Geothermal potential of a high permeable horizon compared to the energy potential of a low permeable sour gas reservoir

J. Behrend; S. Kuhlmann
OMV Austria E & P GmbH, Gaenserndorf
S. Boy; F. Grafe; Th. Wilsnack
IBeWa, Freiberg

Abstract

The Aderklaa Conglomerate (AC) is a ~ 350 m thick and ~ 2000 m deep aquifer horizon in the centre of the Vienna Basin. It is a high conductive aquifer with permeabilities in the range of 0.3 – 5 darcy. In the South of the Spannberg Ridge there is communication between the Aderklaa Conglomerate and the aquifers of the overlaying oil and gas horizons. This hydraulic communication was proven by the production history of the 16. Tortonian and the gas reservoir in the Zwerndorf Sand and pressure measurements in the Aderklaa Conglomerate. Since 1960 separated and cleaned water associated to the oil production has been reinjected into the Aderklaa Conglomerate for pressure maintenance.
As a base for numerical investigations OMV Austria developed a 3D-model of the Aderklaa Conglomerate. The porosity profile was yielded by borehole geophysics (log data). Based on validated hydrodynamic correlations the spatial permeability distribution was calculated. Fall-off-tests and injection history were used to verify the permeability data that were applied in the 3D-simulation model. After history matching the model for the time period from 1952 to 2010 the model was applied for the prognosis of the geothermal potential of the Aderklaa Conglomerate. Beside the hydrodynamic reservoir behavior thermodynamic processes in the reservoir and in the wells were simulated and/or analytically calculated.

The exploration well STR T 4 produces sour gas from a compartment of Triassic dolomite located at a true vertical depth of over 4000 metres beneath the floor of the Vienna Basin. It is characterized by an estimated low porosity of 1.5 % with an associated low permeability of 0.06 mD. Both are entirely supplied by a natural fracture system. An assessment of a realistic range of producible reserves is difficult because the reservoir is too tight for traditional material balance techniques. The approach taken included initially assessment the geologically possible range of values of key properties such as porosity, permeability and compartment size [V.A.-2010-PR]. From this different simulation sector models were created and history matched to the STR T 4 pressure response. Production history and best forecast estimate were used as show case for a well in a low permeable sour gas reservoir.

The gas production potential of the well STR T 4 is compared to the geothermal energy potential of the well S T 29a in the Aderklaa-Conglomerate.

Introduction

The Aderklaa Conglomerate is a ~ 350 m thick and ~ 2000 m deep aquifer horizon in the centre of the Vienna Basin. It is a high conductive aquifer with permeabilities in the range of 0.3 – 5 darcy. Since 1960 separated and cleaned water associated to the oil production has been reinjected into the Aderklaa Conglomerate for pressure maintenance in the hydraulically connected HC-bearing horizons of the Badenian.

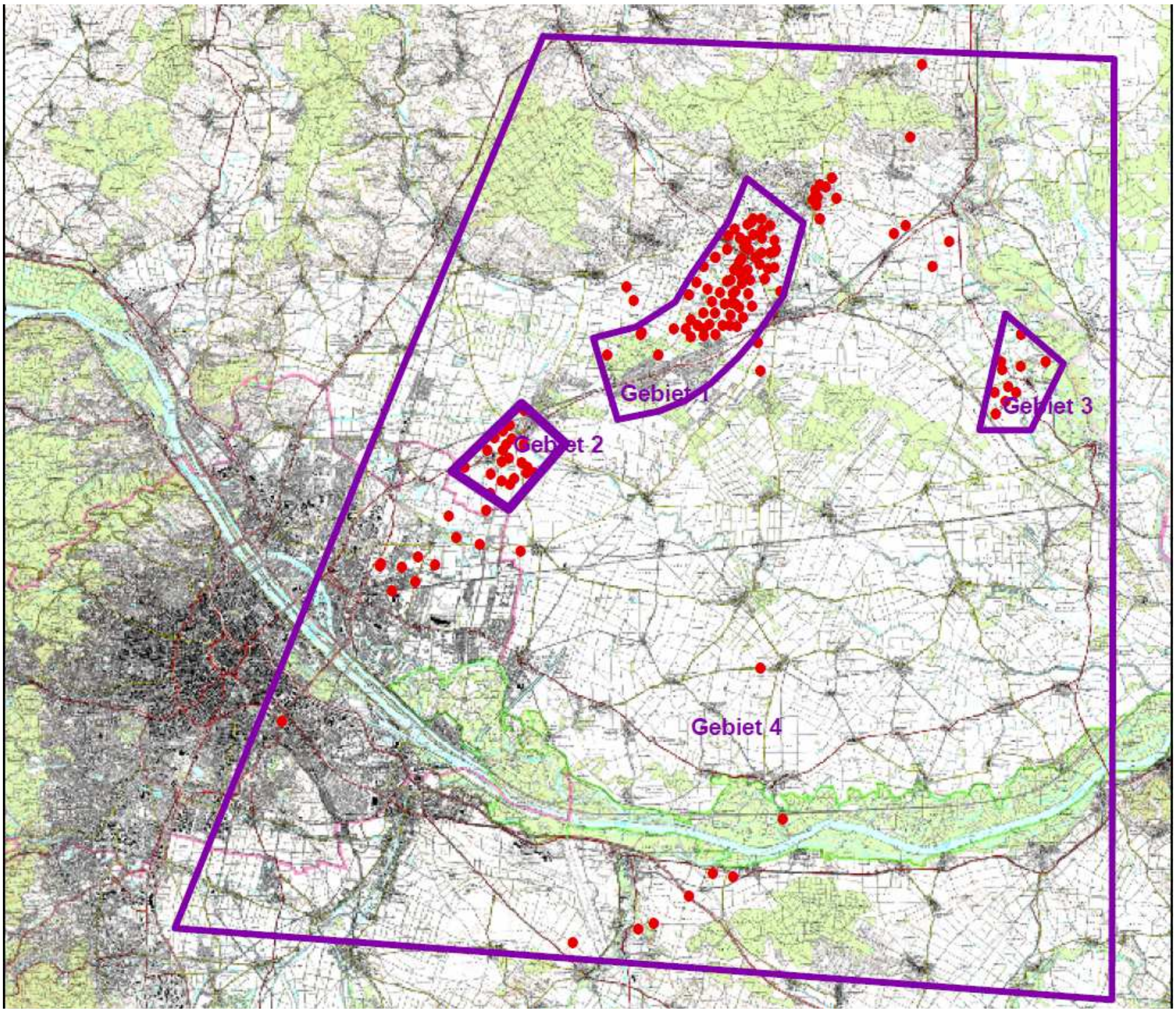


Fig. 1 Wells penetrating the Aderklaa Conglomerate in Eastern direction from Vienna

Due to its size (see figure in 1) and high average permeability it may be suited for geothermal energy recovery.

The exploration well STR T 4 is an example for a tight gas well. It produces sour gas from a compartment of Triassic dolomite located at a true vertical depth of over 4000 metres beneath the floor of the Vienna Basin. It is characterised by an estimated low porosity of 1.5 % with an associated low permeability of 0.06 mD. Both are entirely supplied by a natural fracture system. The reservoir is too tight for traditional material balance techniques. Due to the low permeability pressure and rate decrease quickly during production. The well probably will produce in the transient mode during lifetime. STR T 4 is a well producing gas rates at the economic borderline. So it was an appropriate candidate for a comparison with the potential of a geothermal well in the Aderklaa Conglomerate.

Investigation of the geothermal potential of the Aderklaa-Conglomerate

As a base for numerical investigations OMV Austria developed a 3D-model of the Aderklaa Conglomerate. Figure 2 shows the full Aderklaa-Conglomerate and the chosen wellknown area of interest with an areal extend of ~ 100 km².

