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IDDP. The Chemistry of the Krafla Geothermal System in Relation to the IDDP Well

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ABSTRACT

The first IDDP well was drilled in Krafla in the first half of 2009. The drill rig hit magma at about 2100 m depth and drilling was stopped. The well was designed to be drilled into a high temperature hydrothermal system with the goal of finding a 400 – 600 °C hot superheated or supercritical fluid. The chemistry of the Krafla geothermal system at shallower depths has been thoroughly studied over the last 35 years. The area has been divided into several sub-fields: Leirbotnar (Lower Leirbotnar, Vítismóar), Sudurhlídar, Vesturhlídar, Sandabotnar, Hvíthólar, Vestursvædi, Leirhnúkur. In the Leirbotnar field the system is divided into an upper zone down to 1000-1400 depth which is liquid dominated with a temperature 190-220°C and sulphate is the major anion in the fluid, and a lower two phase zone at about 300°C (on the boiling point curve) with chloride as the main fluid anion. Hvíthólar is a a two phase system following the boiling curve down to about 1000 m depth where chloride is the main fluid anion but is cooler and liquid dominated below that where sulphate is the main anion. One well has discharged in Sandabotnar suggesting a two phase fluid (boiling point curve) from a reservoir at about 260°C with chloride as the main fluid anion . In Suðurhlídar and Vesturhlídar the boiling point curve is followed and a two phase fluid of about 300°C is delivered whose main anion is chloride. The same characteristics were observed for the one well drilled in the Leirhnúkur area. No well has discharged from the Vestursvædi area which seems cool and unproductive. In most areas very deep wells (>>2000 m deep) have been observed with acid fluids near the bottom which have caused corrosion and deposition of iron compounds (sulphides, silicates, oxides) and silica. The recharge in Leirbotnar and Vesturfhlídar is local but in Hvíthólar and Sudurhlídar either from nearby high ground or from far south. The acidity is connected with the chloride anion and it has been suggested that at depth there may be a brine pool from which molecular hydrogen chloride is boiled. The hydrogen chloride rapidly forms hydrochloric acid when saturated with water. It has also been speculated that the acid fluids may be a phenomenon which occurs at a certain depth and might have been cased off in a deeper IDDP well. During the Krafla fires 1975-1984 an excess of magmatic gas entered the geothermal system but this appears for the most part to have disappeared. This gas however facilitated reactions between the fluid and the rock which may be responsible for the acidity and the deposition problems encountered. The origin of the acidity and ways to deal with it will be among the prime challenges of the IDDP well. The results of the chemical work on the fluids from this well and its interpretation in the light of the previous knowledge about the area is due to be reported.

1. INTRODUCTION

The Iceland Deep Drilling Project (IDDP) plans to drill 5 km into an active mid-ocean ridge hydrothermal system to investigate its temperatures and pressures, its permeability structure and the compositions of its fluids and rocks. into an active mid-ocean ridge hydrothermal system to investigate its temperatures and pressures, its permeability structure and the compositions of its fluids and rocks. The Krafla high temperature geothermal system is located in Northeastern Iceland (Figure 1). The geology of the area is characterized by an active central volcano containing a caldera and a magma chamber at 5-8 km depth (Einarsson 1978) (Figure 2). The volcano is crosscut by an active fissure swarm that extends tens of km to the north and the south. The volcanic activity at Krafla is episodic, occurring every 250-1000 years, each episode lasting 10-20 years. The last eruptive period from 1975-1984, resulted in 21 tectonic events and 9 eruptions. The magma chamber is the heat source of the geothermal system.

Three separate upflow channels for geothermal fluids have been identified, the major one associated with the Hveragil fissure. The recharge is essentially local in origin according to isotopic ratios (Darling & Ármannsson 1989) although the Suðurhlíðar and Hvíthólar sub-fields may be recharged from far south (Hjartarson et al. 2004). A conceptual model of the Leirbotnar and Suðurhíðar systems showed a two-part system in Leirbotnar in which the upper part is a liquid dominated system of 200-240°C but the lower part a two phase system following the boiling point curve (Figur 3).

