filtered through a 0.45 µm cellulose acetate membrane filter, $SO_4$ is determined from a filtered sample in which $H_2S$ has been precipitated as ZnS, and the concentrations of metals and trace elements are determined from filtered samples which have been acidified with $HNO_3$ (supra pur). Vapour samples for gas analysis ($CO_2$, $H_2S$, $H_2$, $CH_4$, $N_2$, $O_2$, Ar) are collected through a silicone rubber hose and condensed into evacuated double-port glass flasks containing strong caustic solution (10 M NaOH), and samples for analysis of $NH_3$, Na, B and stable isotopes in the vapour phase are condensed in a stainless steel cooling spiral. Some examples of analytical results are given in Table 1.

As the sampling pressures differ between wells and with time, it is cumbersome to directly compare measured concentrations in the samples and therefore the results are typically presented as reservoir fluid concentrations. The reservoir fluid is calculated by combining the vapour and liquid fractions according to the vapour fraction at collection. The vapour fraction on the other hand depends on the measured sample pressure and the estimated reservoir temperature for each well, which is determined from logged temperatures at the depth levels of the producing aquifers, as well as geothermometry. The established reservoir temperature of the Reykjanes wells ranges between 270 and 310°C. Although most wells in Reykjanes have discharge enthalpy slightly (5-10%) higher than what corresponds to liquid enthalpy at the reservoir temperature (Thorbjörnsson et al., 2013), the excess enthalpy has not been taken into account when calculating the reservoir fluid. This approximation will not affect the calculated concentrations of the non-volatile components, but may underestimate the concentrations of dissolved gases in the reservoir fluid.

## 3. EVOLUTION OF DEEP LIQUID CONCENTRATIONS

### 3.1 Chloride

The Cl concentration in the geothermal liquid prior to 2006 was very similar to that of seawater but the deep liquid concentration of some of the Reykjanes production wells has increased after the 100 MW power plant was commissioned in 2006. The deep liquid Cl concentration in wells RN-8, 9, 12 and 23 is shown on Figure 3A. The scatter in the Cl concentrations in early samples from well RN-8 is believed to be due to unreliable analytical methods rather than reflecting actual changes in the fluid composition.

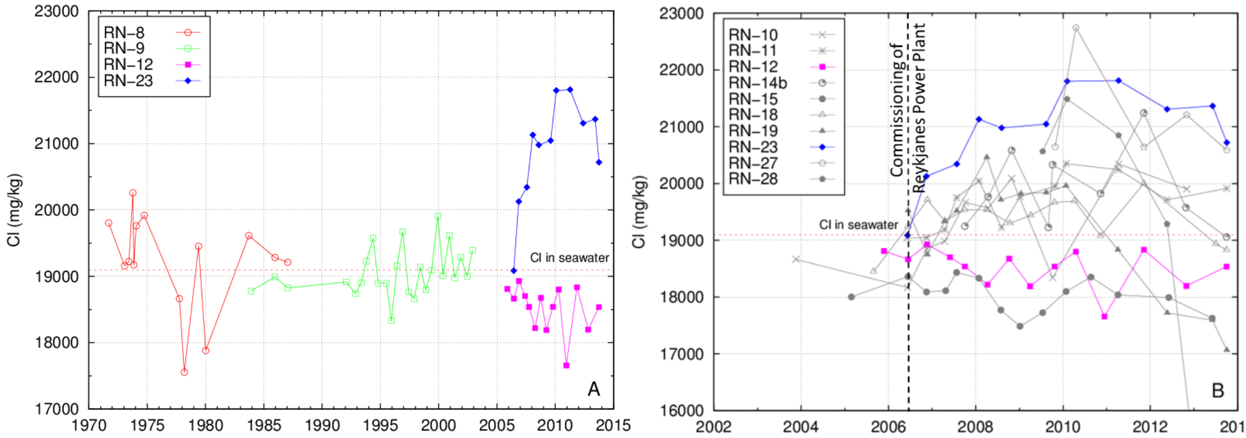

**Figure 3: The diagram on the left (A) shows deep liquid Cl concentration in the Reykjanes system from 1971 to 2013. The Cl concentration of seawater near the coast of Reykjanes, 19100 mg/kg, is shown as a horizontal line for reference. No long term trend in Cl concentration was observed prior to the commissioning of the Reykjanes Power Plant in 2006. The diagram on the right (B) shows the evolution of the deep liquid Cl concentration of all Reykjanes production wells from 2003 to 2013. Commissioning of the Reykjanes power plant is shown with a vertical line. Data from wells RN-13b, -21, -22, -24, -25 and -26 are omitted but data from RN-12 and RN-23 are highlighted.**