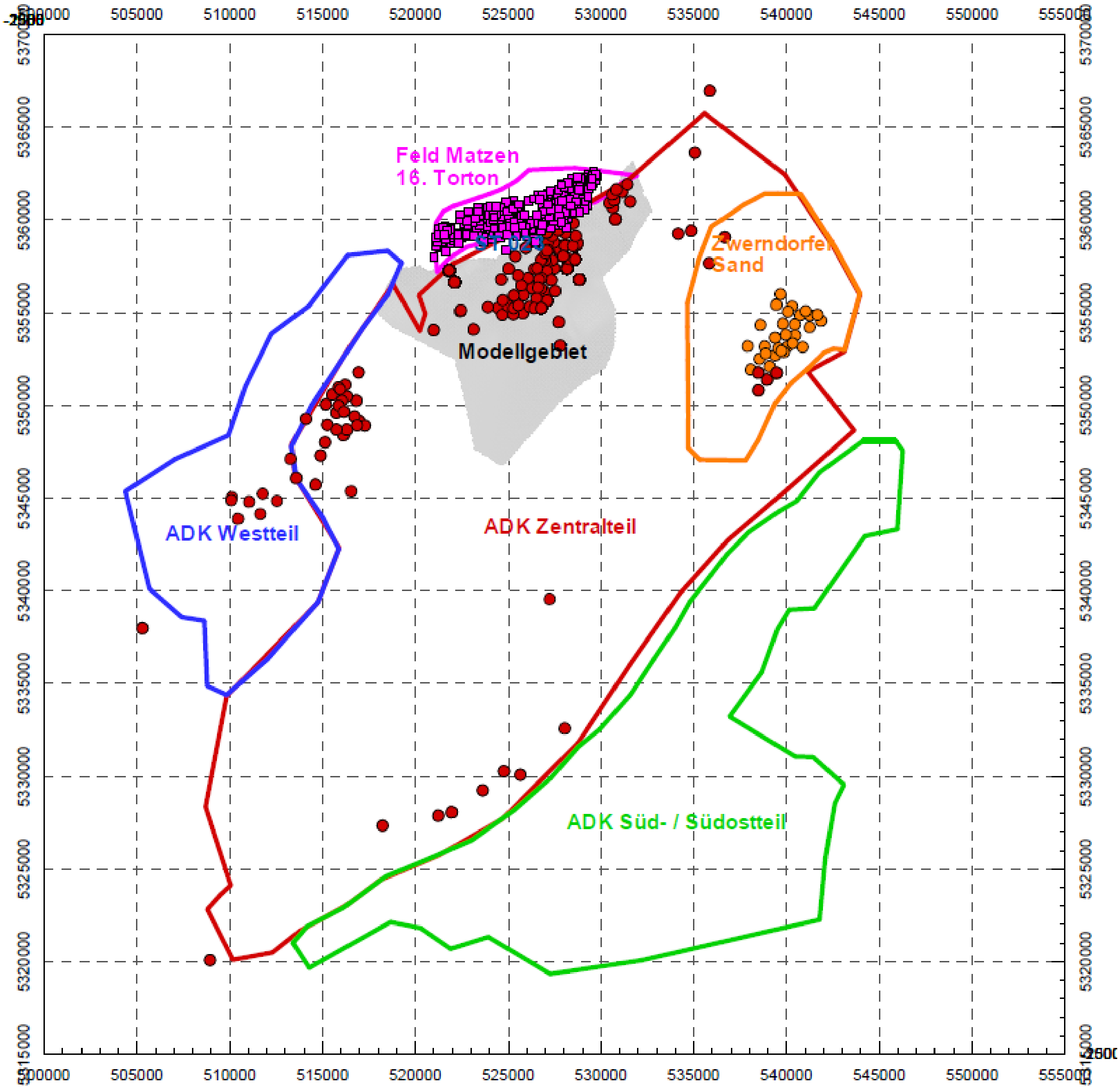


Fig. 2 Aderklaa Conglomerate, model area and points with used well information

At the start of investigation a data mining had to clarify, which wells are penetrating the AC and which of these wells are located in the area of interest. The wells, that had spliced, shifted and interpreted logs (i.e. contribute correct log information) were entered directly into the data base.

Wells with interpretable logs were investigated mineralogically and petrografically in the laboratory. In cooperation between the petrophysical interpreter and the mineralogist the Logs were verified (top & bottom of the AC) and, if possible and necessary, new interpreted using the laboratory results.

Finally tops and bottoms were corrected in OMV´s database, results were delivered to Production Geology as input for the modelling of geology.

Figure 3 shows the well sections that were used for the correlation of top and bottom of the Aderklaa Conglomerate.

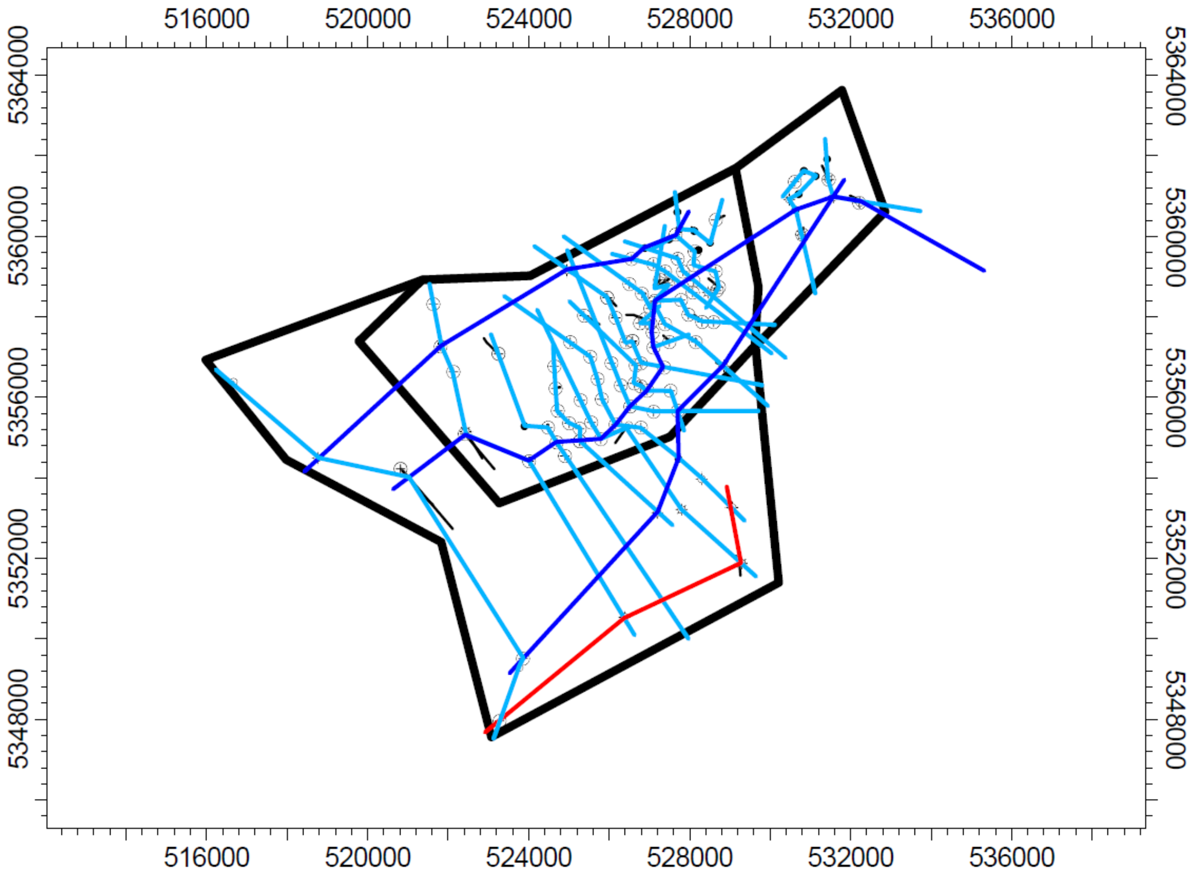


Fig. 3 – Well sections used for correlation of top/bottom of the AC

Figure 4 shows a well correlation panel belonging to one of the cross sections above.

