# Well history and production behaviour- Lessons from the Strasshof Tief Case

Master Thesis

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# Affidavit

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Sandra Roth

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# Abstract

**Well history and production behaviour- Lessons from the Straßhof Tief Case**

In April 2005, the OMV Exploration and Production GmbH started to develop the Strasshof Tief field, a sour gas field in the Vienna Basin. During drilling, testing, stimulating and producing unexpected results were obtained. The approach presented in this thesis is based on detailed analysis of data from the three available wells and attempts to localize opportunities of improvement.

This thesis is subdivided into 8 chapters. Chapter 2 illustrates an overview of the Strasshof Tief field. Chapter 3 delivers an insight to the seismic image. The aim of the subsequent three chapters is to analyze the wells from a historical view. Chapter 7 includes a more detailed analysis of incidents, which affected the productivity most. In the last chapter a conclusion of the results and a future prospect are given.

# Kurzfassung


**Sonden Historie und Produktion Verhalten- Erfahrungen von dem Straßhof Tief Feld.**

Im April 2005 begann die OMV Exploration and Production GmbH das Strasshof Tief Feld, ein neues Sauergasfeld im Wiener Becken, zu erschließen. Während des Bohrens, Testens, Stimulierens und Produzierens ergaben sich unerwartete Ergebnisse. Das Ziel dieser Arbeit ist es die vorhandenen Daten von drei der Sonden dieses Feldes zu analysieren und Verbesserungsmöglichkeiten zu evaluieren.

Aufgebaut ist diese Arbeit in acht Kapitel. Zu Beginn wird ein allgemeiner Überblick über das Feld Strasshof Tief gegeben. Das 3. Kapitel gibt einen Einblick in die Ergebnisse der Seismic. Die darauffolgenden Kapitel befassen sich mit der Analyse der Sonden aus einer historischen Perspektive. Im 7. Kapitel werden Ereignisse, die den Erfolg der Bohrungen am meisten beeinflussten, vertieft analysiert. Das letzte Kapitel schließt die Arbeit und fasst die Ergebnisse und Kenntnisse noch einmal zusammen.

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# List of Abbreviations

| | |
|---|---|
| AD | Aderklaa |
| AGI | Acid Gas Injection |
| APS | Accelerator Porosity Sonde (Porosity Log) |
| BHS | Bottomhole Sample |
| BHP | Bottomhole Pressure |
| BOP | Blow Out Preventer |
| Ca | Calcium |
| $CaCO_3$ | Calcium Carbonate |
| CBL | Cement Bond Log |
| CET | Cement Evaluation Tool |
| $CO_2$ | Carbon Dioxide |
| $CO_3$ | Carbonate |
| CRS | Common Reflection Surface |
| CT | Coiled Tubing |
| DSI | Dipole Shear Sonic Imager |
| DST | Drill Stem Test |
| ECD | Equivalent Circulating Density |
| ECP | External Casing Packer |
| EMW | Equivalent Mud Weight |
| FBP | Formation Breakdown Pressure |
| FBHP | Flowing Bottomhole Pressure |
| FBHT | Flowing Bottomhole Temperature |
| FIT | Formation Integrity Test |
| FMI | Formation Micro Imager |
| FPP | Formation Propagation Pressure |

| | |
|---|---|
| FWHP | Flowing Wellhead Pressure |
| FWHT | Flowing Wellhead Temperature |
| GR | Gamma Ray |
| GWC | Gas Water Contact |
| HALS | High Azimuthally Laterolog Sonde |
| HC | Hydrocarbons |
| HCGR | Computed Gamma Ray |
| HCl | Hydrochloric Acid |
| $HCO_3$ | Bicarbonate |
| $H_2CO_3$ | Carbonic Acid |
| HNGT | Hostile Environment Natural Gamma Ray Spectrometry Tool |
| HPHT | High Pressure High Temperature |
| HRLA | High Resolution Laterolog Array |
| $H_2S$ | Hydrogen Sulphide |
| HSGR | Standard (Total) Gamma Ray |
| K | Potassium |
| KOP | Kick off Point |
| LCM | Lost Circulation Material |
| LGR | Liquid- Gas Ratio |
| LOT | Leak off Test |
| LWD | Logging While Drilling |
| MCFL | Micro Cylindrically Focused Log |
| MD | Measured Depth |
| MDT | Modular Formation Dynamic Tester |
| Mf | Methyl Orange Alkalinity |
| MPD | Managed Pressure Drilling |
| MWD | Measurement While Drilling |

| | |
|---|---|
| NCA | Northern Calcareous Alps |
| NMR | Nuclear Magnetic Resonance |
| OBD | Overbalanced Drilling |
| OGIP | Original Gas In Place |
| OH | Open Hole |
| $OH^-$ | Hydroxyl |
| OHT | Open hole Test |
| PBU | Pressure Build Up |
| Pe | Photoelectric factor |
| PEFZ | Litho- Density Log |
| Pf | Phenolphthalein Alkalinity |
| PI | Productivity Index |
| PLT | Production Logging Tester |
| PSDM | Prestack Depth Migration |
| RHOZ | Density Tool |
| ROP | Rate of Penetration |
| SG | Specific Gravity |
| SS | Sub Sea |
| S T | Schönkirchen Tief |
| S/N ratio | Signal to noise ratio |
| Str T | Strasshof Tief |
| TD | Total Depth |
| Th | Thorium |
| TLD | Three Detector Lithology Density |
| TMD | Total Measured Depth |
| TOC | Top of Cement |
| TVD | Total Vertical depth |

| | |
|---|---|
| U | Uranium |
| UBD | Underbalanced Drilling |
| UBI | Ultrasonic Borehole Imager |
| USIT | Ultra Sonic Imager Tool |
| VSP | Vertical Seismic Profile |
| WHP | Well Head Pressure |
| WOC | Waiting on Cement |
| WOB | Weight on Bit |
| XLOT | Extended LOT |

| | |
|---|---|
| a | Large Half-Axis of the drainage Ellipsoid |
| B | Formation Volume Factor |
| F | Formation Volume Factor |
| h | Height |
| $I_{ani}$ | Vertical- to Horizontal Permeability Anisotropy |
| k*h | Permeability Thickness |
| $k_H$ | Horizontal Permeability |
| $k_V$ | Vertical Permeability |
| n | Saturation Exponent |
| q | Production Rate |
| $R_m$ | Resistivity of the Mud |
| $R_{mc}$ | Resistivity of the Mud Cake |
| $R_{mf}$ | Resistivity of Mud Filtrate |
| $R_{sh}$ | Shale Resistivity |
| $R_t$ | True Resistivity |
| $R_w$ | Water Resistivity |
| $R_{xo}$ | Resistivity of the flushed Zone |

| | |
|---|---|
| s | Skin Factor |
| $S_w$ | Water Saturation |
| $V_{sh}$ | Shale Volume |
| $\Delta p$ | Pressure Difference |
| $\phi$ | Porosity |
| $\mu$ | Viscosity |

# 1 Introduction

In April 2005 OMV started to develop a new sour gas field in the Vienna Basin. The Strasshof Tief case (Str T) is located approximately 30 km northeast of Vienna in the frontal part of the Northern Calcareous Alps (NCA) Nappe-systems. Seven wells were planned involving simultaneous appraisal and development drilling. Based on the commonly „assumed“ reservoir efficiency, a fast Field Development concept has been designed to bring the field on stream as soon as possible. But with increasing field experience, more and more unexpected results during drilling, testing, stimulating and producing were obtained, which were affected by many factors, not necessarily technical, and not all transparent.

The purpose of this thesis is to shed some light on the most important incidents of the field to attain additional knowledge and identify opportunities of improvement. Emphasis will be placed on the technical difficulties and especially on the drilling and completion fluids. Economics are not a subject of this work.

The initial objective was to consider all seven wells including their sidetracks. However, while collecting information, it turned out that an incredible amount of data exist. To consider all of them would have gone beyond the scope of this paper. Therefore, only specific topics were chosen to be processed here.

In contrast, the data compilation turned out to be incomplete. Some reports were not accessible and some events were not recorded. With progress of the Str. T development, less and less data were available. Thus, just the first three wells Str T4, 5, and 6, including their sidetracks Str. T 5a and 6a, were considered.

# 2 Strasshof Tief Project

The Vienna basin, situated at the junction of the Eastern Alps and the Western Carpathians is a post- alpine grabenlike down warp with extent of about 200 km in length and up to 60 km width.

Production from the Vienna basin started in the middle of the 19$^{th}$ century from very shallow depths. The first gas discoveries came across when drilling a water well of 96m depth in 1844/45.

With time search for oil and gas in ever deeper targets was intensely pursued. According to G. Wessely, the exploration for hydrocarbons in depths of 6.5 – 8.5km was undertaken between 1977 and 1983. Four wells were drilled to obtain more information concerning the stratigraphy, facies distribution and depth positions of the autochthonous Jurassic, Upper Cretaceous and Tertiary Molasse along the Eastern flank of the crystalline basement spur of the Bohemian Massif.

As a drilling result a more comprehensive picture of the three tectonic plays of the Vienna basin was acquired, represented in detail by the Zistersdorf and Aderklaa profiles.

The uppermost play is the Neogene basin fill holding the majority of individual and mostly multi-horizon hydrocarbon fields.

The second play underneath the Neogen basin consists of the allochthonous units, Flysch and Calcareous Alps. The Northern Calcareous Alps (NCA) nappe system, where the Strasshof Tief wells are located, is separated into two intensely deformed thrust units. Whereas the front unit of the NCA is called Frankenfels Nappe, the other to south-east direction is the Lunz Nappe.

The last play is superimposed on the Tertiary Molasse and the autochthonous Mesozoic cover of the Bohemian Massive. The only information about this lowermost 'floor' is coined from the four wells mentioned above.

The Strasshof Tief field is located in the Vienna Basin, in the Calcereous Alps. In total six wells, not including the sidetracks, were drilled to appraise and explore simultaneously two different sourgas bearing formations. The two main targets were the Reyersdorfer Dolomit and the Perchtoldsdorfer Dolomit, which were already known from further drilling actions in the surrounding of the Strasshof Tief field.

The higher positioned target, the Reyersdorfer formation, was already a well established reservoir.

The existence of the Perchtoldsdorfer Dolomit relied on information from the Aderklaa wells (e.g. AD 93, 79 and 88) and from the Schönkirchen Tief 11 well (drilled in 1964). In the latter well the dolomite remained untested except an OHT (4,385 -4,416m MD), approximately 50 m below the dolomite, flowed gas and condensate in uncommercial amounts.

Additional information can be drawn from documents of previously drilled Strasshof Tief wells, which are:

A paleontological report for Strasshof Tief 1, created in 1964, where the deepest point of 3128m was mentioned. However, the report does not expose further information about location, depth, or success.

Also a well Strasshof Tief 2 existed- but only the notation of the well appears on some sketches of the geological structure of the Vienna basin and a reference related to Str T4. It is positioned approximately 1km south-east of Str T4.

Furthermore, a well Strasshof Tief 3 exist. A concise profile of this well is available. Thus it appears that the well was located close to Strasshof T6. It was drilled between May and August, 1968 to a total depth of 3579m. The Hauptdolomit was met.

Supplementary information was gained from wells of the surrounding area: In northwest direction the Bockfliess Tief wells are located. Some Schönkirchen Tief (ST) and Reyersdorfer Tief wells are on the level of Strasshof Tief 9 in the same direction. The Aderklaaer fold anticline is positioned south-west of Strasshof Tief. In south east trend most of the Schönkirchen Tief wells are situated. In particular the ST wells and wells from the Aderklaaer field provided a main source of information for planning the Strasshof Tief wells.

In a horizontal projection the actual Strasshof Tief wells were aligned into northeast direction as it is depicted in Figure 35, in Appendix A, showing the structure on top of Perchtoldsdorfer Dolomit. According to 'Strasshof Tief Review G&G' from August 26$^{th}$, 2008 the chronological order of the wells was described as follows:

Strasshof Tief 4 was the first well drilled from February to April 2005 to explore the southwest continuation of the sour gas bearing "Reyersdorfer Trend" as it was predicted by G. Wessely in the mid 80's. Furthermore, it should appraise additional gas accumulation in the deeper dolomite, the Perchtoldsdorfer plate, intersected by S T11 in 1972. As a secondary target the Bockfliess Beds were expected, they had been encountered by the well Str T2. An additional Reservoir between the two main targets was encountered- the Hierlatzkalk/Hornsteinkalk, an interval with promising gas readings.

In 2006, Str. T5 was drilled, situated about 7km northeast of Str. T4, in the central part of the existing Reyersdorfer field. As no gas/water contact was identified in the Perchtoldsdorfer Dolomit at this time, it was planned as a vertical well. For the Reyersdorfer Dolomit no gas was expected but the new Jurassic Reservoir should contain HC´s. Str T5 became a key well to gain additional knowledge about the structural set up.

However, Str T5 was plugged back and sidetracked towards the location of the ST11. The reasoning was: less favourable test results, cementation problems and 'the well was lost due to borehole stability problems of 12 m Rhaetian shale'. However, the Liassic was not encountered in the sidetrack Str T5a, but the Perchtoldsdorfer Dolomit came in with a high HC column.

Subsequently, Str T6 was drilled in the end of 2006, two kilometres away from Str T4. The intention was to test the contact of the Perchtoldsdorfer Dolomit in south-west direction. The well came in deeper than anticipated, but still with HC shows. However, as no flow was obtained by MDT, it was decided to drill a sidetrack.

Str T6a came in as planned, but now the Jurassic was tested wet. For operational reasons the production test failed. A frac job was planned for mid 2008, but due to the economic crisis this project is deferred.

Although the additionally drilled wells are not subject of this thesis, they are mentioned in order to provide completeness:

As Str T4 was declared an oil well, a gas producer to back up the gas production was needed. Therefore Str T11 was drilled next to Str T4. Further it should confirm the gas/water contact of the Perchtoldsdorfer Dolomit, predicted by Str T4, wherefore it was deviated beneath Str T4. Both targets were met.

The intention of Str T9, following Str T11, was to test the primary target, the Perchtoldsdorfer Dolomit 2.3 km north-east of Str. T5. As a secondary target the Hierlatzkalk/Hornsteinkalk was expected to bear sweet oil. Str T9 is located close to the wells ST 78 and 48. Both wells were successfully tested and produce gas at least temporarily from the Reyersdorfer plate. But none of them has ever been used as long-term producer. Strasshof T9 was sidetracked twice- Str T9a and 9b.

The last well drilled was Str T12 in 2008. However, the data about this well is limited, only some Daily Drilling and Geological Reports, some liquid sample analysis and one MDT- Report of the 8 ½" section from July 29$^{th}$ 2008 are available. According to the latter Report gas was found in the lower layers of the Reyersdorfer Dolomit. Contrarily to normal the upper dolomite layer contains water. A shale layer within the lower layers appears as seal. Above this layer an elevated formation pressure indicates a separate compartment, which may communicate with Str T4 via the aquifer.

The formation content shows Str T12 is positioned in different dolomite layers than Str. T4. If a common aquifer is assumed, Str T12 encountered a gas column approximately 200m thick. [1]

Furthermore, Strasshof Tief 13 was planned as an oil well in the Hierlatz-/ Hornsteinkalk. The only available record is a briefing about a "Workshop Strasshof Tief 13" on December 10, 2007. But the well has never been drilled.

However, although a lot of information about the Strasshof Tief field was available, it had many surprises in store, starting with Strasshof's tectonic configuration.

It was assumed that during Upper Jurassic and Lower Cretaceous intense compression folding-phases occurred, forming strongly dipping anticlines.[2] However, when drilling the sidetrack Strasshof T5a geological stratums, which had appeared at Strasshof T5, were totally missing. These abrupt changes of the formation within some meters led to the assumption that the well was drilled along a fault. The unexpected change of the composition of formation waters and the fact that sweet oil was found in between two sourgas reservoirs indicated that the originally assumed geological model is not correct. Even seismic processing was inappropriate to obtain a clear image of the complex section beneath the Neogene strata.

The last assumed geological model shows strongly dipping imbricates. This assumption is more likely to explain the abrupt changes of the formation within a few meters and the varying fluid content of the reservoirs.

In addition, the great depth of the wells, borehole stability problems occurring due to the presence of shale, and the sour gas content, made the project more complicate.

A fast Field Development concept has been designed involving simultaneous appraisal & development drilling. This program was aimed to bring the field on stream as soon as possible.

Two concepts were considered:

- Tie in of Strasshof Tief 4 well to existing gas plant Aderklaa I (including revamp of Aderklaa I and installation of gas dehydration at well site – brown field part
- Drilling of new wells, Installation of a new Central Processing Plant, new gas Pipelines and Surface Facilities at well sites – green field part

Furthermore, a feasibility study has been implemented to analyze if acid gas injection might be an interesting alternative to Claus plants to remove the sour gas components. The potential Reservoirs were either the Reyersdorfer Dolomit or the Schönkirchen Übertief Dolomit.

# 3 Seismic

Today, seismology is playing an increasingly important role in field appraisal and development planning. Reservoir size, shape, and characteristics are the key pieces of information required to get the design right. 3D seismic surveys allow the company to better define prospective oil/gas structures and pinpoint drilling locations thus increasing chances for successful wells. 3D seismic has become an invaluable tool for developing drilling prospects and has become the number one prospecting tool in today's oil and gas exploration industry. [3]

Though finding the oil and gas deposits deep below the earth's surface, in deep and complex structures are very challenging. It is often accompanied by various difficulties such as low signal-to- noise (S/N) ratio at long recording times and/or insufficient source-receiver offset ranges for appropriate data processing. The choice of an efficient data processing sequence is also a critical step in successfully imaging the deep structural features.

In the mid-Nineties, exploration in the Vienna Basin has been focused on the shallow Neogene basin. High-frequency seismic source sweeps (10 – 90 Hz) and limited source receiver offsets (max. 2.8 km) provided high-quality 3-D seismic data, perfectly tuned to image the shallow part of the basin. Pre-stack time migration has been applied to obtain a high-resolution image of the target area.

However, in Strasshof Tief the exploration targets have been shifted to a deeper level where the recorded dataset and the chosen processing approach are inappropriate to obtain a clear image of the complex section beneath the Neogene strata. The complexity of the geological structure created additional difficulty. Due to the high dips (35 to 80 degrees) of the beds seismic imaging became a major problem. Combined with multiples and a low signal to noise ratio only in some places the dipping of uncertain beds could be guessed. [4]

Therefore OMV conducted a comparison of different types of processing- routes which represents the deeper target best.

The seismic signal that is received from deeper depth intervals is generally centred at ~20 Hz. High frequencies in the pre-Neogene section of the Vienna Basin are usually related to noise and/or processing artefacts. Therefore, signal processing tuned to low frequencies has the potential to improve coherency in the final section compared to conventional high-frequency seismic data processing.

Hence a first step towards improved quality of the seismic image was using only the low-frequency component of the seismic signal. Spiking deconvolution, which is used to restore the position of acoustic interfaces by spiked events, was replaced by predictive deconvolution to clear seismic data by predicting and to eliminate multiple reflections. That was followed by band pass filtering the data between 10 – 40 Hz to remove the noise. Finally, post-stack depth migration was applied instead of prestack time migration. Post-stack time migration takes advantage of the fact that post-stack data (multi-fold) in the pre-Neogene section show higher S/N ratio compared to pre-stack data (single-fold) as they are used in the pre-stack time migration approach.

All this yields to significantly improved data quality in the pre-Neogene section. Due to the limited bandwidth, the resolution of the Neogene strata was of course decreased. However, the shallow part of the data was not target anymore.

The final attempt to get a better understanding about the geological structures in the deep Vienna Basin was the application of Common Reflection surface (CRS) processing (Bergler et al., 2002 and Gierse et al., 2006). This special processing technique was applied using the same 3-D low-frequency seismic data set as in the post-stack time migration approach. Unlike the conventional stack, the CRS method is a data driven imaging method, which automatically determines a set of CRS stacking parameters from semblance measurements in the pre-stack and post-stack data. Furthermore, the CRS stacking surfaces extend beyond single common-midpoint gathers, which implies a higher fold that leads to a better S/N ratio, and reflector continuity in the CRS stack. Those attributes of the CRS method are important for the deep Vienna Basin dataset, since it is extremely difficult to derive seismic velocities with the existing 3-D seismic data set and the very low S/N ratio. The result of CRS processing is definitely enhanced, compared to the results obtained from pre-stack time migration and post-stack time migration.

Target-oriented data re-processing should be considered as an effective tool to increase the information content of an existing data set. Focusing on the principal attributes of a dataset using robust techniques (e.g., low-frequency processing, post-stack migration approach, etc.) or targeted techniques (CRS processing) have the potential to reveal information that is not obvious in conventionally processed data. [5]

In order to compose a clear picture of the Pre-Neogene strata a further data acquisition might be necessary. Based on this experience, methods for future data acquisition were recommended: A strong source signal is required to penetrate the deeper levels and to carry the coherent signal back to the surface. Dense source-receiver sampling is essential for the application of multiple techniques and for successful imaging of steep dipping events in the deeper subsurface. Far source-receiver offsets, up to approximately 8km offset traces, would improve the final image significantly and might be the most important approach. [6]

However, conducting a new seismic array in order to get a better image of the deeper target would be very expensive, due to the great area to explore.

# 4 Strasshof Tief 4

The purpose of the well Str T4 was to explore the Perchtoldsdorfer Dolomit as the deeper target and to appraise the Reyersdorfer Dolomit on trends between the gas fields Reyersdorf and Aderklaa.

According to the report 'Intent to drill, Strasshof Tief 4', gas of the latter dolomite body was assumed to be trapped in a recumbent fold anticline with high dips. A new subcrop map from the NCA based on seismic attributes was developed. This led to the assumption that it may be possible that the dolomite extends further in a more straight line from Reyersdorf to Aderklaa. Furthermore, correlations from Aderklaa, where similar seismic features have been drilled within the gas field, confirmed this theory. Based on these conformities a seismic interpretation was feasible.

The first estimates concerning the reserves and the Reservoir of the Str T4 were made based on data from the Reyersdorfer gas field wells, located at a distance of 2 to 6km away.

The estimation of reserves was done in two different ways: deterministic and probabilistic. The deterministic method is to select a single, well known, value for each parameter to input into an appropriate equation. Therefore the calculated reserve values are more tangible and explainable. In contrast, the probabilistic method utilizes a distribution curve for each parameter, also including the most likely as well as the outliers. At the end only the result is given but not the exact value of any input parameter. Hence, it allows the incorporation of more variance in the data. However, for both methods the reliability of the information depends on the quality of the used input data. Comparison of these two methods, as done below, can provide quality assurance to estimate reserves. If the results agree, confidence is increased. [7]

The results of these estimations are listed in Table 1 and Table 2.

**Primary Appraisal Target- Reyersdorfer Dolomit**

For the Reyersdorfer Dolomit a plateau production of 300,000m³/d for 9 years was assumed with a 28% decline per year afterwards.

Table 1: Estimated Reserves of the Reyersdorfer Dolomit [4]

| Deterministic Res. | Min. | Most likely | Max. |
|---|---|---|---|
| OGIP (MMm³) | 85.88 | 1739.6 | 5,637.3 |
| Probabilistic Res. | **P90** | **MEAN** | **P10** |
| OGIP (MMm³) | 101.5 | 2831.8 | 7723 |
| Rec. Rs. (MMm³) | 57.76 | 1608.9 | 4449.4 |

For reserve estimation the Reyersdorfer Dolomit was assumed to reach its highest point close to the proposed well location of Strasshof T4 at a TVD of about 2820m subsea (SS).

To determine the Probabilistic Reserves the following assumptions were made:

P90: 4-way dip closure with approximately 30m of closure and the GWC residing at -2850m SS

Mean: GWC was anticipated at 3100m TVD SS, resulting in a gas column of 280 m and a 4km extension.

P10: GWC was considered at 3150m TVD SS, as in the known part of the Reyersdorf field, resulting in a gas column of 330m.

The Hauptdolomit is always encased in tight sediments (e.g. Jurassic Liasfleckenmergel on top, or Carnian Lunz beds at the bottom) and therefore the lateral seal was assumed to be tight. The top of the folded anticline seemed to be eroded and subsequently covered by Carpathian sediments, which are mainly tight shales and poor reservoir quality sands. On top the Reservoir is sealed as in the Reyersdorfer gas pool. Therefore the risk is negligible.

The Reservoir itself was already well established within the NCA and assumed to be the best producing horizon within the NCA sediments. Porosity mainly occurs from fractures and some matrix porosity.

The risk analysis showed that the major hazard was the actual existence of the dolomite within the targeted structure. The well was planned to be drilled deviated against the anticipated dipping of the beds in order to ensure the encounter of the dolomite. The probability of intersecting the target area is approximately 50%. The existence of the Reyersdorfer gas pool sourcing, timing and migration is certain.

The depth map contains further risks as the seismic is relatively poor and interpretations were driven by concepts. The possibility of missing the dolomite completely due to incorrect seismic picking and/or time to depth conversion accounts for 30%. Furthermore, there was a very small risk that the Carpathian top seal fails (5%).

## Primary Exploration Target- Perchtoldsdorfer Dolomit

To estimate the reserves the same parameters as for the Reyersdorf Dolomit were used and are listed in Table 2. The production assumption resulted in a plateau production of 300,000m³/d for approximately 6 years, the decline afterwards was assumed to be 28% per year.

Table 2: Estimated Reserves of the Perchtoldsdorfer Dolomit [4]

| Deterministic Res. | Min. | Most likely | Max. |
|---|---|---|---|
| OGIP (MMm³) | 167.4 | 1142.25 | 3517.5 |
| Probabilistic Res. | **P90** | **MEAN** | **P10** |
| OGIP (MMm³) | 140.9 | 1450.7 | 3754.2 |
| Rec. Rs. (MMm³) | 79.5 | 836.2 | 2168.2 |

Which assumptions were made to evaluate these values does not arise from the present data.