A more detailed view of the evolution of the deep liquid chloride concentration in the Reykjanes production wells from 2003 to 2013 is shown in Figure 3B. For the sake of clarity, the figure only shows data for ten out of sixteen wells that have produced since 2003, and highlights data from wells RN-12 and RN-23. Figure 3B reveals that most of the production wells exhibited increase in their deep liquid Cl concentration after 2006. This has been most pronounced in wells RN-23, -22 and -11 but only a few wells did not exhibit this trend to some degree, i.e. RN-12, -15, and possibly -18. The Cl increase in wells such as RN-23 was more or less continuous until about 2010 when the Cl concentration in most wells levelled off. Since 2011 the Cl concentrations in most wells have been slowly decreasing and they have reached pre-production values in some of the wells. This includes wells RN-14b, -18, -21 and -24. Three wells, RN-13b, -19 and -28 now have Cl concentrations below seawater salinity. Deep liquid Cl concentrations in wells RN-12 and -15 have remained constant and somewhat lower than seawater salinity.

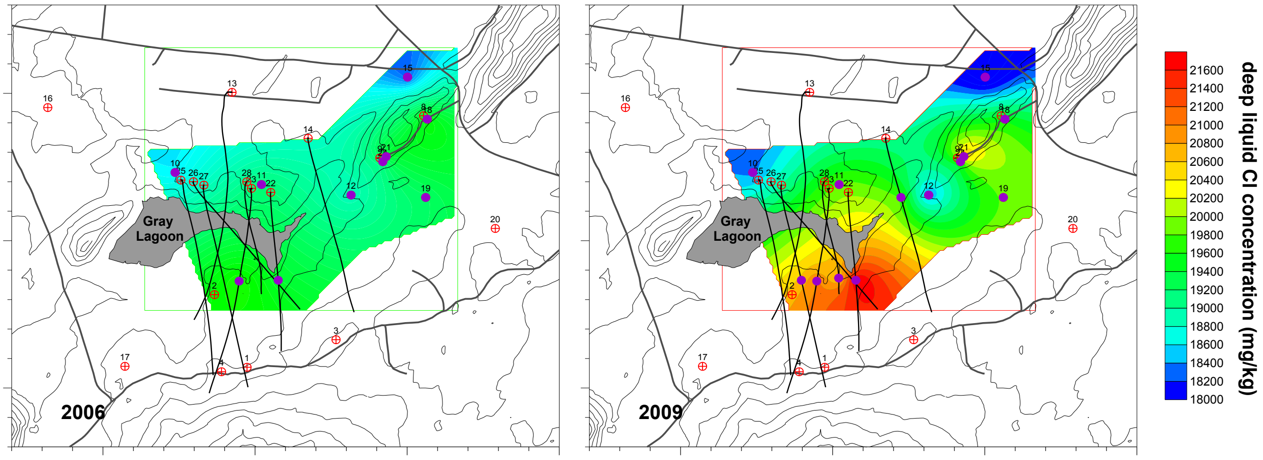

**Figure 4: Maps showing chloride in the deep liquid of the Reykjanes production wells in 2006 (left) and 2009 (right). Well heads are shown with red symbols and the location of the most productive feed points in each well is indicated with a purple symbol.**

Figure 4 shows the deep liquid Cl concentration in the Reykjanes wells on color coded contour maps. The figure reveals that the Cl increase between 2006 and 2009 was most pronounced in wells producing from the south west sector of the production field. Many of the most productive wells in the first years after 2006 are located in this part of the system and most of the wells producing from this zone have relatively shallow feeding aquifers. Production from many of the wells in the SW sector decreased with time and one such well, RN-22, eventually became unproductive. The correlation between aquifer depth and Cl concentration change is illustrated in Figure 5 which shows the depth of the most productive feeding aquifers in each well color coded to show the Cl change in the respective wells between 2006 and 2009. Figure 5 reveals that although most of the wells that exhibited the most intense Cl increase have shallow aquifers, the Cl change was also observed in wells in the SW-sector with relatively deep aquifers and that some of the wells in the NE-sector did not exhibit as intense change in Cl concentration despite having shallow aquifers.