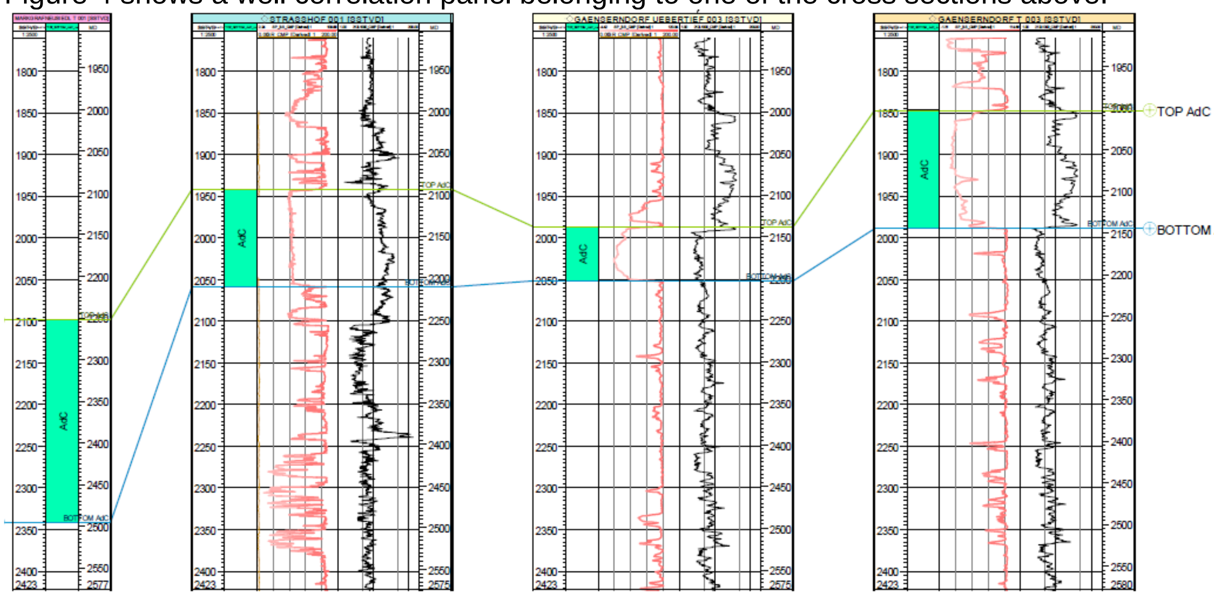


Fig. 4 Well correlation panel 22

Having top and bottom and thus the geologic body of the AC, the structural model had to be parameterized with petrophysical properties. Figure 5 shows the porosity profiles derived from well log interpretations before and after upscaling. In figure 6 the applied spatial porosity distribution is shown.

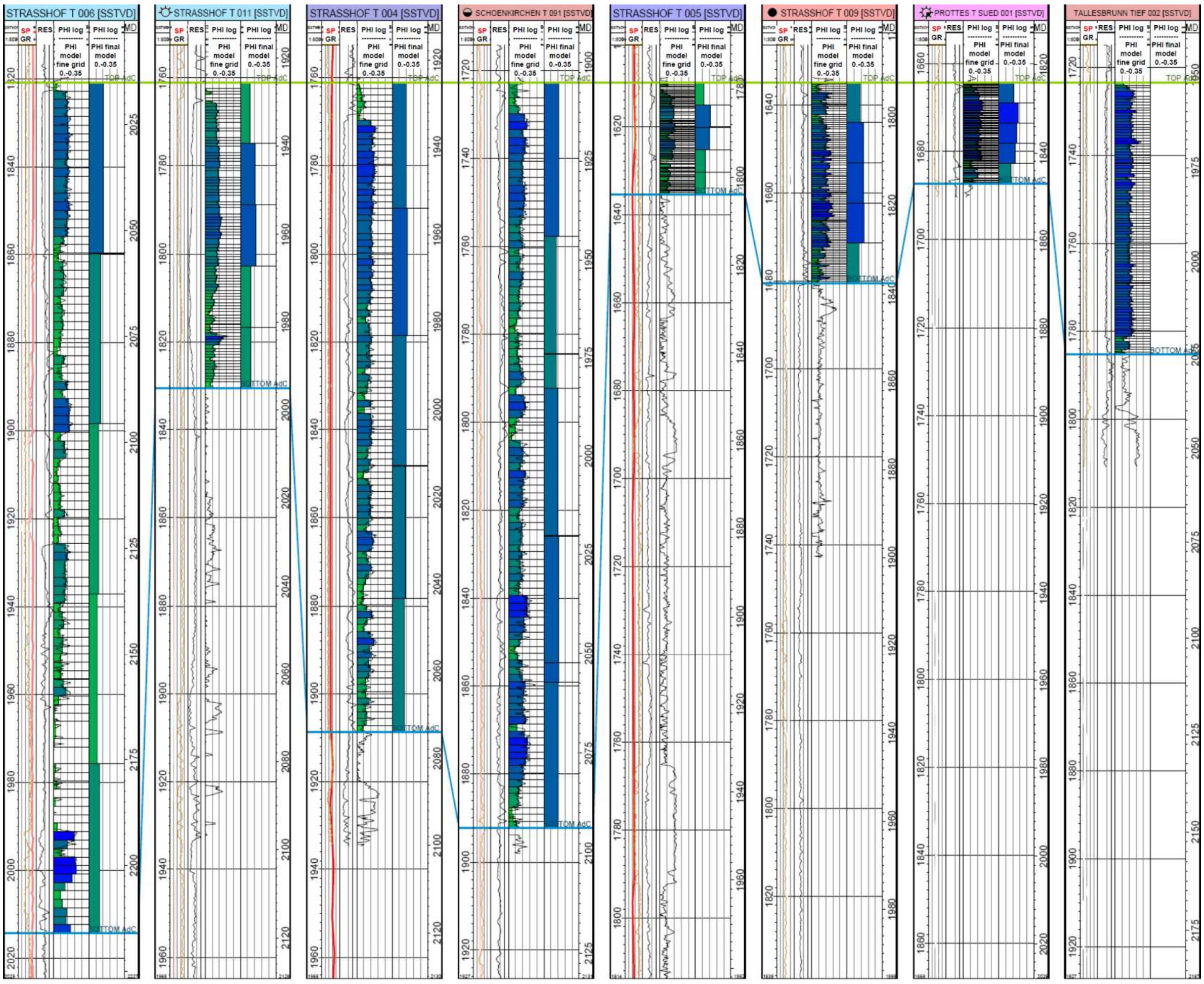


Fig. 5 Upscaling of petrophysical property (porosity)

