IDDP. The chemistry of the Krafla geothermal system in relation to the IDDP well

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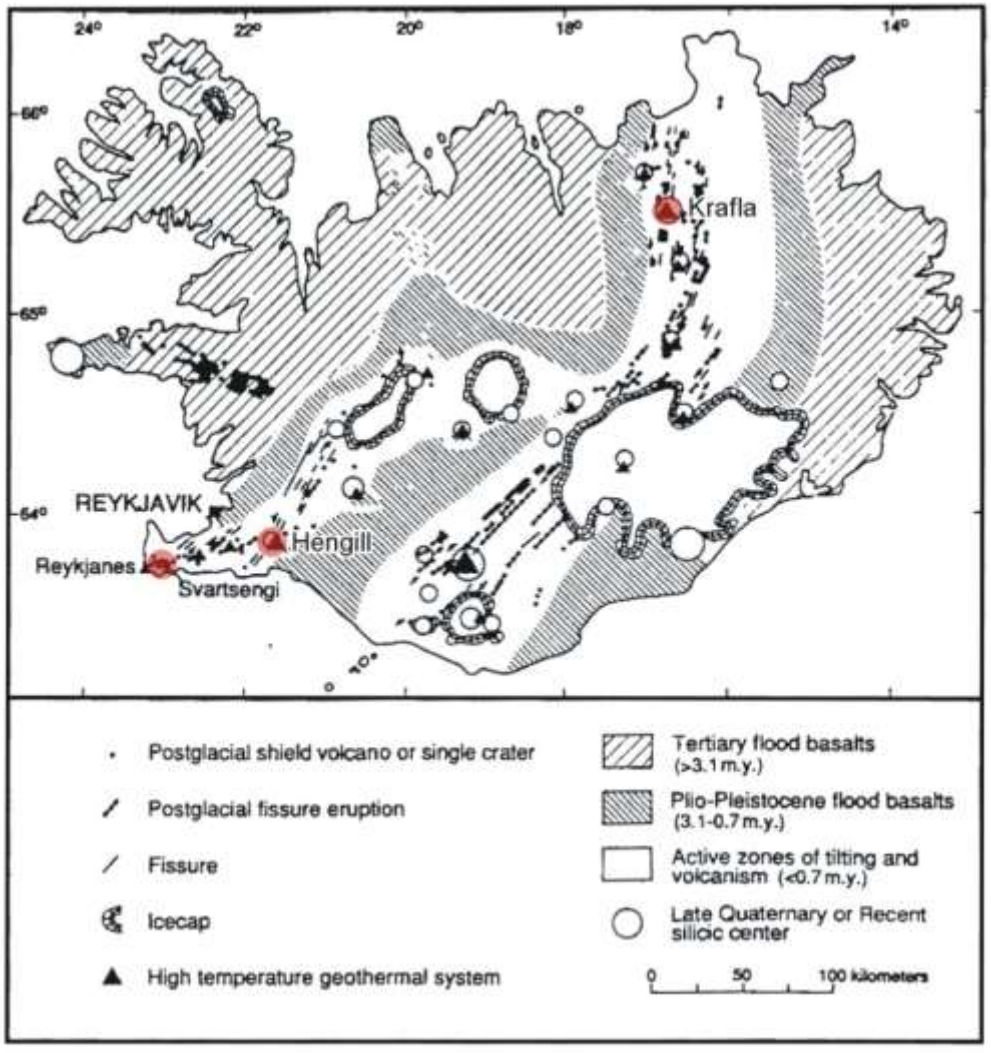
24°
22°
20°
18°
14°
66°
65°
64°
Krafla
REYKJAVIK
Hengill
Reykjanes
Svartsengi
Postglacial shield volcano or single crater
Postglacial fissure eruption
Fissure
Icecap
High temperature geothermal system
Tertiary flood basalts (>3.1 m.y.)
Plio-Pleistocene flood basalts (3.1-0.7 m.y.)
Active zones of tilting and volcanism (<0.7 m.y.)
Late Quaternary or Recent silicic center
0
50
100 kilometers

