H-104 Time lapse seismic for the development of an underground gas storage

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Introduction

For more than 20 years the underground gas storage site Kalle, located in north-west Germany, is in operation. The geologic structure is a smooth anticline striking WNW-ESE. A NW-SE striking normal fault with a throw of some hundred metres borders the north-east flank of the anticline. At the top of this structure, the Volpriehausen-Sandstone with a thickness from 15 m to 20 m is used to store natural gas. Due to changes in the pressure-volume characteristic of the gas storage detected in 1999, a vertical gas migration out of the storing horizon was suspected. This assumption was confirmed by gas saturation logs, which recorded a gas accumulation in the Detfurth-Sandstone, above the Volpriehausen-Sandstone (Fig. 1).

Objectives of the time lapse seismic investigations are to compare the results of two 3D seismic surveys recorded in 1992 and 2000 in order to verify the gas accumulation in the Detfurth-Sandstone as well as to determine the spatial distribution of gas in the Detfurth- and Volpriehausen-Sandstone.

Reservoir mechanical investigations

Because of the changes detected in the pressure-volume characteristics, the storage operation from 1995 up to 2000 was reinvestigated in more detail. Basing on a numerical model which matches the storage history from 1978 up to 1995 very well, the gas pressure was calculated up to the year 2000. The computed gas pressure values and the observed data diverge significantly in course of time. Only with a pressure dependent gas flow out of the storage, starting at 277 bar and resulting into flow rates up to a maximum of 60000 m^3/d, a good match between the numerical simulation and the real operation could be achieved. In addition to the 3D reservoir simulation, the gas saturation of the Volpriehausen- and Detfurth-Sandstone was checked by TDT logs. Comparing the logs of 1994, 02/1999 and 10/1999 at some selected wells an increase of gas saturation in the Detfurth-Sandstone could be confirmed (Fig. 2).

Both the reservoir simulation and the analysis of gas saturation indicate an increasing gas accumulation in the Detfurth-Sandstone which probably starts in 1995/1996.

Seismic data and its comparibility

The time lapse seismic investigation for the determination of the gas distributions is based on two 3D seismic data sets.
The first data set was measured in 1992 and is a subset of a large gas exploration survey in the license Neuenhaus/Emlichheim. At that time, both the survey and the data processing were directed to the depth range of the Zechstein and hence the seismic resolution was not sufficient for a detailed interpretation of the Middle Bunter. In order to improve the seismic

resolution as well as to determine the gas distribution, the data were reprocessed focussing on a time window of 1.3 s up to 1.6 s and the preservation of true amplitudes.
The second data set was measured in 2000. For economic reasons the configuration of the survey was designed for a best fit to the target area and the depth range of the gas storage. A homogeneous offset and azimuth distribution of the completely covered and migrated area as well as a high seismic resolution were the most important aspects of the survey design.

Due to different shot point and receiver arrays of the two data sets, it was necessary to ensure their comparibility. Thus synthetic seismograms of adjacent CDP gathers with the real offset distribution were computed and the amplitudes of the stacked traces were analyzed. It was found that the differences between the amplitudes from both configurations do not exceed 5 % within a confined area of 11 x 11 bins. In comparison to the discrepancy between the reflection amplitudes of water saturated and gas bearing sandstone, numerically modelled after the Biot-Gassmann theory, these differences can be neglected.

Determination of gas distribution

In order to determine the gas distribution, AVO analysis and investigations of the variation of acoustic impedances were performed. The deduced results can always be checked by the known fact that at the times of the seismic surveys the gas storage was filled. It turns out that water bearing areas could not be discriminated from gas bearing areas by AVO analysis. This was also verified by numerical modelling of the AVO behaviour.

Significant amplitude anomalies appear at the top of the structure which can be used for a first estimation of the size of the gas bearing area. As the thickness of the layers of the Volpriehausen- and Detfurth-Sandstone is lesser than the seismic wave length, the amplitudes are possibly affected by wave interference. In order to minimize the interference effects and to optimize the seismic resolution, an inversion was performed under consideration of available sonic and density logs. The inversion results in a distribution of acoustic impedances and with the help of this indicator and the assumption of a constant porosity, water saturated areas and gas bearing areas in the Volpriehausen- and Detfurth-Sandstone can clearly be separated. The water saturated areas show acoustic impedances between 9500 and 10500 [10^3 kg · m^{-2} · s^{-1}] and the gas bearing areas show impedances less than 9000 [10^3 kg · m^{-2} · s^{-1}], depending on gas saturation. By a final attribute analysis, a functional relationship was derived between the calculated acoustic impedances and the gas saturation recorded at some wells.

For the comparison of the results of 1992 and 2000, both data sets were processed according to the same processing sequence and with the same parameters. Additionally, the same inversion method as well as the same functional relationship between acoustic impedance and gas saturation was used.