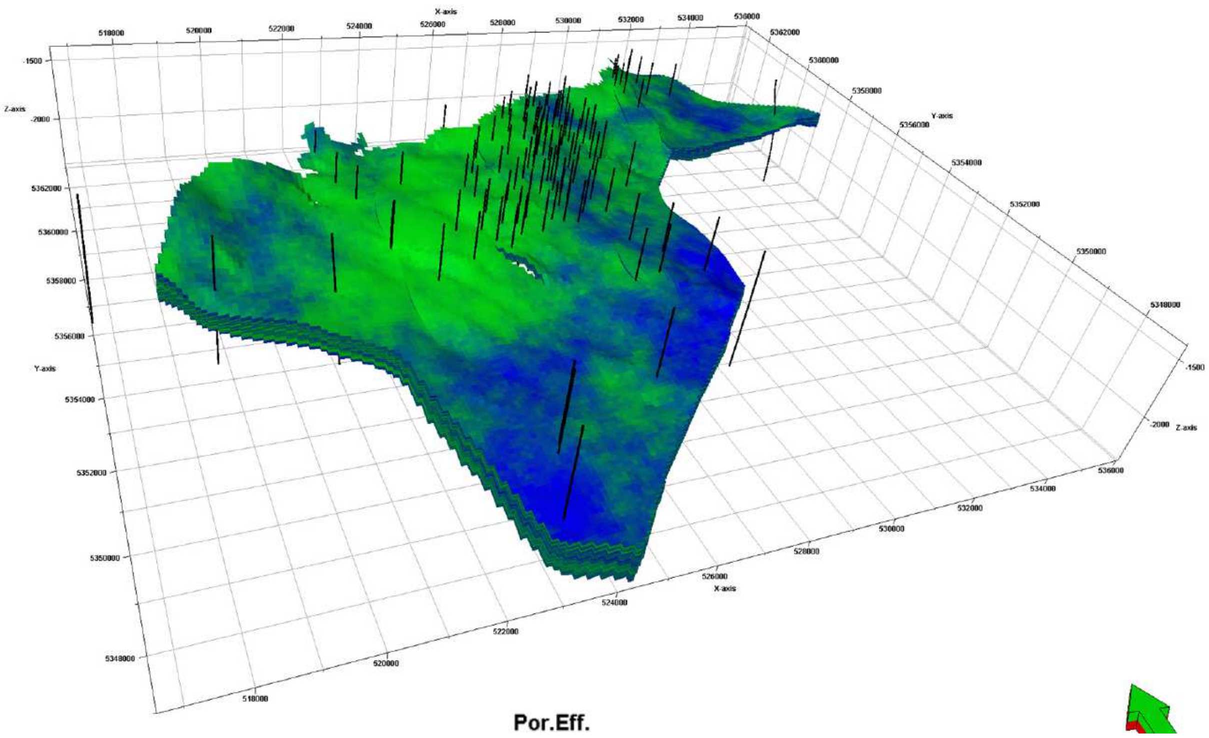
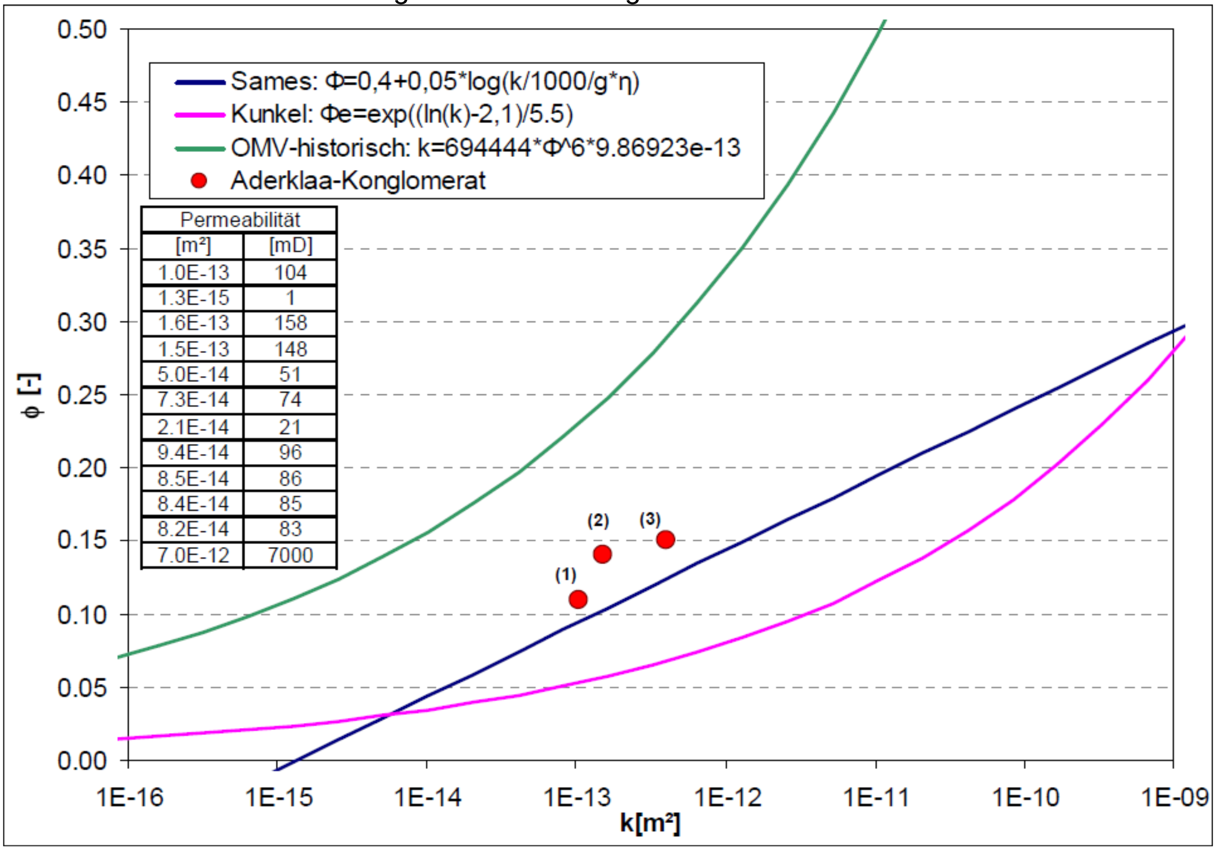


Fig.6 Distribution of effective porosity within the grid model

Having the major AC - model incl. geology and effective porosity created in PETREL, the hydrodynamic history match for the major AC had to be carried out with the permeability as matching parameter. As result of the matching process (rate – volume – pressure behavior) it was revealed that the hydrodynamic relationship from SAMES & Voigt [BOY-SAM-1996] fits the available test data best. Figure 7 shows the good accordance.



Permeabilität	
[m²]	[mD]
1.0E-13	104
1.3E-15	1
1.6E-13	158
1.5E-13	148
5.0E-14	51
7.3E-14	74
2.1E-14	21
9.4E-14	96
8.5E-14	86
8.4E-14	85
8.2E-14	83
7.0E-12	7000

Fig.7 Comparison of measured total permeabilities and data calculated using empirical relationships from OMV, [KUN-1994] and [BOY-SAM-1996]

To evaluate the geothermal potential, the temperature distribution of the AC has to be known. Temperature gradients, measured in different wells, are shown in figure 8.

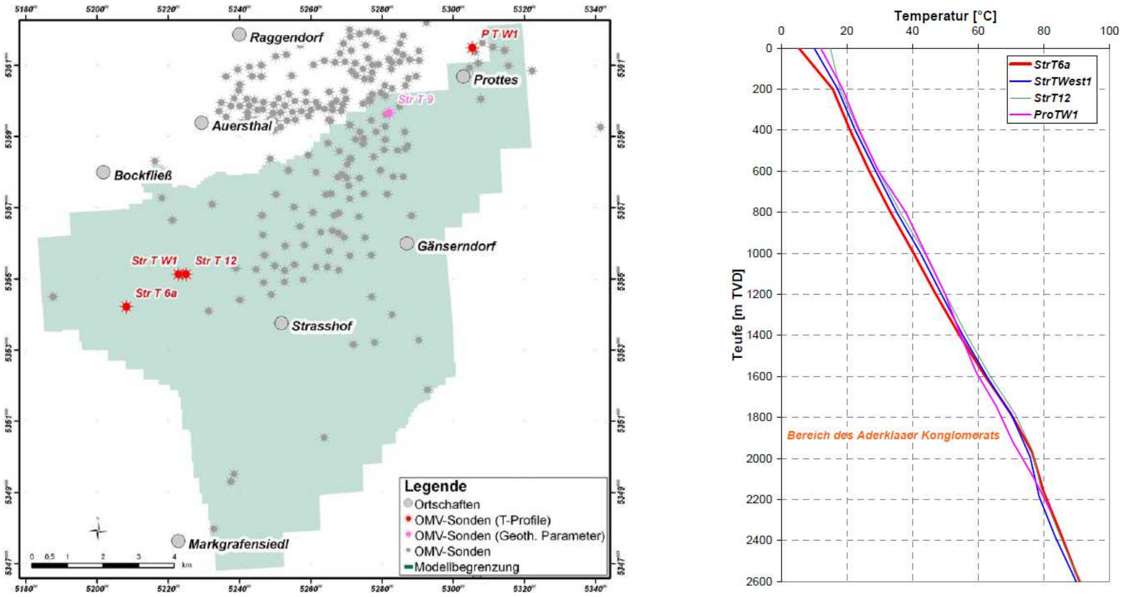


Fig.8 Location and measured temperature gradient of selected wells

In all selected wells almost similar temperature gradients from East to West were measured. From the temperature – depth – curve in figure 8 a small bending can be seen in the depth interval of the AC between 1800 and 2100 m TVD. The more solid rock below the AC exhibits a slightly higher thermal conductivity that results in an average geothermal gradient of < 3 °C/100 m TVD. The Pro T W1, missing the AC closely at its Northern border, doesn´t show this small anomaly in temperature gradient.