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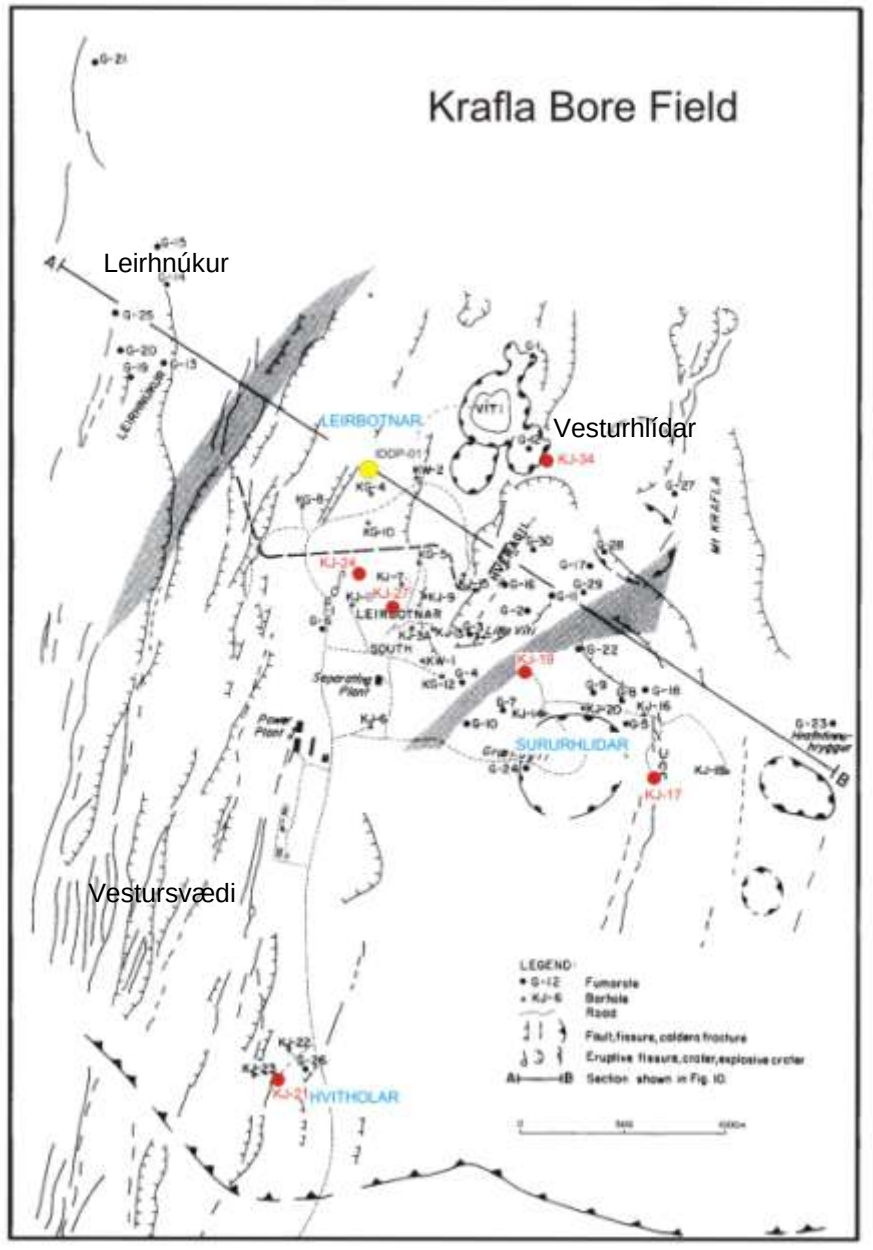
Sub-fields:

Bicarbonate main anion
Leirbotnar .Upper zone
Liquid dominated; sulphate second anion. Lower zone two phase at about 300°C chloride second anion but sulphate significant.
Hvíthólar two phase system
boiling point curve down to about 1000 m, chloride second anion ,cooler liquid but chloride second anion below.
Suðurhlídar and Vesturhlídar: boiling point curve is followed, two phase fluid, second anion chloride
Leirhnúkur well similar.
Vestursvædi cool and unproductive.

Wells >>2000 m deep have acid fluids near the bottom.
Leirbotnar, Vesturfhlídar recharge local Hvíthólar and Sudurhlídar either from nearby high ground or from far south.



Acid wells - History

- KG-4; KG-10 1975- 1976: Vítismóar
- KG-12 1978: Hveragil S
- KG-25 1990: Vítismóar
- KG-26, KJ-27, KJ-29 1991-1998: Leirbotnar
- KJ-33 1999: Vesturhlíðar
- KJ-35 2007: Leirhnúkur
- KJ-36, KJ-38 2007-2008: Vesturhlíðar, Vítismóar
- KJ-39 2008: Suðurhlíðar

