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Results of the geothermal energy project Hamburg-Allerrnoehe

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ABSTRACT

In the south-eastern area of the city of Hamburg, in depths of about 3000 m the Mittelrhaet-Hauptsandstein exists. In order to assess the geothermal potential of this aquifer, in 1997, an abandoned oil production well was deepened from 2178 down to 3305 m. From 3197 to 3290 m, 4 sandstone horizons of 12, 8, 25, and 28 m thickness were found.

The grain size distribution of the sandstone is promising, but the originally large pore volume is mostly cemented with anhydrite. Pumping and injection tests, laboratory examinations, and predictions based on a NMR log yielded comparable permeability values of about 10 mD. Thus, the well yield is too low to allow an economical use, despite a considerable high temperature of 128°C.

So far, it is unknown, whether the anhydrite cementation is limited to small areas and where it occurs. These questions are crucial for any further hydrothermal energy use in this region. In areas without cementation, a high geothermal potential can be expected, as all other parameters of the sandstone have proved to be promising.

The state geological survey (Geologisches Landesamt (GLA) Hamburg) has started to examine the drill cores on geological parameters determining the anhydrite cementation. X-ray radioscopy showed different cementation patterns, which seem to contain important diagenetic information. In addition, strontium and other trace elements analysis with electron and proton microprobe analysis, secondary ion mass spectrometry (SIMS), and laser microprobe for material analysis (LAMMA), examinations with global time markers, microthermometrical as well as mineralogical and sedimentological investigations have started or are planned.

In situ investigations in the borehole Allermoehe 1 are very necessary, but yet not possible, because of a broken liner. After borehole reconstruction, pumping and injection tests, seismic experiments as well as hydraulic and chemical stimulation tests could yield

important contributions to understand the anhydrite cementation and to reduce the drilling **risk** in further hydrothermal exploration projects in Northern Germany.

KEYWORDS

Anhydrite, cementation patterns, diagenesis, hydraulic fracturing, hydrothermal reservoir, permeability.

1. Introduction

In the south-eastern area of the city of Hamburg, in depths of about 3000 m, **a** hydrothermal aquifer, the **Mittelrhaet-Hauptsandstein,** exists (SCHULZ et al. 1994). In order to assess its geothermal potential, an abandoned oil production well was deepened. The project was carried out by the "Hamburgische Electricitaets-Werke AG **(HEW)"** and the "Umweltbehoerde Hamburg".

2. Drilling results

In July/August 1997, the abandoned oil production well Allermoehe 1 (figure 1) was deepened from 2178 down to 3305 m (LENZ et al. 1997, BEECK et al. 1998). Up to 3175 m different shales were found. They are considerably harder than expected. At 3175 m, the first interbedded shalehandstone layer started. From 3197 to 3290 m 4 sandstone horizons were found, being 12, 8, 25, and 28 m thick. They are separated by shale or interbedded shale/sandstone layers of 7, 8, and 6 m thickness. Over all, 73 m of sandstone were found, almost double the value that was expected. Totally, 101 m of drill cores were gained in 4 intervals, where 26 m come from sandstone.

Up to the depth of 2178 m, a 7" steel liner exists. In the newly drilled part of the hole a 4 1/2" glass reinforced epoxy (GRE) liner was installed. During its cementation, for unknown reasons, this liner broke at 2880 m, and its lower part fell 73 m deep to the bottom of the hole. After 42 m of the GRE liner were perforated in the section of the aquifer, a casing lift test yielded the unexpected low production rate of 9 m^3/h. The permeability was found to be about 3 mD, the well productivity 2 m^3/h x Mpa. An injection test, carried out by the "Bundesanstalt für Geowissenschaften und Rohstoffe (BGR), Hannover", in September 1998, showed that the hydraulic contact between the borehole and the aquifers is not good in most parts of the perforated section (TRAN-VIET et al. 1998). During this test, 39 m^3 of brine were injected. The temperature log showed that most of the water infiltrated within a small zone at 3260 m (figure 2). This can be best explained by a natural fracture existing at this level. The permeability results from the injection test are comparable to those from the pumping test. Using the nuclear magnetic resonance (NMR) log, the permeability of the 4 sandstone horizons was determined to be 3.4, 3.2, 1.9, and 7.6 mD (from top to bottom), with maximum values up to 88 mD. The weighted mean value