The trapping style of the exploration target, the Perchtoldsdorfer Dolomit, was assumed to be similar to the Reyersdorfer Dolomit, just located a few hundred meters below. On top the Hauptdolomit was assumed to be sealed off by Upper Cretaceous Shales of the Gosau group. The bottom seal was assumed to be tight Lunz beds or the next Cretaceous sediments below the back-thrust plane. The lateral extension was thought to be 4 km long into northeast direction. Seismic indicated that the dolomite plunges towards southwest, to Aderklaa, and gives a south-west end of the trap.

The risk analysis showed that the sourcing and timing involves no risk as gas pools exists above the Reyersdorf Dolomit and below the Perchtoldsdorfer Dolomit level in Schönkirchen Übertief. The presence of the Hauptdolomit in this structure was assumed to be unlikely but possible. In ST 11 it was met in a down dip position. Due to the seismic quality the reliability of the map is fairly low; only ST 11 located roughly 4 km north-east gives a vague depth point. The risk of containment was considered very low due to the proven gas in Schönkirchen Übertief (800 m TVD gas column).

The total success rate for this target was expected to be 17%. If the well would encounter the Hauptdolomit at this level it would prove the concept and subsequently lower the risk of similar and follow-up projects.

## Secondary Targets

Additionally, the Bockfliesser Schichten, Gänserndorfer Schichten, and two layers in the lower Sarmat were assumed to contain HC. However, in the 'Intent to drill, Strasshof Tief 4' only the Bockfliesser Schichten are described, revealing that Str T2 encountered 4 m oil within this small faulted block, leading to a total production of 2726to oil. In Strasshof T 4 a large unfaulted area was meant to be penetrated. The trap would be similar to the Bockfliess beds in Schönkirchen Tief. However, this bed was not intended to be perforated. An optional OHT was considered in order to test the productivity of the Bockfliess beds for future production.

**Testing**

Production tests from the Reyersdorfer and Perchtoldsdorfer Dolomit were planned to be carried out in 2005. If these tests proved economic reserves production was scheduled for mid 2006.

## 4.1 Well Design

Various aspects need to be considered in well planning as many individuals and disciplines are involved. (mud program, casing program, drill string design, bit program, etc). [8]

Str T4´s well design was finished in May 2004 and is documented in the 'Intent to drill, Strasshof T4' [4]. However, as this report focuses on results it is very challenging to recreate the entire planning process.

### 4.1.1 Drilling Program

In November 2004, it was planned to drill Str T4 as a deviated well from a new location.

The KOP was designed for 2550m (respectively 2230m) in an Azimuth of about 140° and a maximum inclination of about 34° to penetrate all targets in a convenient position. The End of build was planned at a depth of 2688m MD and then drilled tangential to TD. The final depth should not exceed 4300m MD (3997m TVD), as this would surpass the maximum allowable load of the drilling rig H900.

According to the 'Minutes of Technical Review, Strasshof Tief4', the technical description of the casing program and the drilling process were reported as following:

- 13-3/8" conductor casing at 600m to provide a sufficient kick tolerance for drilling ahead to the next casing point at ca. 3000m; cemented to surface
- 9-5/8" surface casing at 3000m MD, set just above the "Reyersdorfer Dolomit; top of cement 50 m above the 13-3/8" casing shoe.
- 7" technical liner at 3755m MD (into the top Gosau formation), top of cement 100 m above the 9-5/8" casing shoe.
- 4 ½" liner at 4300 (=TD), in case of HC shows in the Perchtoldsdorfer Hauptdolomit; top of cement 100 m above the 7" casing shoe.

In order to drill the well fast and safely, the decision was made to use a $K_2CO_3$ mud system for all sections. From the 12 ¼" section Glycol should be added to increase lubrication, filtrate control and shale inhibition. For the 6" section the same mud system with high temperature additives should be used.

A summary of the drilling data is listed in Table 3.

Table 3: Drilling Data Summary [4]

| **Phase** | | **17 ½"** | **12 ¼"** | **8 ½"** | **6"** |
|---|---|---|---|---|---|
| **MD** | | **560 m** | **3000 m** | **3755** | **4300 m** |
| **Casing** | Diameter: | 13 3/8" | 9 5/8" | 7" Liner | 7 " |
| | Running Depth: | 560 m | 3000 m | 3755 m | 4300 m |
| | Weight: | 54,5 #/ft | 47 #/ft | 29# | 13,5 #/ft |
| | Grade: | J-55 | L-80 | L-80 | L-80 |
| | Connection: | STC | Buttress | VAGT | VAGT |
| **Cement** | Type/ Class: | CG 275 | CG 275 (Foam) | CG 275 | CG 275 |
| | Spec. Weight: | 1.60 kg/l/1.86 kg/l | 1.34 kg/25% | (Silicalite) | (Silicalite) |
| | Mass: | 25 to/31.9 to | 77 to | 1.80 kg/l | 1.80 kg/l |
| | Top of Stage 1: | surface | 550 m | 11 to | 6 to |
| | Top of Stage 2: | 280 m | - | 2900 m | 3650 m |
| | Slurry Volume: | [1)] 19.8 $m^3$/38.5 $m^3$ | 77) $m^3$ | 11 $m^3$ | 6 $m^3$ |
| **Mud** | Type: | $K_2CO_3$ System | $K_2CO_3$ System | $K_2CO_3$ System | $K_2CO_3$ System |
| | Specific Weight: | < 1.12 kg/l | < 1.12 kg/l | < 1.17 kg/l | ~ 1,35 kg/l |

1) 50 % excess volume in open hole respectively
2) 30% excess volume in open hole respectively
3) Depend on pressure regime

Possible Risks were taken into account while drilling:

- The risk of severe mud losses in the "Aderklaaer Konglomerat" due to the slightly under-hydrostatic pressure regime.
- The issue of the $H_2S$ content in the formation gas. It was planned to observe the wind direction while retrieving the core, and installing a ventilator to ensure a steady airstream in absence of wind. Furthermore, four stations with automatic $H_2S$ detection devices were planned. The fire brigade should be present during the core retrieval process and will perform training for the rig staff. A number of Drager Tube devices will also be available for $H_2S$ level detection.
- Possible hole stability problems in the Partnacher and Reiflinger layers of the Ladin formation. [9]

### 4.1.2 Well evaluation Program

**Pressure and Temperature gradients**

Pressure gradients were expected to be hydrostatic down to a depth of 3015m, except in the Aderklaaer Konglomerat, they are slightly under hydrostatic. Down to 3792 m over hydrostatic pressure conditions up to EMW 1.15 kg/l and up to EMW 1.30 kg/l down to TD were assumed.

The thermal gradient was assumed to be normal- it averages between 25 to 30°C/km [15°F/1000ft].

**Logging Program**

An intensive logging program was designed, including measurements with Production Logging (PLT) and Modular Dynamic Formation Tester (MDT).

**Sampling Program**

For the sampling program it was planned to collect washed and dried samples as well as a set of wet samples (unwashed and not dried) in intervals of:

| | |
|---|---|
| 0 – 560 m | No samples/spot samples |
| 560 – 3015 m | 20 m/spot samples |
| 3015 - 4300 m | 5 – 10 m/+2.5m wet samples |

For the latter depth range a reduced sample interval based on well site geologist decision and rate of penetration variations was possible.

**Coring**

According to 'Intent to drill, Strasshof Tief 4' and several other reports, a 27 m liner core should be taken at the top of the Reyersdorfer Dolomit, regardless of HC shows. In case of sufficient HC shows, another 27m liner core should be taken from top of the Perchtoldsdorfer Dolomit.[9]

**Testing**

One optional openhole test (OHT) was desired to be performed, but only in case of proven oil by logs within the Bockfliesser Schichten. The aim was to determine the reservoir fluids, the flow potential of the tested formation and the reservoir pressure.[10] Though, nothing indicates that this test was performed.

**Mudlogging Program**

From spud a mudlogging unit was planned to be at the well location.

## 4.2 Realization

The only way to prove the presence of HC is to drill a well into the potential reservoir. The priority should be to define the nature and characteristics of all fluids in place and the characteristics of the pay zone and more particularly the initial pressure, the temperature and the approximate permeability and productivity.

Therefore, a proper design should be done, involving the planning of all operations which can lead to additional information. E.g., samples of the rock cuttings should be taken and examined for their composition and fluid content to identify the type of formation versus depth and to check the presence of HC materials within the rock. Furthermore, it is important to obtain, preserve, and analyse cores of the formations of interest to directly identify e.g. permeability, porosity, etc. While the well is drilled various logs are taken to gather information about rock and fluid properties in respect to depth. Whenever a petroleum-bearing formation is drilled, the well has to be tested while placed on controlled production. These data and information are essential for the development of the field. Former expectations can be specified and the amount of HC can be identified more precisely. Based on this information decisions of further appraisal or abandonment of the well are drawn. [11]

### 4.2.1 Drilling

Drilling of the Str T4 proceeded from February 3rd to April 27th 2005. An overview of the completion scheme and comparison to the initially planned design is listed in Table 4.

Before drilling started, an 18 5/8" guide pipe was carved into the formation to a depth of 8m.

Table 4: Completion and Cementing Scheme of Str T4

| **1st Section** | | **Planned** | **Realized** |
|---|---|---|---|
| **Surface casing** | | **13-3/8" CSG** | **13-3/8" CSG** (L-80/BTC, 54,5lbs/ft) |
| Bit | | **17 1/2"** | **17 1/2"** |
| MD | [m] | 0- 560 | 0- 554 |
| Cementation: | | | |
| Cement | | CG 275 | CG 275 |
| Spec. Weight | [kg/l] | 1,60 /1,86 | Lead 1,60; Tail 1,86 |
| Cement Amount | [m³] | | Lead: 30; Tail: 16 |
| Plug pumped | [bar] | | |
| Cement Elevation | [m] | cemented to surface | 556 -0 (10m³ came to surface) |
| Date | | | 12.- 13.02.05 |

| 2nd Section | | Planned | Realized |
|---|---|---|---|
| **Intermediate casing** | | **9-5/8" CSG** | **9-5/8" CSG** (L-80/BTC, 47lbs/ft) |
| Bit | | **12 1/4"** | **12 1/4"** |
| MD | [m] | 560- 3000 | 0-2908 |
| This section was deviated : | | | |
| KOP | [m] | 2550 | 1800 |
| Inclination | [°] | | 7 |
| Azimuth | [°] | | 162 |
| EOB (MD) | [m] | | 2308 |
| Risks: | | | |
| Fluid loss: | | Aderklaaer Konglomerat | No problems |
| Cementation: | | | |
| Cement | | CG 275 (Foam) | Foam cement |
| Spec. Weight | [kg/l] | 1,34 /25% cement quality | Lead: 1,8; Foam: 1,36; Tail: 1,8 |
| Cement Amount | [m³] | | 64 |
| Plug pumped | [bar] | | No plug pumped |
| Cement Elevation | [m] | TOC 50 m above the 13-3/8 casing shoe | 2332- 260 |
| Date | | | 27. - 28.02.2005 |

| 3rd Section | | Planned | Realized |
|---|---|---|---|
| Intermediate casing | | **7" Liner** | **7" Liner** (29lb/ft; L80VAGT) |
| bit | | **8 1/2"** | **8 1/2"** |
| MD | [m] | 3000- 3755 | 2807- 3707 |
| Drilled tangential | | | |
| Inclination | [°] | | 35 |
| Azimuth | [°] | | |
| Cementation: | | | |
| Cement | | CG 275 (Silicalite) | Foam cement |
| Spec. Weight | [kg/l] | 1,8 | 1,8 |
| Cement Amount | [m³] | | |
| Plug pumped | [bar] | | 153 |
| Cement Elevation | [m] | TOC 100m above 9-5/8 casing shoe | 3710-2807 (TOL) |
| Date | | | 19.-20.03.05 |

| 4th Section | | Planned | Realized |
|---|---|---|---|
| liner | | **4-1/2" Liner** | **4-1/2" Liner** |
| bit | | **6"** | **6"** |
| MD | [m] | | 3609-4514 |
| TVD | [m] | 3755- 4425 | |
| Drilled tangential | | | |
| Inclination | [°] | | |
| Azimuth | [°] | | |

| Cementation: | | | |
|---|---|---|---|
| Cement | | CG 275 (Silicalite) | |
| Spec. Weight | [kg/l] | 1,8 | 1,8 |
| Cement Amount | [m³] | | |
| Plug pumped | [bar] | | 191 |
| Cement Elevation | [m] | TOC 100 m above 7" Casing | 4514-3609 |
| Date | | | 19.-20.04.05 |

**Limitations while Drilling**

Mud losses: During drilling, mud losses appeared. A more detailed description about the losses is summarized within the next chapter.

Gas readings: occurred in a depth of 2955m with 18ppm sourgas, when drilling through the Gänserndorfer Schichten.

At 3238m MD again high gas readings appeared, the connection gas reached up to 26.7%. Therefore, the MW was increased to 1.27 SG in order to ensure safe coring.

Although still mud losses occurred within the 6" section, concurrently high gas peaks up to 85% showed up.

Influx: When running in the 4 ½" liner, at a depth of 572m the borehole started to flow. Hereupon the annular preventer was shut and the pressure build up was measured. A bottom hole shut in pressure of 74bar was determined, with an upward trend. To stabilize the borehole 20.7m³ mud was circulated in with a gravity of 2.0kg/l.[ 12] At 2525m MD again an influx was detected. The kick, with 15m³ influxes, was gradually circulated out and the mud weight was decreased to 1.22kg/l.

As no more influx occurred the 4 ½" casing was run into the hole to TD and subsequently cemented.

**Incidents while Drilling**

Bit performance: In the 8 ½" section directional drilling was slow (2.5 m/hr); the used bit showed counter clockwise tendencies; therefore correction of the azimuth was necessary.

At a depth of 4217m due to poor rates and chert showing in the cutting samples the bit was changed again. It showed one ring out and one nozzle remained in the borehole. All trials to fish the bit nozzle were unsuccessful. After running in the borehole assembly a failure of the MWD was detected. Anyhow it was decided to drill thorough the Hornsteinkalk section to a depth of 4268m MD. Again the bit showed high wear, but with a new PDC the well was drilled to total depth of 4516m without any incidents.

Logging: The well logging was conducted by the company Schlumberger.

Within the 8 1/2" section the logging time lasted more than four days, three days longer than initially planned, due to several problems

The planned logging time of 24 hours within the 6" section was exceeded due to problems while logging and because the company Schlumberger did not allocate the necessary tools in time. A wiper trip had to be conducted until the tools were delivered. After 196 hours the well logging was aborted and a further wiper trip was executed.

**Differences between Plan and Realization**

Overall, the drilling process itself was conducted, as the drilling engineers had planned. Only the rig time was exceeded for 17 days. Due to the deep temperatures in the winter unfreezing jobs had to be done. The well was drilled 209m deeper than initially planned. Coring took longer than expected and logging time was exceeded due to the above mentioned incidents.

The 9 5/8" casing shoe was set 100m above the planned depth, within the Gänserndorfer Schichten and the thermal measured cement head is provided at a depth of 450m. The casing shoe of the 7" Liner was set within the Perchtoldsdorfer Dolomit.

However, a new drilling record was established. The 12 ¼" section was drilled within 8.5 days-2345m in 206 hours.

### 4.2.2 Drilling Mud

Primarily, when planning a mud program, a mud is selected, that will minimize the amount of time lost in the drilling operation. The mud used for the Str. T4 was potassium carbonate ($K_2CO_3$). Potassium mud is environmentally favourable, advantageous for the hole stability and allows fast drilling at a minimum solids content. Table 5 shows the planned mud system as it was summarized in the "Intent to drill, Strasshof T4" compared to the actual used mud.

Table 5: Drilling Mud system [4],[12]

| Section | Planned | Realized |
|---|---|---|
| 17 ½“ section | Spud Mud;<br>MW 1.05- 1.15kg/l;<br>SG <1.12kg/l | $K_2CO_3$:<br>1.08- 1.12kg/l |
| 12 ¼“ section | Potassium Carbonate<br>MW 1.05- max. 1.12 kg/l<br>SG <1.12kg/l | $K_2CO_3$/Glydril<br>(1.10kg/l) |
| 8 ½“ section | Potassium Carbonate<br>MW 1.12- max. 1.30 kg/l<br>SG <1.17kg/l | $K_2CO_3$/Glydril<br>1.27-1.22kg/l |
| 6“ section | Potassium Carbonate<br>MW 1.12- max. 1.30 kg/l<br>SG <1.17kg/l | $K_2CO_3$/Glydril<br>1.23 -1.15Kg/l |

**Mud Losses**

In order to prevent formation fluids from entering the borehole, the hydrostatic pressure of the mud column has to be greater than the pore pressure. Consequently, mud tends to invade the permeable zones. If the mud reacts with the formation fluids, a reduction in permeability can occur. In case of radial flow geometry, only a narrow band of damage around the well bore is necessary to seriously restrict flow of fluids. If the damage zone is sufficiently narrow that the perforations extend beyond it, no serious loss of well productivity will result [13]. In fractured formations, invasion proceeds along the fractures, building a filter cake on the fracture faces. Perforating will not help much and damage removal by acidizing is difficult and incomplete [14].

Unfortunately, in case of Str. T4 major losses of mud occurred, resulting in contaminated zones, which can cause a large reduction in well productivity. Figure 1 gives an overview of these losses (marked red), showing their occurrence and quantity. The blue line indicates the mud weight in each section.

An exact list of the mud losses can be seen in Table 6, where MD stands for the amount of meters drilled on a specific day.

The first losses occurred when the 9 5/8“ casing was run into the hole. At that time the depth of the openhole section extended from 554m to 2910m MD.

When the first gas readings took place at a measured depth of 3328m the mud weight was initially increased from 1.20 to 1.24 kg/l. However, the connecting gas was still above 8% and therefore an increase to 1.27kg/l took place. Three days later, when reaching the Norian Hauptdolomit in-between 3438m to 3519m depth, mud losses occurred again. This happened due to the high mud weight.

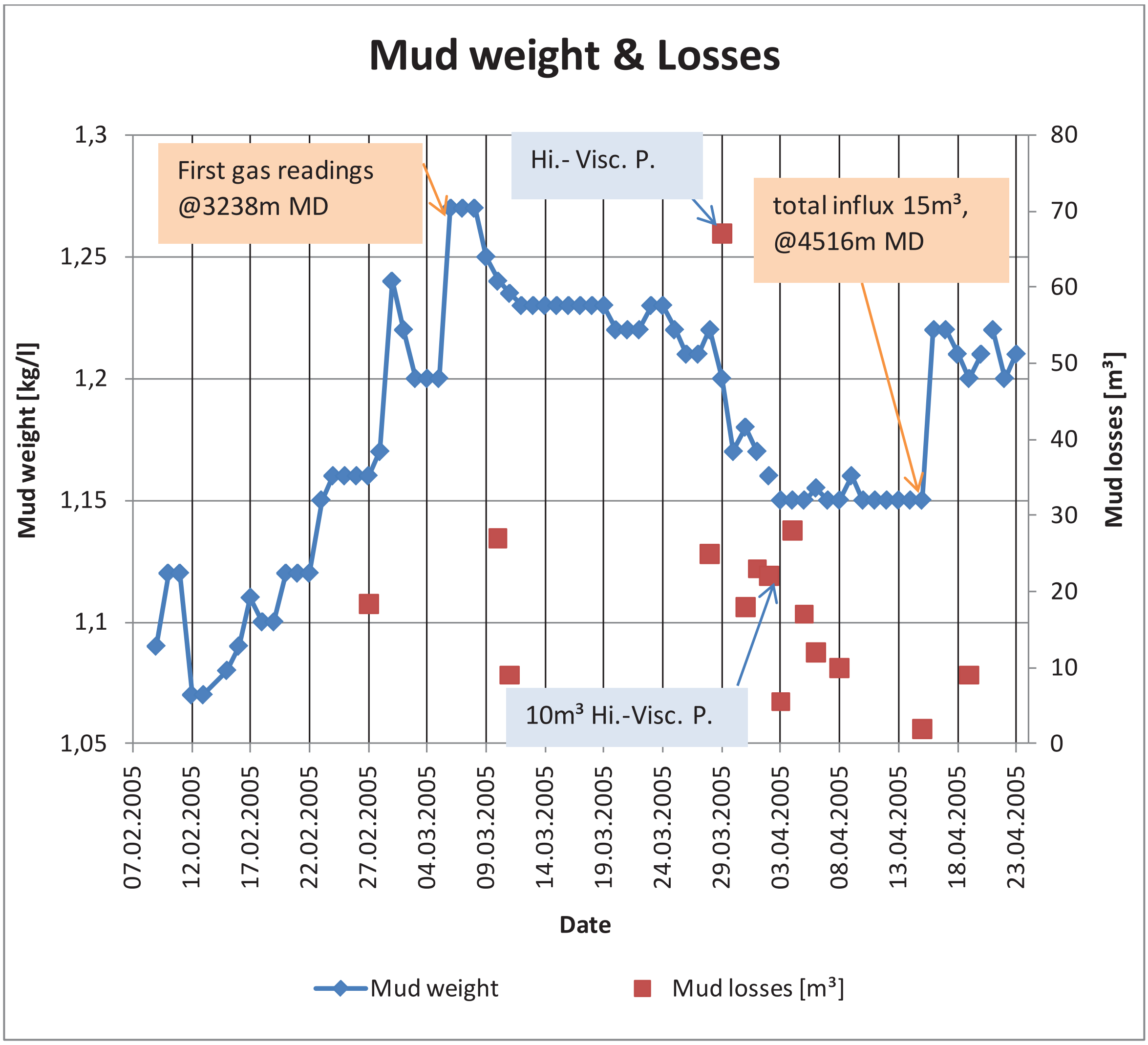


Figure 1: Str. T4, Mud weight and mud losses while drilling.[12]

Figure 1 furthermore reveals that major fluid losses occurred in the last section although the mud weight was constantly decreased until 1.15kg/l. At the depth of 4029m MD the losses suddenly started to occur. Losses of 5400l/hr were observed. A static fluid loss of 4000l/hr was evaluated. On March 29 these losses were slightly reduced, due to the use of about 20m³ of a High Viscous Pill. At a depth of 4268m drilling caused losses of 1000 l/hr.

On April 16, a influx of 15m³ was observed when running in the 4 ½" liner. As a consequent the MW was again increased from 1.15kg/l to 1.21kg/l. The resulting pressure increase resulted again in fluid losses of 9m³, when running the 4 ½" liner.

Overall, the daily drilling reports reveal a total loss of 288m³. MI Swaco reported the total amount of mud invading into the formation. The mud reports exposed that 497m³ were lost, whereas 350m³ went into the 6" section.

Table 6: Mud losses while drilling [12]

| Losses while Drilling | | | | | |
|---|---|---|---|---|---|
| Date | MD [m] | OH section [m] | section [in.] | losses while | total losses [m³] |
| | | | | | |
| 27.02.2005 | 554- 2910 | 554- 2910 | 12 1/4 | RIH 9 5/8 Casing | 13,3 |
| 10.03.2005 | 3438-3507 | 2907- 3507 | 8 1/2 | driling | 27 |
| 11.03.2005 | 3507-3519 | 2907-3519 | 8 1/2 | driling | 9 |
| 28.03.2005 | 4111-4209 | 3707-4209 | 6 | driling | 25 |
| 29.03.2005 | | 3707-4209 | 6 | POOH | 67 |
| 31.03.2005 | | 3707-4209 | 6 | fishing | 18 |
| 01.04.2005 | 4217-4268 | 3707-4268 | 6 | driling | 23 |
| 02.04.2005 | 4237-4268 | 3707-4268 | 6 | tripping and driling | 22 |
| 03.04.2005 | 4268-4296 | 3707-4296 | 6 | tripping and driling | 5,5 |
| 04.04.2005 | 4296-4398 | 3707-4398 | 6 | driling | 28 |
| 05.04.2005 | 4398-4499 | 3707-4499 | 6 | driling | 17 |
| 06.04.2005 | 4499-4516 | 3707-4516 | 6 | driling | 12 |
| 08.04.2005 | | 3707-4516 | 6 | RIH and circulating | 10 |
| 15.04.2005 | | 3707-4516 | 6 | circulating | 2 |
| 19.04.2005 | | 3707-4516 | 6 | RIH 4 1/2 " casing | 9 |
| | | | | **Sum** | **287,8** |

### 4.2.3 Formation Evaluation while Drilling

Exploration and production decisions are complex due to several uncertainties in e.g., the geologic properties, seismic imaging, repeatability, reservoir structure, rock and fluid properties, etc. An important task that petroleum engineers and geoscientists undertake is to provide decision-relevant information.

#### 4.2.3.1 Cuttings

Cuttings are the only "continuous" visual record of the borehole and are used to evaluate HC shows, to enable reservoir and lithological descriptions, geological correlation and formation identification, verification of wireline log response and to design strip logs (lithology vs. depth).

However, due to several problems they are not a totally reliable information source. Cuttings have partially very small grain size or they have artificially altered lithologies due to the interaction of drilling bit with formation. This depends on bit type, drilling velocity etc. Improper mud chemistry may lead to a loss of soluble minerals. Drilling Mud additives e.g. organic materials, nut shells, chalk may contaminate the cuttings as well as caving, which may contaminate the actual samples with rock grains from previous formations or recycling of cuttings.

**Sampling in Str T4**

During drilling, the sampling program was conducted as planned. Only variations in depth intervals were made: No cutting samples have been taken from the first interval.

| | |
|---|---|
| 556-1840m MD | 20m spacing |
| 1840-2850m MD | 10-20m spacing |
| 2850m- TD | 2.5-5m spacing |

Additional samples were gathered based on well site geologist decision and shows. Parallel wet samples (unwashed and not dried) have been collected with the same spacing of washed and dried samples from 556 m to TMD.[15]

**Interpretation**

A detailed analysis of the rock samples vs. depth is described in the 'Final well Report, Strasshof Tief 4'. An overview of the lithology, horizon and depth is listed in Appendix B.

The differences of originally assumed reservoir tops and heights are listed in Table 7.

