GEOCHEMICAL RECONNAISSANCE OF FLUIDS FROM THE KRAFLA AND NESJAVELLIR THERMAL AREAS, ICELAND: BASELINE STUDIES IN SUPPORT OF THE IDDP

Bruce W. Christenson¹, Halldor Armannsson², B.Mack Kennedy³Thijs J. van Soest³, and Gestur Gíslason⁴

¹National Isotope Centre, GNS Science, 30 Gracefield Road, Lower Hutt, New Zealand
²ISOR, Iceland Geosurvey, Grensasvegur 9, 108 Reykjavik, Iceland
³Lawrence Berkeley National Laboratory, Berkeley, CA, USA
⁴Reykjavík Geothermal, Suðurlandsbraut 18, 104 Reykjavík, Iceland
Rationale:

- Goal of the IDDP is to produce supercritical fluid for energy production
- Bold initiative, and poses interesting challenges and opportunities for energy production
- Unique opportunity to chemically and isotopically characterise processes operating from top-to-toe in a magmatic-hydrothermal system
- Develop geochemical exploration tools for these environments
A brief history of the IDDP…..

• Three candidate systems considered:
  – Reykjanes
  – Nesjavellir
  – Krafla
• Early discussions focused on Krafla & Nesjavellir, but Reykjanes chosen!
• Drilling problems led to abandonment & redeployment to Krafla
• Drilling of IDDP-1 undertaken this year
Outline:

• A few facts about the Krafla and Nesjavellir systems
• Interesting aspects of their water chemistry
• Discuss the component sources of gases in the discharge fluids
• Describe where we are headed next
Nesjavellir:

- Northern slopes of Hengill Volcano
- Previous eruption ~ 2000 years bp, through vents partly in the thermal area
- $120 \text{ MW}_e$ & $300 \text{ MW}_t$ production
- 22 production wells
- High enthalpy discharges
- Reservoir is naturally 2-phase (vapour-liquid) at depth
Nesjavellir:

- Production from NE-SW trending fractures
- Kyrdalur fissure hosted the eruption 2000 ybp
- Maximum temperatures (> 380 °C) in NJ-11
- Dilute, alkaline-chloride fluids
- Geo-indicated temperatures 280-300 °C
Krafla:

- A more volcanically active area
- Magma chamber 3-7 km depth
- Recent volcanism (1975-1984)
- 40 production wells
- 60 MWe
- Very high enthalpy discharges
- Natural 2-phase conditions
Krafla:

- The field lies right on the mid-Atlantic Ridge
- Production from NE-SW normal faults related to this tectonic regime
- Hveragil fracture zone most notable
- Three sub-fields or compartments
- Mt Krafla on eastern boundary
- Viti Crater – 1724 eruption
- 1975-1984 eruptive period from fissures in the Leirhnukur area (NW)
- IDDP-1 drilled to 2200 m, well short of critical pressures
Acid Fluids:

- A number of wells have produced acidic fluids
- Limiting factor in production from some parts of the system
- Particulates largely Fe sulfides and oxides (casing corrosion)
- No acid fluids were available in this study
Hauksson & Gudmundsson (2008)
Heat – Cl Relationship (TD):

- Low salinities in both systems
- Inverse relationship between discharge H & Cl
- All liquids in this study are neutral to alkaline pH
- Excess steam is the diluent
Nesjavellir Liquid Phase: $\text{Cl vs } H_{\text{NK}}$

- Na/K geo-indicator temperatures used
- NJ22 has highest liquid enthalpy
- Projection back to system mixing line shows fairly tight compositional range.
- Consistent with a single source fluid
- Base fluid composition of 135 mg/l Cl, $\sim$350 °C
- Modelling shows this source to be from Hengill
Krafla Liquid phase: Cl vs $H_{NK}$

- Here a “system” mixing line is established for KJ34
- Little coherency with respect to Cl between compartments
- Approach not very useful here as Cl is transported as HCl(g) from proximal sources
- Not a single source liquid, but several, locally derived
Krafla Liquid phase: CI vs B/Cl

- Nesjavellir fluids show relatively constant B/Cl ratios
- Krafla B/Cl ratios vary by > factor of 50
- Cannot be accounted for by closed system boiling
- Points to a high temperature (magmatic) source and vapour transport of B at Krafla
Total Discharge $\text{CO}_2$ at $H_m$:

- NG5 and NG9 most gas enriched at Nesjavellir
- Higher enthalpy discharges are relatively $\text{CO}_2$-depleted
- Exploitation effect or natural?
- Very close to Kyrdalur eruption fissures – conductive heat?
- At Krafla – there is direct correspondance between $H_m$ and $\text{CO}_2$
- KJ34 and KJ19 $\text{CO}_2$-enriched by factor of 5
- Tapping source conduits (Hveragil fracture network)
Volatile Chemistry: $\text{N}_2$-Ar-He

- 2 component mixing between meteoric water and He-rich end-member
- He from a mantle (magmatic) source
- KJ34 and KJ19 most enriched in magmatic component at Krafla
- NG5 and NG10 most enriched at Nesjavellir
- Most $\text{N}_2$ derived from meteoric fluid
Volatile Chemistry: $^{3}\text{He}-^{4}\text{He}-\text{CO}_2$

- $^{3}\text{He}/^{4}\text{He}$ ratios for Krafla very close to MORB
- Nesjavellir steam even more enriched in $^{3}\text{He}$
- Points to influence of the Icelandic Hot Spot
- Variation in relative CO$_2$ contents result of reservoir boiling
Volatile Chemistry: N$_2$-Ar-CO$_2$

- Relative compositions N$_2$-Ar-CO$_2$ again point to 2-component mixing between meteoric fluid and mantle gas
- KJ34 and KJ19 again most enriched in CO$_2$
- NG5, NJ9 and NJ19 most CO$_2$-enriched at Nesjavellir
- Boiling is a contributing effect
Volatile Chemistry: He-CH\(_4\)-CO\(_2\)

- Introduce CH\(_4\) as a purely hydrothermal component
- Assume two component mixing
- Calculate vapour loss pathway for NJ11
- Intersection of pathways with tie-line describes “parent” composition
- Nesjavellir more evolved as a geothermal fluid
- KJ19 and KJ34 extensively boiled
Conclusions:

• Identified 3 end-member source components for both systems: meteoric water, magmatic vapour and a derivative geothermal fluid

• Nesjavellir fluids are more highly evolved, and show evidence of a single source (Hengill)

• Nesjavellir fluids are probably less aggressive in terms of magmatic volatiles, and would probably make a better candidate for IDDP activities

• CO$_2$-enriched fluids from KJ34 and KJ19 composite result of boiling driven by fluxing magmatic vapour
Ongoing/Future Work:

- Comprehensive sampling programme in September 2009
- Particularly focused on gas equilibria and gas isotope chemistry ($^{15}$N, $^{13}$C, $^{34}$S, $^{2}$H, $^{18}$O and noble gas isotope systematics)
- Liquid phase isotopes ($^{11}$B, $^{18}$O, $^{2}$H, $^{87}$Sr systematics)
- IDDP-1 will soon discharge again and the senior author, Bruce Christenson is on his way there to collect samples
THANK YOU