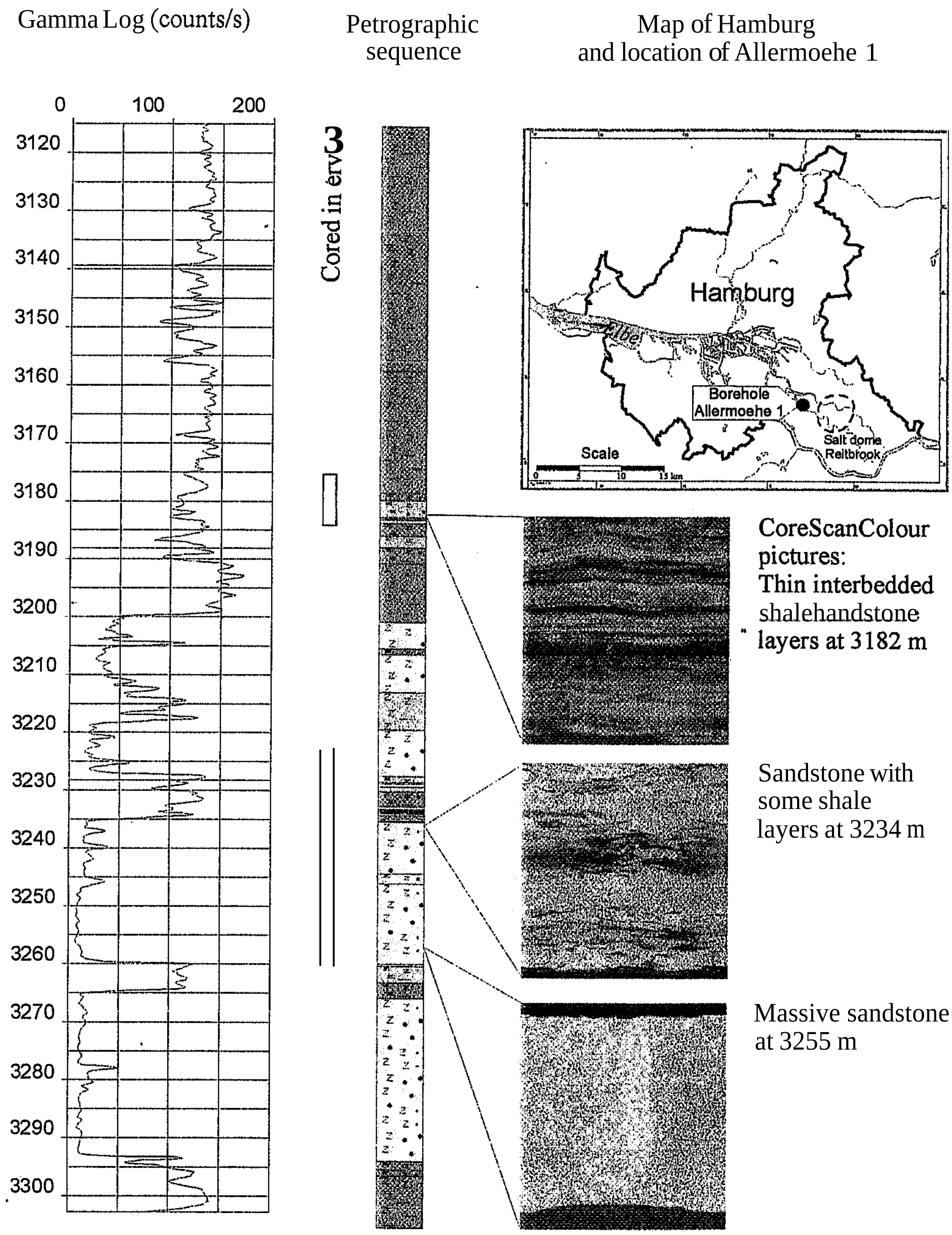


Figure 1: Petrographic sequence of the Raet together with gamma log, CoreScanColour pictures, cored intervals and locations of the borehole Allermoehe 1.