Table 7: Comparison of assumed and actual Reservoir depth and height

| Difference in: | Res. Top | Height |
|---|---|---|
| **Formation:** | TVD [m] | [m] |
| **Reyersdorfer Dolomit** | -209m | -113 |
| **Perchtoldsdorfer Dolomit** | -76m | |

#### 4.2.3.2 Coring

Core drilling by comparison to cuttings collection, is rather expensive but it provides a more reliable view of the formation. To gain an understanding of the composition of the reservoir rock, inter-reservoir seals and the reservoir pore system it is desirable to obtain an undisturbed and continuous core sample of the reservoir. It allows direct measurement of physical properties such as porosity and permeability. Cores enable a direct observation of grain size, sorting and sedimentary structures, which in turn lead to interpretation of the depositional environment. This in turn is used as a key guide to assign geometry and architecture in reservoir models. Cores furthermore permit the calibration to logs, thus enabling direct interpretation from logs in other wells in the reservoir [16].

If no cores are available, the inherent reservoir uncertainties remain high. If poor respectively no recovery in key reservoir intervals becomes the rule, extrapolation of results to other layers and areas might be necessary.

In Strasshof Tief 4 one 27m core on top of Reyersdorfer Dolomit was taken.

## Limitation while Coring

However, the core taken in the Reyersdorfer Dolomit, in depth from 3320 to 3324m MD, was not as successful as planned. The core interval was reduced to 18m due to a low rate of penetration (ROP). After 10 m coring the action had to be aborted due to jamming of the core. Finally, only 4.3m rock remained in the core barrel.

## Interpretation

The report of core analysis 'Core Documentation, Sedimentological and Petrographical Analyses' describes the checkups of the core. The analytical methods conducted were thin-section analysis to determine petrography, mineralogy and porosity type of the rock samples and X-ray diffraction analysis to determine the bulk mineralogical composition and particularly to assess clay mineralogy.

Sedimentological Description:

> *'The core consists of dolomicrite intercalated with cataclastic brecciated dolomite. The cataclastic brecciated dolomite is composed of dolomitized mud- to grainstone and fine grained dolomite clasts. The mudstones clasts show lamination and fenestral fabrics (birdseyes and stromatactis). A supratidal to intertidal setting is considered as original depositional environment.'*

The Petrographical description and reservoir properties are characterised in terms of effective porosity and permeability:

| | |
|---|---|
| Effective Porosities | 0.26- 8.56% |
| Mean Effective Porosity: | 3.15%. |
| Average Permeability: | 2.63mD. |

Porosity: The porosity is described as intercrystalline and fracture porosity. The effective porosity type is fracture porosity

Fractures: The fractures are partly open and partly cemented by dolosparite- and calcite cement.

Fracture facies: lies within the classes 2-3. Whereof fracture Facies 2 describes a closely jointed dolomite. Jointing is characterized by three or more easily recognized joints with average spacing of sub-parallel joints of about 5 to 10 centimetres. Fracture facies 3 is very closely jointed dolomite. Close spacing of intersecting joints at distances of about 1 to 5 centimetres can result in multifaceted rock fragments.

Mineralogical Composition, derived by XRD-analysis, is:

- dolomite ~93%,
- siderite ~1%
- clay minerals ~6%.

A core to log shift could not be conducted, due to bad core preservation. [ 17]

#### 4.2.3.3 Well Logging

Well logging plays a central role in the successful development. Beside the correlation of geological strata and measurement of the volume fraction and identification of HC types present in porous formations, there are many other important subsurface parameters that need to be detected or measured. E.g. in geology and geophysics, logs are used to correlate between wells; locate faults; determine dip and strike of beds; identify lithology; deduce environmental deposition of sediments; determine thermal and pressure gradients; calibrate seismic amplitude anomalies to help identify HC from surface geophysics; calibrate seismic with velocity surveys; etc. In petroleum engineering, logs are used to determine bed thickness, porosity, permeability, water salinity, type and rate of fluid production, estimate formation pressure, identify fracture zones, measure borehole inclination and azimuth, measure hole diameter etc. [ 18]

However, one of the most important steps is to identify potential reservoir rock. Therefore quite a number of logs are conducted and results are juxtaposed. Figure 2 shows which logs where used in Strasshof Tief wells and what kind of information they generated.

**Gamma Ray Log- HNGT**

A first step to identify potential reservoirs is to look at the Gamma Ray (GR). One of its principles is to distinguish between the shales and the nonshales. The clay minerals attendant in the shale complicated the estimation of reserves and producability. E.g. the presence of shale generally lowers true resistivity and, if not corrected, results in an overestimating of the water saturation ($S_w$). Permeability is often controlled by very low levels of clay minerals within the pores. Without precise knowledge of the clay minerals presence, there is a risk of impairing the reservoir permeability by introducing improper fluids. [18]

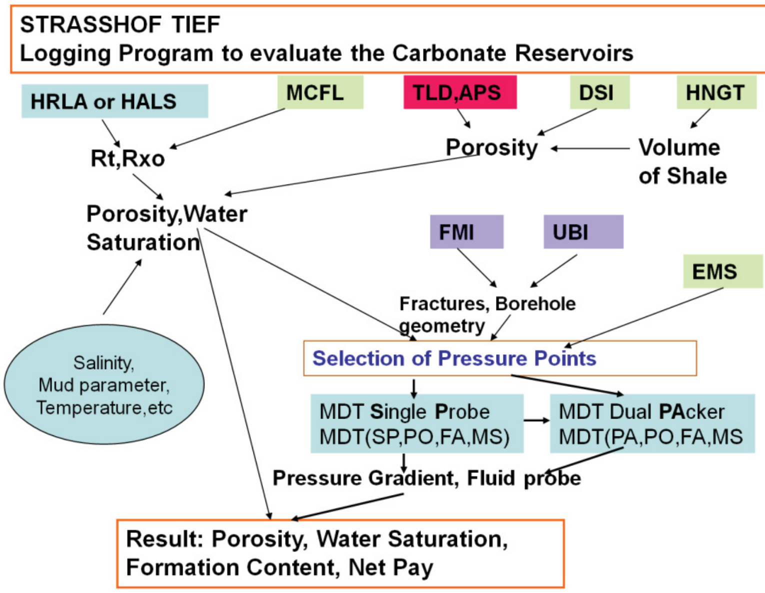


Figure 2: Logging Program used in Strasshof Tief wells [ 19]

In Strasshof Tief 4 the Hostile Environment Natural Gamma Ray Spectrometry Tool (HNGT) was used. It measures the spectrum of natural gamma rays to resolve for Uranium (U), Potassium (K) and Thorium (Th) contribution, which occur naturally in sediments. Due to the relative abundance of these elements within many clay minerals, a high gamma-ray reading is often indicative of relatively high clay content in the sediment. A low gamma-ray reading often signals quartz sands and carbonates. However, there are some factors affecting the GR, e.g. borehole size, mud weight, and the presence of bentonite or KCl in the mud.

GR logs generally run with each logging string for correlation between logging runs. To this purpose HSGR (total gamma ray in API units) and HCGR (computed gamma ray, HSGR minus Uranium component, in API units) are usually displayed, as it can be seen in Figure 3, in the column to the left. [20] In order to distinguish between clay and mica for the resistivity correction, only Potassium and Thorium are taken into account. Further, high K and Th values together with low U usually indicate shaly carbonates, these are deposited in an oxidizing environment which is not favourable for the conservation of organic material.[ 21]

**Porosity Logs: Density (RHOZ), Neutron (APS) and Acoustic tools (DSI)**

The second step is to analys the mineralogy and porosity of the formation. Only formations with a certain porosity will contain HC's. For this purpose the so called porosity logs are available:

Density tools emit medium- energy electrons and measure the returning gamma rays and evaluate the bulk density $\rho_b$ of the formation. A decreased density indicates an increased porosity. Furthermore, this tool has numerous other uses, the main ones being the recognition of gas-bearing zones, and the identification of minerals. In Strasshof the Three Detector Lithology Density (TLD) was used. Figure 3 and Figure 4 show the density tool as RHOZ (the red line in the third column).

Neutron tools emit high- energy neutrons and measure returning radiation, which is a function of hydrogen content. In case pores are filled with gas, rather than oil or water, the neutron porosity will be lowered. The used measurement device was the Accelerator Porosity Sonde (APS). It is labelled as APLC within the log and is demonstrated as the blue line in the third column of the following figures.

A combination of these two logs can be used to distinguish between gas and oil. All porosity logs are designed to measure the porosity in the presence of water and oil, and over- react in the presence of gas. If the Neutron porosity is too high and the density porosity is too low these logs crossover and indicate the presence of gas. Furthermore, the density tool in conjunction with the neutron tool gives one basic method to identify lithologies in a borehole. Commonly it is used to make out limestone in a carbonate sequence. For correct log scales, the density and neutron logs will overlie for limestone and will be separated for dolostone.[21]

Acoustic tools measure the compressional wave speed or, interval transit time $\Delta t$. In case of fluid-filled fractures compressional wave amplitudes are reduced dramatically and shear wave amplitudes virtually disappear. When fractured zones are encountered interval acoustic transit time dramatically increases. According to the presentation 'Loginterpretation, Strasshof Tief wells' a Dipole Shear Sonic Imager (DSI) was used, while this measuring device is not demonstrated within the available well logs of Str T4.

However, most accurate porosity determinations are obtained from laboratory measurements on cores to calibrate the density logs with the porosity of the core.

**Litho- Density Log (PEFZ)**

An additional measurement device is the litho- density tool, which provides the best indication for the existence of a mineral. It measures the Photoelectric factor (Pe), the PEFZ. It gives the sum of two principal contributions, Compton Scattering and Photoelectric Absorption. In the simplest of circumstances Pe is used to distinguish sand (1.81) from limestone (5.08) or dolomite (3.14). The Pe log is demonstrated in the fourth column from the left, the purple line. The resulting interpretation of this log is illustrated at the right side of the following two Figures. Whereas the red zones indicates the presents of dolomite, the blue zone shows the presents of limestone, yellow show sand, and the gray areas demonstrate the existence of clay. [ 22]

## Resistivity Log (HALS; HRLA; MCFL)

Commonly the last step is to determine if a porous formation contains HC's. Resistivity logs measure the conductivity for electrical current. Hence, the water Saturation can be calculated. If it is combined with information about the reservoir thickness, its area and porosity, and fluid formation factors the amount of HC's in place can be calculated.

In principal, if the porous formation contains conductive brine, its resistivity will be low. If, instead, a sizable fraction of non-conducting HC´s are present the formation resistivity will be rather large. Therefore the Resistivity log is also a function of porosity.

To measure the Resistivity at least two logs are run; one, invading deep into the formation, recording the true Resistivity ($R_t$) and one corresponding to the resistivity of the flushed zone, the near wellbore region where drilling fluids may have invaded and displaced the original formation fluids (*Rxo*) [18]. The correlation of them can indicate if a formation is porous and permeable due to the resistivity of the formation water. In the classic response, $R_t$ and $R_{xo}$ will be seen to 'tramline' in tight formation, indicating that no formation fluid displacement has taken place. If a porous formation is present they tend to be 'Mae West' (e.g. a 'mirror image' of each other), with $R_{xo}$ increasing. [ 23]

In Strasshof wells three resistivity logs were used to measure the electrical resistivity of the flushed zone ($R_{xo}$), the uninvaded zone ($R_i$) and the true formation resistivity ($R_t$), as it is sketched in Figure 2:

- HALS (High Azimuthally Laterolog Sonde)is an azimuthal array of electrodes to produce deep and shallow resistivity images
- HRLA (High Resolution Laterolog Array), it provides five independent measurements to get the true formation resistivity in thinly bedded and/or deeply invaded formations.
- MCFL (Micro Cylindrically Focused Log) to measure the invaded zone resistivity.[19]

In Figure 3 in the second column, only two logs are sketched. The red line represents the deep Resistivity log and the black line stands for the shallow one. The same colours are used in Figure 4, additionally a further deep Resistivity log was conducted, signalized as the green line. To illustrate the separations of the deep and shallow logs are collared yellow.

As mentioned above, the resistivities are used to determine the $S_w$ and hence calculate the amount of oil in the reservoir. To interpret a resistivity measurement in terms of water saturation, two basic parameters need to be known: the porosity $\phi$ and the resistivity of the water in the undisturbed formation $R_w$. The true electrical Resistivity, $R_t$ of the HC bearing formation is commonly read from the deep reading device. If these conditions are met, the water Saturation can be calculated. For this, the most common equation is the Archie equation, used for clean zones respectively shale free zones. However, most reservoir sandstones contain shaly material. As mentioned above, the presence of clay and shale can severely complicate the evaluation of $S_w$ and porosity. Therefore a number of equations are published that attempt to model the relationship of $S_w$ and $R_t$.

One of these equations is the Indonesian equation, which was also used for the Str T4. Based on Archie's equation, this form additionally accounts for the volume of shale, respectively of clay and its resistivity. In its simplest form the equation results in:

$$S_{\mathrm{w}} = \frac{1}{V_{\mathrm{sh}} * \sqrt{\frac{R_{\mathrm{t}}}{R_{\mathrm{sh}}}} + \sqrt{\frac{R_{\mathrm{t}}}{F * R_{\mathrm{w}}}}}$$

$V_{sh}$ stands for the Volume of shale and can be evaluated with different methods, e.g. from GR, or Neutron and Density Logs, etc. A common way to determine the shale resistivity $R_{sh}$ is to take the resistivity of adjacent shale. F is the Formation volume factor and defined by Archie's first law with the general expression for Carbonates as [ 24]: $F = \frac{1}{\phi^m}$.

The simplest form of the Indonesian equation can only be used under certain conditions, depending on two parameters the Archie 'm' and 'n'. It can only be applied when both, m and n equal 2. [25] The saturation exponent n is based on the rock type and fluid distribution and equals 2 for limestone and dolomite. The lithology or cement exponent m is related to rock fabrics, specifically to vuggy porosity. Its value for non- touching- vug carbonates ranges from 1.8 up to 4. If fractures and other touching vug pore types are present, the m value may be less than 1.8; In case of plane fractures m can even drop to 1. In order to calculate m within fracture porosity the total porosity of neutron or density logs should be related to sonic velocity. Another possibility to determine m is to evaluate it from cores. If no other information is available a m value of 2 is conventional used. However, if the range in m values is not properly accounted for the resulting water saturations will be too low if m is larger than 2, and too high if m is smaller. E.g. by decreasing the m value from 3 to 2 the water saturation changes from 71% to 32%, or from water- to oil -productive. [26] In Str Tief 4 m and n were assumed to be 2.

According to the report 'Preliminary Loginterpretation- Strasshof T4' the logs were corrected as per the latest charts taking into consideration mud properties and borehole temperature. For correlations the Salinity of the water was taken from a MDT sample from 3456m MD. The sample contained 80% water with a salinity of 60000ppm and 20% mud filtrate. The $R_w$ equals 0.04Ohmm at 110°C. Further information about the mud were the Resistivities at 16°C of the mud ($R_m$=0.1092Ohmm), of the filtrate ($R_{mf}$=0.0992Ohmm) and the mud cake ($R_{mc}$=0.209Ohmm). The MW used in this section equalled 1.155 g/cm³. [ 27]

Figure 3 shows the well logs conducted in the 7 ½" section, in the Reyersdorfer Dolomit and Figure 4 explains the logging runs within the 4 ½" section.

It is noteworthy, that the GR is relatively high for the actual formation. Usually these values can be reached, if the dolomite contains Uranium. However, the comparison of HSGR and HCGR (where the Uranium content is subtracted) in Figure 3 shows no great difference between these two logs except in some areas. This may lead to the conclusion that the high GR value is less influenced by the Uranium content of the dolomite than by the presence of Potassium and Thorium. In the latter Figure, only a HSGR log was run, showing an overall decreased gamma radiation, although in the area between 4185 and 4318m higher shale content is visible.

**Caliper Log**

Additionally a Caliper Log was run; the black vertical line within the left column. The Caliper Log is a tool to measure the diameter and shape of the borehole. If the borehole is smaller than the bit size it may be an indication of either sloughing shale or development of mud cake in porous and permeable formations. A calliper log, larger than bit size, may signalize either a weak formation or a formation that is soluble in drilling mud. [15]

Between 4210 and 4220m Caliper log shows a zigzag line, indicating that large fractures may be present. On the one hand the log is smaller than 6" due to an additional filter cake. On the other hand the peaks to the right are signalling an enlarged borehole. As previously mentioned the major fluid losses, ca.67m³, started to occur at a depth of 4209m MD. This means that the mud invaded the lower part of the Hornsteinkalk.

**Interpretation**

Resistivity logs only decrease in the presence of saline water in porous formations and shale. They tend to 'Mae West', indicating a porous formation, showing slight crossovers within the formations of interest. The GWC`s cannot be clearly defined from log interpretation. Most likely this is the result of using a constant m to calculate the $S_w$ in a medium with variable m. To clearly define the content of this area and the GWC the MDT was run. The GWC was assumed to be at 3386m MD (pressure gradient of 0.18kg/l), demonstrated in Figure 3 as the blue horizontal line.[15]

Another Reyersdorfer Dolomit layer with similar signals was found inbetween 3451 to 3477m MD, where the $S_w$ is less than a 100%. The MDT revealed a clear water gradient. It was assumed that the HC in this layer are residual and the major amount of HC´s already migrated elsewhere.

The Resistivity logs most clearly cross over within the section between 4130 and 4230m, especially for the lower Hornsteinkalk, where oil, besides gas, was present.

Within the Perchtoldsdofer Dolomit the Resistivity logs intersect only slightly. The MDT showed a gas gradient of 0.22bar/m, not showing a GWC.

Usually if Density and Neutron log cross over, with a decreasing bulk density, this may indicate the presence of HC. In case of a fractured dolomite body, where just small amounts of gas are present, these two porosity logs are reacting as demonstrated in Figure 3 in the depth between 3300 to 3400m MD. It is noticeable, that the logs shown in Figure 3 have the neutron porosity on the left regardless of their formation content. Within the upper section of Figure 4 they cross over and then run upon each other within the Perchtoldsdorfer Dolomit. In the latter figure between 4080m and 4320m the porosity logs do not vary, although the Resistivity logs show increased porosities, except some peaks at the lower Hornsteinkalk.

The Photoelectric factor for fluids is usually low and therefore the Pe decreases if HC or water is present. However, it only shows a clear decrease within the Hornsteinkalk and again increases within the Fleckenmergel, although the formation content is similar, indicating that oil or gas may be present.

**Interpretation Results**

According to the report ‘Preliminary Loginterpretation- Strasshof Tief 4’, from March 7, 2005 and the presentation of ‘Loginterpretation Straßhof Tief Wells’ the results were listed as follows:

To calculate the HC volumes some cut- off values were defined:

- Clay Volume: <30%
- Porosity: >3%
- Water Saturation: <60%

Common porosity cut- offs in low porosity areas are about 8% in carbonate reservoirs. In this well, the porosities clearly fall below this value. Therefore the $S_w$ should only be used as a HC indicator.

The results of the interpretation are summarized in Table 8.

Table 8: Summation of Loginterpretation [19], [27]

| Formation | Depth Top | Depth Bottom | Gross pay Interval | Net Pay Interval | Average $\phi$ | average $S_w$ |
|---|---|---|---|---|---|---|
| | [m] | [m] | [m] | [m] | [%] | [%] |
| Reyersdorfer | 3301 | 3386 | 85 | 73.9 | 7.3 | 36 |
| Hierlatzkalk | 4150 | 4186 | 36 | 0.8 | 4 | 32 |
| Hornsteinkalk | 4186 | 4226 | 40 | 11.6 | 14 | 42 |
| Plattenkalk | 4310 | 4365 | 55 | 45.6 | 6 | 38 |
| Hauptdolomit | 4365 | 4400 | 35 | 27.4 | 5 | 37 |
| Plattenkalk invers | 4400 | 4432 | 32 | 16.8 | 5 | 41 |
| TOTAL | | | | 102.1 | | |

Correlating logs with information obtained from cores and to run an acoustic log would help to interpret these measurements.

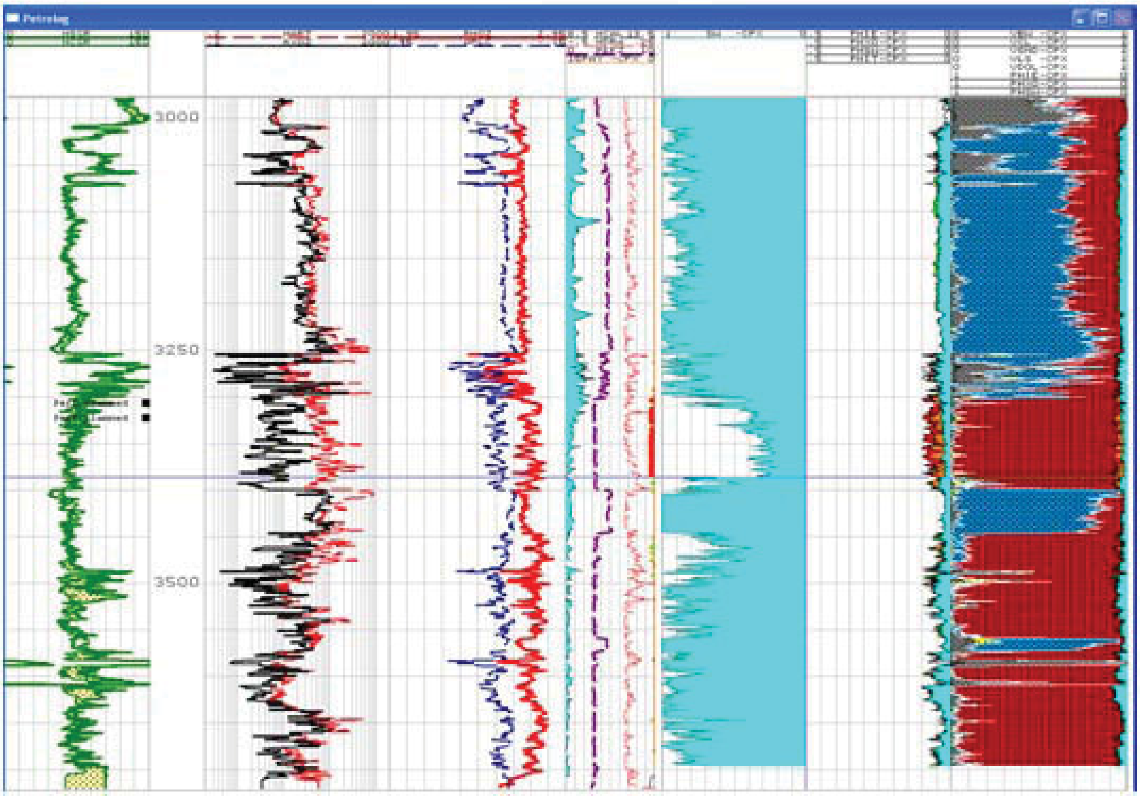


Figure 3: Well Logs of the Reyersdorfer Dolomite [ 28]

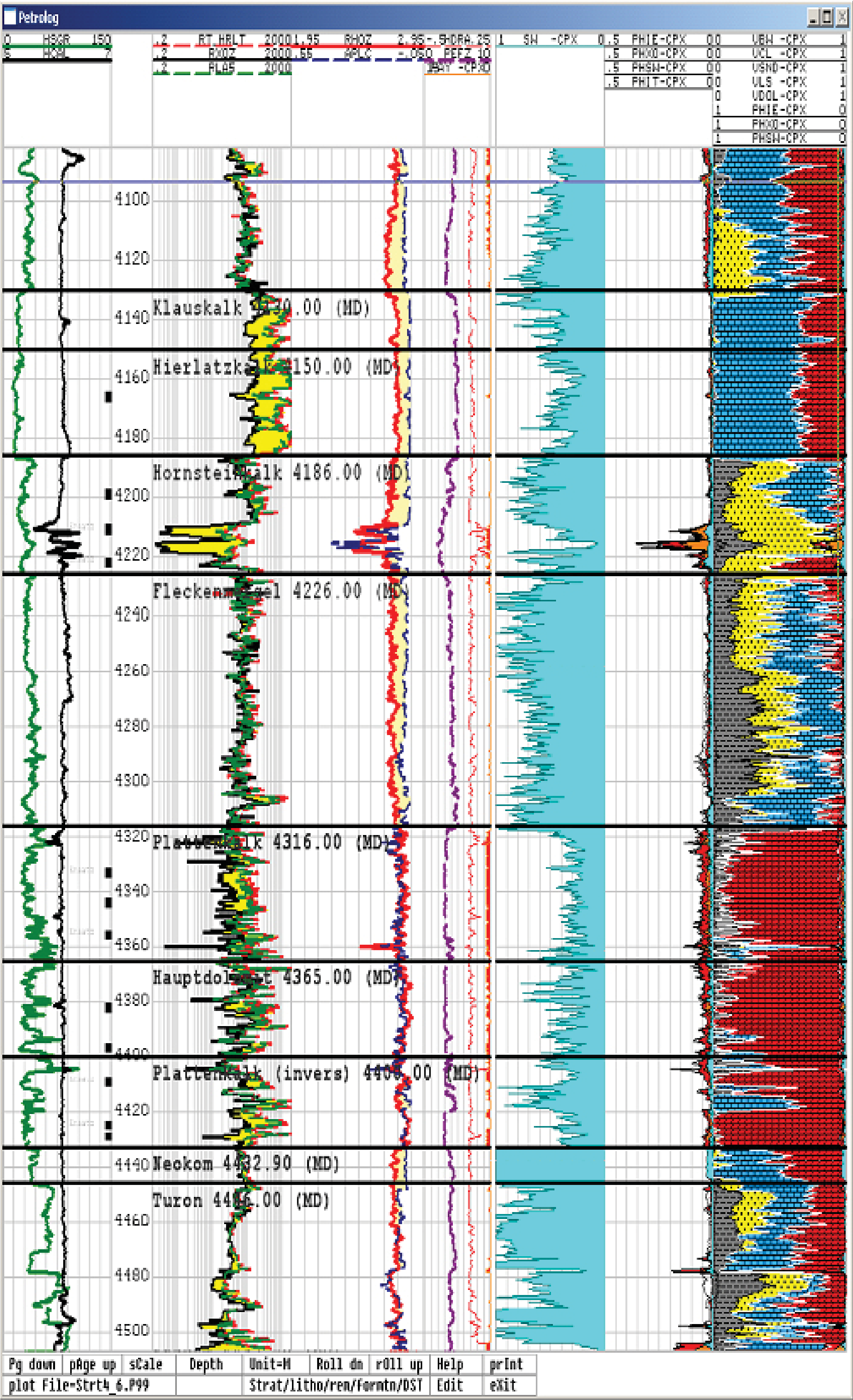


Figure 4: Well Logs conducted in Str T4 from 4080m down to 4500m MD [28]

#### 4.2.3.4 Borehole Imaging

Tight gas- and oil-bearing carbonate reservoirs often have a very low matrix permeability, but the well may flow due to the presence of natural or mechanically induced fractures in the fromation, as in Strasshof Tief. Hence, if there is no extensive fracture system providing fluids to flow, the well will either water out or die very quickly. Clearly the ability to detect fractures and their orientation e.g. to identify the area where to perforate, is extremely important. [29]

Borehole imaging logs are the main tool to detect fractures while logging. There exists a wide variety of imaging tools, though these predominately fall into two categories: resistivity and acoustic imaging tools. They both produce an unrolled 'picture' of the borehole to identify dips and strikes of all features such as fractures and sedimentary structures.[29]

Resistivity imaging tools consist of four- or six caliper arms, with each arm ending with one or two pads with arrays of electrodes which maintain a constant electrical potential against the borehole wall. High-resolution resistivity images identify fractures by contrasts in conductivity between the fracture and the adjacent borehole wall. [30]

In Strasshof Tief 4 the Formation Micro Imager (FMI) was used to deliver an electrical image of the fractures and their content. Parallel the Ultrasonic Borehole Imager (UBI) was used.