Ármannsson et al. (1987) divided the fluids from Krafla wells into 7 groups according to chemical composition and geography: Leirbotnar upper zone (1), Leirbotnar lower zone N (2) and S (3), Hveragil (4), Suðurhlíðar (5), Hvíthólar upper (6) and lower parts (7). Isotopic ratios suggest two sources, local (for Leirbotnar) and nearby mountains (for Suðurhlíðar and Hvíthólar) (Darling and Ármannsson 1989). All these groups contain dilute waters close to neutral pH. Bicarbonate is often the major anion when deep water concentration is considered depending on whether a boiling portion is found from calculation and whether excess magmatic gas is present but in Leirbotnar, upper zone, Leirbotnar S lower zone, Hveragil and in the upper part at Hvíthólar there is more sulphate than chloride but in Leirbotnar N lower zone, Suðurhlíðar and the lower part of Hvíthólar there is more chloride than sulphate in the liquid phase. Magmatic gas probably affects the composition everywhere but it is more likely that excess is only observed in the areas closest to the magmatic inflow and equilibrium is not established.

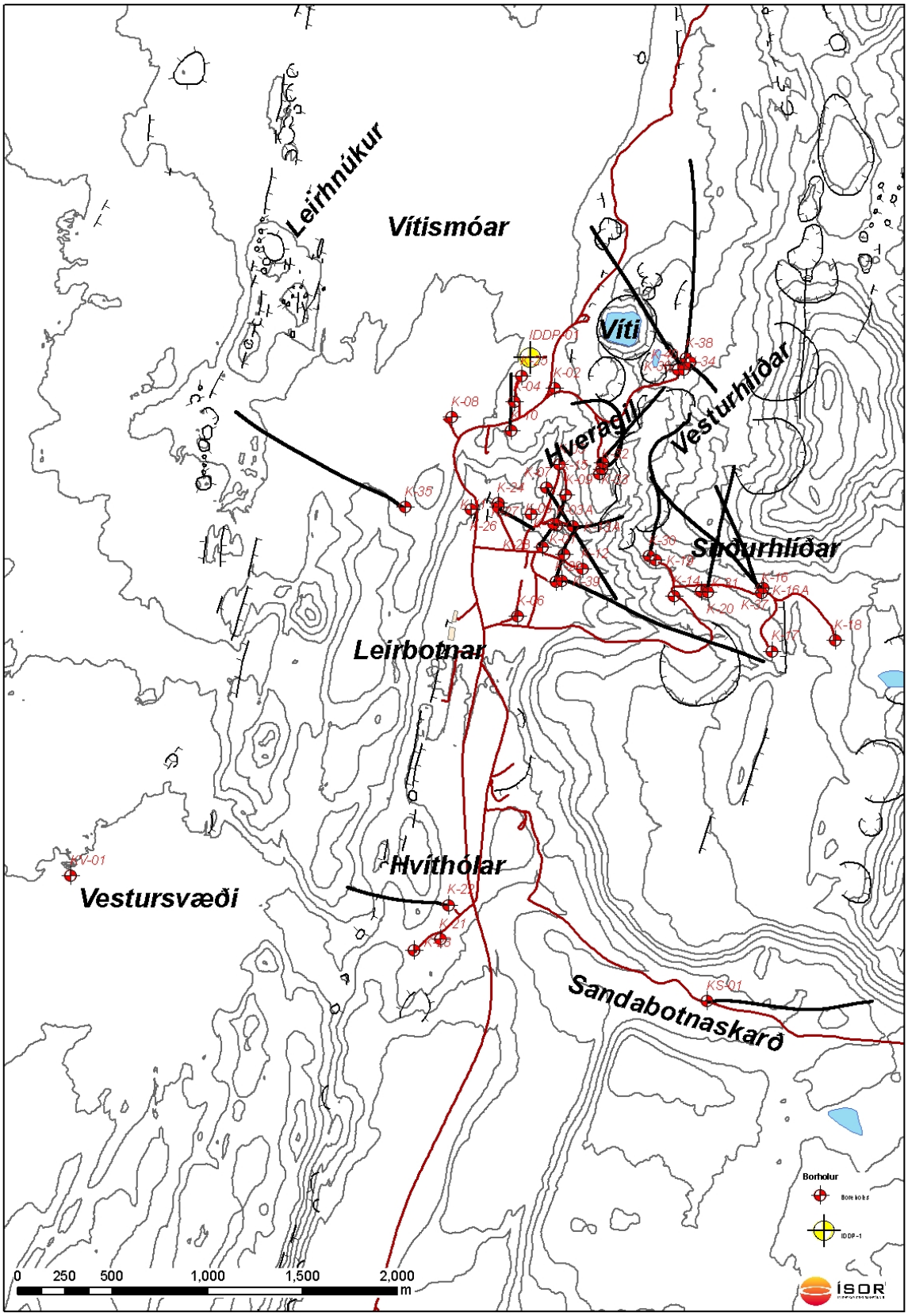


Figure 1. The Krafla area, showing the locations of wells

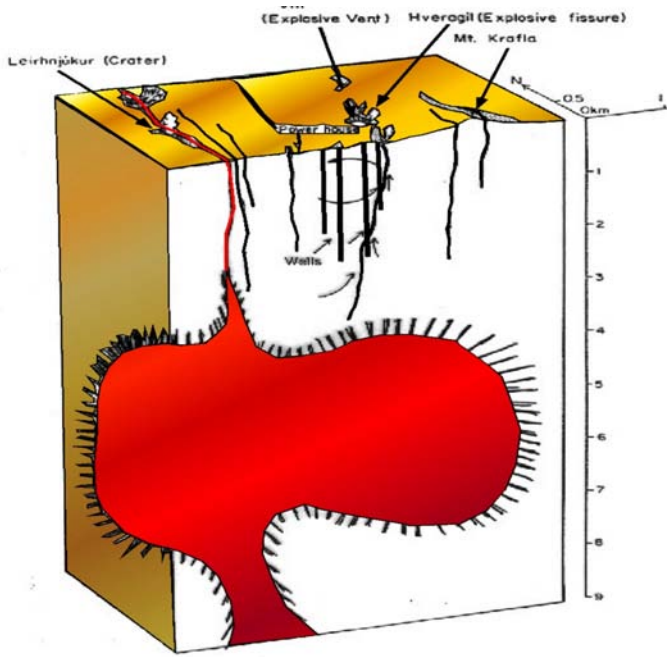


Figure 2. The Krafla magma chamber

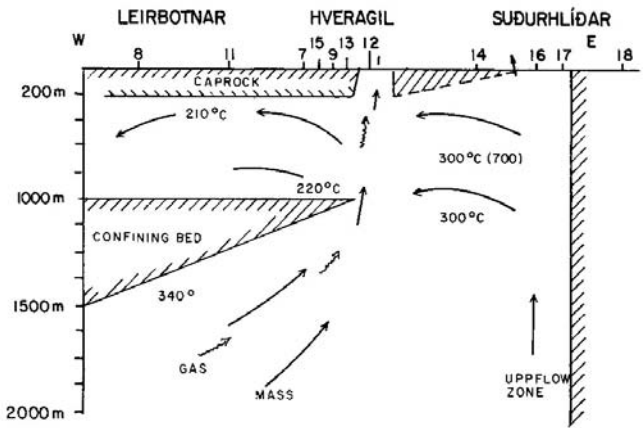


Figure 3. A conceptual model of the Leirbotnar and Sudurhlídar fields, Krafla

2. ACID FLUIDS

Acidity in Krafla well fluids is not recently discovered. Its first obvious manifestations were found in the stream formed when well KG-4 went out of bounds in 1976 and a pH of 1.86 was observed (Gíslason and Arnórsson 1976). The composition of the stream water suggested sulphuric acid but later computations with comparison with later nearby acid wells KG-10 and KG-25 and nearby shallow well KW-2 suggested that the acidity was due to hydrochloric acid but the sulphate originated from shallower inflows (Ármannsson and Gíslason 1992). The acidity has been associated with magmatic activity in the Krafla volcanic system 1975-1984 which manifested itself in excess gas in the geothermal system and deposition of iron sulphides, iron silicates, iron oxides and silica (Ármannsson et al. 1982, 1989).

