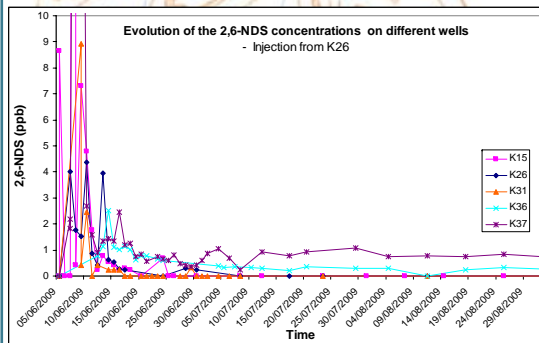


# HITI STREP: High Temperature Instruments for supercritical geothermal reservoir characterization and exploitation

## Tracing tests using organic compounds in a very high temperature geothermal field, Krafla (Iceland)



Partners : ISOR, Landsvirkjùn



Géosciences pour une Terre durable

**brgm**

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# Introduction

Within the HITI project, the use of organic compounds in one or two tracing test(s) had a triple aim :

- to validate them in **very hot temperature surroundings**, at Krafla and, if possible, in the IDDP-1 borehole;
- to learn about the **circulation of the Krafla geothermal fluid**;
- to monitor the behaviour of a (locally) supercritical geothermal fluid, supposed to strongly increase the power generation.

# Tracer testing in high temperature geothermal fields

Tracer tests can provide information on **transport properties** and **hydraulic connections in the geothermal reservoir** determining the heat exchange or the fluid re-injection.

## The 7 tracers requirements:

(1) **absent from the geothermal fluids**, (2) **environmentally safe**, (3) **thermally stable**, (4) **conservative**, (5) **easily soluble**, (6) **detectable at very low concentrations (<5ppb)** and (7) **low cost**.

## The 3 kinds of liquid phase organic tracers:

(1) fluorescein, (2) aromatic compounds (sodium benzoate,...), and (3) poly-aromatic sulfonate compounds such as **naphtalene (di, tri) sulfonate (nds)** family.

The last ones were used from the end of the 90s in several US fields (P. Rose, 2001), in New Zealand, Salvador, Japan, Philippines, Indonesia but also in Germany and in France (B. Sanjuan et al.2006).



# Means and Methods

## Selection of tracers:

Poly-aromatic sulfonates answer to the criteria of validity of tracers in a high temperature field: their **stability was tested until 230°C** but they were never used in a vapour dominated system such as Krafla.

**1,5-nds and 2,6-nds** were selected for a first test with an injection **from K-26**, the Krafla injection well.

For the second test, injection **into IDDP**, the **1,6-nds** was selected.

Bottom hole temperatures range **from 250 to 350°C** => opportunity to validate the behaviour of the nds far beyond their experimentally tested field of stability.

## Injection of tracing solution at K26:

On the 5th of June, at 11:25 am.

Carried by the re-injection fluid, the tracing solution would have reached the reservoir, 2,100 m lower, from 15 to 22 minutes later on.