Hydraulic simulation including heat transport considering the injection history and the initial pressure – temperature conditions yielded the pressure and temperature distribution with state of 2010 (figures 9 and 10).

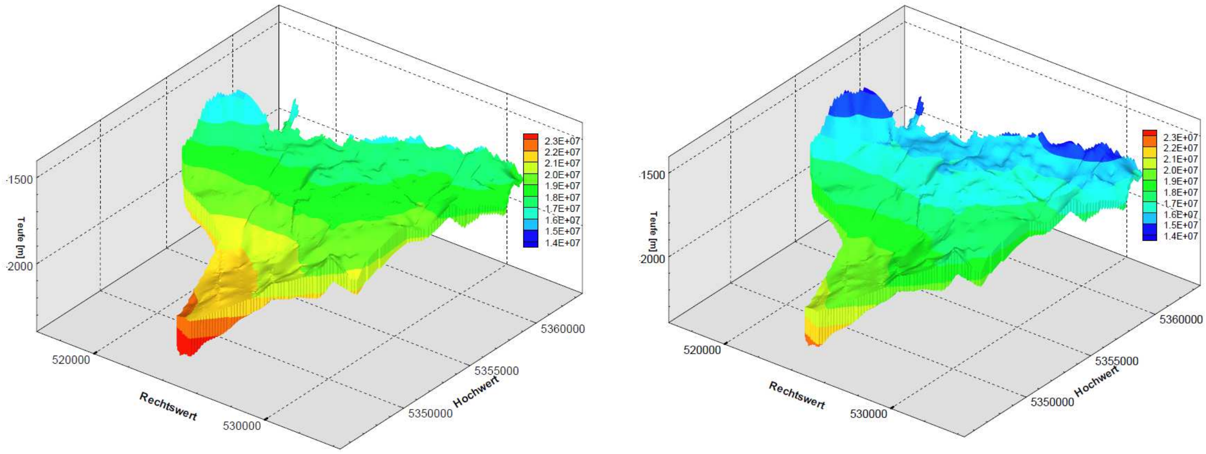


Fig. 9 AC-pressure distribution in E+7 Pa, initial state (left) and status 2010

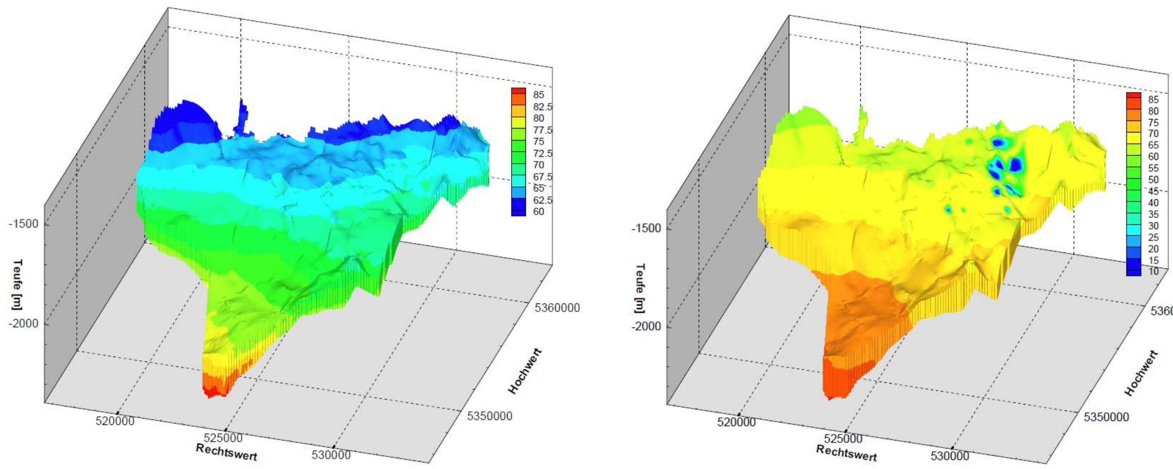


Fig. 10 AC-temperature distribution in °C, initial state (left) and status 2010

During the last ~ 50 years the pressure in the AC has dropped by ~ 20 bar due to production, mainly from the hydraulically connected Zwerndorf gas reservoir and the 16th Badenian oil horizon. Currently, there is equilibrium between injection and withdrawal. Consequently, the pressure in the AC has stabilized on a ~ 20 bar lower level.

Due to the injection history the temperature within the injection area of the AC decreased and reached injection water temperature at the surface of the injection wells. Several kilometres away from the injection area the temperature did not show any significant change.

The theoretical rededication of the existing well Gae UeT 1b as geothermal production well was the focus of scenario 1 in order to minimize necessary investment costs. The Gae UeT 1b is a relatively new injector at the Southern edge of the injection area (figure 11).

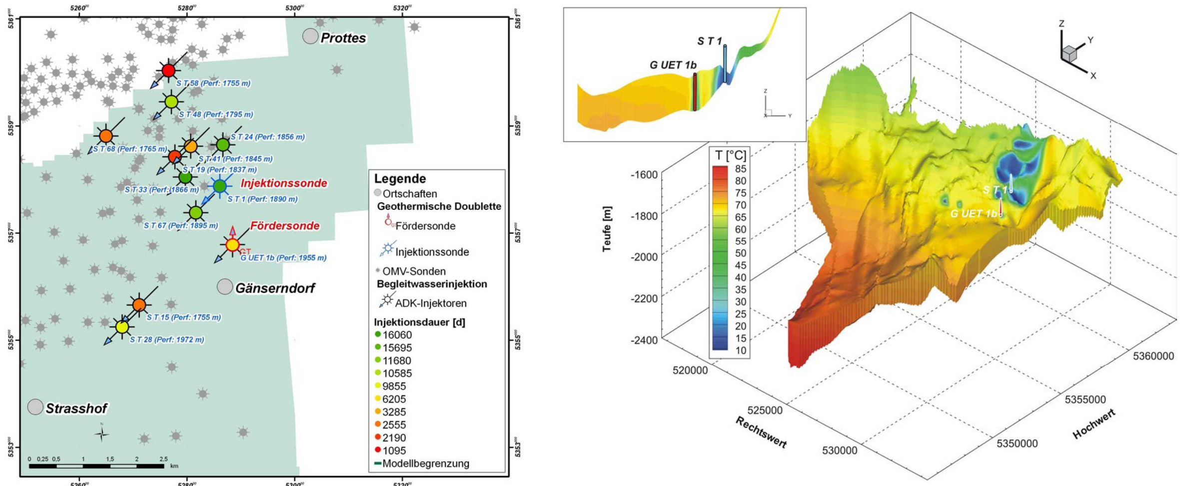


Fig. 11 Location of the geothermal producer Gae UeT 1b in the AC (scenario 1)

Because of the high permeability of about 1 darcy and the moderate reservoir temperature of ~ 75 °C a direct heating in continuous operation with a return temperature of 35 °C was an appropriate approach for geothermal energy recovery.
The energy recovery is directly depending on the water production rate and the temperature difference between produced and re-injected water.
Figure 12 shows the dependency between water production rate and wellhead flowing temperature (WHFT) calculated on the basis of approaches from Tschekaljuk [TSCH-1965] and Köckritz [KÖCK-1979]. The water production rate should be equal or greater than 10 m³/hour to keep temperature losses in the wellbore small.