**Limitations**

As mentioned before the core analysis of the Reyersdorfer Dolomit showed that the fractures are partly open and partly cemented by dolosparite and calcite. Calcite has a similar electrical resistivity as gas. When illustrating these fractures they were clearly visibly on the FMI but it was not possible to distinguish between gas bearing and calcite cemented fracs.

Therefore the UBI was used; which delivers a continuous acoustic image of the borehole wall and of the borehole geometry. Acoustic image logs are produced by bouncing an ultrasonic acoustic pulse from the borehole wall. An acoustic pulse is both emitted and recorded by a transducer. The travel time of the pulse from the transducer to the wall and back indicates the dimensions of the borehole and the relative position of the tool. The energy of the returning pulse is recorded as amplitude. It is a function of the degree of scattering of the pulse due to the borehole shape and rugosity as well as the acoustic impedance contrast between the borehole fluid and wall.

Therefore, in Strasshof Tief both tools were used, the FMI detected the fractures, whereas the UBI identified the content of the fractures.

**Interpretation**

Unfortunately, there was no borehole Image of the well Strasshof Tief 4 available. The only information about this approach was found in presentations of well logs conducted in Strashof Tief.

### 4.2.3.5 Pumping pressure tests

In Str T4 one Formation Integrity Tests (FIT), one Leak off Test (LOT) and one extended Leak off Test (XLOT/ELOT) were carried out immediately below the newly set casing.

These tests are used to investigate the cement seal around the casing shoe and the wellbore capability to withstand pressures in order to collect regional information on formation strengths and stress magnitude for proper well planning. [31]

A FIT is conducted to evaluate the strength of the formation to identify the fracture gradient. However, the principal function of leak-off tests is to assess casing integrity, by increasing the pressure until a predetermined pressure. Therefore a LOT is unlikely to obtain information on stress magnitude. During an XLOT pumping continues beyond the formation breakdown pressure (FBP) until the fracture propagation pressure (FPP) is reached. Therefore the XLOT is a more appropriate method for stress estimation. [32], [33]

In Strasshof Tief 4 the pressure tests were conducted by Halliburton. The results are listed in Table 9.

Table 9: Pumping Pressure Tests, Str T4

| **Test** | **Location** | **Mud Weight** [kg/l] | **Leak off Pressure** [bar] | **EMW** [kg/l] | **Formation Closure Pressure** [bar] |
|---|---|---|---|---|---|
| FIT | below 13 3/8" Casing | 1.08 | 28 | 1.60 | |
| XLOT | below 12 1/4" Casing | 1.18 | 251 | 2.05 | 239 |
| LOT | below 7" liner | 1.22 | 245 | 1.92 | |

The pressure and pump rates of the XLOT are illustrated in Figure 5.

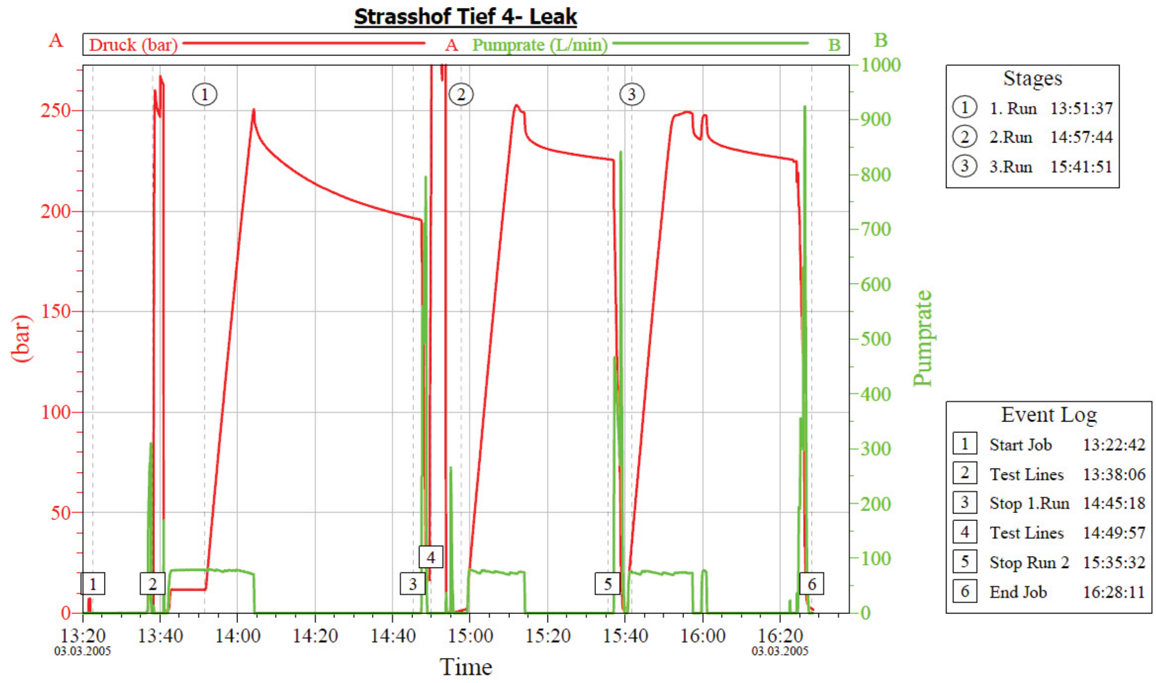


Figure 5: Str T4- XLOT below the 8 1/2" casing [ 34]

The pressure and pump rates of the LOT are illustrated in Figure 6.

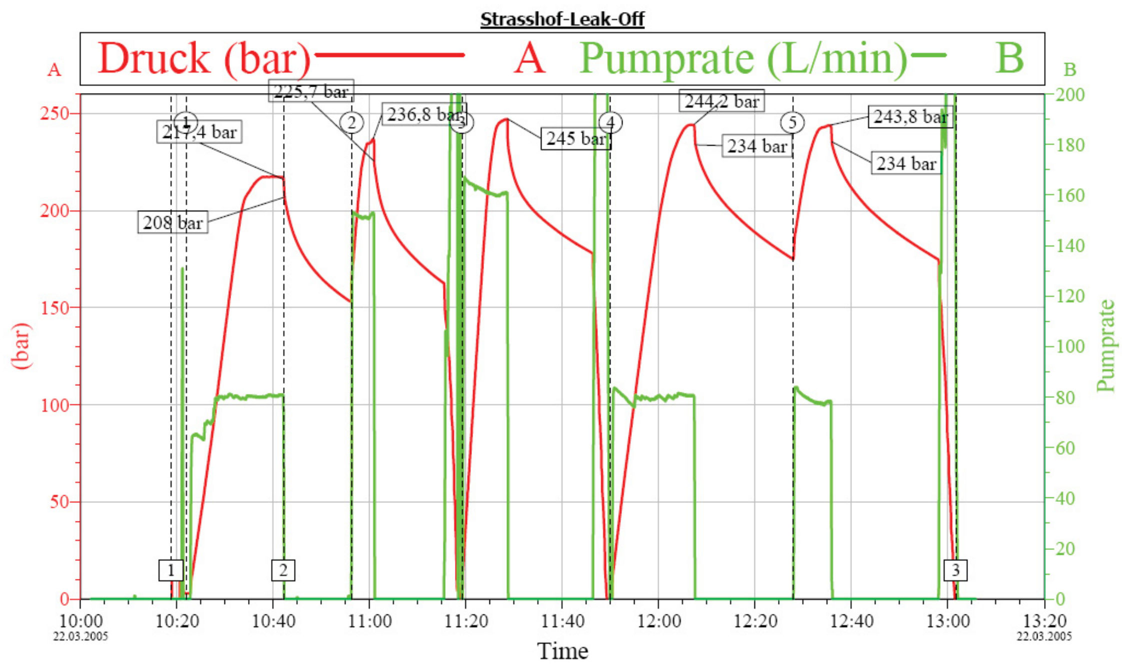


Figure 6: Leak off Test of Strasshof Tief 4 at 7" liner casing shoe [ 35], [ 36]

### 4.2.4 Completion and Testing

The completion operations conducted in Strasshof Tief 4 after the well was drilled are described in a roundup of workover reports. The most important events are summarized here:

The perforations which were made, are listed in Table 10, including the perforated horizons, the depth, the date, and the subsequent conducted tests. According to the report of May 11th 2006 (Behandlungsbesprechung 11.05.2006- 'Strasshof Tief 4'), the perforations are listed in Table 10.

Table 10: Perforation interval of the well Strasshof Tief 4

| Formation | Perf. Interval (MD) [m] | Date of Perf. | Tests |
|---|---|---|---|
| Perchtoldsd. D | 4335 -4350<br>4375-4395 | Mar. 13th 2006 | 1st Gas test |
| Perchtoldsd. D. | 4328-4335<br>4420-4433 | April 20th 2006 | 2nd Gas test |
| Hierlatz-<br>/Hornsteinkalk | 4158-4167<br>4210-4224 | April 30th 2006<br>April 29th 2006 | 1st -5th Oiltest |
| Kössnitzer Schichten | 3589-3590<br>3569-3572 | Sep. 27th 2006<br>Sep. 28th 2006 | Tubing Puncher Perforation |
| Perchtoldsd. D | 4323-4328<br>4328-4335<br>4335-4350<br>4375-4395<br>4395-4405<br>4420-4433 | 2008 | 3rd Gas test |

After the perforations were made, the respective future production zone was stimulated with acid and subsequently tested:

#### 4.2.4.1 Testing the Perchtoldsdorfer Dolomit

Within the Perchtoldsdorfer Dolomit three pressure build-up tests were conducted to measure and analyse the bottomhole pressure, acquired during the shut-in of a producing well. Its major purpose was to determine well flow capacity, permeability thickness (k*h), skin effect (s) and the reservoir pressure. The tests are listed in Table 11.

Table 11: Gas test conducted in the Perchtoldsdorfer Dolomit

| Tested Formation: | Perchtoldsdorfer Dolomit | |
|---|---|---|
| Conducted Tests: | 1. Gas test | 03/15-04/19/2006 |
| | 2. Gas test | 04/22-05/11/2006 |
| | 3. Gas test | February 2008 |

**Pressure gradient surveys and Production Logging during testing**

Pressure gradients surveys and production logging runs were performed during testing.

The gradient surveys showed:

- No significant liquid column above the perforations.
- Fluid inflow occurs only at a depth of 4344m MD and 4381m MD.

According to the presentation 'Short Test Overview Str T4' most of the water is produced from the lower perforations and gas is mainly produced from the upper layer. The total interpretation of the PLT measurement is reported in the File 'Summary PLT'. However, this file was not accessible.

#### 4.2.4.2 Testing the Hierlatzkalk/ Hornsteinkalk

After the first two gas tests within the Perchtoldsdorfer Dolomit, it was planned to test the Hierlatzkalk/Hornsteinkalk. If the result of the test had shown that no economical production from both reservoirs can be achieved, the reservoir would have been temporarily plugged and the Reyersdorfer Dolomit perforated and further tested on medium, rate and HC content. In case, a fair rate would be achieved a PLT should be conducted to answer the occurring questions. If an economical rate of the Hierlatz/Hornsteinkalk were possible, further development would depend on test results of the well Str T5. [37] (An economical production rate is achieved if the oil production exceeds 50m³/d, respectively the gas production exceeds 240,000 Nm³/d. )

The conducted well tests are listed in Table 12.

Table 12: Oil tests conducted in the Hierlatzkalk/Hornsteinkalk

| Tested Formation: | Hierlatzkalk/Hornsteinkalk | |
|---|---|---|
| Conducted Tests: | 1.Oiltest | April |
| | 2. Oiltest | 06/19-07/12/2006 |
| | 3. Oiltest | 07/12-08/06/2006 |
| | 4. Oiltest | 08/25-03/26/2006 |
| | 5. Oiltest | December 2006 |
| | 6. Oiltest | 02/22-26/03/2007 |

#### 4.2.4.3 Incidents during Completion and Workover Operations

**<u>Incidents during Testing:</u>**

2. Oiltest Between PBU#3 and PBU#4 the electronic memory gauge recorder was replaced, due to several problems. Among others it showed heavy deposits. A measurement of the inner diameter of the production tubing at the end of testing showed a loss of 40% in diameter due to these deposits.

4. Oiltest During testing slight mud losses occurred. To solve this problem an inflatable packer was set at 4120m and subsequently pressure tested. Rapidly it turned out that it was leaking. Several attempts to tighten the packer at different heights failed. Only when setting the packer above 3610m, between the XN- landing nipple and the liner seal assembly, it became tight. Two further trials with new inflatable packers led to the same result. It was assumed that the liner seal assembly was leaky.

**Limitations during Workover:**

Reduced well diameter: Following to the 4. Oiltest a too narrow well prevented the setting of a bridge plug. After acid cleaning with 4m³ 15% HCL, 2% Cronox, and 0.6% Sapogenat the bridge plug was set at 4125m, above the perforations of the Perchtoldsdorfer Dolomit and the Hierlatzkalk/Hornsteinkalk. Subsequently, the well was shut in for about 11 hours. The pressure equalled 43bar when reopening the well. After 20m³ liquid were produced, the free- flowing phase ended. The remained liquids were lifted with nitrogen and subsequently the well was filled with KCl mud.

Fishing On August 31, it was decided to pull the Bridge Plug. Therefore the releasing tool was connected to it and the plug was pulled loose. However, the Bridge Plug and a part of the Releasing Tool remained in the wellbore and a fishing job became necessary. Several attempts with numerous different fishing tools were not crowned with success and the releasing tool and the Bridge Plug remained in the hole. After the 6th run the spring of the releasing tool was caught. At the 12th fishing effort, the pressure within the well was bled off and the hole was filled with KCL mud.

Lead Impression: During fishing one run with a lead impression block was conducted, which resulted in a mold of the pipes, with an outer diameter of 60.8mm (the 4 ½” casing (13.5lbm/ft; L-80 Grade) should have an inner diameter of 99.5mm).

Sudden Pressure drop: The well again was pressurized up to 60bar, when suddenly the pressure dropped down to 40bar. Further pumping increased the pressure again until a sudden pressure drop from 160bar to 120bar, obviously the packer was released.

Salt Pill: On September 1st, 9m³ salt pill were circulated into the perforation via CT, starting at the lowest point of the perforation (at 4225m). Afterwards a flow check was conducted with a pressure build up of 24bar in 45min. When the pressure was bled off, 1200l fluids were reproduced and the well was shut-in.

High Viscous Pill: When reopening the well the next day, the pressure had increased to 70bar. Every try to set the well under pressure was followed by a sudden pressure drop. Therefore, again a High- Viscous- Pill was circulated in. This procedure was repeated twice, but the pill was not produced back. About 4.5m³ mud were lost in the hole.

Absorbing Well: On September 3rd it was observed that the well started to absorb the mud.

N-Seal Pill: On 20th of September 5m³ N-Seal Pill was circulated in. Afterwards KCL mud with a density of 1.1kg/l was pumped with 400l/min and 240bar. Then the well was shut in for one hour and the pressure decreased to 8bar. When reopening the well the next day, it still absorbed the mud.

Unstable Pressure: The pressure observation showed that the pressure was stable for about 45min.; this was followed by a decrease and a further increase to 2.5bar. The pressure was then bled off, the well was filled up again and observed for another hour, but the pressure stayed constant.

1.Tubing Puncher Perforation: A Tubing Puncher perforation was conducted at a depth of 3589 – 3590mMD. This kind of perforation gun is used to punch holes in a tubing string to establish pressure equalization or circulation between the tubing and the annulus, without damaging the surrounding outer string.

Mud Loss: When the perforation was tested- mud was pumped down either through the tubing or the annulus. It should be produced back through the contrary pipe but was lost instead.

2.Tubing Puncher Perforation: After the second perforation of the 4 ½" tubing, between 3569 and 3572m MD, was made, the annular pressure decreased from 45bar to 27bar.

Mud Loss: After the perforations were made, a total of 10m³ N-Seal Pill was mixed and circulated into the hole. During this operations mud losses occurred, about 11m³ KCl mud invaded into the formation.

Free flowing Well: On October 2nd, the well was suddenly free flowing. Circulation with KCI mud stabilized it again.

Diverse dismounting operations and safety arrangements were conducted and the well was shut down for about 2 months until the 5. Oiltest was conducted.

**Mud losses while completion**

During workover major mud losses got into the Hierlatzkalk/ Hornsteinkalk. The amount was listed by the Laboratory of Exploration & Production and is shown in Table 13.

Table 13: Mud losses during workover into the Hierlatz- Hornsteinkalk [ 38]

| **Losses into Hierlatz Hornsteinkalk while Workover** | | |
|---|---|---|
| Date | losses [m³] | lost fluid |
| | | |
| 11.09.2006 | 9 | saltpill |
| 12.09.2006 | 5,2 | 2% KCL |
| 13.09.2006 | 9 | saltpill |
| 13.09.2006 | 4,5 | KCL |
| 14.09.2006 | 2,6 | KCL |
| 19.09.2006 | 3 | KCL |
| 20.09.2006 | 33 | KCL |
| 20.09.2006 | 5 | N-Seal Pille |
| 27.09.2006 | 2 | KCL |
| 29.09.2006 | 15 | KCL |
| 27.02.2007 | 8 | 10%HCL, 2%Cronox, 1%Sapogenat T 139, 0,4%SCA130 |
| **Sum** | **96,3** | **m³** |

### 4.2.4.4 Realization of Well Tests

**Realization of the 1. Gas Test**

The first gas test was conducted from March to April 2006. Table 14 gives an overview of production rates and bottomhole pressures during testing.

Figure 7 shows an overview of the first bottom hole data acquisition period during the production test from 15$^{th}$ to 18$^{th}$ of March, 2006.

At the end of the first flow period, slight slug flow was observed. During PBU#1 the pressure increased from 134.2bar-g to 356.8bar-g within 33 hours. It still had the tendency to rise with 1.5bar/h. The unusual shape within the first hours of the second shut in period is attributed to wellbore effects such as phase separation and redistribution due to the surface shut- in of the well.

When reopening the well it was tried to produce the well at higher rates, trying to avoid water production. However, this led to a rapid decrease of the well head pressure to 30bar and an increase of water production to 10m³/h. After a short pressure build up period (PBU), it was tried to achieve a continuous gas rate of 7500 m³ Vn/h. Within two days the rate dropped to 5500m³Vn/h, with a liquid production of 4m³/h due to the continuous surface pressure decreases. [ 39]

Table 14: Realization of the 1. Gas Test.

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. Gas Test | | | | | | |
| Perforation: | 4335-4350 | m MD | | | | |
| | 4375-4395 | m MD | | | | |
| Electronic Memory Gauge | 3602 | m MD | | | | |
| BHP prior opening the well: | 456.3 | bar-g | | | | |
| 1. production rate: | 7500 | m³Vn/h | | for | 12 | h |
| liquid rate: | 2 | m³/h | | | | |
| 2. production rate: | 10000 | m³Vn/h | | for | 12 | h |
| liquid rate: | 2.5 | m³/h | | | | |
| 3.production rate: | 12000 | m³Vn/h | | for | 12 | h |
| liquid rate: | 4 | m³/h | | | | |
| BHP at the end of the flow period: | 134.2 | bar-g | | | | |
| PBU#1 | | | | | | |
| BHP after shut in: | 356.8 | bar-g | ↑ | for | 33 | h |
| 4.production rate: | 12000 | m³Vn/h | | for | 12 | h |
| liquid rate: | 4.5 | m³/h | | | | |
| 5.production rate: | 21000 | m³Vn/h | | for | 12 | h |
| liquid rate: | 10 | m³/h | | | | |
| After a short PBU, it was tried to achieve a continuous gas rate: | | | | | | |
| 6. production rate: | 7500 | m³Vn/h | ↓ | | | |
| 7. production rate: | | | | for | 10 | h |
| PBU#2 | | | | | | |
| BHP prior opening the well: | 193.3 | bar-g | | | | |
| | 392.4 | bar-g | | for | 515 | h |
| Total produced liquids | 727 | m³ | | (formation water) | | |
| Total produced gas | 1.5 | MMm³ | | | | |
| gas specific gravity: | 0.65 | | | | | |
| H2S content | 1.5 | % | | | | |
| CO2 content | 7.5 | % | | | | |

A second pressure build-up period was conducted; after the well was flowing for about 10hours and its production history is plotted in Figure 8. Again during the first six hours of the shut in period the pressure build up was dominated by large wellbore effects. After 515 hours shut in the pressure increased from 193.9bar-g up to 392.4bar-g and the bottom hole pressure stabilized.

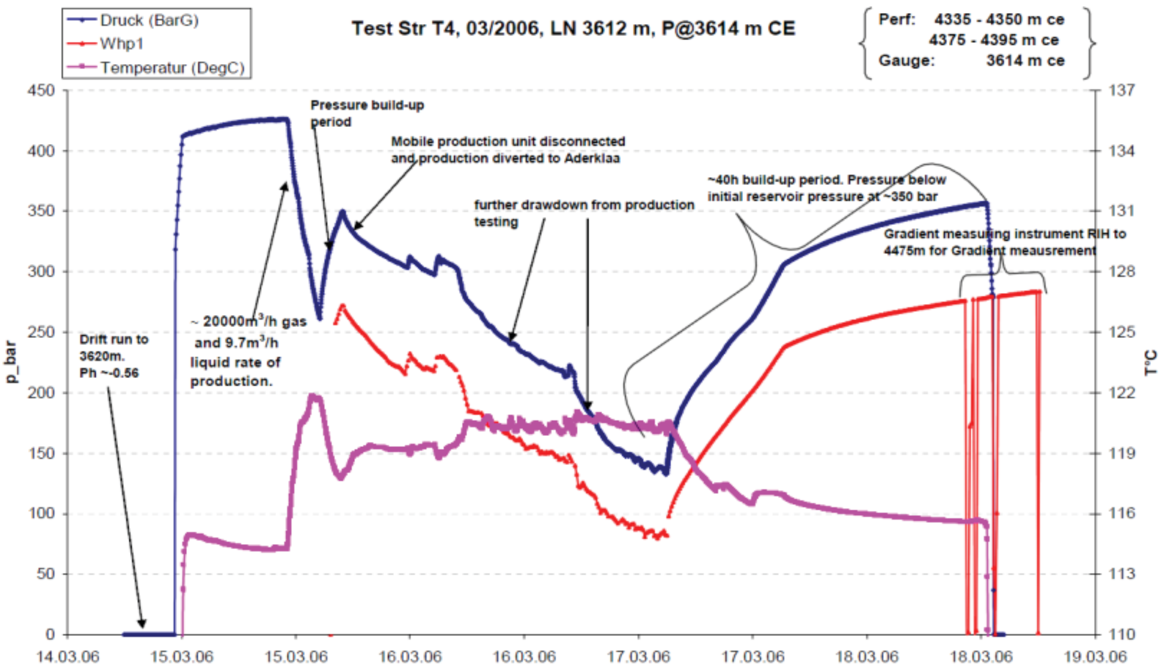


Figure 7: PBU#1 and 2, from March 15 to 19,2006 [ 40]

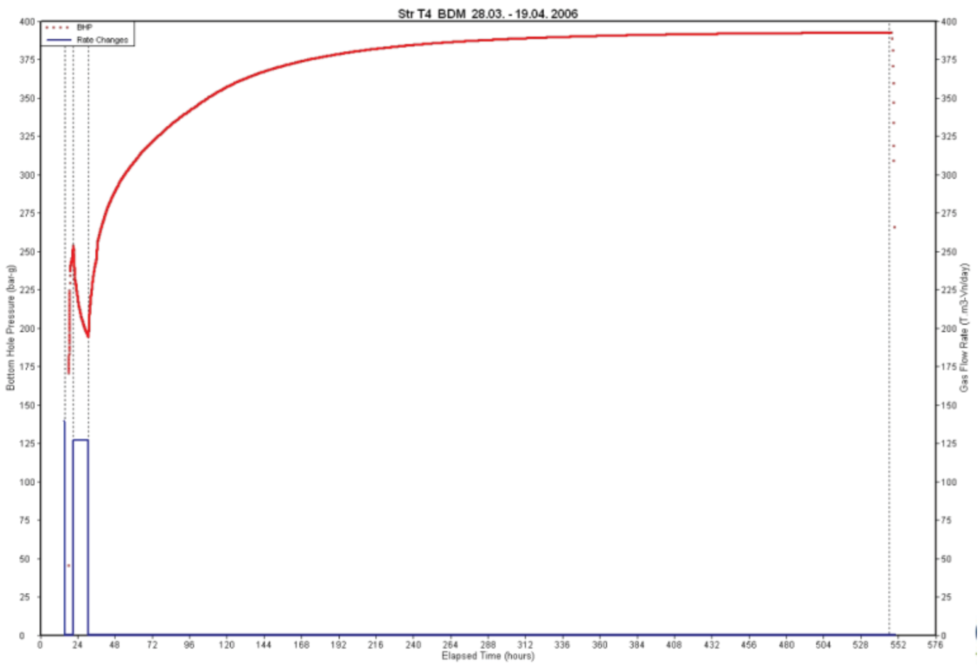


Figure 8: PBU#3 between March28 and April 19, 2006 [40]

On 19th of April 2006 the first production test was completed and the well was shut-in again. During testing no constant, economical gas rate was achieved due to modest reservoir permeability. The high water cut from the lower perforation (4375-4395m MD) further reduced the gas production and led to surface problems for dehydration and treatment.