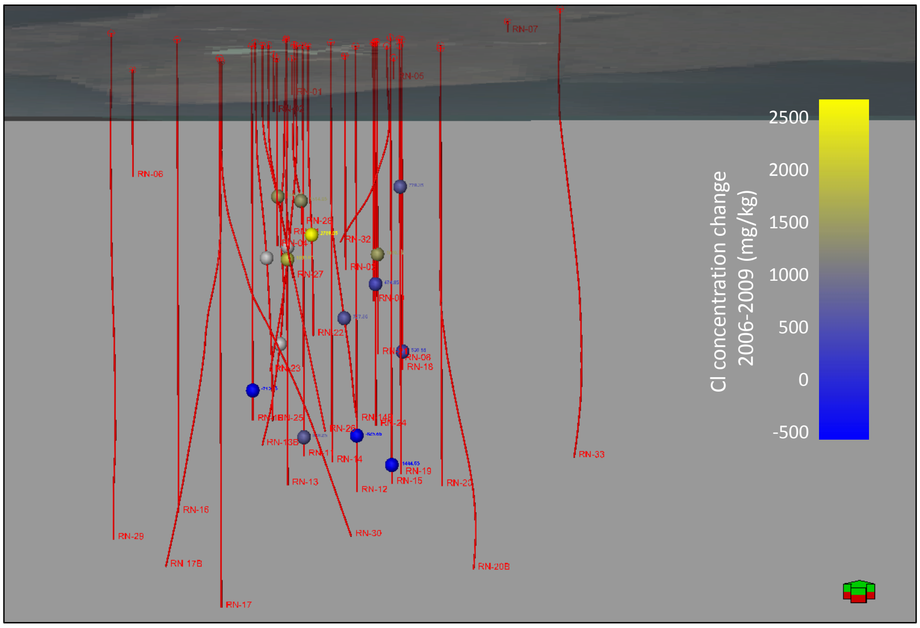

**Figure 5: Low angle oblique view of the Reykjanes subsurface, looking north. The figure shows the well paths in the Reykjanes geothermal system. The most productive feeding aquifers in each well are indicated by circles. The symbols are color coded to show the change in deep liquid Cl concentration between 2006 and 2009.**

The Cl concentration change in some of the Reykjanes production wells has been interpreted to be a result of progressive boiling of the fluids in the SW sector. The idea is that the relatively shallow aquifers in the SW sector had limited recharge and continued boiling of the same liquid resulted in increasing Cl concentrations. Limited recharge is consistent with the abrupt pressure drop between 2006 and 2010 shown in Figure 2. The levelling off and eventually the decrease of the deep liquid Cl concentration coincides with the change in pressure decline in 2009-2010. This may indicate that the system found a new recharge/production balance as production from the SW-sector declined after the first few years. Excess discharge enthalpy and decreasing liquid withdrawal indicates that the wells in the SW-sector are now producing less liquid from the shallow aquifers, than before.