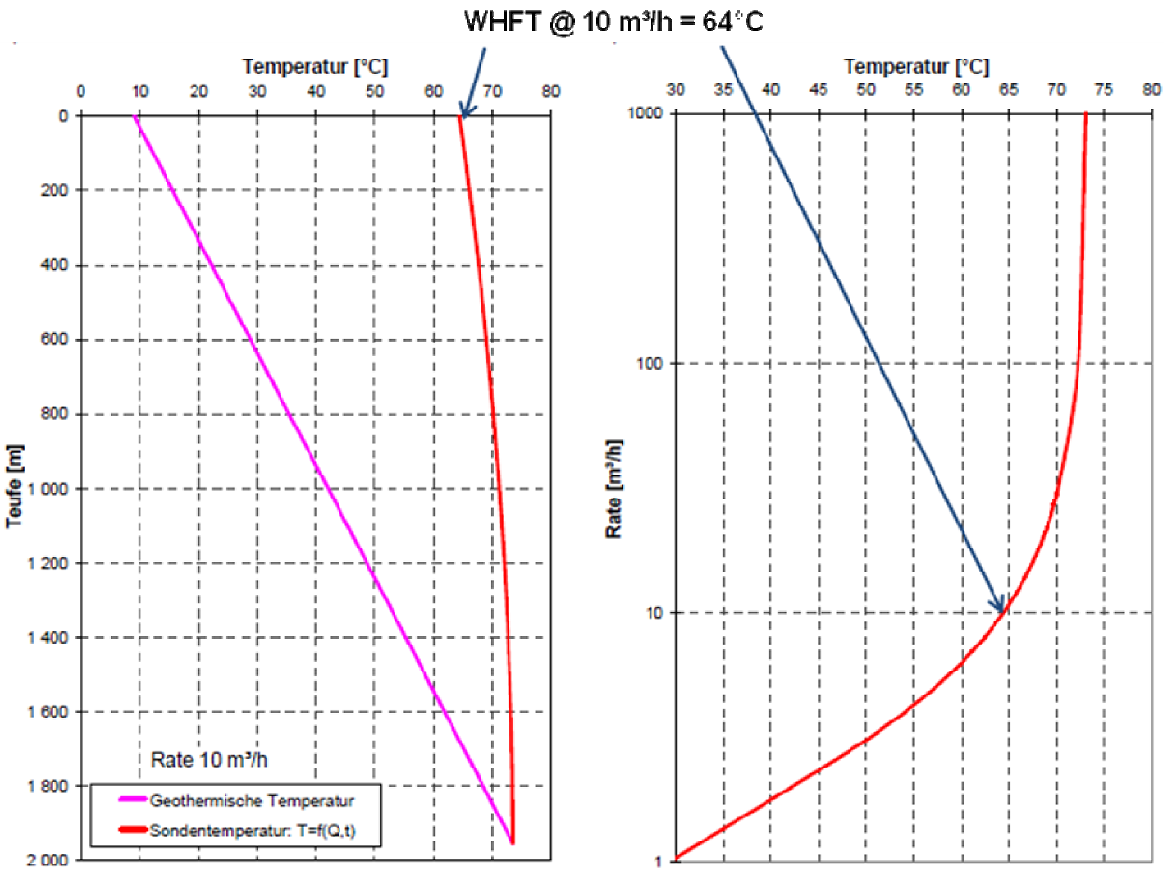


Fig.12 Dynamic water temperature profile in the geothermal well @ 10 m³/hr (left) and water rate vs. WHFT (right)

At a reservoir temperature of about 75 °C and a water rate of 10 m³/d the WHFT reaches 64 °C constantly. With a re-injection temperature of 35°C there is a temperature difference of ~ 30 °C, able be used for geothermal energy recovery.
Due to injection history the AC around Gae UeT 1b doesn´t exhibit the above mentioned initial reservoir temperature of 75 °C. The near field of the reservoir is cooled down close to the surface injection temperature. As shown in figure 13, it would need more than 10 years of continuous water production to reach surface flowing temperatures > 50 °C. In case the wellhead flowing temperature exceeds 55 °C, a geothermal power of 250 $kW_{thermal}$ can be reached after a long production period.

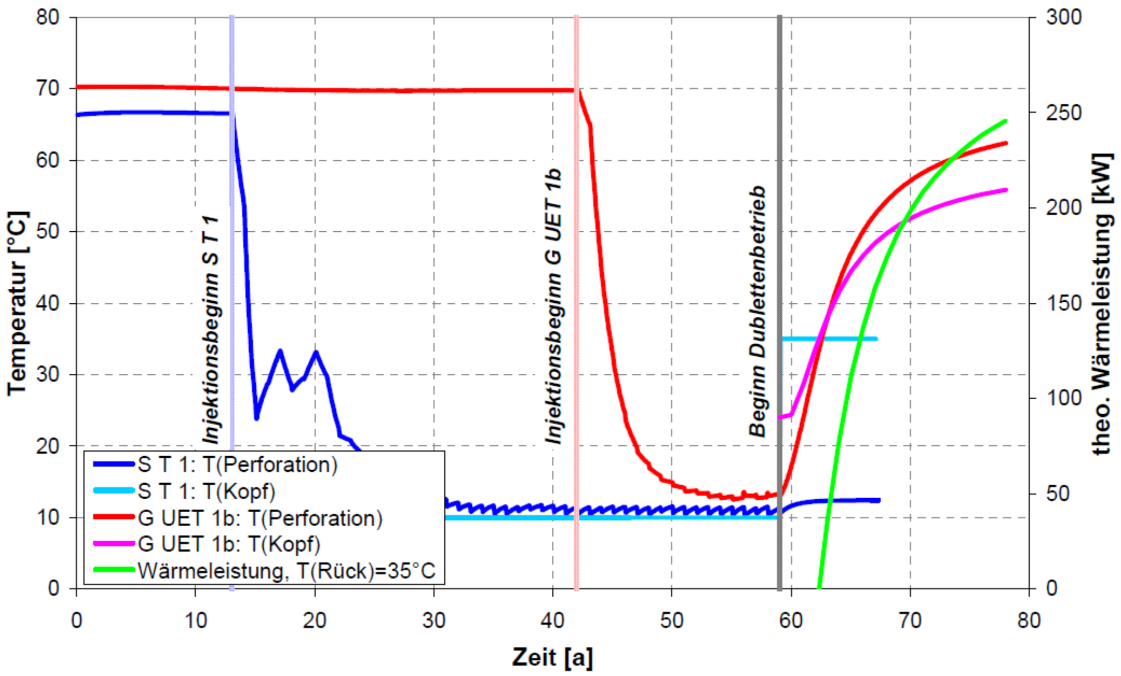


Fig. 13 Geothermal potential of former injector: G UE T1b (10 m³/h)

The rededication of an existing injector in a good permeable reservoir is the cheapest concept available. However, the time to reheat the near field of the reservoir is too long for an economic project. A better suited candidate would be a former oil producer more distant from the cool injection area, e.g. S T 29a (figure 14). This was investigated in scenario 2.