Conclusions

In combination with the structural interpretation and the reservoir mechanical considerations the established gas distribution of the Volpriehausen-Sandstone exhibits a reliable image of the state of filling of the underground gas storage. Comparing the gas saturation maps of the Detfurth-Sandstone of 1992 and 2000, an increase of the gas accumulation in the vicinity of two wells was determined (Fig. 3), which indicates a possible migration path for gas out of the storage.

Acknowledgement

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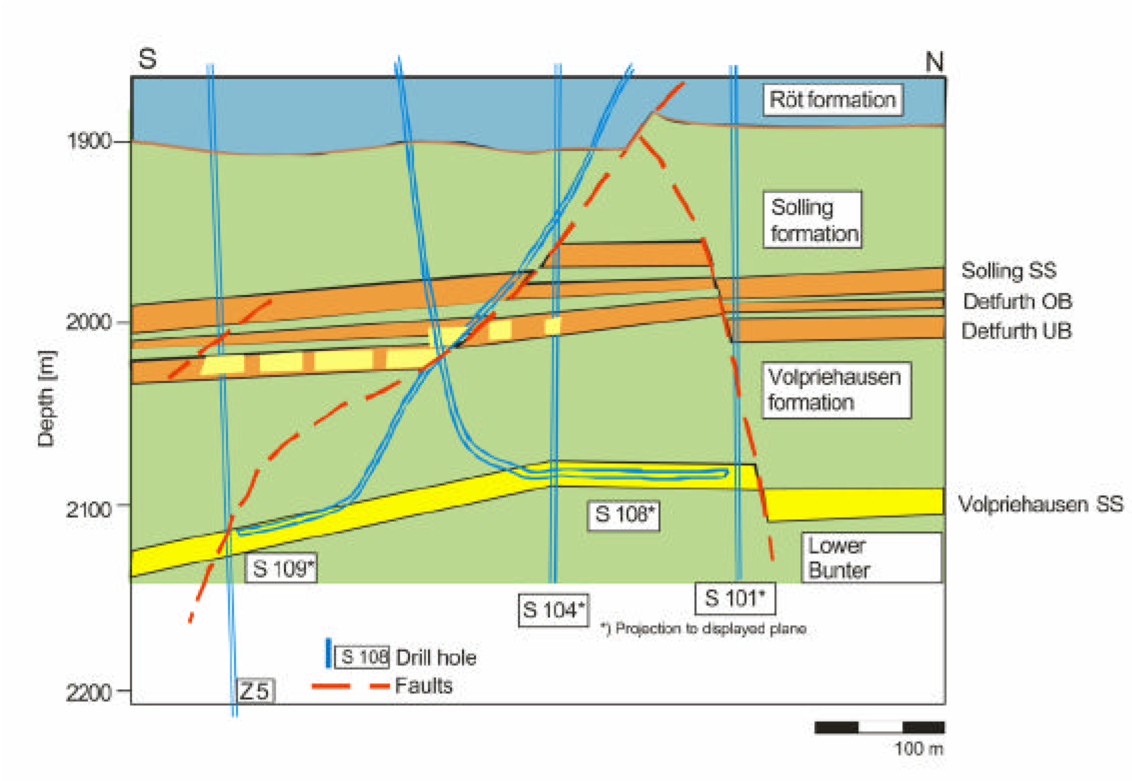

Figure 1: Schematic image of the geological structure of the underground gas storage in the Volpriehausen-Sandstone.