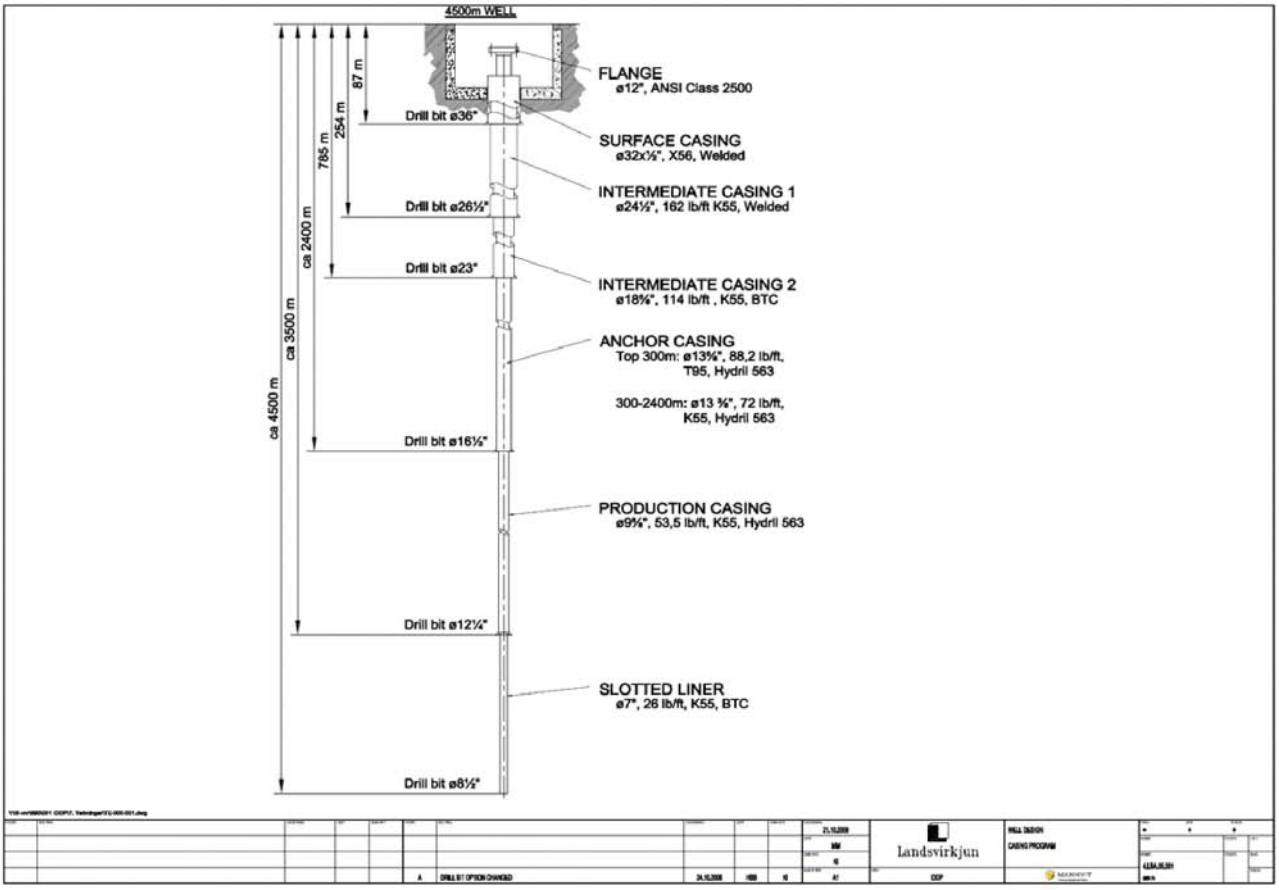
The initial discharge of well KG-12 was described by Hauksson (1979). The flow soon became superheated steam containing a substantial amount of molecular HCl which turned into hydrochloric acid upon condensation causing severe corrosion during which particles were formed which in turn caused the erosion of the turbine blades in the power plant. The problem was solved by insulation of the wellhead and by mixing the flow with that from the liquid dominated well KJ-9. Truesdell et al. (1989) proposed a mechanism involving the existence of a brine from which the HCl rich steam was boiling at depth. Evidence for this brine was found in flow of a saline liquid from nearby well KJ-7 which had a burst of a very saline flow in March 1977 that was interpreted as being from a deep inflow into the well which at most other times was blocked. All these occurrences were thoroughly dealt with in the IDDP feasibility report (Fridleifsson et al. 2003). The fluid from well KG-26 was specifically reported on by Fridleifsson et al. (2006) at which time there were plans to drill the IDDP well close by. There fluids turned out to be acid and chloride concentration relatively high for Krafla fluids but gas concentration moderate. The same pattern has been followed in subsequent wells where fluids have shown acid character (e.g. KJ-27, KJ-29, KJ-33). Well KJ-36 drilled in 2007 turned out to be very powerful but soon damaged due to acid fluids and deposits but gas concentration was relatively low. This well draws fluids near to the present IDDP well and a re-evaluation of the location of the drillsite was carried out with reference to these results and it was still concluded that this was a suitable drillsite from which a lot could be learnt about fluid handling (Fridleifsson et al. 2008).