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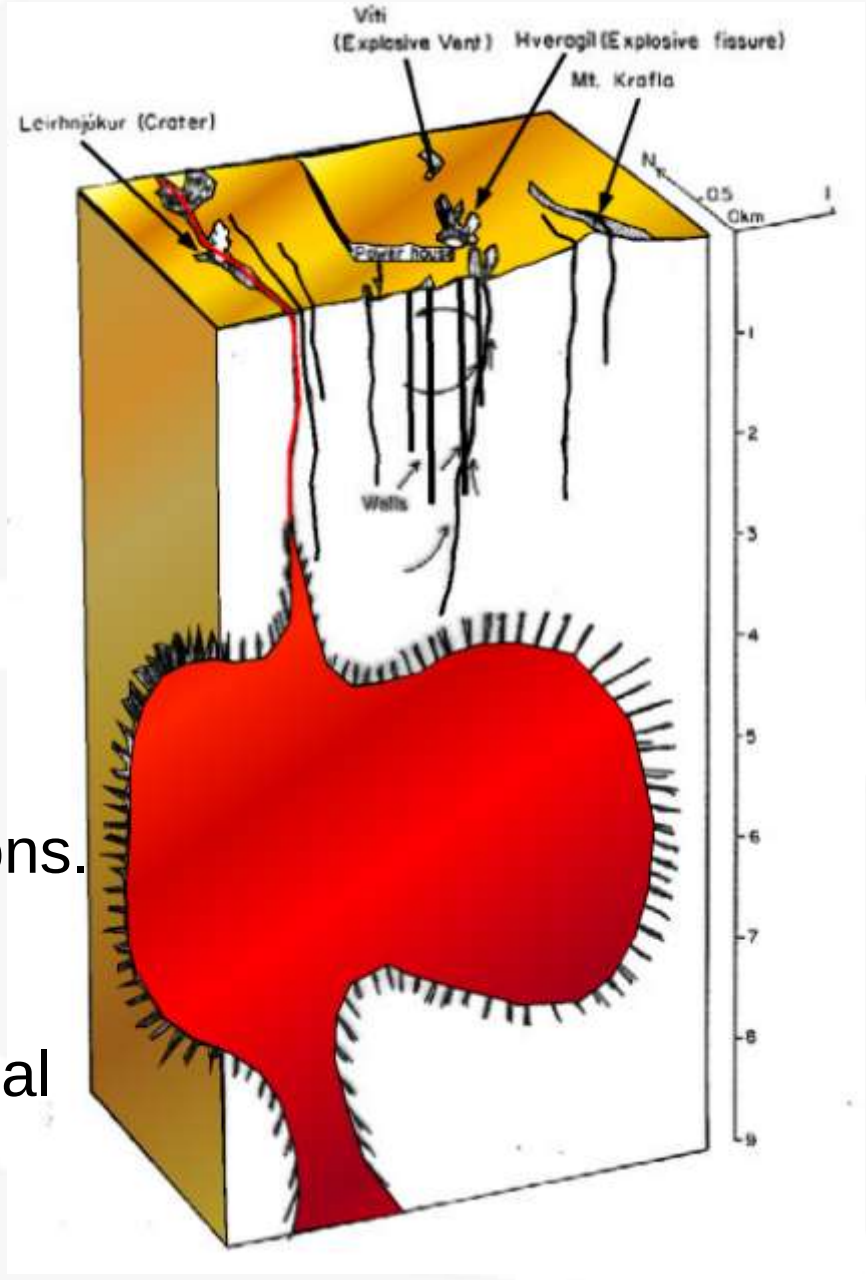
Geological conditions