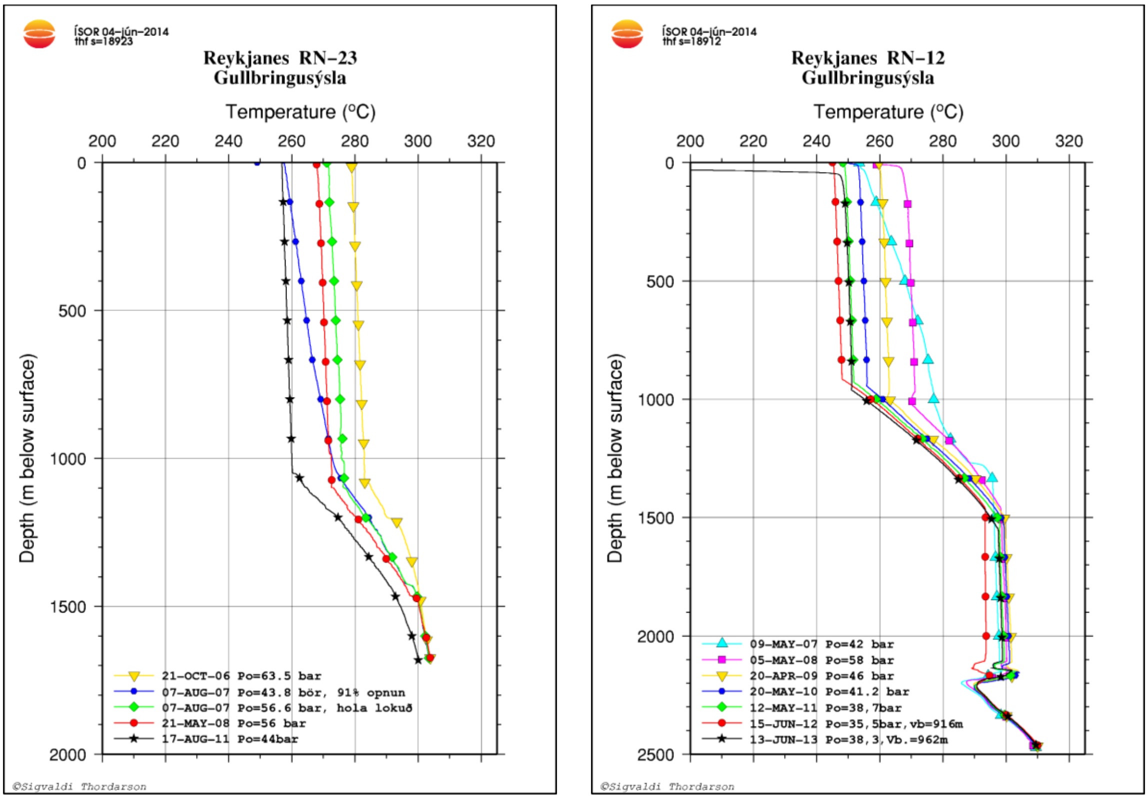

**Figure 6: Static temperature profiles for wells RN-23 (left) and RN-12 (right). Well RN-23 has experienced more cooling above 1500 m depth than well RN-12.**

The deep liquid Cl concentration decline that started after 2010 may also possibly be caused by partial condensation of steam in the zone around the production wells. Figure 6, above, shows temperature logs from well RN-23 (Figure 6A) and RN-12 (Figure 6B). It can be seen that well RN-23 has been gradually cooling with time above 1500 m depth but this is less pronounced in well RN-12. Steam condensation seems to be the only possible explanation for the recent Cl concentrations in wells RN-13b and -28, which have Cl concentrations well below that of seawater in the latest samples. Monitoring of the Cl concentration trend in the coming years will reveal whether the deep liquid concentration in most production wells levels off at pre-2006 values or if it continues to drop as in RN-28. If the Cl concentrations level off a new recharge/production balance has been found whereas continued drop in Cl concentrations below pre-2006 levels indicate steam condensation in the formation around the wells.

The Cl decrease in well RN-19 is most likely caused by communication with the reinjection well RN-20b. Solute concentrations in this well have been gradually decreasing following a peak in 2010 and Cl concentrations are now at a historical low of about 17000 mg/kg. The well head of RN-20b is only about 250 m away from RN-19 and the best feeding aquifers in both wells are at 790 m depth which is well above the kick off point in RN-20b (Mortensen et al., 2006). A tracer test of 2013 also showed a clear connection between the two wells (Matthíasdóttir et al., 2015). The reinjection fluid was until the summer of 2012 a mixture of separated brine and condensate, then only condensate was injected into the well for about a year, but since August 2013 the reinjectate is an approximately 3:1 mixture of separated brine and condensate and the rate of reinjection is about 120 kg/s (Geir Þórólfsson, personal communication). In both cases the concentrations of dissolved solids in the reinjection fluid are lower than in the deep fluid in the system and mixing of the two fluids would result in lower concentrations of dissolved solids in the fluid from RN-19.

### 3.2 Silica

The deep liquid silica concentration in the Reykjanes production wells from 2003 to 2013 is shown in Figure 7. Quartz solubility in water with the salinity equivalent of that of the Reykjanes liquid at three different temperatures is indicated by the horizontal lines (von Damm et al., 1991). There is significant scatter in the data, both between wells and also between samples from the same well, although the latter is less pronounced since 2011.