The Fluid Handling Group of the IDDP has been studying possible solutions to the acid fluid problem. One possibility is that the acid fluids only occur over a limited depth interval in which case they may be cased off with suitable material. If they persist at all depths means should be available to transport them to the wellhead without condensation, i.e without forming an acid, and protecting the wellhead by the use of resistant materials and furthermore by a shallow injection of NaOH. If all else fails deep injection of NaOH could be effected.

The boreholes that have provided additional information after the re-evaluation (Fridleifsson et al. 2008) are well KJ-35, drilled in 2007, KJ-38 and KJ-39, drilled in 2008. The results for KJ-35 suggest that there are acid fluids at depth close to Leirhnúkur, those for KJ-38 show that acid fluids extend quite far to the north of Víti, and those for KJ-39 acid fluids at depth in the Sudurhlídar area. Furthermore it is shown by KJ-39 that magma may be encountered at 2.5 km depth in the Sudurhlídar area, i.e. a considerably shallower depth than previously envisaged.

Thus the new information is that magma may be encountered at a shallower depth than previously considered possible and that the acid fluids are probably spread over the whole area at > 2000 m depth but are not confined to a specific part. Neither of these observations make any difference to the siting of the IDDP well which was always known to be in an area where there was a considerable risk of hitting acid fluids and the MT diagrams suggest that drilling directly into the magma chamber is possibly avoided but that drilling will be close to it and thus there is a greater probability that a critical fluid be drilled into. Hence the new information does not give rise to new siting nor to abandoning the well.

Enthalpy and flow measurements are to be carried out using differential pressure across orifices (James 1966).