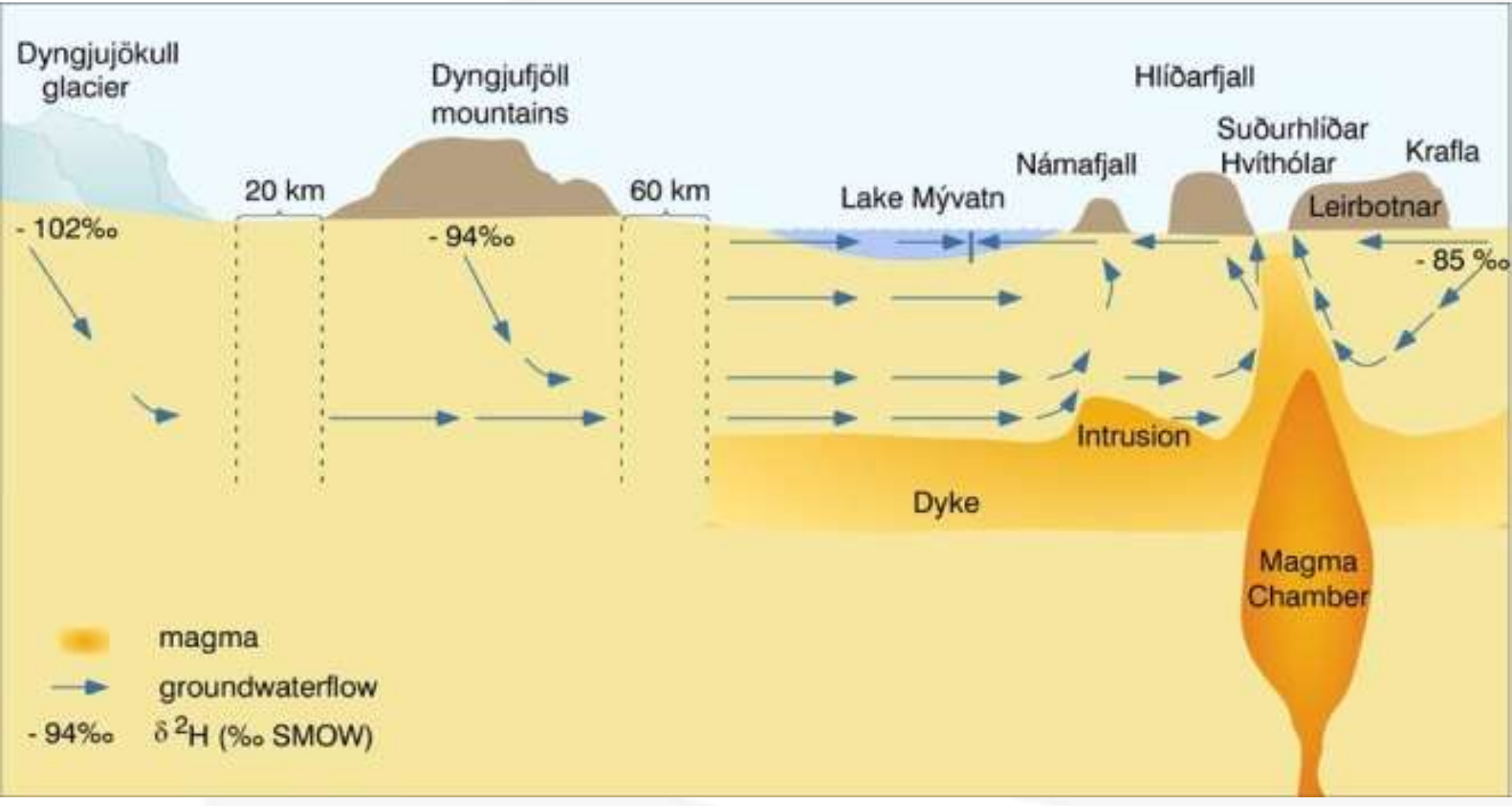
Active central volcano containing a caldera

Magma chamber at 5-8 km depth (Einarsson 1978)

The last eruptive period 1975-1984 resulted in 21 tectonic events and 9 eruptions.

The magma chamber is the heat source of the geothermal system.




Dyngjujökull glacier
Dyngjufjöll mountains
Hlíðarfjall
Suðurhliðar Hvíthólar
Krafla
Námafjall
20 km
60 km
Lake Mývatn
Leirbotnar
- 102‰
- 94‰
- 85 ‰
Intrusion
Dyke
Magma Chamber
magma
groundwaterflow
- 94‰
δ 2H (‰ SMOW)