According to the report 'Interner Betriebsplan Sonde: Strasshof T4, CT Säuerung und Fördertest' the interpretation of this test and the conclusion are memorized in the File: 'Teammeeting_20060330.doc. However, this report was not accessible.

**Realization of the 2. Gas Test**

On the 20th of April the Perchtoldsdorfer Dolomit was perforated above and below the last perforations (Table 15) and subsequently stimulated via CT. The production in course of testing the two additional perforations in the Perchtoldsdorfer Dolomit confirmed the first test.

Table 15: 2. Gas test of the Perchtoldsdorfer Dolomit

| 2. Gastest | | |
|---|---|---|
| Perforation: | 4328-4335 | m MD |
| | 4335-4350 | m MD |
| | 4375-4395 | m MD |
| | 4420-4433 | m MD |

**Realization of the 3. Gas Test**

According to the sample analysis, further perforations were made in February 2008 and tested (Table 16). However, this is the only information suggesting that another test was conducted.

Table 16: 3. Gas Test of the Perchtoldsdorfer Dolomit

| 3. Gastest: | | |
|---|---|---|
| | 4323-4328 | m MD |
| | 4328-4335 | m MD |
| | 4335-4350 | m MD |
| | 4375-4395 | m MD |
| | 4395-4405 | m MD |
| | 4420-4433 | m MD |

**1. Oiltest**

On April 29-30, 2006 the Hierlatzkalk/Hornsteinkalk was perforated on wire line and subsequently stimulated. A bridge plug was set to close the two water producing perforations below 4375m MD. On May the 2nd a supposed gas test within the new reservoir was conducted.

Table 17: Realization of the first Oiltest

| | | | |
|---|---|---|---|
| 1. Oiltest: The production had to be stopped, due to paraffin plugging of the surface equipment. | | | |
| Perforation: | | 4158-4167 | m MD |
| | | 4210-4224 | m MD |
| Electronic Memory Gauge | | 3606 | m MD |
| Bridge Plug: | | 4375 | m MD |
| BHP prior opening the well: | | 260 | bar |
| Production Rate: | | 10000 | m³Vn/h ↓ |
| | FWHP after 70min. Production | 112 | bar |
| | Oil Rate for the next 37 min | 5.5 | m³/h |
| | FWHP | 151.5 | bar |
| | H2S concentration dropped from | | 1.4 to 1% |

Within the first 70min the wellhead flowing pressure decreased by 148bar, at a production rate of about 10000m³Vn/h. In the next 37min about 5.5m³ Oil were produced free flowing and the wellhead flowing pressure increased up to 151.5bar, while the gas rate decreased to 1000Nm³/h. Simultaneously the $H_2S$ concentration dropped from 1.4% to about 1%. At this point the production had to be stopped, due to paraffin plugging of the surface equipment.

**2. Oiltest**

Another production test of this interval with several flow and shut-in periods using heated surface production equipment was conducted between June 19 and July 12, 2006. Liquid flow rates of 110-150 m³/d were achieved with a gas-oil-ratio of 100-200 m³ Vn/d and a water cut of 20-30 %. Furthermore, a static pressure gradient survey was performed during test operations. The recorded pressures at the end of each period are summarized in Table 18.

The flowing pressure of the first period did not stabilise, due to the very short flow period. The next FBHPs appear as stabilized at the end of the periods. The build-up pressures at the end of the second and third shut-in period were still increasing. During the third PBU a reduced pressure support is noticeable, showing a pressure difference of 7bar after 12 hours.

Between PBU#3 and PBU#4 the electronic memory gauge recorder was replaced, due to several problems. When the well was reopened for the fourth flow period, a shut-in pressure of 361.3bar-g was recorded. [ 41]

The pressure increase of the last build up period appears faster than the previous PBU´s, probably due to the much lower bottom hole flowing pressure. The shut in pressure after 204 hours was still increasing for 0.05bar/h.

Table 18: Realization of the 2. Oiltest

| 1. Oiltest with heated surface production equipment | | | | | | |
|---|---|---|---|---|---|---|
| Perforation: | 4158-4167 | m MD | | | | |
| | 4210-4224 | m MD | | | | |
| Electronic Memory Gauge | 4161 | m MD | 3899 m TVD | | | |
| Electronic Memory Gauge | 4240 | m MD | 3947 m TVD | For the last PBU´s | | |
| Bridge Plug: | 4375 | m MD | | | | |
| liquid Production Rates | 110-150 | $m^3/d$ | | | | |
| GOR | 100-200 | $m^3Vn/d$ | | | | |
| Water cut | 20-30 | % | | | | |
| Pressure history: | | | | | | |
| BHP prior opening the well: | 364 | bar-g | | | | |
| 1. Flow period: | 212.7 | bar-g | | for | 1.5 | h |
| PBU #1 | 368.9 | bar-g | | for | 61 | h |
| 2. Flow period: | 217 | bar-g | | for | | h |
| PBU#2 | 362.9 | bar-g | ↑ | for | | h |
| 3. Flow period | 227 | bar-g | | for | | h |
| PBU#3 | 357.5/ 361.3 | bar-g | ↑ | for | 12 | h |
| 4. Flow period: | 135 | bar-g | | for | 98 | h |
| PBU #4 | 357.5 | bar-g | ↑ | for | 204 | h |
| Total produced liquids | 915 | $m^3$ | | | | |
| dead oil gravity | 25 | °API | | | | |
| gas specific gravity: | 0.63 | | | | | |
| $H_2S$ content | 0.9 | % | | | | |
| $CO_2$ content | 5.5 | % | | | | |
| The produced water appears to be mainly formation water with some contamination of technical fluids. | | | | | | |

## 3. Oiltest

From June 23 to July 11, 2006 another pressure measurement including a PLT measurement was conducted. The results thereof are reported in File ‘strt4_plt01.doc‘. [41] The pressure histories of these tests are demonstrated in the Figures below.

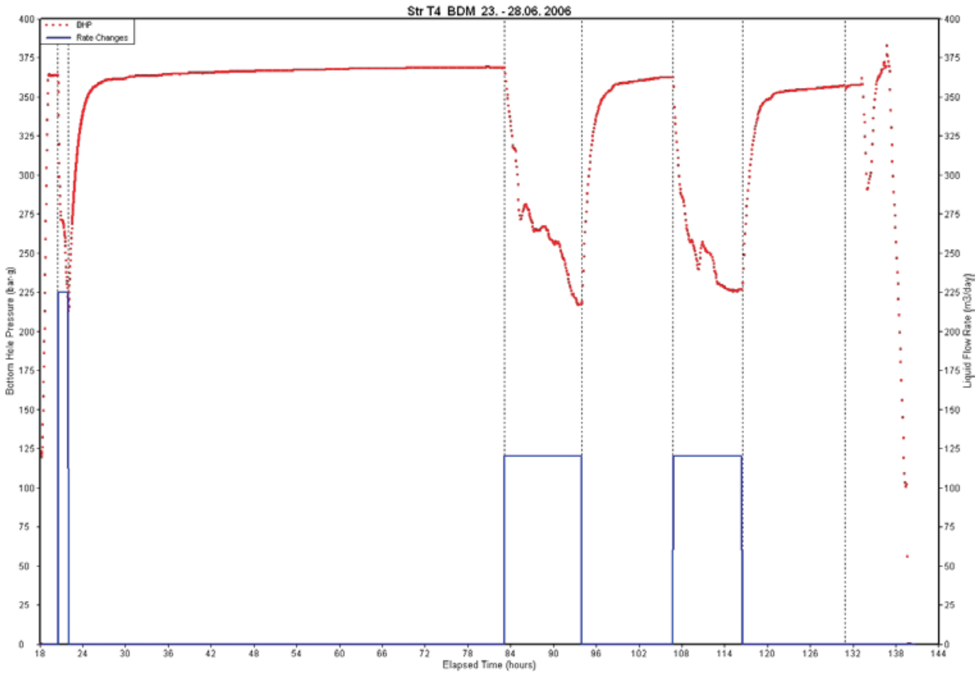


Figure 9: PBU#1- 3, June 23 - 28, 2006 [41]

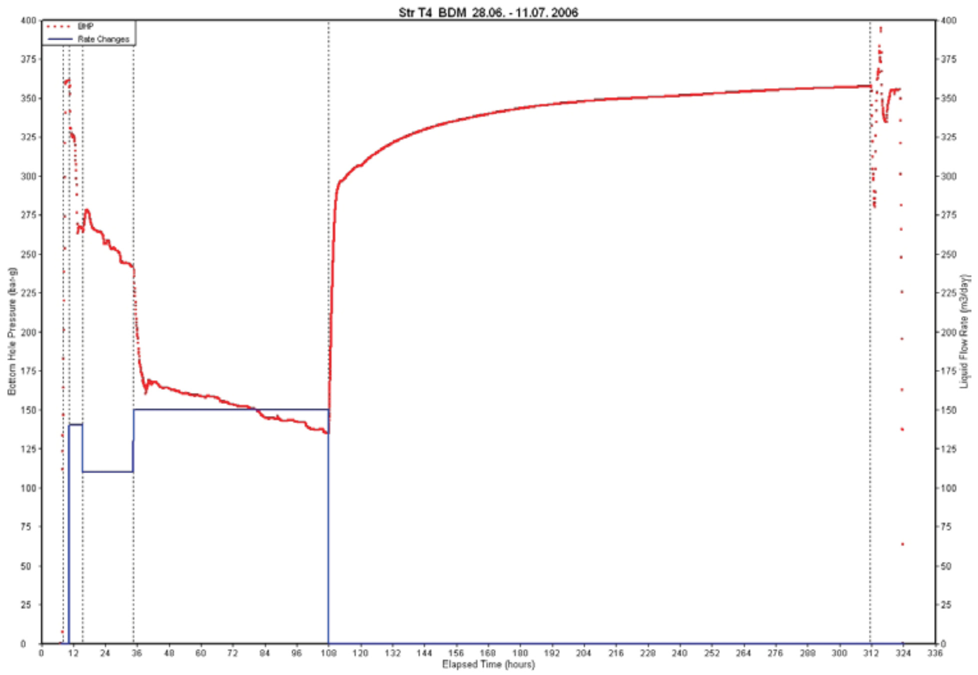


Figure 10: PBU#4, June 26 - July 11, 2006 [41]

## **4. Oiltest**

Between the 7th and 14th of August, 2006 a bottom hole pressure survey was conducted (Table 19). Before pressure build up, a stabilized flow rate was achieved, while the bottom hole flowing pressure increased for 0.22bar/h. At the end the well flowing pressure reached 198.9bar-g with a production rate of 100m³/d (50% drawdown). The pressure history is shown in Figure 11.

Table 19: Realization of the 4. Oiltest

| 4. Oiltest: Bottom Hole Survey from 7. to 14. August 2006 | | | | | | |
|---|---|---|---|---|---|---|
| Perforation: | | 4158-4167 | m MD | | | |
| | | 4210-4224 | m MD | | | |
| Electronic Memory Gauge | | 4161 | m MD | 3899 m TVD | | |
| 1. Flow period | | 100 | m³/d | stabilized | | |
| | BHP increase: | 0.22 | bar/h | ↑ | | |
| | FBHP | 198.9 | bar-g | | | |
| PBU#1 | | 348.5 | bar-g | for | 95 | h |

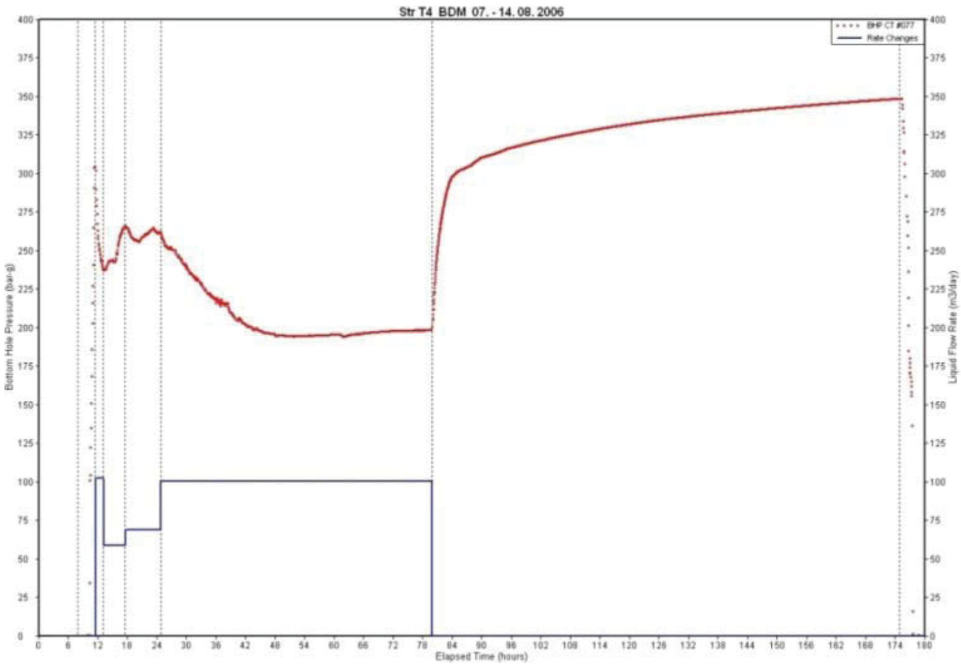


Figure 11: PBU#5, August 7 - 17, 2006 [41]

## 5. Oiltest

On December the 7th another oil-production test was conducted (Table 20). The WHP and the casing pressure equalled zero. The following stimulation with 5m³ acids was unsuccessful. The pressure started to increase when the liquid in the well was lifted with $N_2$. About 23m³ liquid and 7000m³ gas were produced. The well was shut in for the night. When it was reopened the WHP increased from 90bar to 210bar, the annulus was still pressureless. After about 1 hour of production the WHP dropped for 150bar while liquids were produced. Overnight the well was shut in again. The pressure increased within half an hour to 40bar, but no additional pressure build up was observed. On the next day the production rate was about 4m³/h liquid and 1500m³/h gas. The casing pressure equalled 100bar- liquids were produced from it.

Table 20: Realization of the 5. Oiltest

| 5. Oiltest | | | | | | | |
|---|---|---|---|---|---|---|---|
| Perforation: | | 4158-4167 | m MD | | | | |
| | | 4210-4224 | m MD | | | | |
| Electronic Memory Gauge | | 4240 | m MD | 3947m TVD | | | |
| WHP prior opening the well | | 0 | bar | | | | |
| | acid stimulation with: | 5 | $m^3$ | (8%HCL, 2% Cronox, 4l SCA-130) | | | |
| | liquid lifting with N2: | pressure increased again | | | | | |
| | liquid | 23 | $m^3$ | | | | |
| | gas | 7000 | $m^3$ | | | | |
| BHP prior shut in | | 90 | bar | | | | |
| PBU#1 | | 210 | bar | | for | 12 | h |
| | 1. Flow Period | 60 | bar | | for | 1 | h |
| PBU#2 | | 100 | bar | | for | 12 | h |
| | 2. Flow Period | | | | | | |
| | liquid rate | 4 | $m^3/h$ | (80% water and 20% oil) | | | |
| | gas rate | 1500 | $m^3Vn/h$ | | | | |
| | casing pressure | 100 | bar | | | | |
| Total produced liquids | | | $m^3$ | | | | |
| Total produced gas | | | $m^3$ | | | | |
| | gas specific gravity: | | | | | | |
| | H2S content | 2 | % | | | | |
| | CO2 content | | % | | | | |

The development of this production test is demonstrated in Figure 12.

On 11th of December the production started to decrease. It was assumed that this was affected by the N-Seal Pill, used before.

In April 2007 the decision was made, to end pressure build up tests. It was assumed that no stable flow rates would be achieved and therefore no additional information would be gained, to justify the high expenditures. A production profile should be developed with the present data and a further stimulation should be conducted. [39]

However, the well was tested again. In February 2007 a sixth Oiltest was conducted within the Hierlatzkalk. In 2008 additional perforations were made within the Perchtoldsdorfer Dolomit. According to the water analysis also these perforations were tested. Though, no information about these two tests was available.

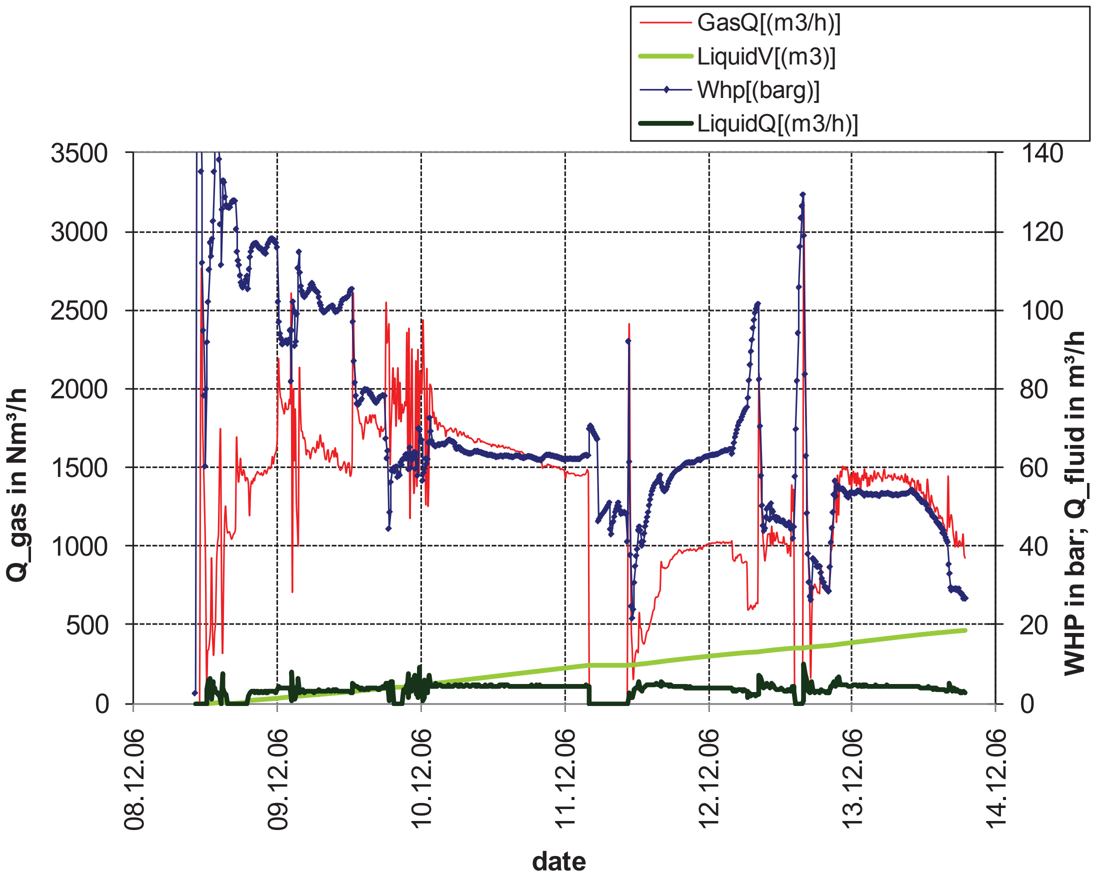


Figure 12: Pressure History from oiltest in December 2006 [39]

**<u>Reyersdorfer Dolomit</u>**

Contrary to the plans, the Reyersdorfer Dolomit was never tested.

#### 4.2.4.5 Well Test Interpretation

The main purpose of interpreting well test responses is to characterize the ability of the fluid to flow through the reservoir and into the well. In contrast to geological data and log data; tests provide a description of the reservoir in dynamic conditions. Pressure curve analysis makes it possible to determine permeability, reservoir heterogeneities, boundaries, and pressures. Moreover, data about the Production potential of the well, and its geometry can be gained. Comparison of routine test results can provide information about changes of productivity and rate of reservoir pressure decrease.

A complete production test is composed of several characteristic flow regimes, initial wellbore storage and near wellbore conditions, to late time boundary effects. The log-log diagnostic plot is generally preferred as a well test interpretation method, due to its ability to characterize all flow regimes on a single plot, to provide a diagnosis of the complete well behaviour and thus defining the appropriate interpretation model.

However, on log-log scales, the pressure curve is not very sensitive to small variations in the response and on the derivative curve the constant skin factor is only present on early time data. Additionally, the derivative response can be affected by noise. To refine the initial log-log results the semi-log superposition match is used. Due to the linear y-axis of the semi-log superposition scale, the definition of the pressure response is improved, without being affected by data processing such as smoothing.

In Strasshof Tief 4 these analysis methods were used as standard interpretation methods for both reservoirs, the Hierlatzkalk/Hornsteinkalk and the Perchtoldsdorfer Dolomit.

During the flow periods stabilized flow conditions could not be achieved in both reservoirs. Therefore, the derived reservoir parameters should be used with caution and a meaningful connected gas volume could not be calculated in both reservoirs. Whenever skin factors were calculated, they resulted in a negative value. This may indicate an improved inflow performance due to acid stimulation or natural fractures.

Within the first minutes of the PBU´s ideal wellbore storage effects were observed. Afterwards non-ideal wellbore effects, like phase separation and redistribution, dominated large parts of the pressure build- up periods, masking the true reservoir response due to the surface shut in. This can already be observed in the “history plot” of the first pressure buildup period, as mentioned above. After the first test it was recommended to use downhole shut-in tools to improve data quality.

**Perchtoldsdorfer Dolomit**

Within the Perchtoldsdorfer Dolomit two pressures build up periods (PBU) were analysed. For the interpretation the full rate history of the well was taken into account. Other input parameters used and there sources are summarized in the following table, Table 21.

In the beginning both pressures build up periods, showed similar properties. On the log- log plots, ideal wellbore storage effects were observed for the first 0.1hours. The trend of the pressure derivatives, demonstrated by the blue line within both Log- Log plots, followed a half-unit slope. This might be an indication for fracture linear flow. However, both tests were influenced by non ideal wellbore effects, for PBU#1 to a greater and PBU#2 to a lesser extent. The peaks within the plots of both tests are too abrupt to indicate a true reservoir response. Presumably, they mark the end of the wellbore effects.

Table 21: Input parameters for the production test of the Perchtoldsdorfer Dolomit [ 42]

| Parameter | Unit | Value | Source |
|---|---|---|---|
| Formation thickness (net pay) | m | 73 | Log Interpretation |
| Average Formation Porosity | % | 5 | Log Interpretation |
| Water Saturation | % | 37 | Log Interpretation |
| Layer Pressure (@ gauge depth] | bar-g | 400 | Gauge Reading |
| Layer Temperature (@ gauge depth) | °C | 120 | Gauge Reading |
| Gas Specific Gravity (air=1) | - | 0.65 | Produced Gas Sample |
| Water Salinity | ppm NaCl | 60,000 | MDT Water Sample |
| Rock Compressibility | $bar^{-1}$ | $8.5*10^{-5}$ | Correlation |
| Total System Compressibility | $bar^{-1}$ | $1.8*10^{-3}$ | Correlation |

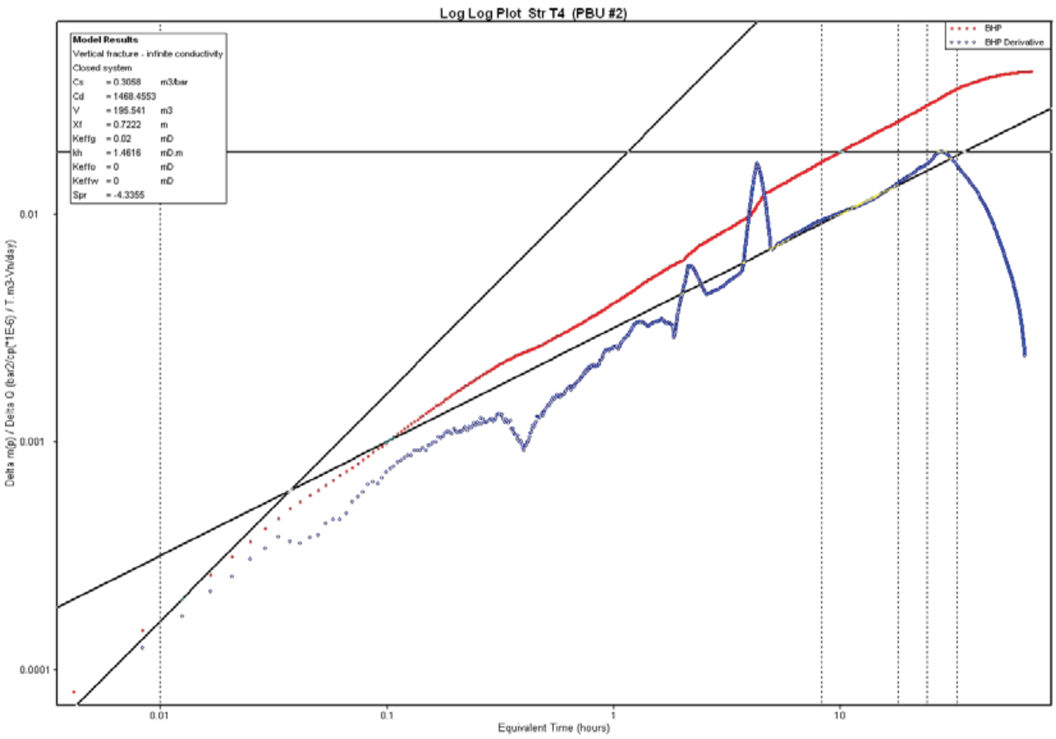


Figure 13: Log- Log Plot of the 2nd PBU, Str T4

Within the first pressure build up period, after an equivalent time of 10 hours (marked by the vertical dotted line at the right side) the derivative becomes horizontal. This might be an indication of a radial flow regime showing a homogenous, infinite acting reservoir.[ 43]

PBU#2 shows a similar behaviour until the equivalent time of 25 hours, or 440 hours real time. Then the derivative passes form a positive to a negative slope, indicating a closed reservoir system, although the late time pressure response again appears too abrupt for a true reservoir response. The stabilization of the bottomhole shut- in pressure is obvious until the transition to a negative slope. For the interpretation the transition zone was assumed to indicate a short radial flow.