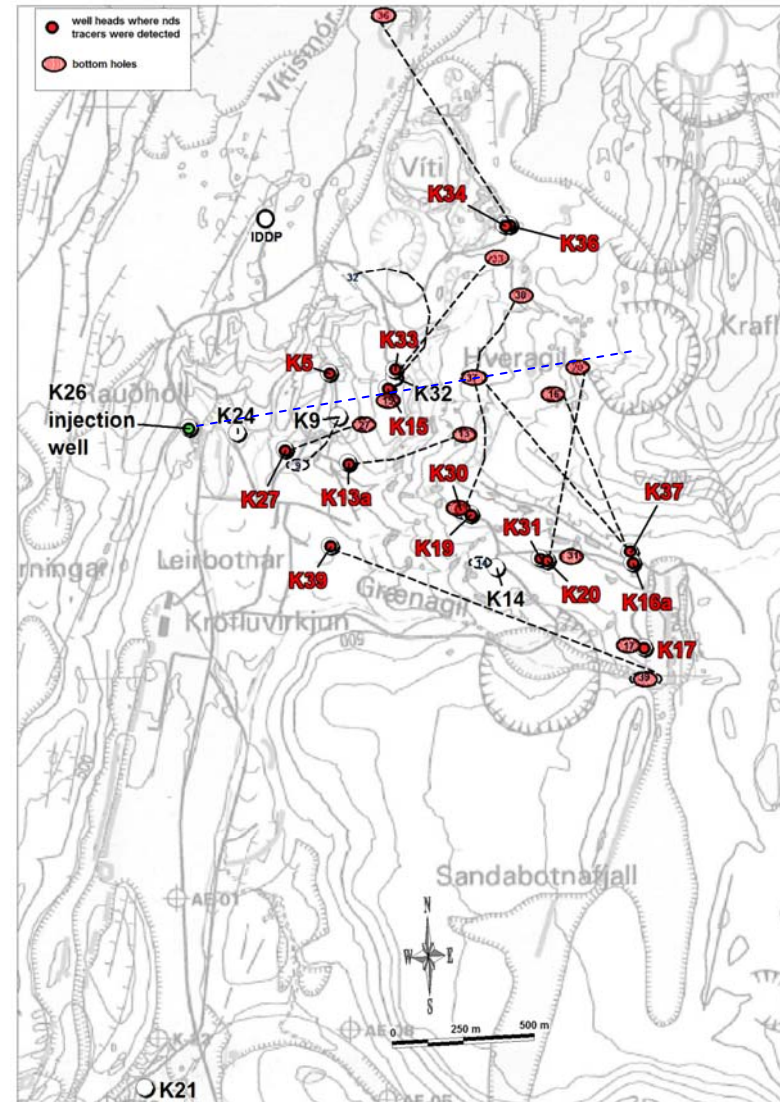
## Monitoring strategy:

The criteria of selection of the wells to be monitored were (i) the **proximity of the K26 re-injection well** and (ii) the wells tapping, as K26, the **lower part of the reservoir** beyond 2000 m depth.

The **3 sequences of sampling** were (i) K15 and K32, then K35, K19 and K14, (ii) K37 and K26 and (iii) when the signal was approximately stabilised :

- on a daily basis: K15, K20, K26, K31, K36, K37 and K39;
- on a weekly basis: K5, K9, K13a, K14, K16a, K17, K19, K24, K26, K30, K32, K33 and K34.

The test was carried out during usual **summer maintenance operations** and variations of the vapour / liquid ratio could have impacted the nds content of samples.



Distribution and status of the wells distribution of the 1,5- and 2,6- nds occurrences after injection into the K26 well

## SAMPLING METHOD AND TOOLS

Three ways of sampling were tested according to the characteristics of the wells:

- a **“T” piece** that could be screwed on the well heads allowing a quick operation and a rough **separation of the vapour** from the sampled liquid;
- a **cooler system** connected to the well head allowed to collect samples including a big part of the vapour. This tool was locally designed and included (i) a separator, (ii) a (car) cooling exchanger and (iii) a serpentine pipe;
- a **tank** gathering the water **downstream the separator** for the wells that were not connected to the production net.

The **“T piece”** was the best way to recover the nds tracer as the latter concentrates in the liquid phase. The other methods, including a larger part of the vapour phase, diluted it.



## ANALYTICAL ISSUES

A Cary Eclipse **Fluorescence spectrophotometer** (Varian) was sent and used at Krafla power plant laboratory. Thanks to this first step, it was possible:

- to highlight the matrix effects;
- to reduce or overcome the sulphide and silica precipitation effects;
- to rule out possible polymers effect;
- to identify the main tracers breakthrough at the right wells (K15, K31, K37) and at the best time possible;
- in the case of K15 well, to get the same quantification as the HPLC;
- to localise some of the wells where no signal could be detected (K24, K32, K33).

However, the spectrofluorimeter **cannot be considered as a reliable way** to detect the nds in the geothermal fluids and, all the more in the Krafla field, due to multiple parasitic molecules in this range of wave length. Further interpretations will thus be based on the HPLC analyses.

The **HPLC** (Waters) **coupled to a fluorimeter** worked at the BRGM laboratory. It reached lower quantification levels (0.25 ppb) and discriminated properly between both the nds molecules.