calculated for 73 m of sandstone is 4.5 mD, and the transmissibility is 326 mD x m (PAPE et al. 1998). At aquifer level at 3260 m, a fairly high temperature of 128°C was measured. This corresponds to the relatively high temperature gradient of 3.6 W100 m. The pressure level of the aquifer was found to be 87 in below ground level. The density of the aquifer water is 1.146 kg/l, the mineralization 218 g/l.

3. Core examinations

The core samples show, that the **Mittelrhaet-Hauptsandstein** consists of white grey **fine** sandy middle-grained sandstone. Relatively often, thin layers, parts of layers or bulk sized particles up to 3 cm thick consisting of shale and/or coaly shale are included in the sandstone (figure 1). Core samples showed porosity values from 2 to 12 % with an average of 6 %. The permeability varied from 0 to 19 mD. Thus, the sandstone is of a low porosity and poor permeability, not sufficient for an economic extraction of hydrothermal energy. Thin section microscopy revealed the reason for the unexpected low permeability of the sandstone: Most of the original pore volume is cemented with anhydrite. The state geological survey (GLA Hamburg) has started to examine this anhydrite cementation in core samples. The goal is to receive more information about the anhydrite formation conditions and about the geological structures possibly associated with cemented and -not cemented sandstone areas.

In July 1998, all core pieces were registered and scanned with the instrument CoreScanColour from "DMT - Gesellschaft fuer Forschung und Pruefung mbH, Essen" (figure 1). Comparison of the scan pictures with the high resolution formation micro scanner *(HFMS)* data allowed to determine the exact depth of the core samples and, in part, to determine their north-south orientation. Radioscopic examinations (BAERMANN 1999) with x-ray penetrating **3** to **5** mm thick discs showed that the anhydrite cement is not distributed homogeneously in the pore volume of the sandstone, but small areas with completely cemented pores usually exist next to small areas without cement. By this, quite regular cementation patterns are formed, which can well be seen in the x-ray photographs (figures 3a-d). Depending on the form and size of the cemented and uncemented areas, **5** different cementation patterns were classified so far:

- Up to 1 mm large areas with cemented pores build little islands, which are surrounded by **an** uncemented area.
- 1 – 10 mm large cloudy areas with cemented pores are surrounded by uncemented areas. Some of the cemented areas are interconnected.
- Up to 1 mm thick layers with cemented pores alternate with 1 – 2 mm thick layers with uncemented pores. The layers are oriented more or less horizontally.
- 1 – 15 mm thick layers with cemented pores alternate with 1 – 2 mm thick layers with uncemented pores.
- The pore volume is completely and homogeneously cemented with anhydrite. No structures can be seen in the x-ray photographs.

So far, these anhydrite cementation patterns were analysed in a limited number of samples. Thus, it is yet not known, if these patterns change continuously with increasing depth or if there are discontinuities, possibly at thin shale layers. Already yet, the results indicate that the cementation patterns regularly change with increasing depth, and this happens three times in the examined, *25* m thick aquifer. This regularity seems to be caused by some characteristics of the cementation process, which are yet not known but which might be revealed in further examinations. A statistically relevant number of core samples are planned to be examined by x-ray radioscopy. The goal is to get a detailed picture of the cementation patterns and their changes with increasing depth, and to find out, if the cementation patterns correlate with other petrophysical properties of the sandstone. Surprisingly, the cementation patterns detected by radioscopy were less good or not at all detectable by thin section microscopy.