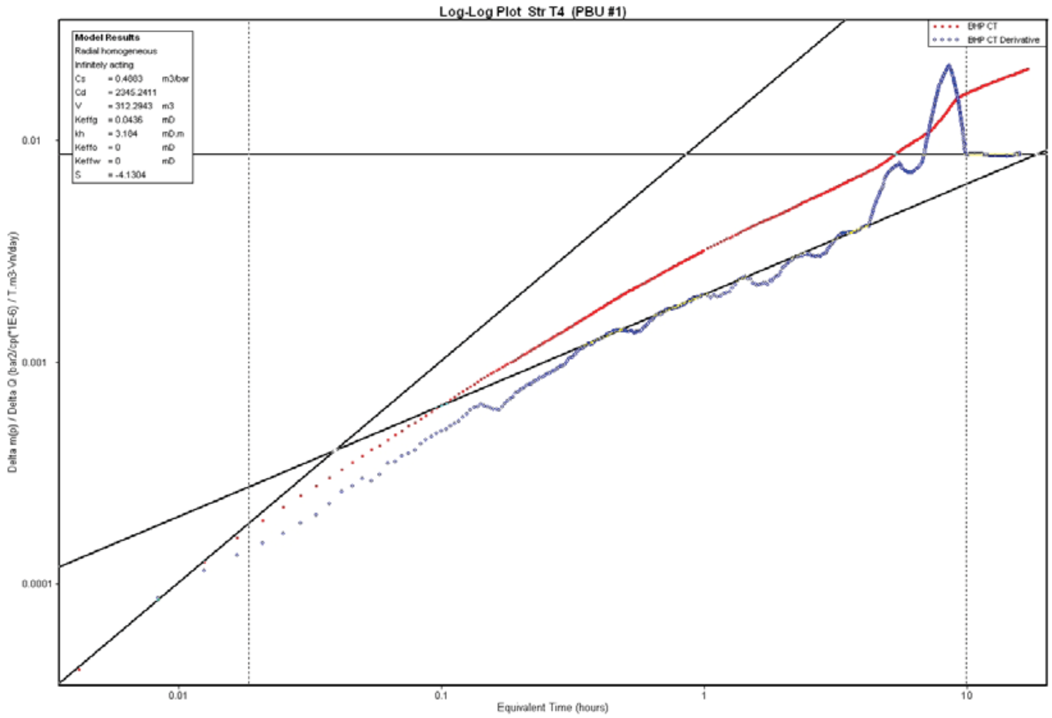


Figure 14: Log- Log Plot of the first PBU, Str T4 [ 44]

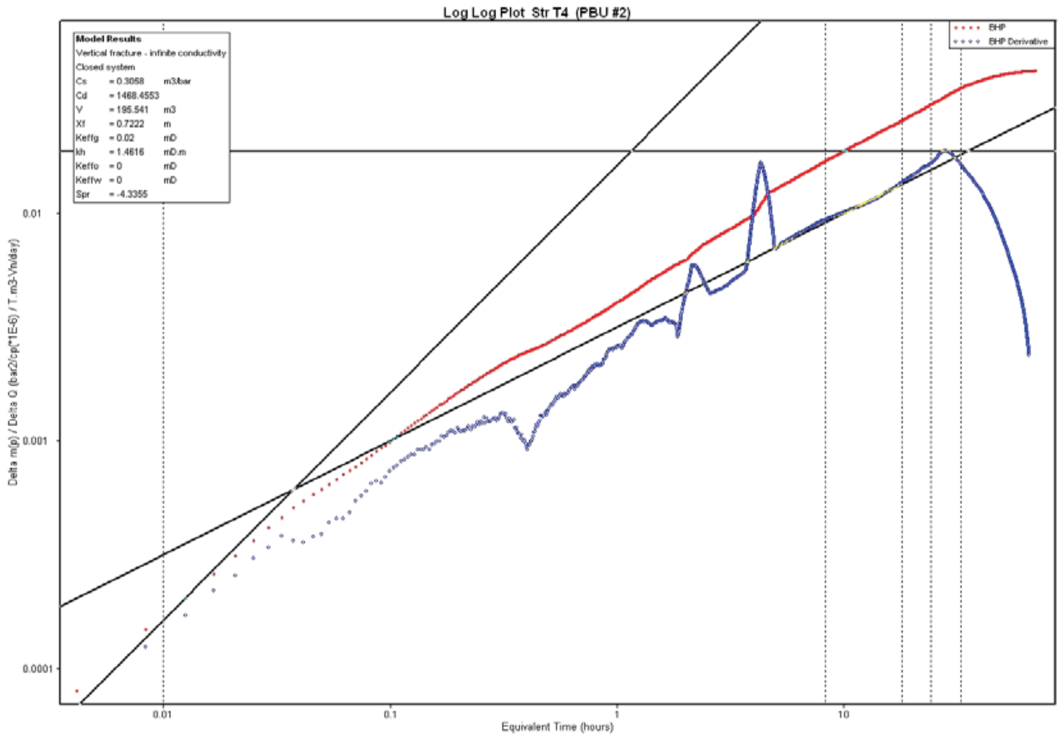


Figure 15: Log-Log Plot of the second PBU, Str T4 [44]

## Interpretation Results:

The results, evaluated from the radial flow regime are listed in Table 22, compared to the pressure measured by MDT. In case of 2nd PBU the extrapolated reservoir pressure is too high, due to neglecting late- flow period.

Table 22: Interpretation Results

| Evaluated Reservoir Parameter | Units: | PBU#1 | PBU#2 | MDT |
|---|---|---|---|---|
| k*h | [mD*m] | 3.18 | very low | |
| S | [-] | -4.13 | negative | |
| **Reservoir Pressure** | | | | |
| extrapolated from radial flow regime | [bar-g] | 413 | | |
| calculated @ 4087m TVD | [bar-g] | 427 | 406 | 451 |
| Radius of Investigation | [m] | < 27 | > 1500 | |
| fluid gradient | [bar/m] | | | 0.216 |
| Reservoir Temperature @ gauge depth | [°C] | 120 | 120 | |

Overall, the interpretation of the production test of the Perchtoldsdorfer Dolomit indicates a tight formation with few open fractures of varying conductivity. Outer flow boundaries could not be interpreted, although interpretation of the second PBU indicates a closed reservoir compartment and the pressure extrapolation indicates depletion from production during testing.[44]

## Hierlatzkalk/Hornsteinkalk

Within the Hierlatz- Hornsteinkalk five pressure build-up periods were analysed. The first production test had to be aborted, due to solidified oil plugging and was not taken into account for analysis. For the first four pressure build up periods the memory gauge was set at a depth of 3899m TVD, for the last test bottom hole data was measured at 3947m TVD. Overall, the pressure build up periods showed a similar reservoir response, although the second and third pressure build-up periods are different, due to the short shut in.

The full rate history was taken into account for the interpretation of the bottomhole data. Additional input parameters used are summarized in Table 23.

Again, all pressure build-ups showed a large ideal wellbore storage at the beginning and were then influenced by non-ideal wellbore effects.

The first three PBU´s are demonstrated together in one single Log- Log plot, Figure 16. Whereof, the different colours stand for diverse pressure build ups, red marks the first PBU, blue the second and green the third. PBU#4 and 5 are demonstrated in Figure 17.

Table 23: Input data for Interpretation of test data [41]

| Parameter | Unit | Value | Source |
|---|---|---|---|
| Formation Thickness | m | 69 | Log Interpretation |
| Average Formation Porosity | % | 10 | Log Interpretation |
| Water Saturation | % | 35 | Log Interpretation |
| Layer Pressure (@ gauge depth] | bar-g | 370 | Gauge Reading |
| Layer Temperature (@ gauge depth) | °C | 118 | Gauge Reading |
| Oil Gravity | °API | 25.1 | Produced Oil Sample |
| Gas Specific Gravity (air=1) | - | 0.63 | Produced Gas Sample |
| Produced GOR | $m^3$ (Vn)/$m^3$ | ~150 | Test Production |
| Water Salinity | ppm NaCl | 30,000 | Prod. Water Sample |
| Oil Formation Volume Factor | $m^3/m^3$ | 1.3760 | Correlation |
| Oil Viscosity (@ res. cond.) | cp | 0.6950 | Correlation |
| Rock Compressibility | $bar^{-1}$ | $7.0522*10^{-5}$ | Correlation |
| Total System Compressibility | $bar^{-1}$ | $3.3556*10^{-4}$ | Correlation |

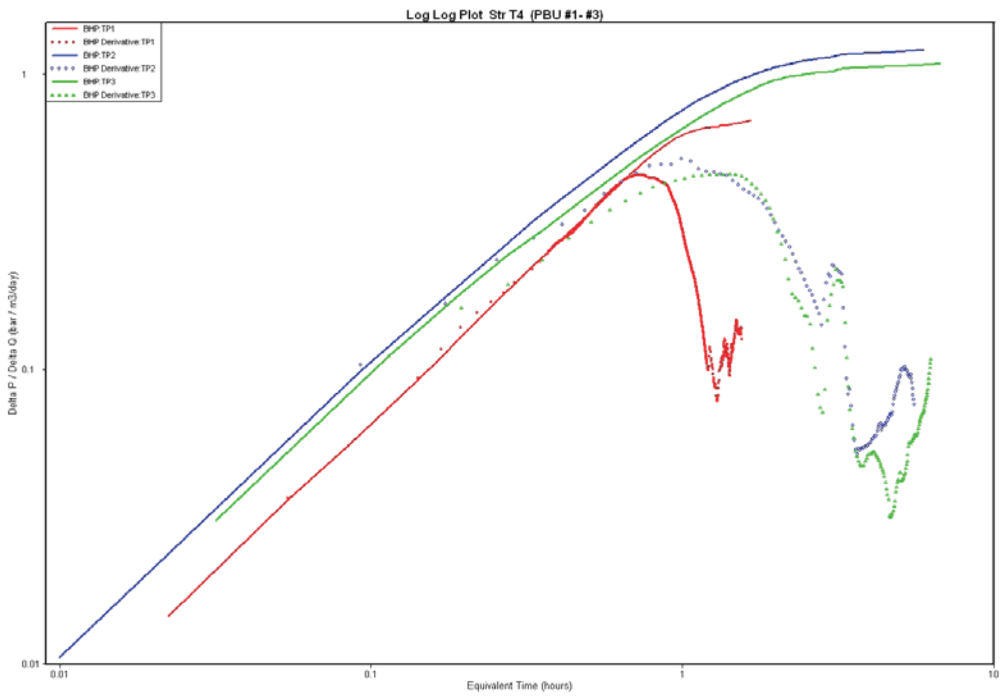


Figure 16: PBU1, 2&3 [41]

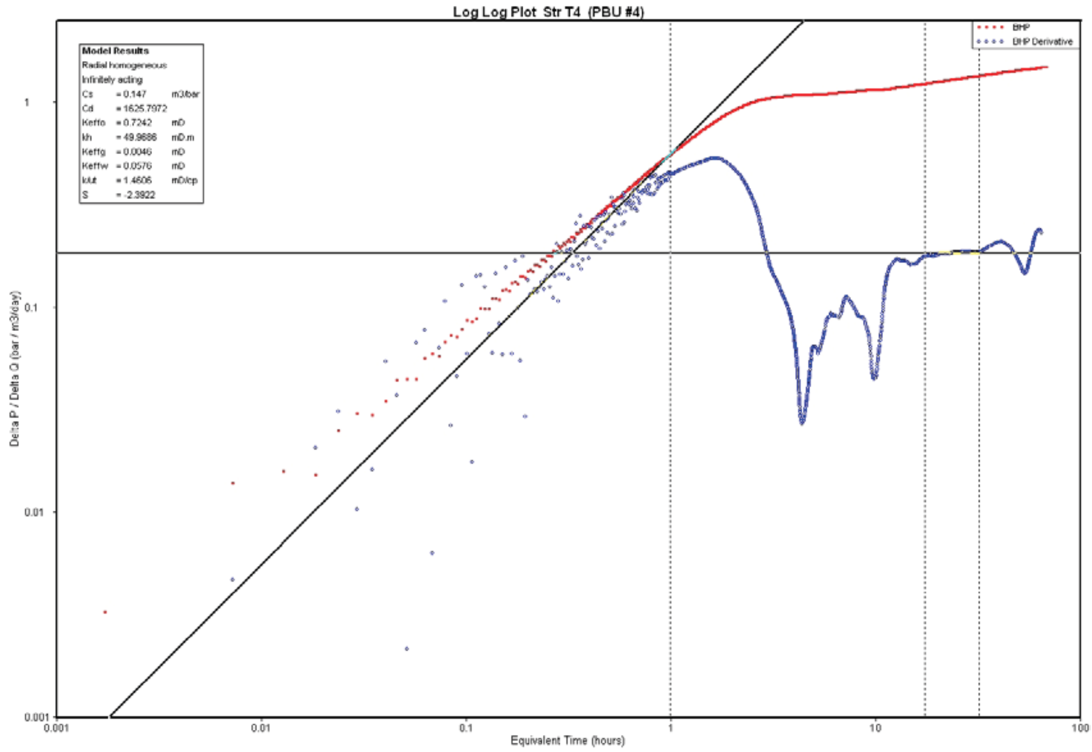


Figure 17: Log- Log Plot of PBU#4 [41]

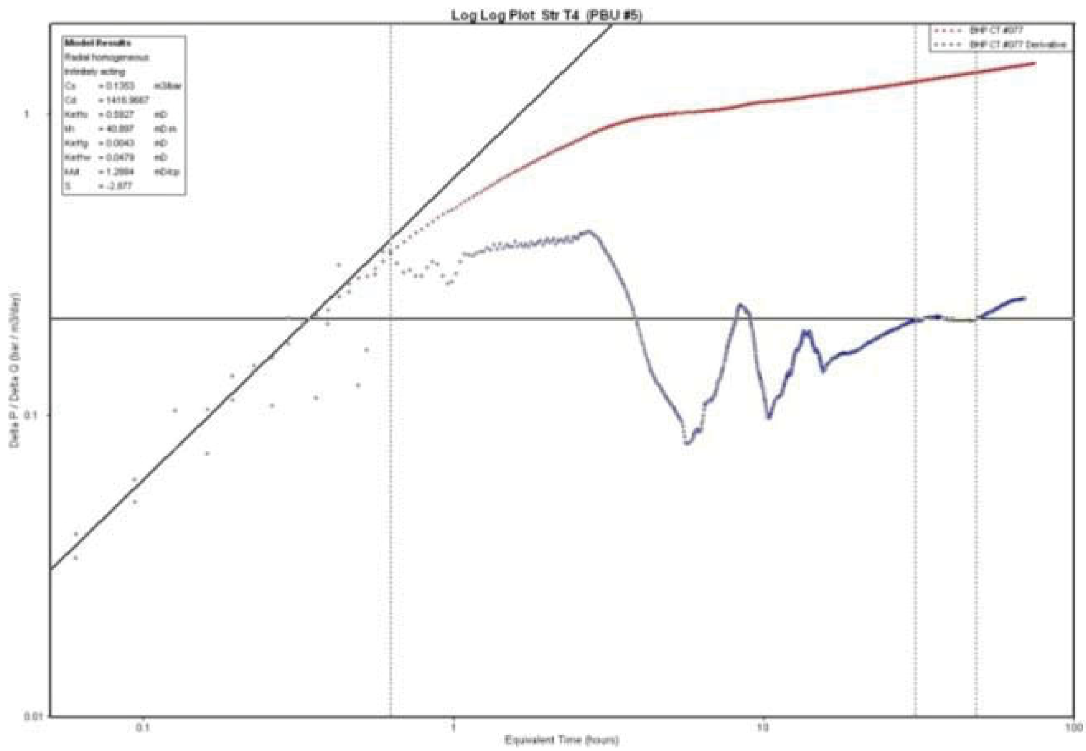


Figure 18: Log-Log Plot of PBU#5 [41]

Radial flow regime with a zero slope was identified for the first, fourth and fifth pressure build-up, although almost the entire PBU four was dominated by large non-ideal wellbore effects. The second and third analysed periods are completely dominated by wellbore effects and radial flow is never reached due to free gas in the production string, the surface shut in and a much shorter shut in time.

The half unit slope of the pressure derivative of PBU#5 indicates fracture linear flow before and after radial flow. However, for a significant frac, the pressure response occurred delayed. Also the flattening of the derivative is unusual for the presence of parallel flow barriers. A changed mobility or net thickness might be an explanation of the noticed late pressure response.

## Interpretation Results

The results, evaluated from the radial flow regime are demonstrated in Table 24. For the PBU#4 the period between 21 and 46 hours elapsed time was presumed to demonstrate radial flow (marked with the two dotted vertical lines to the right in Figure 16).

The pressure derived from radial flow plots is smaller than identified by MDT. However, the pressure of PBU#1 might be affected by supercharging and is therefore, not fully representative. In case of PBU#4, the reservoir pressure extrapolated from radial flow might be slightly too low, because the late time pressure response was not fully taken into account. The reservoir pressure from PBU#5 was extrapolated from the last measured pressure value at a gauge depth of 4240m MD.

Table 24: Interpretation Results of the Hierlatzkalk/ Hornsteinkalk [41]

| Reservoir parameter | Unit | PBU#1 | PBU#2 | PBU#3 | PBU#4 | PBU#5 |
|---|---|---|---|---|---|---|
| k*h | [mD*m] | 79 | | | 50 | 40.9 |
| S | [-] | -2.3 | | | -2.4 | -2.9 |
| **Reservoir pressure @ 3899m TVD** | | | | | | **@ 3947m** |
| Extrapolated from radial flow regime | [bar-g] | 373 | 369 | 366 | 371 | |
| Calculated with fluid gradient of 0.0825bar/m | [bar-g] | 411 | 407 | 404 | 409 | 389.3 |
| Radius of Investigation | [m] | 71 | | | 97 | 60.4 |
| Reservoir Temperature @ 3899mTVD | [°C] | 118 | 118 | 118 | 118 | 124 |
| Reservoir Pressure identified by MDT | 429 bar-g | | | | | |

The interpretation of the test results indicates a low permeable matrix with open fractures to unknown extent. Semi steady state flow regime was never reached; therefore no meaningful oil volume could be derived from bottomhole data. Also outer flow boundaries could not be identified. Contrary to the Perchtoldsdorfer Dolomit, pressure depletion due to production was not observed.

#### 4.2.4.6 Fluid sampling and analysis

Reservoir fluid property measurement plays an important role in field development, especially in the early exploration stage. For instance, basic PVT studies are applicable for production facility design, reservoir engineering and well test interpretation. Knowledge about the $H_2S$ content is important for safety, corrosion, etc. Water analyses identify corrosion potentials, scale formations etc.

Although data obtained in an early stage may not be the most accurate, 'experience demonstrates that even imprecise data gained at an early stage generally have a much higher "information value" than precise data at a later stage of development.' [45]

In general formation fluid exhibits wide variations in composition and properties. Typical ions like lithium, bromide and iodide give information about the fluid type and its origin. Their existence indicates that formation water is present in the sample. The drilling mud for Str T wells is based on potassium carbonate containing also some organic compounds, sodium, sulphate and nitrate impurities. An excess of them indicates a contamination with mud. A low pH value shows that the area was stimulated with acid, whereof a high value indicates the dilution with mud. Identifying the content of the sample shows if it is representative for a certain fluid or if it is diluted.

First downhole samples were taken during drilling via Bottomhole Sampling (BHS), respectively by MDT. The sampling date and depth were not known. Furthermore aqueous samples of drilling mud, and reference water were analysed for comparison. Table 25 shows the composition of the aqueous phase samples.

The BHS contained about 80% of formation water. An enhanced pH-value and potassium concentration (compared to formation water analyses from ST wells) and the presence of nitrate indicate a dilution with mud. [46]

The MDT samples contained residues of drilling mud, diluted 1:200 with condensed water, due to the small sample volume. Formation water may be present in traces. It is not recommended to see the data obtained from MDT as absolute values. They can only give an idea of the ion-distribution in the collected liquid. [47]

Table 25: Composition of Aqueous Phase Samples [46], [47]

| Sample | Drilling mud | Reference water | HOR / PE 800 / 91 | BHS liquid | MDT | |
|---|---|---|---|---|---|---|
| LEP-Nr: CHE2005 | 0313 | 0314 | average ST38,48, 58 | 0326 | 0580 | 0582 |
| pH value | 11.2 | 8.3 | | 9.4 | | |
| Conductivity at 25°C, mS/cm | n.d. | n.d. | | 98400 | | |
| Sodium, mg/l $Na^+$ | 1820 | n.d. | 19368 | 18828 | 2180 | n.d. |
| Potassium, mg/l $K^+$ | 117025 | 9.4 | 716 | 23093 | 26913 | n.d. |
| Ammonium, mg/l $NH_4^+$ | n.d. | n.d. | 47 | 65.5 | | |
| Lithium, mg/l $Li^+$ | 0.1 | n.d. | n.d. | 23.9 | 0.8 | n.d. |
| Chloride, mg/l $Cl^-$ | 6102 | 238 | 31396 | 28131 | 2845 | 2510 |
| Bromide, mg/l $Br^-$ | 2.0 | 0.2 | 53 | 41.7 | n.d. | n.d. |
| Iodide, mg/l $I^-$ | <2 | <0.2 | 17 | 28.2 | n.d. | n.d. |
| Sulfate, mg/l $SO_4^{2-}$ | 928 | 256 | 377 | 1118 | 1170 | 866 |
| Nitrate, mg/l $NO_3^-$ | 118 | 97.8 | n.d. | 30.9 | 100 | 86 |

n.d. = not determined

During completion and testing operations fluid samples were consistently taken from the well Strasshof Tief 4 and analysed in the laboratory with respect to their chemical composition. The most representative water samples have been repeatedly compared to each other. In Table 26 the results of the analyse are listed.

The sample taken on March 28, 2006, (sample 10) is assumed to be representative, whereof the water cannot be related to a certain horizon. The sample of the 2nd gas test (sample 31) contained residues of chemical fluids and some formation water. Although the probe is diluted, it is comparable to the sample of the first test.

The samples taken from the 1st and 2nd oiltest (sample 45 and 51) consist mainly of formation water, which is similar to the former samples (Chloride, Bromide, Iodide, Lithium and Sodium). The concentrations of alkaline earths ions (Magnesium, Calcium and Strontium) are clearly decreased, which might be caused by contact of formation water with alkaline mud. It was assumed that these ions were precipitated when coming in contact with the used mud, building Carbonate ('carbonate scaling').

It was assumed that, due to a casing leak, the water samples of these tests were derived from one and the same horizon. Chemical and mud residues may have originated from respective perforation intervals. [48]

Table 26: Comparison of Formation Water Samples [ 48], [ 49]

| | **1. Gas test** | **2. Gas test** | **1. Oiltest** | **2. Oiltest** | **4. Oiltest** | **5. Oiltest** |
|---|---|---|---|---|---|---|
| Sample | HDSeparat or Liquid 06:30-07:00 | Seperator Liquid 15:50 | Choke manifold Liquid 23:35 | Choke manifold Liquid 07:50 | Choke manifold Liquid 12:30 | Choke manifold Liquid 09:45 |
| Sampling Date | 03/28/06 | 04/25/06 | 07/02/06 | 07/18/06 | 12/13/06 | 03/05/07 |
| LAB-Nr. | 20060681 | 20060880 | 20062036 | 20062176 | 20063626 | 20070686 |
| pH | 6.0 | 6.5 | 7.7 | 7.5 | 10.0 | 8.5 |
| Cl, mg/l | 37825 | 39126 | 36439 | 36754 | 43402 | 41232 |
| Br, mg/l | 50.2 | 43.7 | 49.1 | 49.5 | 64.5 | 63.2 |
| J, mg/l | 26.2 | 22.7 | 27.2 | 30.5 | 23.5 | 22.7 |
| SO4, mg/l | 439 | 461 | 601 | 459 | 702 | 391 |
| Li, mg/l | 35.3 | 36.5 | 34.7 | 37.4 | 20.4 | 31.8 |
| Na, mg/l | 21207 | 20419 | 19664 | 22047 | 19728 | 21446 |
| K, mg/l | 963 | 1566 | 3162 | 869 | 23479 | 12538 |
| Mg, mg/l | 410 | 1074 | 185 | 206 | 48 | 181 |
| Ca, mg/l | 1467 | 2482 | 460 | 1103 | 19 | 445 |
| Sr, mg/l | 208 | 201 | 139 | 202 | 16 | 89 |
| °dH | 313 | 317 | 113 | 215 | 15 | 110 |

The sample taken in December 2006 (sample 76) was separated from oil via the centrifuge. Approximately 3ml water could be gained and analyzed. This sample contained formation water, mud residues and potassium chloride. The concentration of the earth base ions decreased, indicating additional carbonate scaling.

The sample taken at the 5$^{th}$ oiltest (sample 83) also contains formation water and mud residues. [49], [ 50]

### 4.2.4.7 Carbonate Scaling

Mud invading into the formation can alter the temperature, pressure, and composition of the fluids in the near wellbore region and tubing. Consequently, the thermodynamic and chemical balance may change in favour of precipitation, crystal growth, and scale formation. Fluid losses in the formation can change the wettability and permeability of hydrocarbon bearing rock and cause scale formation, thereby clogging tubing and pore throats.[ 51]

Inorganic scale has been a recurring problem in wells, separators, and flow lines in the Strasshof Tief project and is already well known from the Matzen field area. Deposition of calcium carbonate tends to occur at locations where the ionic equilibrium has been disturbed due to pressure or temperature changes. ('Final Report, Evaluation of Carbonate Scale Inhibitors').