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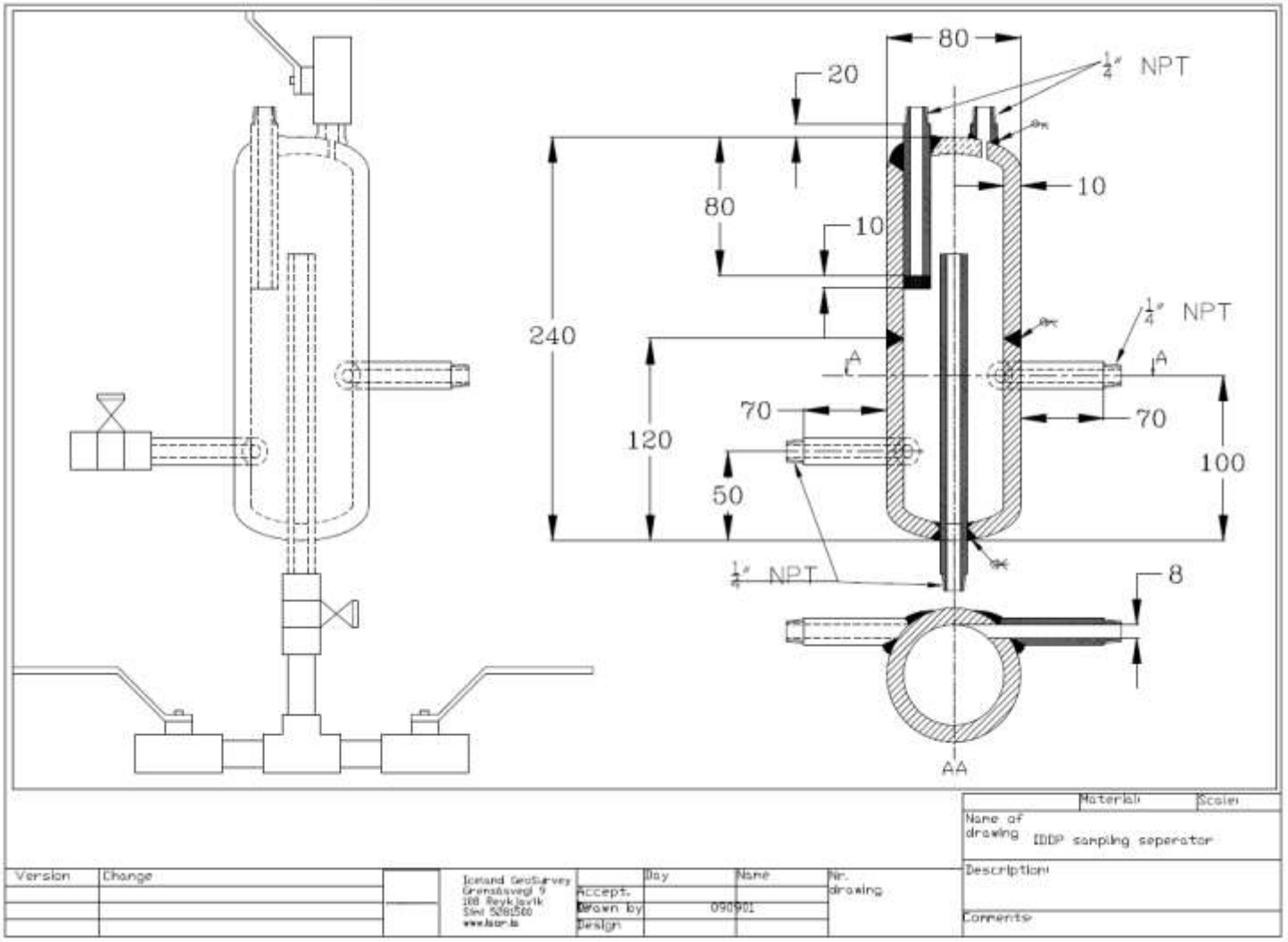
Results of analysis of fluids collected during bleed prior to discharge

Date	Time	Fl. kg/s	t°C	Gas p. bar	pH/°C	Con-duct-ivity µS/ 25°C	CO_2 mg/ kg	H_2S mg/ kg	H_2 mg/ kg	N_2 mg/ kg	CH_4 mg/ kg	Ar mg/ kg	Fe mg/ kg	Cl mg/kg
19.03	10:30	0.08	46.5	17.62	4.47/21.4	59	2584	760	16.0	6.58	8.83	0.28	4.0	5.6
21.03	21:30	0.08	139.8	16.64	5.00/24.8	424	1184	586	14.1	30.86	5.13	0.40	11.4	n.d.