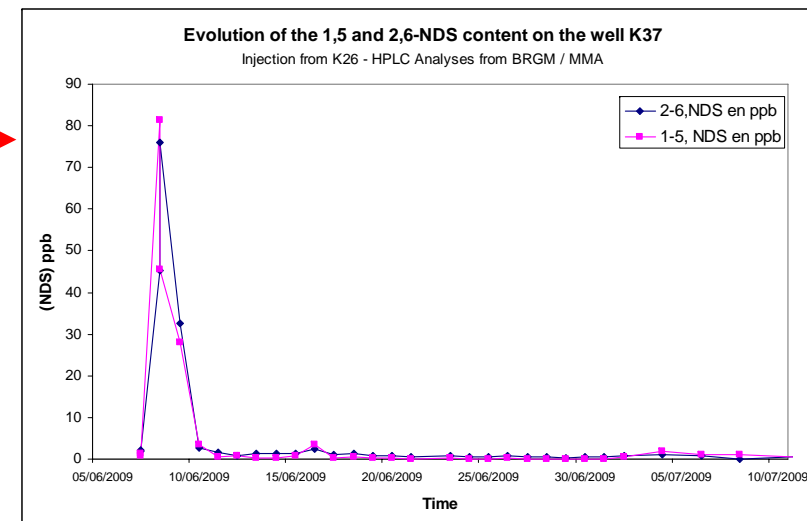
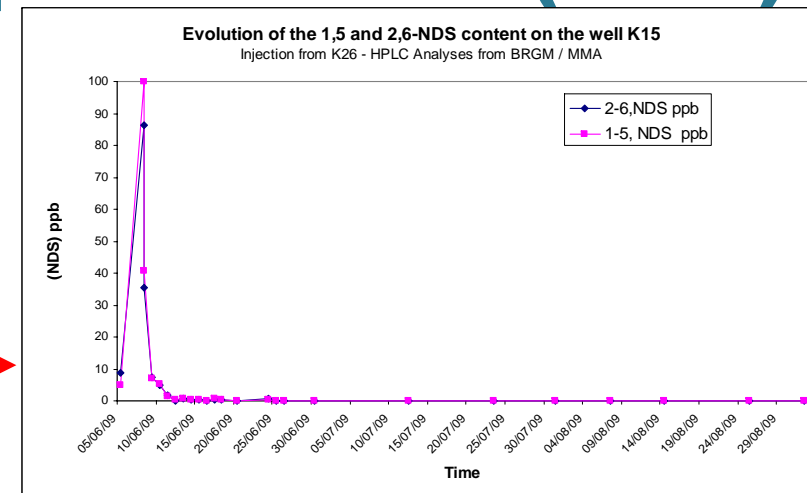
# Results and interpretations (K26)

## Breakthrough times

❖ K15: 1,5- and 2,6- nds were **detected 5:35** after their injection. The peaks of each tracer appeared 70 h after the injection

❖ K37: the tracers were **detected 50 h** after the injection and the peak breakthrough 80 h after the injection, a little later than in K15

For both the samples, the breakthrough time of the tracer (first detection) is likely to be overestimated. The baseline before the peak breakthrough is not well defined and **the tracers could have occurred earlier**



## Breakthrough location

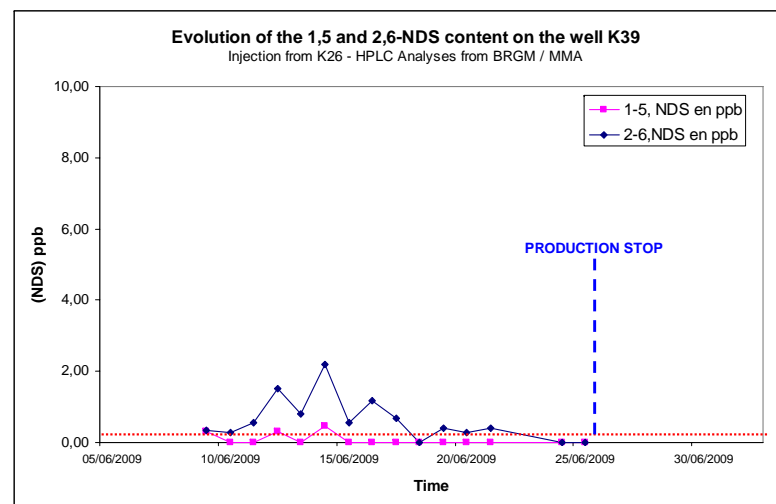
**K26, K15 and K37 are on a same N85 line** (slide n°6) and approximately at the same depth (from -1929 to -2100m).