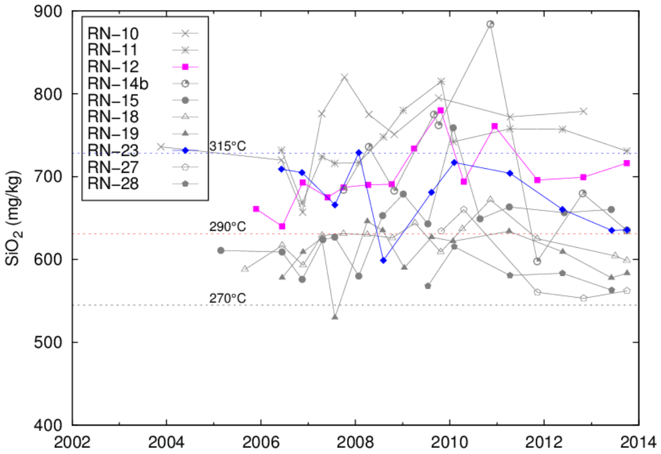

**Figure 7. Concentration of silica in the deep liquid of the Reykjanes production wells, 2003–2013. Quartz solubility in saline geothermal water at three temperatures is shown as horizontal lines. Data from from wells RN-13b, -21, -22, -24, -25 and -26 are omitted but data from RN-12 and RN-23 are highlighted.**

The concentration of silica in the geothermal liquid in the Reykjanes system is assumed to be controlled by equilibrium with quartz. The data in Figure 7 support this assumption as the wells that have reference temperatures between 295 and 310°C, such as RN-10, -11, -12, and -14b, tend to have higher concentrations of dissolved silica that correspond to equilibrium with quartz within this temperature range. Similarly, the silica concentrations in the liquids from wells that have reference temperature between 275 and 285°C (RN-15, -18, -21, and -24) are in the range expected for equilibrium with quartz in this temperature range. Wells RN-27 and -28 have the lowest reference temperature of the production wells; 270°C.

As stated above, the silica data are quite scattered, particularly in the years 2007 to 2010, when the mass production was greatest and the chloride data above indicate that considerable changes were taking place in the reservoir. Since 2011, the scatter has been less pronounced in most wells. The extensive scatter in the silica concentrations between 2007 and 2010 is not a result of analytical error as reference sample results from this period did not show increased scatter. Furthermore, samples from other fields analysed together with the Reykjanes samples in this period did not exhibit similar scatter in the silica values.

Wells RN-13b and -14b are somewhat unique with respect to the silica concentration scatter as they have exhibited more dramatic changes in silica concentration, particularly the latter. Both wells have oscillating well head pressures (±3.5 and ±2.5 bar, with periods of about 5 and 4 hours, respectively), indicating that the contributions from different aquifers in the wells may vary periodically.

Silica concentrations in wells RN-27 and -28 originally indicated reservoir temperatures of about 285 to 290°C, but both concentrations declined significantly in 2010 and now appear to be stable corresponding to temperatures of approximately 270°C. These two wells are shallow and produce high enthalpy fluid from relatively shallow aquifers. It is likely that boiling in the host rock around the wells has caused local cooling around the wells. Finally, the silica concentrations in well RN-19 have fallen gradually since 2011, indicating that the well may be experiencing cooling due to reinjection into RN-20b. This interpretation is supported by the Cl data above as well as the results of tracer injection into RN-20b (Matthíasdóttir et al., 2015).

### 3.3 Gas concentrations

The concentrations of the most abundant reactive geothermal gases, $CO_2$ and $H_2S$, in the Reykjanes reservoir fluid, have not changed much with time. The concentrations of these two gases are often controlled by equilibria with minerals and that appears to be the case in Reykjanes. More specifically, $CO_2$ seems to be buffered by calcite, quartz, prehnite and epidote, and $H_2S$ is considered to be in equilibrium with anhydrite, wollastonite, magnetite, quartz and pyrite (Óskarsson et al., 2014).

The $CO_2$ concentrations, depicted in Figure 8, range from about 500 to 2500 mg/kg and variations in concentration for individual wells are generally small. Although $CO_2$ concentration seems to be buffered by minerals to some extent, there are some wells that do not follow the predicted relationship between $CO_2$ concentration and temperature, for example well RN-15, which has a reference temperature of 285°C but nonetheless has fairly high $CO_2$ concentrations.