Scaling also occurred as a major problem at the Strasshof Tief wells and caused production shut downs. Various tests have been conducted in order to analyse samples of deposits and solids. The results exposed that several solids were paraffin-like substances; others were inorganic and predominately consisted of calcite. [52]

For the Strasshof Tief 4, the first documented case occurred with the first gas test on memory gauge (CHE 2006-0469). It revealed a 2mm thick, black, flaky coating, a substance are soluble in hydrochloric acid. After the cleaning process using acetone the remaining solids were analysed via X-ray diffraction showing that they consisted of calcite.

Next, residua on the filter F-6 have been found (CHE20060652). The produced water of the Str. T4 was temporarily delivered to the gas station Aderklaa via tank truck, causing a blockage of filter F-6. This already occurred on March 25th 2006 and worsened till a sampling was drawn on March 29th 2006. The result of the x-ray diffraction again revealed that it was calcite. An additional microscopic test showed that it was probably freshly precipitated calcite.

On July 12th 2006, during pulling out of memory gauges, samples of deposits have been drawn from 3650m MD. The solids were identified as calcite with magnesium carbonate intrusions which were contaminated with crude oil.

In December 2006, during the oil test, the failure of an electricity generator caused a shut in of the well for several hours. When restarting the testing on the Dec. 13th 2006 a continuous decrease of the production rate occurred although the choke position was held constant. However, even by reducing the choke from 32/64" to 20/64" the well did not produce any more oil. (CHE 20070085).

In order to explain the narrowing at 4117m depth three hypotheses were advanced:

H1: Mechanical failure (e.g. dog leg, over pressure, etc.)

H2: Fish

H3: precipitated carbonates and used fluid loss - control material (N-Seal Pill)

A mechanical failure seemed unlikely due to the constant lead impression. A tubing collapse would be one-sided. Furthermore, it can be dismissed that the narrowing was caused by paraffin deposits as the temperature was too high. In addition, H2 has been categorically dismissed.

As problems caused by recently precipitated calcium carbonate already occurred in earlier tests, it is very likely that H3 cannot be falsified. In order to find the cause of the blockage Halliburton's N-Seal Pill was analysed for its composition. It was found that the fibre which was added to the pill was fibre glass which in combination with carbonate is most likely to have caused the problem.

In order to treat the blockage it was recommended to clean it with 10% HCl which should directly be delivered to the narrowing using the coil tubing (treatment with hydrofluoric acid was excluded). Furthermore, it was suggested to add 15% mutual solvent Musol and 2% CRONOX corrosion inhibitor in order to remove oil coating the formation. During this operation regular samples should be drawn to check the amount of reactive acids and calcium concentration.

Each volume unit of 10% acid can dissolve 5.3% of its volume in solid $CaCO_3$. This means that the twentyfold volume of acid has to be used to remove the expected cubature. However, in order to apply this cleaning treatment, the resistance of the internal coating TK 216 had to be tested.

The treatment of the blockage was conducted on February 22, 2007, when the oil test of the Hierlatzkalk/Hornsteinkalk was conducted. The stimulation quickly led to success and the residual acid (about $3m^3$) was pumped into the formation. Due to the TK 216 coating the use of Musol was avoided.

As the well had clogged-up again, coil tubing was utilised to get solids out of the well (CHE 200608336). Again, tests revealed that the samples contained oily calcium carbonate. Analysis with the optical microscope showed that it was a matter of recently precipitated calcite which even included oil droplets. This shows that in-depth filtrated mud liquid and formation water can lead to precipitation by mixing during flow-back because the acid does not penetrate deep enough to redissolve the precipitate. High volumes of retarded acid might be necessary to do the job.

The report clearly shows that the Str. T4 scaling problems occurred because the mud was incompatible with the formation water. The hard and highly saline water intensified the whole situation. In addition, the extreme losses of mud going deep into the fracture system caused significant formation damage. Under these circumstances it is especially important to avoid or at least reduce the filtration. Apparently, nobody was really aware of the risks, resulting in irreversible production losses.

#### 4.2.4.8 Acid Stimulation

Fracture acidizing with hydrochloric acid (HCl) is an effective method of improving the production of many carbonate reservoirs. The success of fracture treatment depends on two factors: fracture conductivity and depth of fracture penetration. The amount of conductivity depends on both the amount of material removed and where it is removed from along the fracture faces. While many factors control the action of acid in removing the formation material, concentration of the acid can play an important role in increasing conductivity. Used HCl concentrations may vary between 3% (for tubing- cleaning application) and 35%, but they are typically between 15% and 28%. Acid solutions with concentrations above 15% HCl are called high- strength acids.[53] Use of them became popular, due to their success in areas where conventional treatment had failed or had shown only limited results. E.g., in reservoirs of high water saturation, which make weaker acid solutions ineffective, because of rapid dilution. Penetration increases due to a more rapid initial drop in area-to- volume ratios, and the following retardation produced by higher concentrations of the acid itself and of the reaction products in solution in the partially spent acid.[54]

The Laboratory of Exploration and Production requested to use a high strength acid due to the massive damage of the formation, in order to provide a deeper penetration of the dolomite, and the rapid acid consumption at high temperatures of 150°C. For a most effective job an acid recipe with a 28% HCl was suggested.[55]

However, discussions about this matter and its effect on the coil tubing were going on. In June 2007 a stimulation of the well Strasshof T4 was conducted to test this acid recipe and to prevent future discussions whether to pump 28% HCl if requested by OMV or not.

To allay all doubts, it was decided to conduct one acid operation with a 28% HCl. To penetrate the fractures as deep as possible a pressure, slightly below the frac pressure was recommended from the Laboratory. [56] For comparison CT was inspected before and after the operation to check for any damage caused by the acid. Therefore, a piece of CT from the lowest end was cut before and after the treatment. During the operation a total of 23m$^3$ 28% HCl were pumped over a period of about three hours. The CT remained in the hole for about an hour after the acid had been squeezed into the formation.

According to the report 'Corrosion Attack of Coiled Tubing' the two measurements coincide and show an average corrosion loss of max. 50µm. The CT was not attacked by the 28% acid, even under the severe conditions of the high reservoir temperature, the presence of $H_2S$ and the very narrow annulus of the last 150m. The inhibition was found sufficient based on the field observations.

Therefore a new acid recipe was developed as a standard formulation:

28% HCl

5% Acetic acid

3.6% A201 (85 percent Formic acid acting as stabilizing agent for the “CRONOX 242 ES”)

2% CRONOX 242 ES

0.2% A255 ($H_2S$ Scavenger) [1]

It was agreed, that this recipe could be used for OMV Coiled Tubing Operations. The recipe came with the following caveats:

For any operation with high strength acid it must be ensured that the CT will not be exposed to the acid for more than 8 hours, nor that it will be run in acid which had been sitting in the wellbore for an extended period. Every effort must be undertaken to limit the exposure of the CT to the acid. Furthermore, the Coiled Tubing must be properly neutralized, flushed with fresh water and inhibited directly after the operation.[ 57]

This high strength acid recipe was then used for further stimulations. However, later reports of matrix stimulation again reported the use of a 20% HCl, in contrast to this recommendation.

# 5 Strasshof Tief 5 and 5a

Str T5 appraised the Norian/Rhätian Perchtoldsdorfer Dolomit and the Liassic Hierlatzkalk and Hornsteinkalk within the Frankenfels/Lunz Nappe. The surface location is approximately 7 km NE of Str T4. Due to the poor seismic in this area, the well was located approximately 500m North-West of the well ST11, in the central part of the existing Reyersdorfer field, to allow for a better understanding of the dolomite structure.

**Perchtoldsdorfer Dolomit**

The main purpose was to establish the GWC of the Perchtoldsdorfer Dolomit and hence, to act as a decision base for further investments. As no contact was encountered in Str T4, Str T5 should test the downdip extension of the gas column. Due to the possibility of a contact below 4700m TVD from MDT data, the planned well depth was 5000 m MD.

The probabilistic reserve estimation showed that in case of a contact at about 4300m the well could contain more than 5,700 MMm³ gas within the Perchtoldsdorfer Dolomit (Table 27). [58] At best the GWC is at 4500m. In this case about 11,000MMm³ gas could be encountered.

Table 27: Estimated Reserves of the Perchtoldsdorfer Dolomit, Str T5[59]

| Probabilistic Res. | P 90 | P50 | P10 |
|---|---|---|---|
| IGIP (MMm³) | -- | -- | 19100 |
| Rec. Res., (MMm³) | 800 | 5700 | 11050 |

The thickness of the gas-bearing dolomite was assumed to be near 200 m (100 m in Str T4), though it should be drilled normal to the bedding.

In case the Perchtoldsdorfer Dolomit did not have a sufficient gas-bearing layer (at least 100 meters) or were identified to be water bearing the well was planned to be sidetracked to a structural higher position, immediately.

**Reyersdorfer Dolomit**

The Reyersdorfer Dolomit was planned as a secondary target. Although it was not perforated and tested in Str T4, it had gained importance due to the upcoming acid gas injection (AGI) project. To prove the technical possibility of AGI a special evaluation program was designed involving intense coring and development of a new PSDM seismic. A new reservoir map was to be created, based on data of this well and on a new seismic.

From the older depth map, the well was assumed to target the crest of the closure of the Reyersdorfer Dolomit structure. Therefore, it was assumed that gas should be found within this target, though with a higher secondary GWC. Nevertheless, the depth of this formation is very variable due to the vertical dip. A few meters aside could result in structural losses in tens of meter.

The probabilistic reserve estimates are listed in Table 28.

Table 28: Estimated Reserves of the Reyersdorfer Dolomit, Str T5 [59]

| Probabilistic Res. | P 90 | P50 | P10 |
|---|---|---|---|
| IGIP (MMm³) | -- | -- | 3050 |
| Rec. Res., (MMm³) | 200 | 1050 | 1500 |

**Hierlatzkalk/Hornsteinkalk**

A further secondary target was the Jurassic (Liassic) Hierlatzkalk/Hornsteinkalk, which mimics the structure of the Perchtoldsdorfer Dolomit and the Reyersdorf Dolomit of the older part of the gas field Reyersdorf. These horizons were not encountered within ST 11, as they were often missing on top of the anticlines. Therefore, mapping this target was difficult and needed to be checked by hard facts such as wells and cores.

Moreover, the recoverable reserves were registered in the ‚Intent to drill, Strasshof T5‘ and listed here, in Table 29.

Table 29: Estimated Reserves of the Hierlatzkalk/Hornsteinkalk, Str T5 [59]

| Probabilistic Res. | P 90 | P50 | P10 |
|---|---|---|---|
| IGIP (MMm³) | -- | -- | 1500 |
| Rec. Res., (MMm³) | 0 | 620 | 850 |

Within the Perchtoldsdorfer Dolomit and the Hierlatzkalk/Hornsteinkalk a $H_2S$ content of 3% and about 13% $CO_2$ were expected.

## 5.1 Well Design

Similar to the former well, the main source of information about design and expectations is the ‘Intent to Drill, Strasshof T5 and T5a.

The well was planned before its location was determined. In August 2005, the well had to be realigned, as the owner and renter did not agree to the initially planned location. Therefore, a revision of the project became necessary, resulting in the final report about the well (the Intent to drill, Strasshof T5, 5a). [60]

### 5.1.1 Drilling Program

The well was to be drilled vertically to test the GWC of the Perchtoldsdorfer Dolomit. In case Str T5 were unlikely to deliver an economic gas rate, the net pay were less than 100m, or the primary target were intersected below the GWC, the well should have been deviated. The anticipated KOP was designed to be within the Reyersdorfer Dolomit, below the GWC, at a depth of 3200m. The total depth of the sidetrack was planned for 4500m MD. [61] It was scheduled to be deviated with a maximum inclination of 36° in an azimuth of approximately 140°, to guarantee that the primary target would be hit above the GWC.

The casing program for Str T5 was planned as follows:

- 18-5/8“ surface casing 0- 600m, cemented to surface
- 13-3/8” casing:0- 2760m top of cement 100m above the 18-5/8“ shoe.
- 9 5/8” casing: 0- 4100m, top of cement 100m above the 13 3/8” shoe.
- 7“ production casing: 0-5000m (TD), as an alternative a 7“ liner was planned: 41500 - 5000m; top of cement 100 m above the 9 5/8” casing shoe.

The 9 5/8” casing ‘setting point’ was planned to be above the Hornsteinkalk to avoid fluid loss.[62]

Due to the expected cement elevation a foam cementation was scheduled in the 13 3/8“ and 9 5/8“ section. For the 7“ section a gas proof silicalite cement was planned.

A thermal measurement of the cement head should be conducted to define the real top of cement (TOC).

A $K_2CO_3$ mud system was planned for all sections. Below the 18 5/8 casing glycol should be added.

Table 30: Str T5, Drilling Data Summary

| Phase | | 24" | 17 1/2" | 12" | 8 ½" |
|---|---|---|---|---|---|
| MD | | 600m | 2760m | 4100m | 5000m |
| Casing | Diameter:<br>Running Depth:<br>Weight:<br>Grade:<br>Connection: | 18 5/8"<br>600m<br>87,5 #/ft<br>K-55<br>BTC | 13 3/8"<br>2760m<br>77 #/ft<br>L-80<br>BTC | 9 5/8"<br>4100m<br>53,5 #/ft<br>L-80<br>VAGT | 7"<br>5000m<br>32 #/ft<br>L-80<br>VAGT |
| Cement | Type/ Class:<br>Spec. Weight:<br>Top of Cement:<br>Cement Volume:<br>(kalkuliert) | CG 275<br>1.60 kg/l/1.86 kg/l<br>surface<br>63 & 25 m³<br>(lead & tail) | CG 275 (Foam)<br>1.34kg/l /<br>500m<br>121m³<br>(unverschäumt) | CG 275<br>1.80 kg/<br>2650m<br>89 m³<br>(tail) | CG 275<br>(Silicalite)<br>4000m<br>14,5 m³<br>(tail) |
| Mud | Type:<br>Specific Weight: | $K_2CO_3$ System<br>< 1.12 SG | $K_2CO_3$ / Glycol<br>< 1.12 SG | $K_2CO_3$ / Glycol<br>1.10 - 1.25 SG | $K_2CO_3$ / Glycol<br>1.12- 1.30 SG |

### 5.1.2 Well evaluation Program

**Pressure and Temperature Gradients**

Hydrostatic to slightly lower hydrostatic pressure (in the Aderklaaer Konglomerat) conditions were expected down to 2868m MD. Over hydrostatic pressure conditions were assumed to be at the top of the Reyersdorfer Dolomit (1.025 SG), the Hornsteinkalk (1.07 SG) and the Perchtoldsdorfer Dolomit (1.05 SG).

For the sidetrack Str T5a a pressure gradient of 1.11 SG was expected at the top of the Perchtoldsdorfer Dolomit.

The temperature gradient was expected to be normal (3°C/100m).

**Logging Program**

A logging program, similar to Str T4, was designed for Str T5 and 5a. In case the GWC in Str T5 was measured, the logging should be reduced and an LWD was planned to be run.[62]

**Coring Program**

Seven liner cores were planned to be taken with each having a length of 18m to determine the reservoir and the sealing parameters.

1. Core Bockfliesser Schichten or Neokom to evaluate the seal for the AGI project.

2.& 3. Core: Top Reyersdorfer Dolomit, regardless shows

4. Core: Top Hornsteinkalk regardless shows.

5. Core: Top Perchtoldsdorfer Dolomit regardless shows

6. & 7. Core: Perchtoldsdorfer Dolomit in case of HC within the Dolomite body.

For the sidetrack one optional core of 18m length should be taken from the Perchtoldsdorfer Dolomit.

**Testing**

An MDT should be conducted in the Reyersdorfer Dolomit, the Hornsteinkalk, as well as in the Perchtoldsdorfer Dolomit.

Also, in Str T5a a MDT should be conducted in the main target.

An XLOT was planned in the upper part of the 12" and 8 ½" section. [61]

**Mud logging**

A mud logging – Unit should be used from spud.

## 5.2 Realization of Strasshof T5

The well Str T5 was drilled in winter 05/06 from a new location, close to the well ST11. Unlike Str T4, this well was not drilled by OMV´s well experienced personnel. Instead, OMV commissioned the company KCA Deutag to do the drilling. According to the 'Well Test Report, Strasshof Tief 5a' it appeared that the rig crew was less skilled.

### 5.2.1 Drilling

Drilling lasted from December 13 to March 28, 2006. [63] An overview of the completion scheme and comparison to the initially planned design is listed in Table 31.

Table 31: Completion Scheme of Str T5

| 1st Section | | Planned | Realized |
|---|---|---|---|
| conductor | | **18 5/8** | **18 5/8** |
| bit | | 24" | 24" |
| MD | [m] | 0 - 600 | 0- 659 |
| Cementation: | | | |
| cement | | CG 275 | |
| Spec. Weight | [kg/l] | 1.6- 1.86 | Lead 1.6; Tail 1.86 |
| Cement Amount | [m³] | | Lead 85; Tail 15 |
| Plug pumped | [bar] | | |
| cement elevation | [m] | cemented to surface | 15m³ to surface |
| Date | | | |

| 2nd Section | | Planned | Realized |
|---|---|---|---|
| Surface casing | | **13 3/8** | **13 3/8** |
| bit | | 17 ½ | 17 1/2 |
| MD | [m] | 0-2900 | 0-2697 |
| Cementation | | | |
| cement | | CG 275 Foam | |
| Spec. Weight | [kg/l] | 1.34 | Lead, Tail: 1.8 |
| Cement Amount | [m³] | | Lead: 4m³; 103 unfoamed =143 foamed; Tail:6 |
| Plug pumped | [bar] | | |
| cement elevation | [m] | TOC 100m above the 18 5/8 casing shoe (500m) | TOC 220 (measured) |
| Date | | | |

| 3rd Section | | Planned | Realized |
|---|---|---|---|
| Intermediate casing | | **9 5/8** | **9 5/8** |
| bit | | 12 | 12 |
| MD | [m] | 0-4300 | 0-4400 |
| Cementation: | | | |
| cement | | CG 275 Foam cement | |
| Spec. Weight | [kg/l] | 1.8 | Lead:1.55, Tail:1.85 |
| Cement Amount | [m³] | | Lead: 52; Tail 5 |
| Plug pumped | [bar] | | 160 |
| cement elevation | [m] | TOC 100m above 13 3/8 casing shoe (2650m) | TOC 2475 |
| Date | | | |

| 4th Section | | Planned | Realized |
|---|---|---|---|
| Liner | | **7** | **7" liner** |
| bit | | 8 1/2 | 8 3/8 |
| MD | [m] | 0-5000 | 4279-5435 |
| Cementation | | | |
| cement | | gas- tight silicalite cement | Squeeze cementation |
| Spec. Weight | [kg/l] | | 1.8 |
| Cement Amount | [m³] | | |
| Plug pumped | [bar] | | |
| cement elevation | [m] | TOC 100m above 9 5/8 casing shoe (4300m) | |
| Date | | | |

**Limitations and Occurrences while Drilling**

The 17 ½“ section was drilled vertically to a depth of 800m. Suddenly the pressure increased from 187bar to 230bar, due to a defect DP-sieve. This was followed by another sudden pressure increase, leading to a total breakdown of the MWD.

From 1344m to 2091m MD repeated pressure fluctuations were observed due to a defect of the downhole motor. (The Rotor Catcher was totally eroded, the upper connection of the motor had loosened, and three bit nozzles were plugged with rubber pieces of the stator).

At 2421 another failure of the new downhole motor occurred and necessitated another motor changed. During drilling down to TD of the 17 ½” section (2697m) repeatedly motor problems occurred. In addition, problems with the HGNS tool required four logging runs.

During drilling of the 12” section to 3280m, problems with the mud pumps, occurred repeatedly. However, the type of problems is not specified within the ‘Final Well Report, Strasshof Tief5/5a’.

While coring, the ROP was unacceptable. After two meters the operation was aborted and the drill string was pulled out of the hole. The core catcher showed serious harm and some pieces remained in the borehole. (Only 1m was recovered.) To remove this debris a 12” bit with a Junk Basket was run in hole. When reaching 3285m MD it was tried to extract a second core. However, again only 1.3m core were recovered (3285-3287m). It was assumed that jamming of the core was the cause of the breakdown.

When drilling down to 4400m (TD of the 12” section) several incidents occurred. At frequent intervals, of about 50m, the BHA had to be changed due to very low performance. PDC bits and the stabilizers repeatedly showed heavy wear and tear. Furthermore, the MWD signal was repeatedly interrupted and slow mud losses were frequently observed. (At 4099m increased strike and slip appearances were observed.)

Subsequently, four logging runs were conducted and the 9 5/8” and a FIT was conducted.

When drilling the next meters, a slight inflow was observed. Therefore the MW was increased from 1.12kg/l up to 1.14kg/l. The reversed out gas showed peaks up to 98%.

Within this section again an 8 3/8” coring assembly was twice run into the well. A 9m and an 8.5m core were recovered between 4630 and 4639m, and 4815 and 4824m depth respectively. When pulling out the coring assembly of the first core, a slight influx was observed. Therefore, the MW was increased to 1.17kg/l.

The bit had to be changed repeatedly due to a continuously decreasing ROP. From a depth of 4990m down to TD of 5435m, increased caving was observed.

When trying to run the wireline tool to TD, the tool stood up twice at a depth of 4989m. Also the reamer could not pass the depth of 4980m. During the following wiper trips a discharge at the shale shaker was observed. To measure the 8 3/8” section a Logging While Drilling (LWD) tool was used. Again resistances and pressure fluctuations were detected, resulting in upwards logging of the formation pressures.

After logging, a second reamer trip was conducted. At 4704m the bit stood up for the first time. Due to the observed caving, the MW was increased to 1.25kg/l. When pulling the drill string out of the well, it became stuck twice at 5027m and 4910m. The following trip out of the drill string and running in the 7” Liner occurred without any incidents, apart from the Liner becoming stuck at 4980m. However, this problem was solved quickly by circulating and rotating the Liner till it reached TD.

Setting and releasing of the setting tool was associated to several problems, e.g. sudden pressure increases, including lost circulation. During this operation circulation was not possible. Also, heavy discharge of the shale shakers was observed.

Due to the problems described above, it was impossible to cement the liner. A CBL measurement was conducted to evaluate the location where the hole sealed off.

Afterwards two intervals (from 5000-5002m and from 5393-5395m) were perforated to conduct a squeeze cementation. When circulating out, 10m³ mud- cement mixtures were produced.

The casing was pressure tested and evaluated to be tight. Further Cement Bond Log (CBL) measurements were conducted to test the quality of the cementation. After a Vertical Seismic Profile (VSP) measurement was executed, the liner head was pressure tested with 150bar. [63]

### 5.2.2 Drilling Mud

The mud system used for each section is listed in Table 32.

Table 32: Mud System

| Section | Planned | Realized |
|---|---|---|
| 24” section | $K_2CO_3$<br>SG< 1,12 | $K_2CO_3$ |
| 17 ½” section | $K_2CO_3$/ Glycol<br>SG< 1,12 | $K_2CO_3$ |
| 9 5/8” section | $K_2CO_3$/ Glycol<br>SG: 1,1-1,25SG | $K_2CO_3$ |
| 8 1/2” section | $K_2CO_3$/ Glycol<br>SG: 1,12-1,3 | $K_2CO_3$ |

When running in the 13 3/8" casing down to 2694m about 28m³ drilling mud were lost. [63]

### 5.2.3 Formation Evaluation while Drilling

#### 5.2.3.1 Cuttings

A set of washed and dried samples was collected with a spacing of 10 m from 590 to 660m. After setting the 18 5/8" casing the sampling interval was increased to a spacing of 20m, until a depth of 1800m MD. Down to 2600 m MD samples were again collected with 10m spacing, followed by a spacing of 5m down to TD. Additional spot samples were collected based on well site geologist decision and HC shows.

#### 5.2.3.2 Cores

Five liner cores, each planned to be 18m long, were taken. The core description is summarized in a detailed LAB – core report. According to this, the reservoir properties are abstracted in Table 33.

All cores showed similar reservoir properties, having a very low matrix porosity, which decreased with depth. The only visibly effective porosity was fracture porosity.

The first Core was taken from the Bockfliesser Schichten to establish the seal rock properties. Furthermore, its purpose was to get fresh shale reference material in order to obtain undisturbed samples to perform a proper petrophysical and chemical testing program.

From the Reyersdorfer Dolomit two cores were taken. The core recovery of both cores was relatively poor, especially of core#2 due to a heavily damaged core catcher. Partially, only broken core fragments came up. Some larger fragments were recovered and showed sedimentary beddings with dips of approximately 75 to 80°.