## Apparent Linear Velocity (ALV)

Assuming a circulation within a straight fracture from K26 bottom hole, the ALV is at least comprised between **10.8 m/h** (K15) and **13.2 m/h** (K37). At Soultz-sous-Forêts, during 2005 tracer testing, using fluorescein and 1,6-nds (Sanjuan et al., 2006), the A.L.V. was comprised between 0.3 and 1.1 m/h.

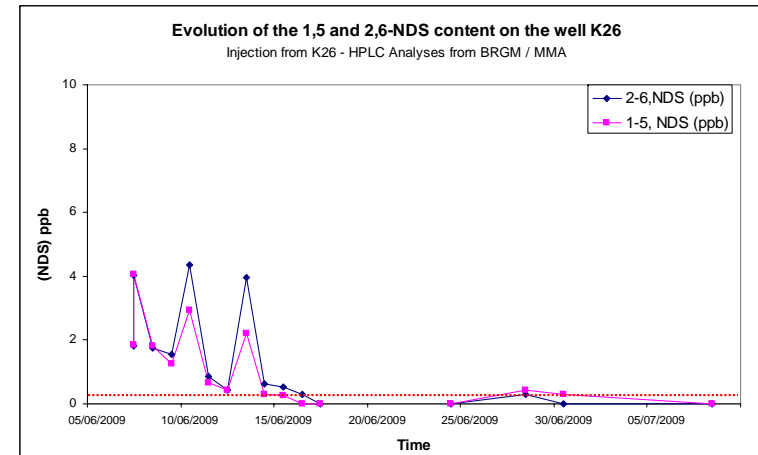
## Differences between tracers

They display the same breakthrough time. The **2,6-nds** breakthrough time is generally higher than the 1,5-nds one which is consistent with its **higher thermal stability**. The higher ratio 2,6- / 1,5-nds in K39 (and K36) can be related to a supercritical zone at the bottom of well K39 and the presence of low resistivity zones (superficial magma chambers according to Massiot, 2009).



## Breakthrough cycles

Cyclic peaks appear in the **K26** analyses chart. A first peak occurs 51 h after the initial injection, followed by peaks occurring successively 72 and 67 h after the previous one. Assuming a re-injection of the tracers coming from different wells, it can be inferred that **a significant breakthrough peak, likely of higher concentration, was missed before the first one** in the productive wells K15, K37 and K31



## Restitution rate

A rough estimation display less than **0.4% of 1,5-nds and 0.5% of 2,6-nds were recovered**, i. e. significantly lower than classical rates (23.5% of total fluorescein recovery in Soultz according to Sanjuan et al., 2006).

Several factors could explain this loss in tracer:

- the intensely fractured and active rift (+ caldeira) area,
- the likely huge volume of groundwater,
- the possible degradation of the tracers in a supercritical (or nearly) context.

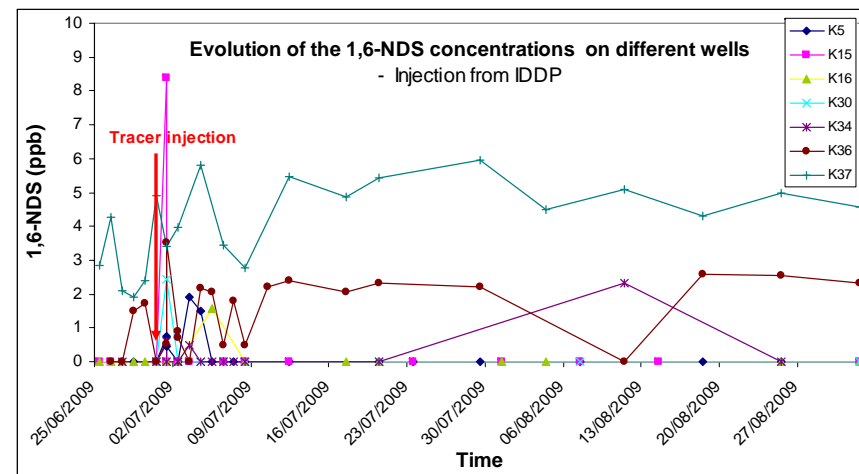
# Results and interpretations (IDDP-1)