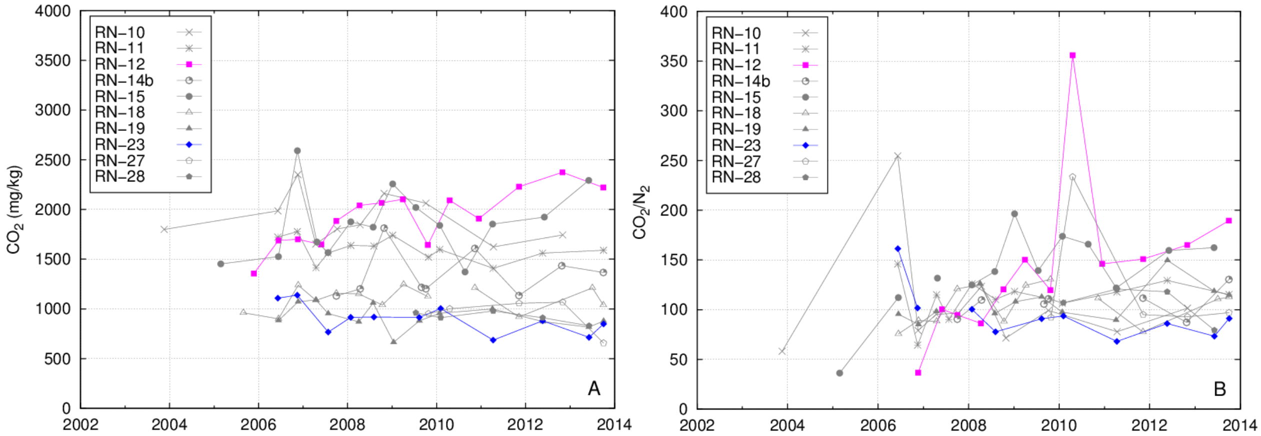

**Figure 8. The diagram on the left (A) shows the concentration of $CO_2$ in the deep liquid at Reykjanes, 2003 to 2013. The diagram on the right (B) shows the mass ratio of $CO_2$ to $N_2$ in the Reykjanes deep liquid, 2003 to 2013. Samples which have obviously been contaminated by air during sampling or analysis are omitted. Data from from wells RN-13b, -21, -22, -24, -25 and -26 are omitted but data from RN-12 and RN-23 are highlighted.**

$N_2$ and Ar are considered non-reactive in the sense that their concentrations in the deep liquid are not controlled by mineral buffers, but rather by the inflow (from magma or fresh water) and outflow (in steam) of these gases to and from the reservoir. The $N_2$ and Ar concentrations in the Reykjanes deep liquid decreased slightly from the commissioning of the Reykjanes Power Plant in 2006 to about 2010, but have been fairly constant since then. Studies of gas isotopes at Reykjanes indicate that Ar is largely derived from air and that the same applies to $N_2$ in recent years, but at the onset of production more magmatic $N_2$ was present in the system (Óskarsson et al., 2015). The $N_2$/Ar (mass) ratio in the reservoir decreased somewhat from 2009 to about 2011 but has been fairly constant at about 32 to 40 since then. The value for air-saturated water is 26 (Hamme and Emerson, 2006). The high $N_2$/Ar ratio in the deep liquid up until 2010 is believed to result from the presence of magmatic nitrogen in the liquid (Giroud, 2008).

Figure 8B shows the mass ratio of $CO_2$ to $N_2$ in the Reykjanes deep liquid, 2003 to 2013, excluding samples which have obviously been contaminated by air during sampling or analysis and thus have anomalously high $N_2$ concentrations. The $CO_2$ to $N_2$ ratio increased in each production well in the period 2006 to 2010, from about 10–130 in 2007 to 70–180 in 2010. Since 2010 the $CO_2$ to $N_2$ ratio has mostly levelled off although fluctuations are seen, and possibly an increase in RN-12, and now spans the range 70–190. The same applies to the $H_2S$ to $N_2$ ratio. The increase in the $CO_2$ to $N_2$ and $H_2S$ to $N_2$ ratios in the period from 2006 to 2010 is taken as further evidence for progressive boiling in the reservoir. The more stable values seen since 2011 indicate that the extent of boiling is reaching a steady state. This is in an agreement with the decreased drawdown rate shown in Figure 2 and the constant $N_2$/Ar ratio discussed above.

### 3.4 Stable isotopes

Figure 9 shows the isotopic shifts of D ($^2$H) and $^{18}$O in the Reykjanes deep liquid, 2003 to 2013. Both isotope ratios are presented as per mille deviations from the measured isotopic shifts in standard mean oceanic water (SMOW). Also shown are isotopic ratios of local groundwater from a potable water well near Sýrfell (green dots), local seawater from the wells that provide the power plant with cooling water (cyan dots) and the Global Meteoric Water Line (Craig, 1961).