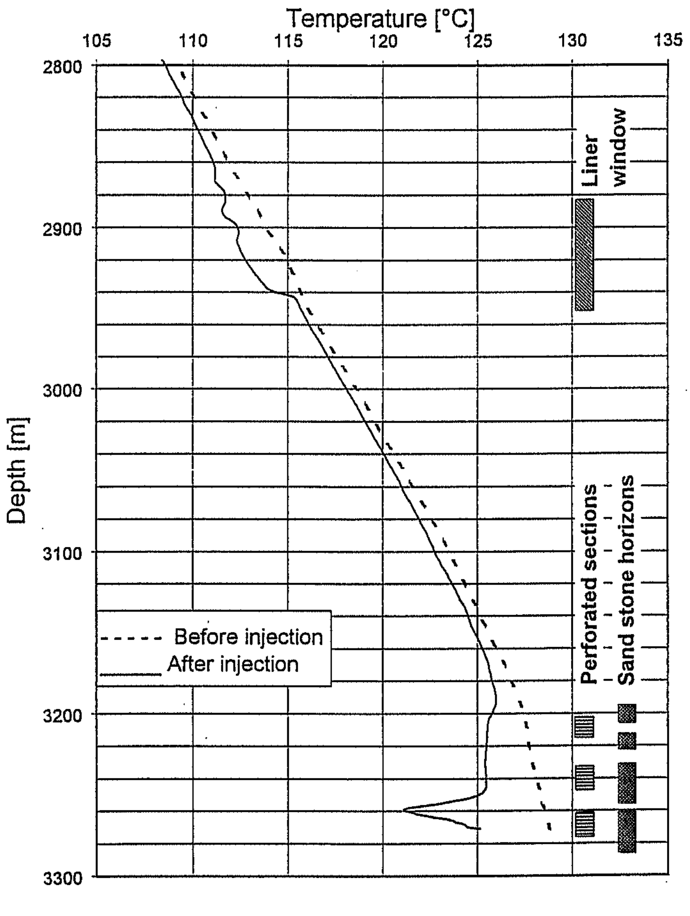
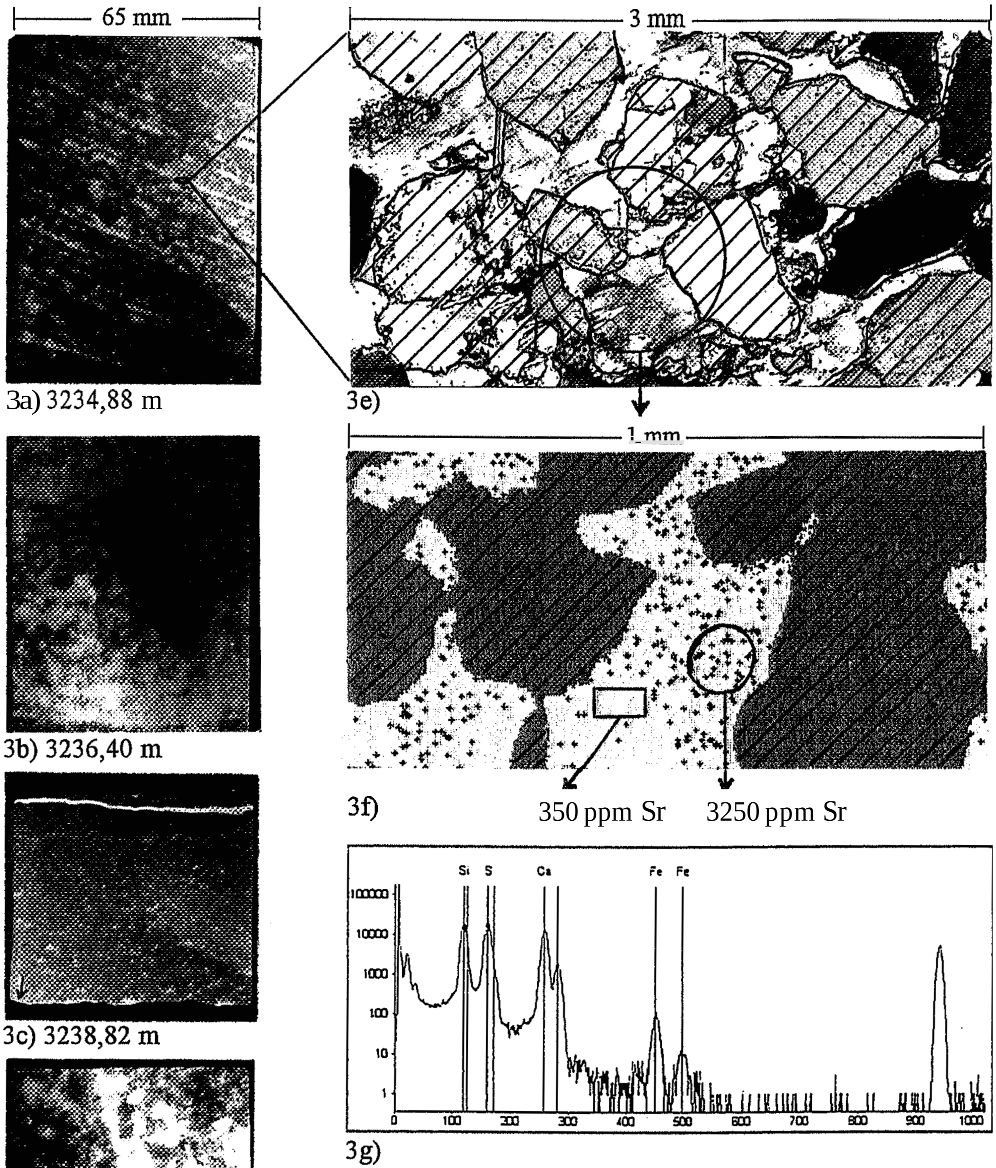