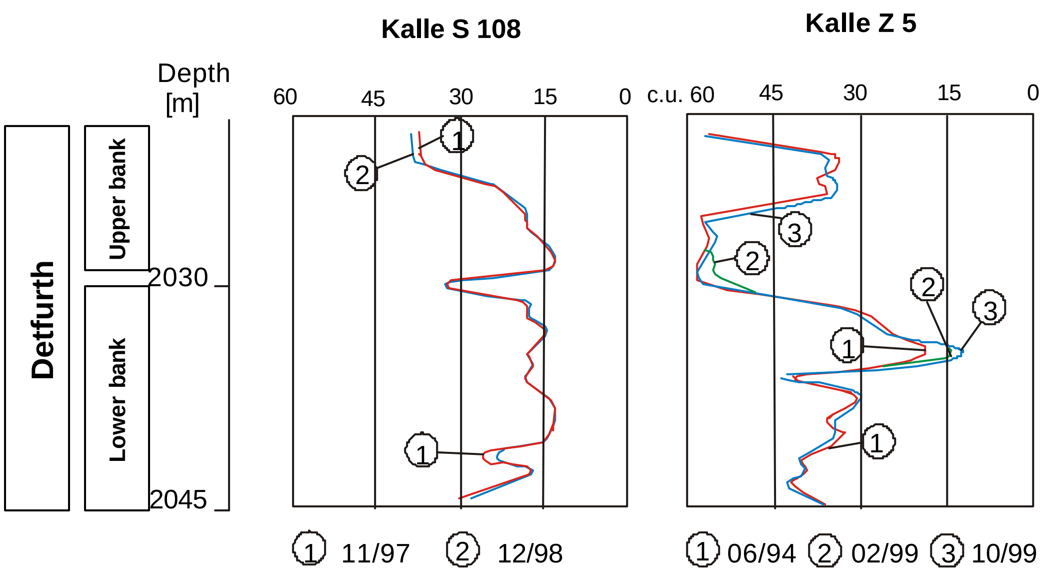

Figure 2: TDT logs (sigma curves) for the determination of gas saturation.

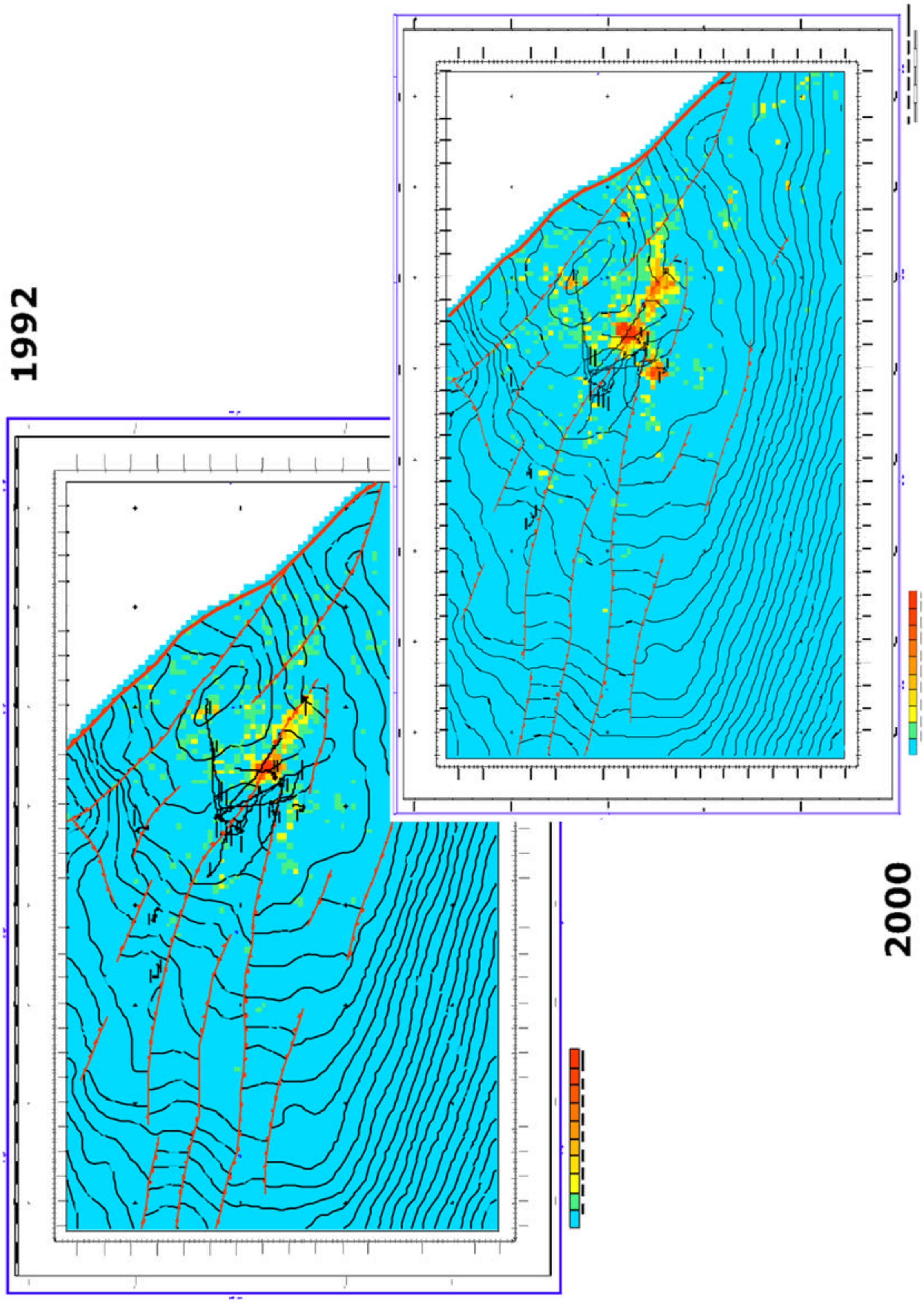

Figure 3: Gas saturation maps of the Detfurth-Sandstone of 1992 and 2000.