Little changes have been observed in the isotopic composition of the water since the commission of the power plant, and there are no indications of influx of either seawater or groundwater into the system. The only trend that has been observed is that the liquid phase samples from wells that draw from the SW-part of the field seem to have become slightly more enriched in $^{18}$O since 2010. This is likely due to progressive boiling in that part of the field, which was also seen in the chloride data above.

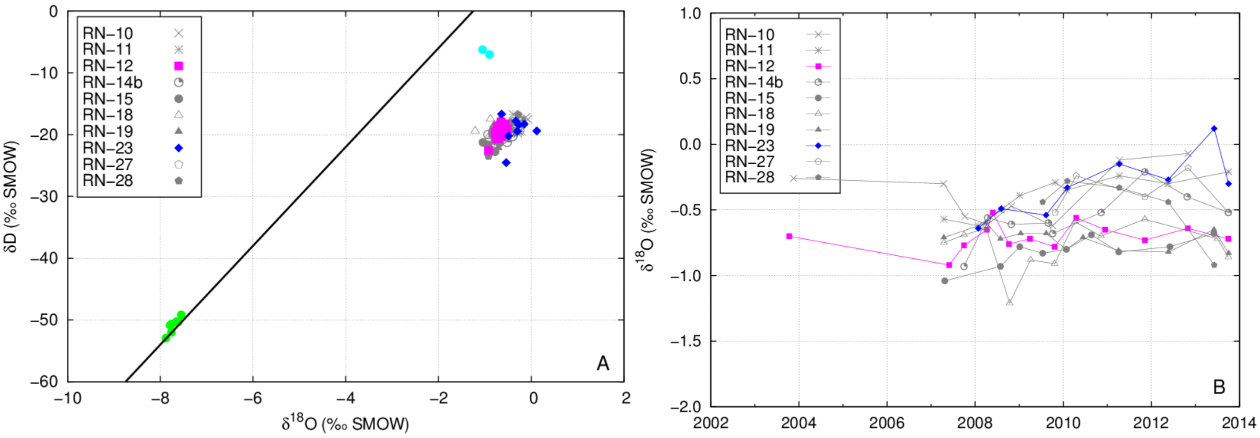

**Figure 9. Stable isotope composition of the Reykjanes deep fluid. The diagram on the left (A) shows the δD and $\delta^{18}$O values of the Reykjanes thermal fluids. Also shown are values for local groundwater (green dots), local seawater (cyan dots) and the Global Meteoric Water Line. The diagram on the right (B) shows the evolution of the $\delta^{18}$O in the fluids from 2003 to 2013. Data from from wells RN-13b, -21, -22, -24, -25 and -26 are omitted but data from RN-12 and RN-23 are highlighted.**

## CONCLUSIONS

Chemical monitoring in the Reykjanes field in the period from 2003 to 2009 has shown that the fluid in the system has changed in response to production. The initial increase in Cl concentration after the commissioning of the 100 MW Reykjanes Power Plant in 2006 is explained by progressive boiling of the geothermal fluid. This effect is most pronounced in the wells producing from the SW-sector that are characterized by relatively shallow aquifers. These wells have also shown decreasing gas content in the deep liquid for many wells, that is consistent with progressive boiling. Slight increase in $\delta^{18}$O in these wells also supports this interpretation.

Reversal of the Cl trend in 2010 is not fully explained. It may indicate that a new balance between recharge and production has evolved but partial steam condensation in the formation around the wells may explain the Cl decrease. The fluid evolution in the years to come will shed light on this question.

Deep liquid silica concentration has been relatively constant in many wells since 2010 at levels consistent with equilibrium with quartz at measured down hole temperatures. The exceptions to this are well RN-19, -27 and -28. RN-19 seems to be experiencing cooling due to reinjection into RN-20b, located some 250 m away. Inflow of reinjection fluid is also supported by decreasing Cl concentration in this well and rapid returns of tracer injected to RN-20b in 2013. The decreasing silica concentration of the fluid from RN-27 and -28 seems to indicate cooling of the shallow aquifers from some 290°C to about 270°C due to boiling.

The chemical and isotopic data do not show any signs of incursion of cold water into the system.