Figure 2: ***Temperature log (logging depth) before and after injection of** 39 m^3 **of water, together with borehole information (drilling depth) (TRAN-VIET et al. 1998)***



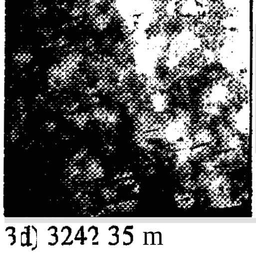


Figure 3: Anhydrite cementation examinations (BAERMANN 1999):
a) – d): X-ray photographs of different cementation patterns.
e): Thin section microscopy of a completely cemented area (quartz particles are lined)
f): Proton microprobe pixel picture with Sr reflection points (+) and results of integral energy spectrums from 2 areas.
g): Integral energy spectrum for element quantification.

Thin section microscopy showed a wide range of quartz and anhydrite content. Anhydrite varies from **3** to 40 %. A correlation between the size of the sand particles and the amount of anhydrite could not be found so far. Depending on the position of the thin section slide with respect to the cementation pattern, the anhydrite values can vary a lot. ***So,*** when thin section analysis is carried out, the cementation pattern should always be taken into account. Besides quartz and anhydrite, the following components were found up to **15 %** kaolinite and chlorite, up to ***5*** % stone fragments and feldspar, about **3** % quartz cement, and up to **2 %** opaque minerals, as well as traces of zirconium silicate, tourmaline, and titanium oxide. The x-ray diffraction analysis yielded similar results as the thin section microscopy.

Strontium and barium analysis were started in order to find out the origin of the solutions yielding the sulphate for the anhydrite cementation. The first results of the x-ray fluorescence analysis of anhydrite cemented sandstone samples showed 0.1 to 0.016 % strontium and 0.01 to ***0.06*** % barium. With electron microprobe analysis of individual anhydrite crystals, different values for strontium were found depending on the depth. The content of strontium seems to descend, if the size of the cemented islands increases. Using high resolution proton microprobe analysis, the distribution of strontium within individual anhydrite cemented pores (1.6 x **0.8** mm) could be analysed (figures 3f-g). Depending on the depth, **300** to 11 **900** mg/kg of strontium were found. Further examinations must show, whether different zones with different strontium content were built during the growth of the anhydrite crystals. This would indicate, that the solution changed chemically during the cementation process. It is planned to use also the more sensitive SIMS (Secondary Ion Mass Spectrometry) and LAMMA (Laser Microprobe for Material Analysis) to analyse the distribution of strontium, barium, and other trace elements within individual anhydrite crystals. With **SIMS** analysis, global time markers like $^{87}Sr/^{86}Sr$ can be detected, too.