Sampling separator



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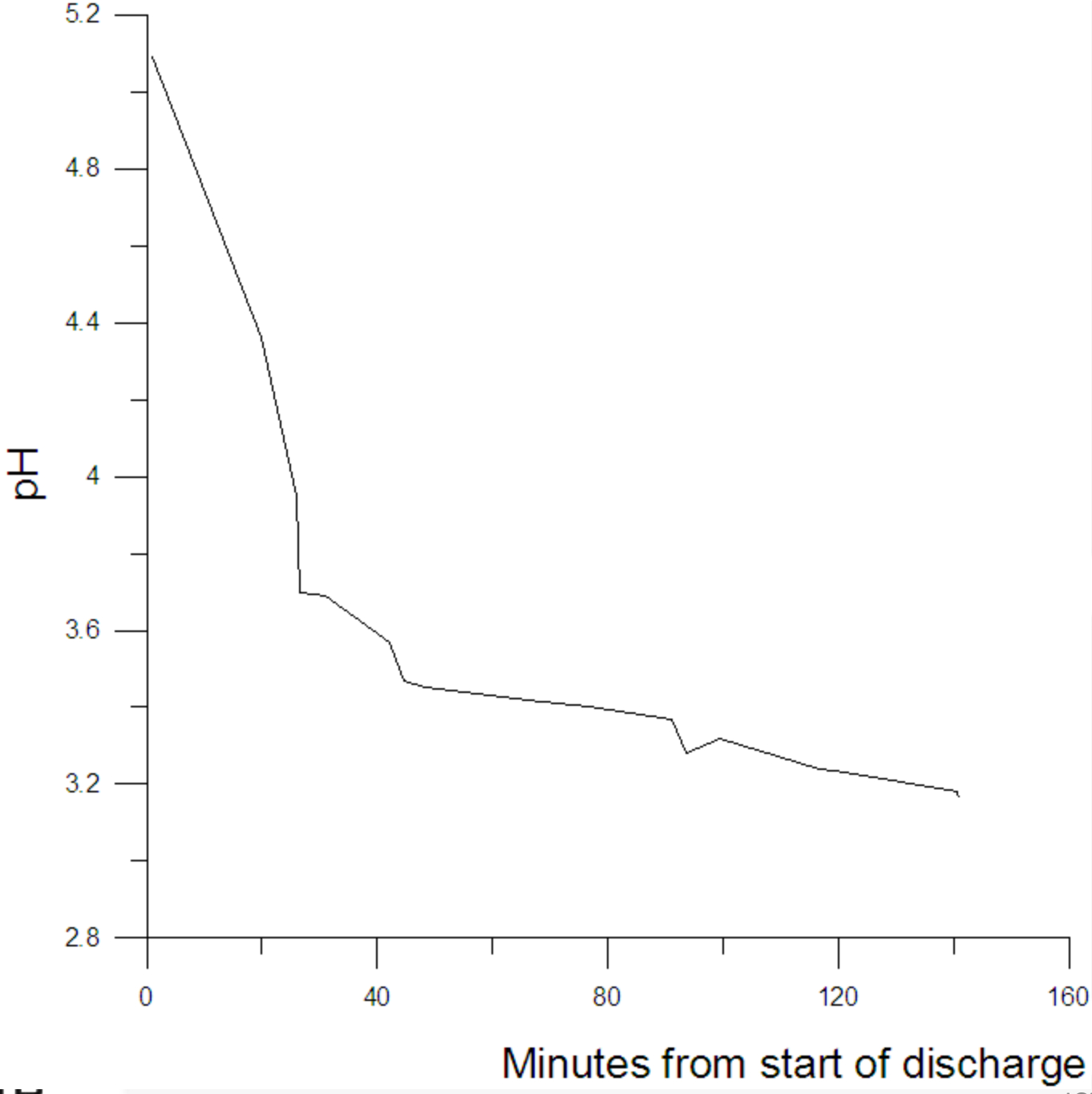
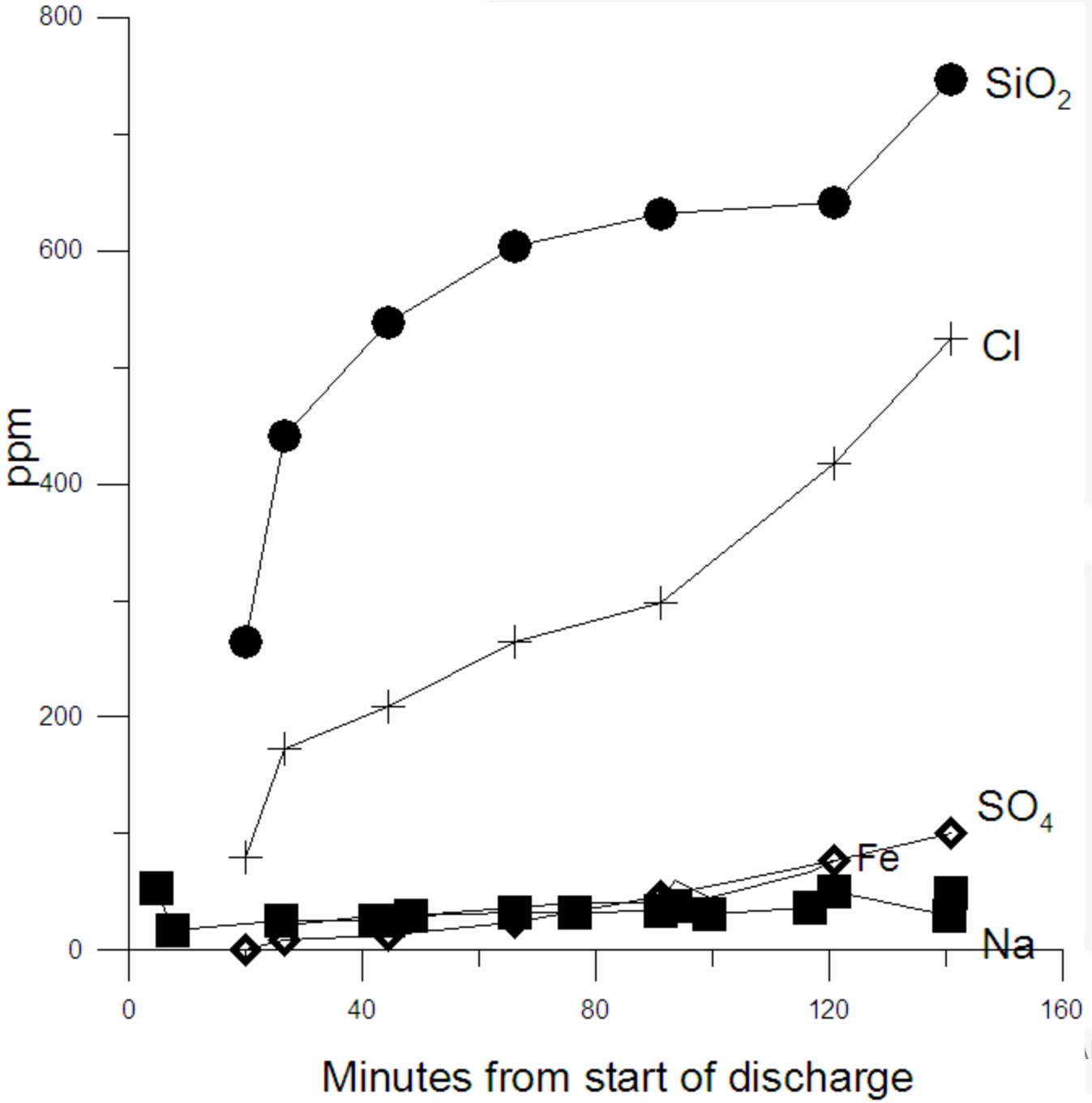
No.	Date	Time	t°C	pH/25°C	Cond.	Fe	Cl	H_2S	SO_4	Na	F	SiO_2
	22.3	15:00		5.09								
	22.3	18:30								53		
	22.3	21:25								17		
20100093	23.3	10:00	320	4.36	276		79.7	176	0.78		1.69	264
	23.3	16:00		3.95						25		
0094	23.3	16:30	326	3.70		21	173	179	9.31		2.36	441
	23.3	21:00		3.69								
	24.3	08:15		3.57		30				25		
0095	24.3	10:30	328	3.47	371	30	209	87	12.7	26	2.70	539
	24.3	14:15		3.45		30				29		
0096	25.3	08:00	311	3.42	468	37	264	75	24.5	32	3.48	604
	25.3	18:30		3.40		41				33		
0097	26.3	09:00	275	3.37	662	41	298	35	47.	34	4.90	632
	27.3	11:30		3.28		60				38		
	27.3	17:30		3.32		45				31		
	28.3	10:50		3.24		63				36		
0098	29.3	15:00		3.23	819	77	417	27	77.1	50	6.83	642
	30.3	10:50		3.18	895					29		
0099	31.3	11:00	272	3.17	946		524	12.3	101	49	8.11	747