The drilling operations stopped at 2104 m depth, in June 2009, by **meeting a magma intrusion.**

A **tracing test** was decided using the **injection of superficial water** to cool the borehole. It took place on the **1<sup>st</sup> of July 2009 at 10:35 am.**

The method of tracer injection and monitoring were similar to the test into K26. Only **1,6-nds** was injected and a minimum of 12 960 m<sup>3</sup> of fresh water pushed the tracing solution. The samples were shipped by mail without on site spectrofluorimeter analyses.



## Characteristics of the IDDP-1 tracing test

- The **recovery of the tracer was far lower** than in the previous test:
  - a great majority of peaks were more time-limited,
  - the peak magnitudes were much lower,
  - the spreading of the tracer itself was reduced.
- The **anomalies were also stronger**: occurrence of 1,6- nds before its injection (K36, K37 and K39) or in a non productive well (K9).
- The **breakthrough times are very short**.
- The estimated **apparent linear velocities** (ALV) range from **323 m/h** for the first 1,6-nds peak in K5, 227 m/h for the main peak in K15 and 12.5 m/h for the K16a single peak.
- The distribution of 1,6-nds signals have **several features in common** with the previous 1,5- and 2,6-nds test (the wells K15 and K37 display the main signal but there is an absence of signal of 1,6-nds on the wells K31, K21, K19, K17 and K9).

This tracing test suggests the following conclusions:

- ✓ the IDDP-1 borehole is **well connected** to the Krafla geothermal system;
- ✓ the **ground water flows very fast** (> 20 times faster than during the previous test);
- ✓ the selected tracers displayed **locally anomalies** that must be highlight.



# Conclusions

## K26 injection test

- The estimated **apparent linear velocity (14 m/h)** is quite high and the **recovery rate very low (around 0.5%)** in comparison with other tracing tests.
- The monitoring of the re-injection well displays that **at least a first peak was probably missed**, meaning still faster circulation of groundwater.
- Several slower peaks indicate a **fracture network with various directions** of the groundwater circulation.
- The **recovery rate** of 1,5-nds is lower than the 2,6-nds one, especially in the zones of very high temperature. It is confirmed by the slightly **lower stability** of the alpha substituted compounds (like 1,5- or 1,6-nds) with respect to the beta substituted naphthalene sulfonates (like 2,6-nds).
- Those measurements can be interpreted as results of (i) the **intensely fractured area** of the Krafla geothermal field, (ii) the **high water / rock** ratio and probably also of (iii) the **very high temperature** and supercritical conditions existing in some places of the field.

## IDDP injection test

- **Lower recovery rate**, a significantly **higher apparent linear velocity** (320 m/h) and **more marked anomalies** in the wells considered as very hot. As IDDP-1 bore hole is known to be drilled near a superficial magma body, those characteristics converge and confirm locally the **impact of the thermal conditions** on the selected tracers.
  - The main breakthrough peaks were measured at the two same wells highlighting (i) the **strong link between IDDP-1 and the Krafla geothermal field** and (ii) the **presence of major fissures** of different direction near the wells or crossing them.

## What are the perspectives of future works?

- ✓ **Modelling** the tracer restitution could give a new dimension to the information (connectivity, storativity) of the future tests;
- ✓ monitoring could begin at least one week before the tracer injection in order to get a **proper definition of the tracer baseline** and **more frequent measurements** on a limited amount of wells to improve the peak shape;
- ✓ the vapour / liquid ratio has a determining impact on the result as the tracer is concentrated in the liquid phase; this ratio is determined both by the **way of sampling and by the production rate**; the “T piece” was a reliable way of sampling ; it is better to keep the production rate constant during the monitoring period;



**Thank you for your attention!**