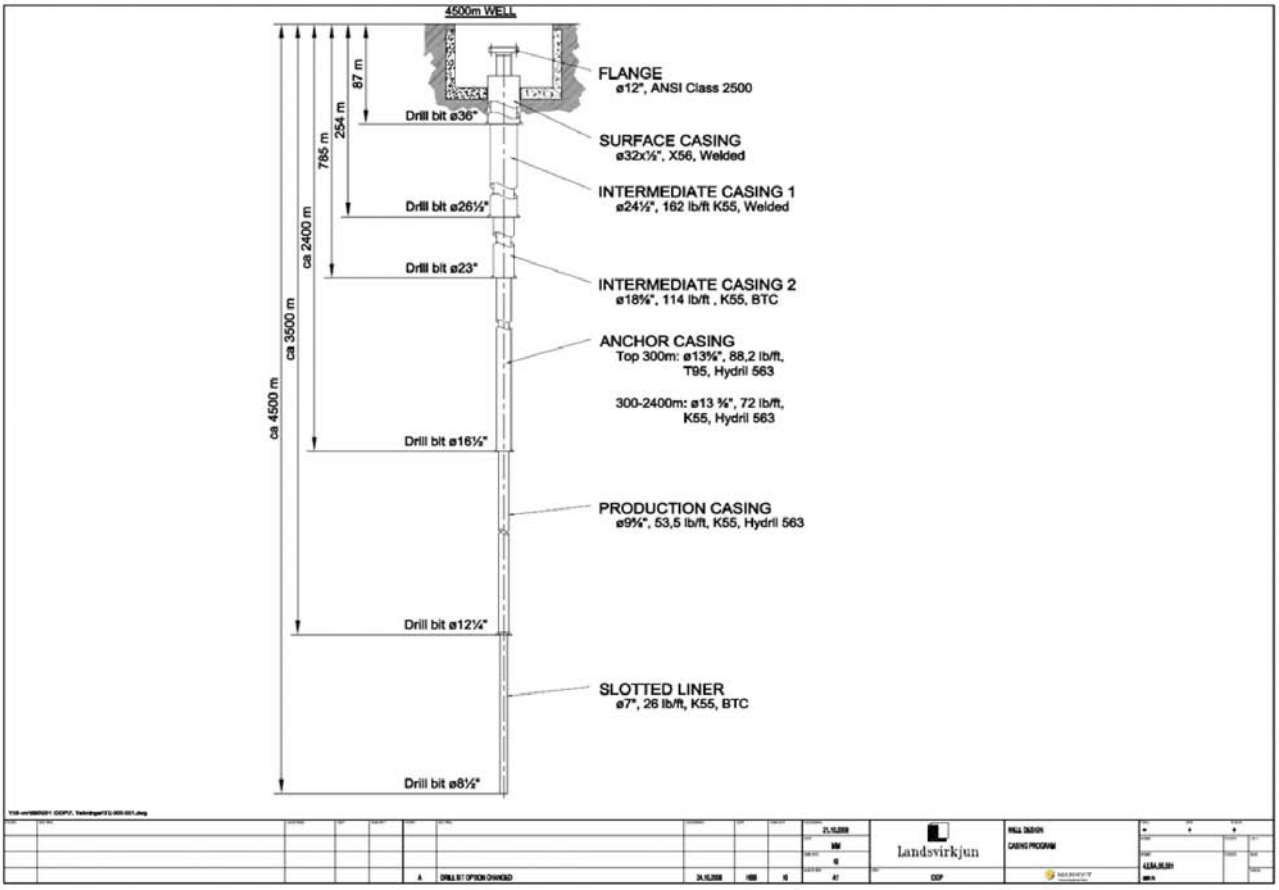


Figure 4. The design of the IDDP well, Krafla

3. THE IDDP WELL

The IDDP well is in the Northern Leirbotnar field in the Krafla area ((Figure 1). Its original design down to 4.5 km depth is shown in Figure 4. During drilling a conventional logging programme is followed,i.e. geophysical logs (temperature, pressure,) are carried out at each stage of casing (see Ingason et al., this volume. Upon completion a flow test programme including enthalpy and flow measurements and chemical sampling is to be initiated. The main features are described below but it is described in more detail by Ingason et al. (this volume).

Conventional logging was carried out down to the bottom of the well (Ingason et al. 2010, this volume).

During drilling pH of the drilling fluids was monitored.

A special steam-liquid separator was designed for this project to obtain wellhead samples (Ingason et al. 2010, this volume).

4. CHEMICAL COMPOSITION

The pH of the drilling fluids was relatively constant at 8.5-9.5. At the time of writing the well has not discharged so no samples of the fluid have been obtained. From the above considerations and its position in relation to other wells it might be expected to discharge dry HCl bearing steam such as was observed in ells KG-12 and KJ-36 when they first discharged. The main features of the chemical composition of the dry steam from these two wells when it had been condensed is shown in Table 1.

Table1. The chemical composition of condensed steam from the dry steam wells KG-12 and KJ-36

Constituent	Concentrationr mg/kg	
	KJ-36	KG-12
pH/°C	3.30/21	3.48/19
CO_2	6463	17077
H_2S	3320	1127
Cl	400	112
F	8	0.24
SO_4	6.5	n.d.

5. CONCLUSIONS AND RECOMMENDATIONS

As condensed steam from the well can be expected to be acidic due care should be taken to prevent corrosion. In the case of the present well precautions could be the use of titanium or high alloy steel and/or shallow or deep injection of an alkali such as sodium hydroxide. The well is not likely to produce from supercritical conditions as originally intended but will yield useful information on the composition of hot fluids in proximity to magma.

The next IDDP well should avoid such proximity to magma and be drilled either in the Reykjanes or the Hengill area. As the salinity of fluids at Reykjanes might complicate the outcome drilling of the next well in the Hengill area is desirable.

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