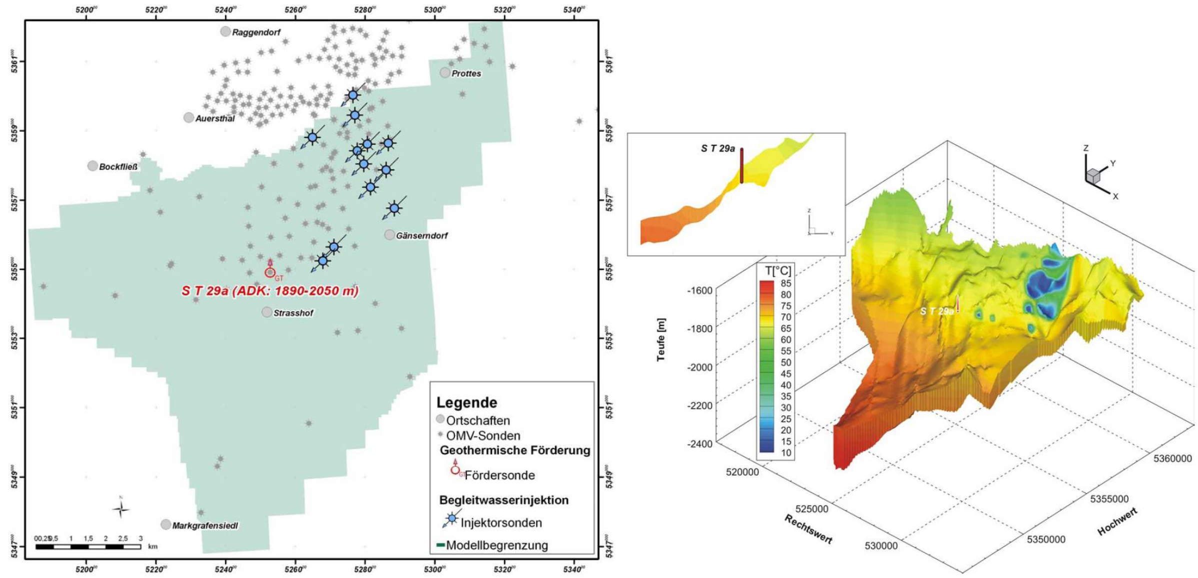


Fig.14 Oil producer S T 29a distant from the cool injection area as candidate (scenario 2)

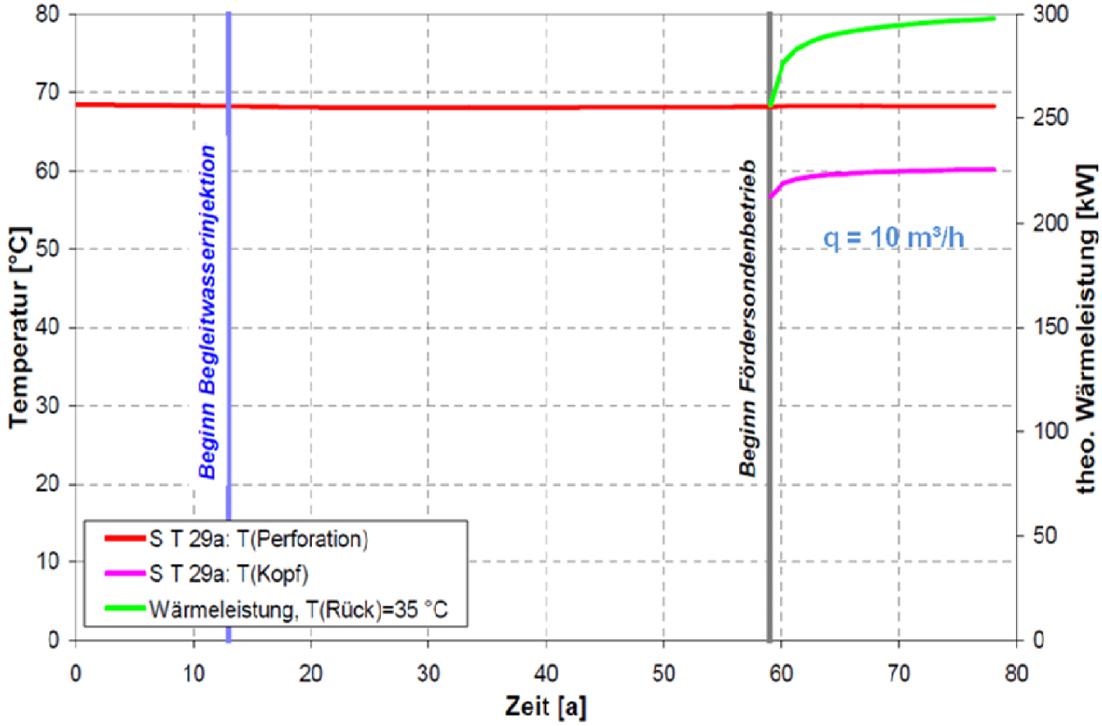


Fig. 15 Geothermal potential sufficiently afar from the cooled area: S T 29a (10 m³/h)

Simulation of geothermal production using S T 29a (fig. 15) as a well with almost initial reservoir temperature reveals that water production would start with a much higher wellhead temperature of about 57 °C. Right from start of the operation geothermal power > 250 $kW_{thermal}$ can be recovered.

Wells located in an aquifer horizon in ~ 1800 m depth with initial reservoir temperature may reach thermal power in the order of 1 $MW_{thermal}$ at water production rates of about 35 m³/h.

Investigation of the potential of a sour gas well in a low permeable reservoir

Several deep gas reservoirs in the Vienna Basement have been developed. A number of these exist in the fractured “Hauptdolomit” which is generally located at a depth of 4000 m TVD or greater.

STR T 4 produces sour gas from a compartment of Dolomite located at a true vertical depth of over 4000 metres beneath the floor of the Vienna Basin. The reservoir is characterised by an estimated low porosity of 1.5 % with an associated low permeability of 0.06 mD. With no near aquifer support, STR T 4 produces almost exclusively through gas expansion.

Table 1 shows a representative gas composition of the reservoir.

Component	Proportion (Vol%)
CH4	90.84
C2H6	0.56
C3H8	0.15
I-C4H10	0.03
N-C4H10	0.07
I-C5H12	0.03
N-C5H12	0.03
C6+	0.15
CO2	6.23
N2	0.78
H2S	1.13
Total	100.00

Table 1: Sour gas composition of the STR T 4

From the start of production the wellhead pressure was lowered from 325 bar (WHP) down to ~ 80 bar, the minimum possible WHFP during the first production years until the start of the compressor. Due to the low permeability the gas rate showed a nominal decline of ~ 50 % p.a. (fig. 16).

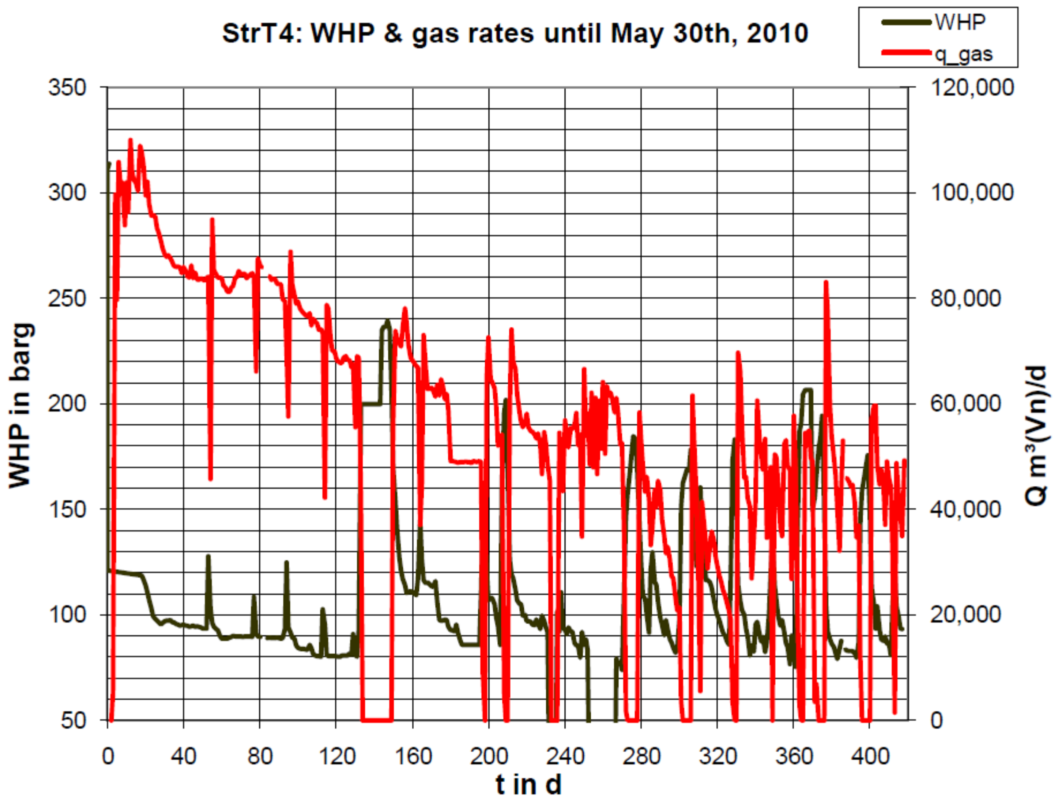


Fig. 16: Gas production rate and WHFP vs. time

Figure 17 shows the pressure change in the tight reservoir after 1.5 years of gas production.