Some additional information about the temperature and fluid history might be receivable by analysing inclusions of fluids in the sandstone by microthermometrical methods. For the same purpose, the vitrinite reflection is planned to be measured over the whole depth of the drilling. Meanwhile no carbonate cements occur in the sandstone cores from about **3240** m, such cements like dolomite and ankerite were detected in the thin interbedded shale/sandstone layers at about **3180** m. Additional mineralogical and sediment petrological examinations are planned to find out how the cementation of these two areas is related.

4. Further borehole examinations

The possibilities to use the borehole Allermoehe 1 for further investigations **are** very limited, due to the window in the broken 4 $^{1/2}$" GRE liner at **2880 – 2953** m, and because of the fallen liner blocking the aquifer. A removable **2**$^{3/8}$" coiled tubing **(N 80)** was installed within the broken GRE liner to allow measuring devices to be introduced safely. **As** there exists no other borehole in Northern Germany that allows to investigate the anhydrite cementation in situ, the reconstruction of Allermoehe 1 would be of great importance. For this, the broken GRE liner has to be milled and removed. Probably, the lower part of the liner is not cemented and eventually can be removed without being milled. Liner cement and other materials clogging the sandstone have to be removed by undercutting in order to get a good hydraulic contact between the borehole and the aquifer. Then, a new liner, preferably made of steel, must be installed. The reconstructed borehole Allermoehe 1 would give the opportunity to carry out a large in situ investigation program, dealing with the problem of the anhydrite cementation. Before installing the new steel liner, all geophysical borehole measurements requiring an open borehole can be carried out, e. g. vertical seismic profiling (VSP), seismic borehole experiments, high resolution formation micro scanner (HFMS), and nuclear magnetic resonance *(NMR* Total Porosity).

Pumping and injection tests would yield the over all productivity and permeability of the aquifer. It can be expected to be considerably higher than the values received from the former well production tests. Additional flowmeter and temperature logs can show, how much the permeability varies locally. They can also detect natural fractures or high permeable zones, which already showed up in the first injection test (Fig. 2) as well as in some core samples. Due to those fractures, the well productivity might be considerably higher than indicated by core examinations and NMR log (CLAUSER 1992). Injection tests can also find out, whether the anhydrite cementation is limited to a small area around the borehole and whether uncemented, high permeable areas exist close to the hole. High permeable fractures in the closer vicinity of the borehole can also be detected.

The reconstructed borehole Allermoehe 1 would also be a favourable place to test hydraulic fracturing techniques. They have been developed in the Hot Dry Rock (HDR) projects for granite, but they have not been applied to cemented sedimentary rocks so far. During those tests, up to several thousand cubic meters of water are pressed into the aquifer. Afterwards, hydraulic tests are applied to find out the effectiveness of the fracturing, and geophysical borehole measurements can show the location and orientation of the produced fractures. These techniques are yielding especially good results, when natural fractures in the vicinity can be connected to the borehole. Theoretically, the productivity of anhydrite cemented aquifers can also be stimulated by dissolving the anhydrite using special water/salt solutions at lower temperatures. The reconstructed borehole Allermoehe 1 would be a good place to test those chemical stimulation techniques in situ, too.

There is a good chance that those stimulation techniques can increase the productivity of a cemented aquifer to economically feasible levels. In situ investigations and tests are also important to prove and complement laboratory and mathematical simulation results. Thus, reconstruction of the borehole Allermoehe 1 and performing the described in situ investigation program would yield an important contribution to the reduction of the drilling risk in further hydrothermal exploration projects in Northern Germany.

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