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**Table 1. Results of chemical analyses for four two-phase well samples from the Reykjanes field. Concentrations are given as mg/kg of liquid or vapour (condensate) unless otherwise noted.**

| **Well** | RN-12 | RN-15 | RN-19 | RN-23 |
|---|---|---|---|---|
| **Date** | 30.10.2012 | 3.6.2012 | 23.5.2012 | 21.5.2012 |
| **$P_S$ (bar-g)** | 29.7 | 23.6 | 25.0 | 26.3 |
| **LIQUID PHASE** | | | | |
| **pH ( /°C)** | 5.57 / 22.3 | 5.80 / 22.5 | 5.75 / 22.0 | 5.29 / 21.9 |
| **$CO_2$** | 64.0 | 44.5 | 23.0 | 23.0 |
| **$H_2S$** | 4.90 | 3.16 | 0.74 | 0.62 |
| **$NH_3$** | 1.28 | 1.17 | 1.29 | 1.64 |
| **B** | 8.40 | 8.92 | 8.60 | 10.2 |
| **$SiO_2$** | 830 | 780 | 691 | 783 |
| **Na** | 10710 | 10500 | 10530 | 12910 |
| **K** | 1550 | 1560 | 1600 | 1940 |
| **Mg** | 0.93 | 0.68 | 0.69 | 2.22 |
| **Ca** | 1890 | 1790 | 1630 | 2250 |
| **F** | 0.24 | 0.23 | 0.21 | 0.23 |
| **Cl** | 21380 | 20830 | 20100 | 25260 |
| **Br** | 75.9 | 73.4 | 72.9 | 93.6 |
| **$SO_4$** | 17.8 | 16.6 | 20.9 | 28.5 |
| **Al** | 0.121 | 0.0427 | 0.122 | 0.153 |
| **As** | 0.116 | 0.0814 | 0.136 | 0.144 |
| **Ba** | 10.2 | 8.67 | 9.50 | 14.0 |
| **Cd** | <0.00005 | 0.000144 | <0.00005 | 0.000072 |
| **Co** | <0.00005 | <0.00005 | <0.00005 | <0.00005 |
| **Cr** | 0.000122 | 0.000918 | <0.0001 | <0.0001 |
| **Cu** | 0.00134 | 0.000843 | 0.00305 | <0.0005 |
| **Fe** | 0.310 | 0.119 | 0.110 | 0.677 |
| **Hg** | <0.000002 | 0.000006 | 0.000003 | <0.000002 |
| **Mn** | 3.08 | 1.73 | 1.12 | 2.59 |
| **Mo** | 0.00410 | 0.0125 | 0.0147 | 0.0134 |
| **Ni** | 0.00367 | 0.0174 | 0.00273 | 0.00622 |
| **Sr** | 9.89 | 10.2 | 8.26 | 10.4 |
| **Pb** | <0.0003 | <0.0003 | <0.0003 | <0.0003 |
| **Zn** | 0.033 | 0.00552 | 0.0176 | 0.151 |
| **TDS** | 36746 | 38148 | 35258 | 43832 |
| **δD (‰SMOW)** | -20.5 | -21.3 | -19.6 | -18.3 |
| **$\delta^{18}O$ (‰SMOW)** | -0.34 | -0.34 | -0.57 | 0.05 |
| **CBE (%)** | -0.70 | -0.45 | 1.13 | 1.36 |
| **VAPOUR PHASE** | | | | |
| **$CO_2$** | 13700 | 13620 | 6530 | 5120 |
| **$H_2S$** | 370 | 330 | 180 | 240 |
| **$H_2$** | 0.67 | 1.88 | 3.07 | 2.04 |
| **$N_2$** | 83.8 | 84.1 | 44.1 | 59.9 |
| **$O_2$** | <0.01 | <0.01 | <0.01 | <0.01 |
| **Ar** | 2.45 | 2.41 | 1.17 | 1.71 |
| **$CH_4$** | 1.32 | 1.23 | 0.30 | 0.52 |
| **$NH_3$** | 4.41 | 3.50 | 4.40 | 3.55 |
| **Na** | 0.13 | 0.32 | 0.25 | 0.24 |
| **B** | 0.72 | 0.72 | 0.79 | 0.76 |
| **δD (‰SMOW)** | -19.8 | -21.4 | -19.9 | -19.2 |
| **$\delta^{18}O$ (‰SMOW)** | -2.13 | -2.38 | -2.45 | -1.84 |