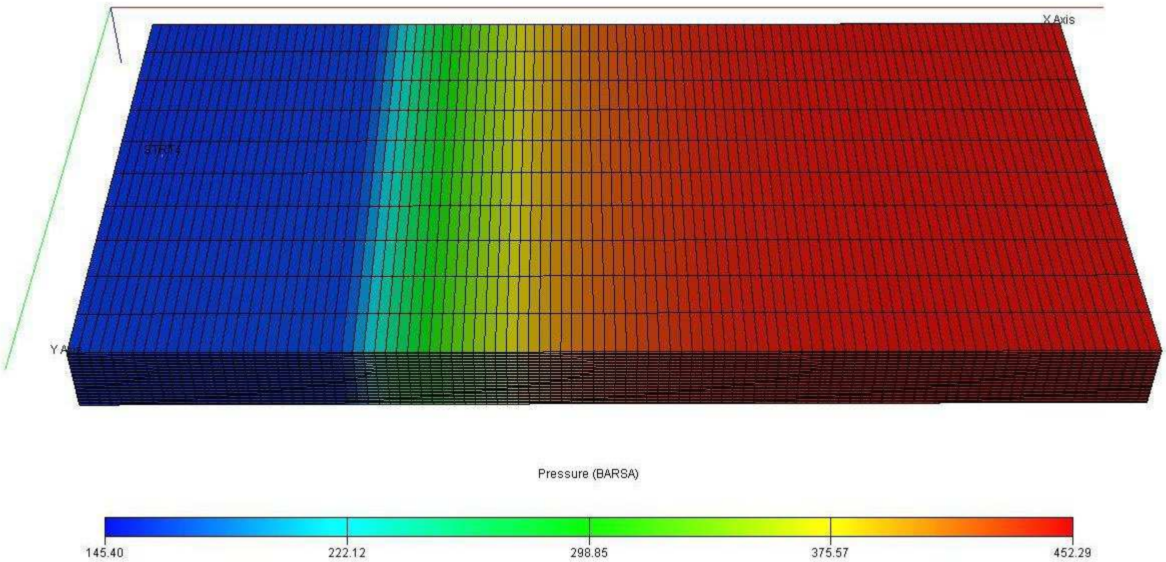


Fig. 17: Pressure change due to 1.5 a production (model length ~0.7 km)

The pressure around the STR T 4-well dropped from ~ 450 bar of initial pressure to 145 bar. Due to the low permeability the pressure wave and thus the area of influence propagate very slowly. The well probably will produce its whole lifetime in transient mode. At a constantly low wellhead flowing pressure the rate will keep on dropping with time.
The low permeability doesn´t allow any reliable material balance calculation. Initial gas in place and reserves have to be estimated considering the geological assumptions about size and properties of the reservoir. The simulation can only prove the currently dynamically reacting gas volume in the reservoir. Figure 18 (left graph) shows the history match proving a radius of investigation in the earlier production phase. The (slowly) increasing area of investigation requires a of bigger sized simulation model to get the history match after a longer production history (right plot).

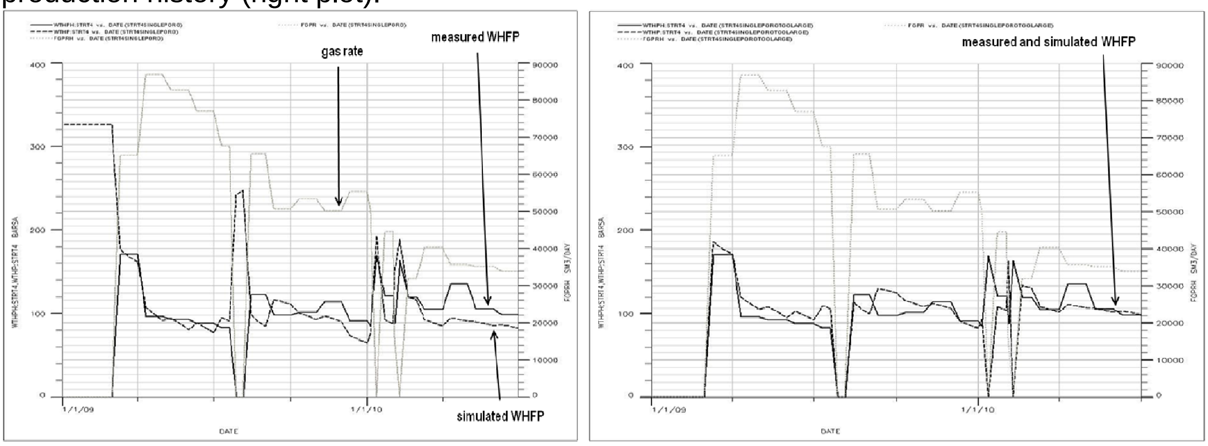


Fig. 18: Early time (left) and later time history match (right) of the rate-WHFP-behavoir

The real size of the reservoir can not be calculated this way, but knowing the probable size and properties, a reliable forecast can be made (table 2).

m³ (Vn)	boe
0	0
19,920,000	123,922
11,380,000	70,795
5,000,000	31,105
3,600,000	22,395
3,098,549	19,276
2,666,946	16,591
2,295,461	14,280
1,975,722	12,291
1,700,520	10,579
1,463,651	9,105
53,100,848	m³ (Vn) cum.

Table 2: Gas production scenario (history match and forecast) of STR T 4

Comparison geothermal well with tight sour gas well

- The gas produced by STR T 4 (table 1) exhibits a lower heat value of 10 kWh/m³.
- 2,400 m³/d gas rate correspond to 24,000 kWh/d.
- 24,000 kWh/d correspond to a performance of 1.0 MW

That is the same amount of thermal power a geothermal well from the Aderklaa Conglomerate would deliver with a water production (and reinjection)-rate of ~35 m³/h.
The STR T 4 well with a depth of 4450 m will be an economically positive project including fees and taxes for a gas well, if the well starts production one year after drilling and if the sum of all capital expenses doesn´t exceed 6.7 mn €. “Grenzwirtschaftlich” means, that the NPV is not negative, but zero after 10 years.

excl. taxes:	NPV	: 5.0 Mio €
(10% Shrinkage)	Pay Back Period	: 1 year
	IRR	: 65%
	„Grenzwirtschaftlich“	: CAPEX < 9.8 Mio €
incl. taxes	NPV	: 2.1 Mio €
(10% Shrinkage)	Pay Back Period	: 1.9 years
	IRR	: 33%
	„Grenzwirtschaftlich“	: CAPEX < 6.7 Mio €

As a last point of this investigation it is interesting to compare the energy of an economically producing gas well with a geothermal well, were aquifer horizon and gas reservoir are located both in 1800 m depth, the depth of the above investigated Aderklaa Conglomerate.
When does a ~1600 – 1800 m (e.g. from a Badenian tight gas horizon, 10 % shrinkage due to gas composition like STR T 4) deep gas well deliver economically?
With the assumption of a constant gas rate a gas producing well has to deliver

- ~5600 m³ (Vn)/d over 10 years to be „Grenzwirtschaftlich“ incl. taxes.
- 4300 m³ (Vn)/d over 10 years to be „Grenzwirtschaftlich“ without taxes.
- 4300 m³ (Vn)/d correspond to power content of ~ $43 \cdot 10^3$ $kWh_{thermal}$.

For an equal amount of thermal energy like 4300 m³ (Vn) of gas, a hydrothermal well like S T 29a had to produce 1500 m³/d of 65 °C warm water.

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