5.2
4.8
4.4
4
3.6
3.2
2.8
pH
0
40
80
120
160
Minutes from start of discharge


800
600
400
200
0
ppm
0
40
80
120
160
Minutes from start of discharge
SiO2
Cl
SO4
Fe
Na

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Enthalpy and flow

- Equipment for determination of enthalpy and flow not present. Estimates from differential pressure over orifices and liquid flow estimated from rock muffler suggested initial flow through 10 mm orifice (with P = ca. 120 bar, and t°C = ca. 320°C) 6 kg/s total with 1 kg/s liquid, but with a combined flow through 22 mm and 50 mm orifices (P = ca. 70 bar and t°C = ca. 275°C) a flow of 33.5 kg/s with 0.4 kg/s liquid

Reflections on initial results of chemical analysis

- Assuming all Cl is derived from steam and using the above estimations of steam fraction Cl in steam is 10-15 mg/kg which is low compared to nearby acid wells
- SO_4 concentration is significant
- Assuming mean Fe concentration 100 mg/kg and liquid flow 1 kg/s a total of 78 kg Fe were discharged
- The SiO_2 concentration in the last sample suggests a fluid temperature of about 300°C suggesting that the fluid discharged towards the end of this test might be largely a geothermal fluid and only a small fraction of drilling fluid
- Persistent low pH suggests undersaturation w.r.t. Fe

Preliminary results of gas analysis

Sample No.			20100096/25.03		20100099/31.03	
Ar	%	mg/kg	0.29	0.95	0.11	0.27
CH_4	%	mg/kg	1.00	1.31	0.0	0.00
H_2	%	mg/kg	84.6	13.87	97.4	11.98
N_2	%	mg/kg	11.82	27.12	2.07	3.56
O_2	%	mg/kg	2.28	5.98	0.41	0.81
CO_2	mg/kg		860		760	
H_2S	mg/kg		800		550	

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Reflections on preliminary results of gas analysis

- CO_2 is very low (CO_2 geothermometer shows <200°C) but H_2S (H_2S geothermometer shows >300°C) high in comparison
- Larger atmospheric component in first sample might reflect on drilling fluid contribution. Other samples (not reported here) showed larger atmospheric contribution

Results of ICP analysis of first samples from well IDDP-1

ELEMENT	SAMPLE	20100093 IDDP-1	20100094 IDDP-1	20100095 IDDP-1	20100096 IDDP-1	20100097 IDDP-1	20100098 IDDP-1	20100099 IDDP-1
Filtrerad		NO	NO	NO	NO	NO	NO	NO
Ca	mg/l	1,9	4,76	2,99	3,61	5,25	6,16	7,89
Fe	mg/l	0,999	19,9	40	46,6	59,7	117	165
K	mg/l	12,5	18,3	20,1	22,6	24,3	30,4	34,9
Mg	mg/l	0,243	0,525	0,494	0,485	0,288	0,402	0,954
Na	mg/l	39,4	68,1	84,1	109	128	171	203
S	mg/l	1180	212	17,5	19,8	22,3	31,7	38,6
Si	mg/l	95,1	245	245	261	280	327	380
Al	µg/l	48,5	73,9	53,1	144	164	99,3	138
As	µg/l	1,41	9,8	1,47	32,1	79,6	107	122
Ba	µg/l	73	58,3	42,2	25,6	28,9	27,2	36
Cd	µg/l	<0,01	<0,01	<0,02	<0,02	<0,02	<0,04	0,224
Co	µg/l	0,201	0,388	0,32	0,301	0,216	0,699	0,321
Cr	µg/l	1,78	1,84	3,7	3,54	3,15	2,72	6,16
Cu	µg/l	<0,5	<0,5	<1	<1	<1	<2	<2
Hg	µg/l	<0,002	<0,002	<0,002	<0,002	0,0032	<0,002	<0,002
Mn	µg/l	4980	1980	1750	1470	1480	2570	3460
Mo	µg/l	<0,3	<0,3	<0,5	<0,5	1,25	<1	1,18
Ni	µg/l	5,11	13,6	12,1	8,06	6,37	31,8	4,91
P	µg/l	11,1	38,8	29,6	21,4	25,2	<20	21,3
Pb	µg/l	<0,05	<0,05	<0,1	0,701	40,8	<0,2	<0,2
Sr	µg/l	26,6	41,9	44,4	82,1	145	205	253
Zn	µg/l	3,75	455	57,1	345	130	259	301

Reflections on results of ICP analysis

- Fe concentrations comparable to those obtained on site
- High Mn concentrations confirm that Fe is derived from well pipes
- Some other trace metals,e.g. Cr and Zn in relatively high concentrations suggesting same

Concentration of selected components in liquid phase of some recently drilled deep wells

Well No.	35	36	39	IDDP-1
Area	Leirhnúkur	Vesturhlídar (dry steam)	Sudurhlídar	Leirbotnar
pH	7.96	3.96	6.56	3.17
SO_4	12.8	29	0	101
Cl	267	885	436	524
Fe	0.015	292	338	165
Mn	0.0015	37.4	7.16	3.46
Cr	0.00006	59.4	0.155	0.006

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SUMMARY

- Fluid contains small but significant liquid fraction
- Liquid phase acid
- Chloride main anion but significant sulphate concentration
- Gas concentration small. CO_2 concentration low, but H_2S concentration relatively high

Step 2. Discharge from May 10

- **Heating up process step 1** (48 hours), bleeding through 1.8 mm orifice.
- A.1 Measure pH three times a day
- A.2 Collect samples for Cl analysis once a day (200 ml Ru)
- A.3 Collect samples for Fe analysis once a day (200 ml Ru + 0,8 ml HNO_3 => Ra)
- **Heating process step 2** (48 hours), bleeding through 5 mm orifice.
- B.1 Measure pH three times a day
- B.2 Collect samples for Cl analysis once a day (200 ml Ru)
- B.3 Collect samples for Fe analysis once a day (200 ml Ru + 0,8 ml HNO_3 => Ra)

The flow test

C.1 Measure pH three times a day

C.2 Collect samples for Cl analysis once a day (200 ml Ru)

C.3 Collect samples for Fe analysis once a day (200 ml Ru + 0,8 ml HNO_3 => Ra)

C.4 Collect samples for SiO2 analysis once a day (Rd)

C.5 Complete samples of water, gas and steam will be collected on day 2, day 4, day 6, day 10, day 20..... etc.

Acknowledgements

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Thank you!