Core #4, recovered from the Liassic Hierlatzkalk, shows very frequent calcite veins and stylolites, horizontally and vertically oriented. The matrix mainly consists of very tight limestone interrupted by some large vugs and a few large and open fractures. The fractures are still open or evidenced by calcite crystals. Analysing zones with large fractures was impossible. Within this core some oil droplets were found. [64]

From the uppermost part of the Perchtoldsdorfer Dolomit one core, core#5, was recovered. The dolosparit matrix was identified to be nearly completely tight.[65]

Table 33: Coring Program of Strasshof T5 [64]

| Coring Program | Planned | Realized |
|---|---|---|
| Lithology | Bockfließer Schichten | Bockfliesser Schichten |
| Depth | | 2701-2719m |
| Recovery | 18m | 18.15m (100%)<br>A Fiberglas Core Barrel was RIH and POOH when it was assumed to be full |
| Porosity | | |
| Lithology | Reyersdorfer Dolomit | Reyersdorfer Dolomit |
| Depth | | 3280-3282m |
| Recovery | | 0.9m<br>Recovery: 1m: due to a heavily damaged core catcher (partly remained in the well) |
| Porosity | | 0,4-3,6% (higher porosities are probably influenced by micro fractures |
| Matrix porosity | | ~0,7% |
| Permeability | | 0,003-0,004mD |
| Lithology | Reyersdorfer Dolomit | Reyersdorfer Dolomit |
| Depth | | 3285-3287 |
| Recovery | | 1.6m respectively 1.3m |
| Porosity | | 0.4-3.6% (higher porosities are probably influenced by micro fractures |
| Matrix porosity | | ~0.7% |
| Permeability | | 0,003-0,004mD |
| Lithology | Hornsteinkalk | Hierlatzkalk |
| Depth | in case mud losses occur- | 4630-4639.18 |
| Recovery | forebear from taking the core | 9.18m |
| Porosity | | 0.2-.03% |
| Permeability | | Very low |
| Lithology | Top Perchtoldsdorfer Dolomit | Perchtoldsdorfer Dolomit |
| Depth | | 4815-4824m |
| Recovery | | 8.7m |
| Porosity | | 0.1-.06% |
| Permeability | | 1.6-35.1mD |
| Lithology | 6. Perchtoldsdorfer Dolomit | |
| Depth | | |
| Recovery | only if HC show | |
| Lithology | 7. Perchtoldsdorfer Dolomit | |
| Depth | | |
| Recovery | only if HC show | |

#### 5.2.3.3 Logging

Logging of the Reyersdorfer Dolomit (3245-4370m MD) was performed in two separate runs. The upper dolomite body, is illustrated in Figure 18. According to the log, the formation is very tight. The water saturation is less than 100% apart from a few exceptions, which are more likely to be caused by artefacts of the logs, than by the actual formation. The net thickness equals 1.4m. Via MDT a water gradient of 1.01kg/l was revealed.

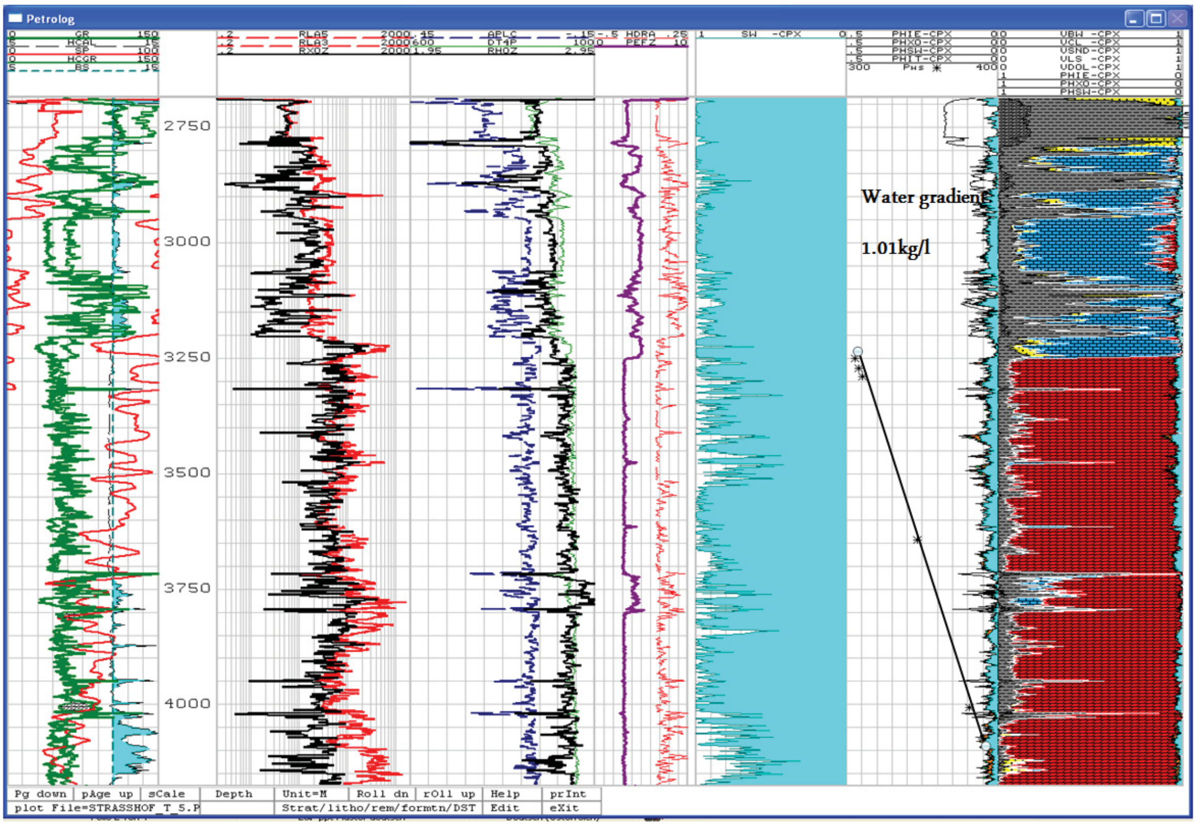


Figure 19: Well Logs conducted in Str T5 of the Reyersdorfer Dolomit [28]

The lower Reyersdorfer Dolomit is part of the 8 3/8” section. However, this area is only partly illustrated. Figure 18 shows the top of the lower dolomite body and the bottom is demonstrated in Figure 19. The former figure clearly illustrates that the resistivity logs are separating and that the water saturation is reduced, indicating better reservoir properties.

The lower Reyersdorfer Dolomit has several thin intervals of HC bearing sections. The computation was based on the assumption that gas is present, but it might be oil. The net thickness accounts to 5.6m.

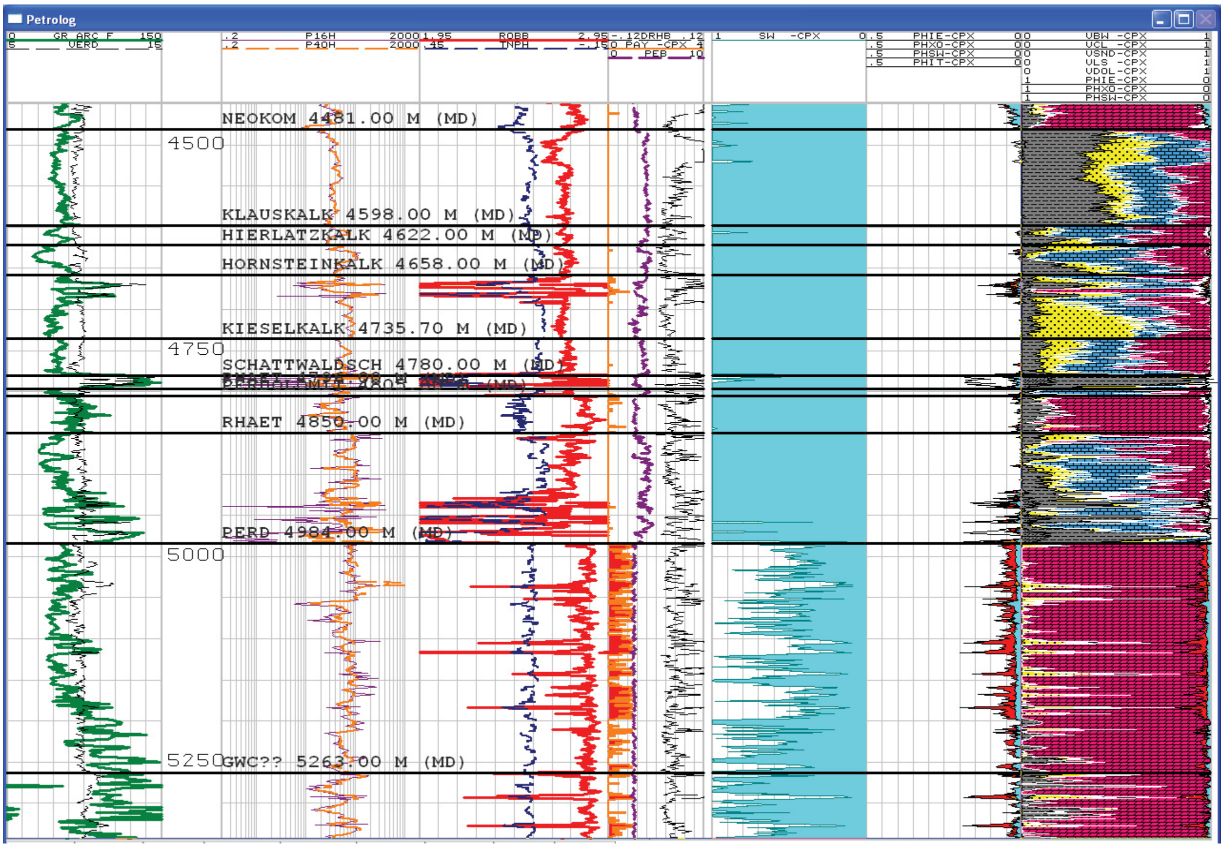


Figure 20: Well Log conducted in Str T5 from 4450 to 5350m MD [28]

The formation of the lowest section was only measured via LWD and therefore, provides less information. The log interpretation appears as a tight formation, which is almost entirely water bearing. Some porosity log crossovers are noticeable.

The Hierlatzkalk showed only very little indications of HC. The better reservoir is the Hornsteinkalk.

The Rhaet Dolomit is separated into two sections. Within the upper section a clear separation of the density logs can be seen. It has three thin sections where HC shows. The lower section from 4850 to 4984m has many thin indications of HC.

The second Perchtoldsdorfer Dolomit was the main target of the well. The computation was made with the assumption that gas is present. According to the 'Final Well Report, Strasshof T5' a HC-Water contact was encountered at 5263m MD due to a crossover of the resistivity logs. However, it was assumed that the logs and subsequently their interpretation were incorrect. However, the interpretation resulted in a net thickness, of 74.3m. (LWD) [64]

**Interpretation Results**

According to the presentation 'Loginterpretation, Straßhof Tief field', the following cut off values were defined:

| | |
|---|---|
| Water Saturation | 50% |
| Shale volume | 30% |
| Porosity | 0% |

The results of the interpretation are summarized in Table 34.

Table 34: Log Interpretation Results, Str T5

| Formation | Depth Top | Depth Bottom | Average $\phi$ | Average $S_w$ |
|---|---|---|---|---|
| | [m] | [m] | [%] | [%] |
| Reyersdorfer | 3245 | 3715 | 6 | <100 |
| Reyersdorfer | 3790 | 4370 | 4-8 | 29-48 |
| Hierlatzkalk | 4598 | 4622 | 3 | |
| Hornsteinkalk | 4465 | 4658 | 4-6 | 29 |
| Rhaet | 4850 | 4984 | 4 | 26 |
| Perchtoldsdorfer | 4850 | 4984 | 3-6 | 28-47 |
| Perchtoldsdorfer | 4365 | 4400 | 6 | 30 |

### 5.2.3.4 Borehole Imaging and Fracture Identification

According to report 'Formation Image Interpretation Report', penned in May 2006, Schlumberger's FMI and UBI were also used within the well Str T5. The Image was interpreted by Fronterra Integrated Geosciences Inc. The FMI was run and interpreted from 2,683.9m to 4,402.5m, respectively form the Bockfließer Schichten down to the Reyersdorfer Dolomit. The UBI only ran within the Reyersdorfer Dolomit, from 3,193.84m to 3,509.6m in order to better characterize the fracture system within this interval.

Distinct fault planes are rarely imaged, due to the extremely complex structure within the Str T5 together with the relatively uniform lithology of the reservoir rock. Instead, the intersection of faults, which are commonly associated with considerable brecciation and shearing of the rock, resulting in boudinage features and low angle glide planes, are identified. Tectonofacies classes of breccias and boudinage are of particular interest, because these facies may represent intervals of increased fracture porosity.

Overall, four distinct structural units have been identified within the imaged section, whereof each unit was internally divided by numerous faults. The dip angles within each structure unit show a gradual increase from the base towards the top. Numerous dip magnitude changes and dip reversals, suggest additional frequent small scale faulting.

In total, 66 faults appeared within the logged section. Whereof, 10 open and 26 closed and cemented faults, with dip angles above 45°, were identified. They were related to the overall strike of the structure and thrust faults. Furthermore, 30 faults with dip angles below 45° were indentified, which are related to the dominant fault orientation, NW- SE. Faults, striking form WSW to ENE, represent the strike of tension fractures and will be the best candidates together with NNE- SSW striking fractures to form conduits in the reservoir. NNW-SSE and NW-SE striking fractures are probably closed shear fractures, which are possibly filled with gouge material.

The lack of directly observed thrust faults might be explained by the degree of rock brecciation, which resulted in relatively long intervals without identifiable bedding and fractures.[66]

#### 5.2.3.5 Pumping Pressure Tests

According to the 'Intent to Drill, Str T5' two FIT and one XLOT were carried out.

Table 35: Pumping Pressure Test, Str T5 [59]

| Test | Location | Mud Weight [kg/l] | Leak off Pressure [bar] | EMW [kg/l] | Pressure Gradient [bar/10m] |
|---|---|---|---|---|---|
| FIT | below 18 5/8" Casing | 1.10 | 26 | 1.50 | |
| XLOT | below 9 5/8" Casing | | | | 1.84 |
| FIT | below 7" liner | 1.12 | 207 | 1.6 | |

### 5.2.4 Completion and Testing

Accessibility of reports about completion operations of Str T5 is limited. Only the 'Well Test Report, Strasshof Tief5' was available.

#### 5.2.4.1 Mud Losses While Completion

Mud losses of 25m³ during testing were reported.[ 67]

#### 5.2.4.2 Testing

Two drill stem tests (DST) were conducted within the Perchtoldsdorfer Dolomit in May/June 2006. Three intervals within the main target were perforated underbalanced and subsequently tested. (Table 36).

Table 36: Perforation intervals of the well Str T5

| Formation | Perf. Interval MD [m] | Date of Perf. | Annotation |
|---|---|---|---|
| Perchtoldsdorfer D. | 5275-5285 | 05/18/2006 | DST#1 |
| Perchtoldsdorfer D. | 5050-5060<br>5068-5080 | 05/24/2006 | DST#2, DST#2a |

The first DST started immediately after perforation, on May 19, 2006. During the short shut in period of 75min the BHP increased from 240bar to 288bar. Subsequently, the choke manifold was opened and pressure decreased to 0bar in 1½ hours. Throughout the following shut in period the pressure build up was observed. The BHP's were recorded at 5245.7m MD. (Table 37). The pressure history is illustrated in Figure 20.

Table 37: Tubing pressure evaluated by testing [67]

| Key Tubing Pressure | [bar-g] |
|---|---|
| Initial Hydrostatic BHP | 585.07 |
| BHP after Perforation | 375.10 |
| Final BHP Initial Flow (Choke Manifold closed) | 491.65 |
| Minimum BHP (after bleeding off N2 cushion) | 267.37 |
| Final BHP | 506.57 |
| Final Hydrostatic BHP (after reverse circulation) | 583.92 |

A total of approximately 16m³ mud filtrate, completion brine, and formation water were recovered by reverse circulation.

A bridge plug was set at 5223m MD and was pressure tested for 150bar-g, in order to ensure that the perforation interval was isolated. On May 24, the last two perforations were conducted, roughly 200m above the first one. The pressure increase after perforation equalled 1bar/min.

Subsequently, DST#2 was conducted. Due to behind pipe channelling via technical perforation it was decided to retry the test. Therefore the packer was set above the upper technical perforation. The gas production rates during the second test were too low to be measured. The produced liquid was identified as mud from the annulus.

On May 27, DST#2a was initiated. After the initial flow and pressure build up period (05/27/2006) the well was stimulated with 25m³ of 28% HCl to improve well deliverability. The results are summarized within the chapter Acid Stimulation.

Afterwards, five main flow and pressure build up periods were conducted. The well was opened to flow at 7:30 a.m. and shut in at 6:30 p.m. as flaring was limited to 12 hours per day. Due to the short shut in time, stable flowing conditions could not be achieved.

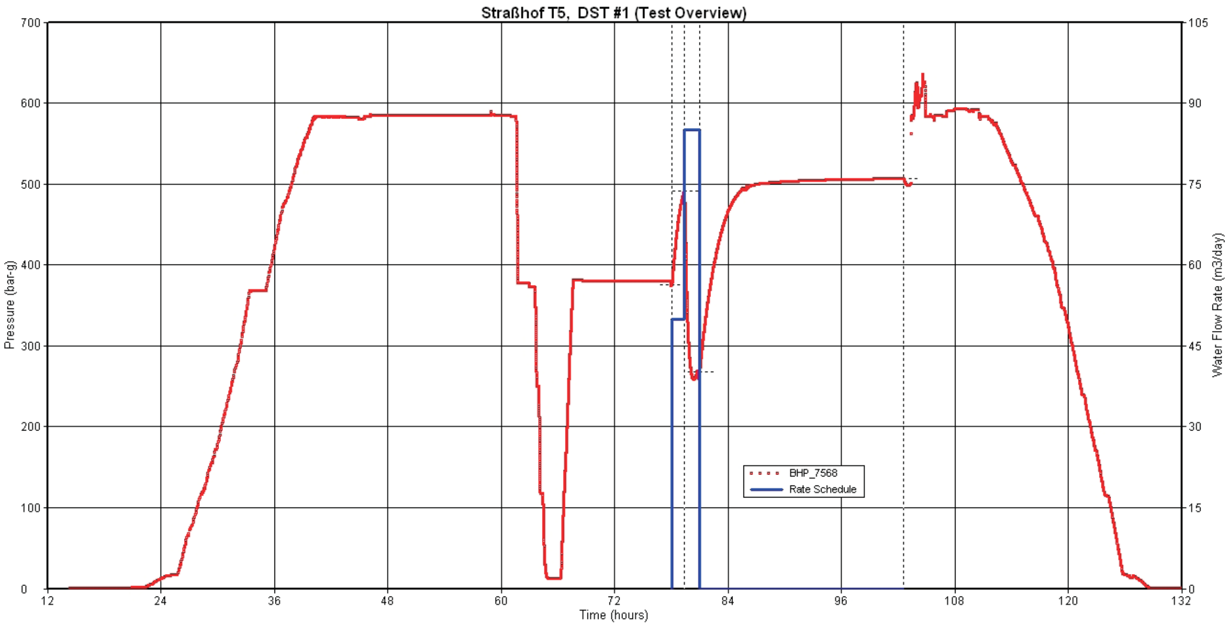


Figure 21: 1. Production test [67]

During the first main flow period, gas was produced at a rate of 550,000m³-Vn/d on a fixed choke of 40/64". Due to a limited production rate of 480,000m³-Vn/d, a 36/64" fixed choke was used during the following four flowing periods.

At the end of each flowing period the gas rate was less than 450,000m³-Vn/d. The FWHP dropped from 195bar-g to approximately 180bar-g. Also, liquid flow rates constantly decreased throughout the test, except for the final flow period the rate stabilized at around 25m³/d. The corresponding liquid-gas ratio (LGR) equalled 58m³/MMm³-Vn (0.058 l/m³).

During the shut in periods, the final WHP decreased from 353bar-g, before the first main flow period to 328bar-g, prior the fifth main flow period.

While testing, the gas flow rates were constantly measured and recorded electronically. The average liquid flow rates were estimated exclusively by manual surge tank readings every 30 minutes. The final BHP, measured by Memory Gauges at 4955.52m MD, constantly dropped with each period, although flow rates were relatively constant during the last four flow periods. At the end of the last PBU period the BHP was still rising linearly by 0.25bar/h.

BHP and gas flow rates of DST #2a are illustrated in Figure 22. Whereof, the recorded key BHP's are summarized in Table 38 and the main flow data are listed in Table 39.

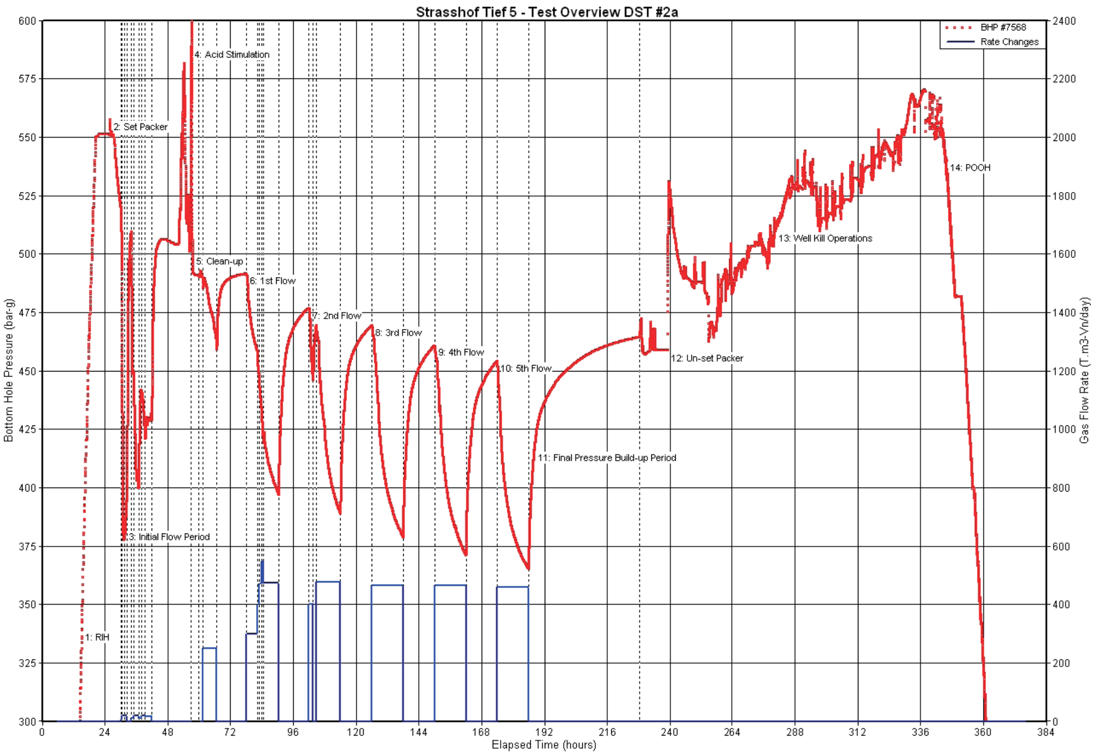


Figure 22: DST#2a pressure history [67]

Table 38: Key pressures of Str T5 [67]

| Key Tubing Pressure | [bar-g] |
|---|---|
| Initial Hydrostatic BHP | 551.45 |
| Final BHP Initial Flow | 428.97 |
| Maximum BHP during Acid Stimulation | 599.65 |
| Final BHP Clean- up Flow Period | 459.39 |
| Final BHP Initial Pressure Build-up period | 491.66 |
| Final BHP First Main Flow Period | 396.63 |
| Final BHP First PBU period | 476.88 |
| Final BHP Second Main Flow Period | 388.70 |
| Final BHP Second PBU period | 469.55 |
| Final BHP Third Main Flow Period | 378.63 |
| Final BHP Third PBU period | 461.06 |
| Final BHP Fourth Main Flow Period | 371.16 |
| Final BHP Fourth PBU period | 454.18 |
| Final BHP Fifth Main Flow Period | 364.99 |
| Final BHP Final PBU period | 464.53 |
| Final Hydrostatic BHP | 553.28 |

At the end of the fifth shut in period, a pressure gradient survey was run. It showed that the test string was entirely filled with gas. A pressure gradient of 0.024bar/m was derived and a BHP of 467bar-g was measured on top of the perforation.

Electronic memory gauges were positioned at 5245.7m MD for the first DST, at 5022.67m MD for the second one, and at 4955.52m MD during DST2a. Four gauges were used for each test, whereas one gauge failed during the last test. Comparison of the absolute pressure readings of the gauges, showed nearly identical pressure measurements throughout the entire testing period.

Table 39: Comparison of the Test Data [67]

| Test Data | Unit | 05/27 17:05 | 05/29 17:40 | 05/30 17:45 | 05/31 17:45 | 06/01 17:45 | 06/02 17:45 |
|---|---|---|---|---|---|---|---|
| Choke Size | Inch | 28/64 | 36/64 | 36/64 | 36/64 | 36/64 | 36/64 |
| Gas Rate | $m^3$-Vn/d | 14.845 | 460.271 | 460.231 | 450.562. | 445.323 | 435.036 |
| Liquid Rate | $m^3$/d | 79.4 | 51.4 | 32.1 | 17.6 | 26 | 24.4 |
| LGR | l/$m^3$ | 5.349 | 0.112 | 0.070 | 0.039 | 0.058 | 0.056 |
| FBHP | barg | 429.4 | 399.2 | 389.5 | 379.4 | 371.7 | 365.4 |
| FBHT | °C | 145.0 | 148.3 | 148.5 | 148.6 | 148.5 | 148.5 |
| FWHP | barg | 134.2 | 185.2 | 183.9 | 179.7 | 179.1 | 174.4 |
| FWHT | °C | 21.7 | 35.9 | 34.8 | 34.9 | 37.1 | 32.8 |
| Draw Down | Bar | 64.7 | 94.9 | 104.6 | 114.7 | 122.4 | 128.7 |
| PI | $m^3$/d/bar | 229 | 4.850 | 4.4 | 3.928 | 3.638 | 3.380 |
| Separator p. | Barg | 17.8 | 20.2 | 15.4 | 15.2 | 15.3 | 14.4 |
| Separator T. | °C | 47.3 | 59.7 | 59.4 | 56.8 | 58.3 | 56.3 |
| G Liquid (water=1) | | 1.15 | 0.81 | 0.86 | 0.84 | 0.82 | 0.81 |
| G gas (air=1) | | 0.70 | 0.71 | 0.71 | 0.71 | 0.71 | 0.70 |
| H2S | ppm | 5 | 21 | 22 | 20 | 20 | 22 |
| CO2 | % | 8 | 12 | 12 | 12 | 12 | 12 |
| Daily Gas Prod. | $m^3$- Vn | 5 | 225 | 200 | 200 | 200 | 225 |
| Daily Liquid Prod. | $m^3$ | 21 | 24 | 14 | 15 | 14 | 13 |
| Cum. Gas Prod. | $m^3$- Vn | 5 | 275 | 475 | 675 | 875 | 1100 |
| Cum. Liquid Prod. | $m^3$ | 21 | 63 | 77 | 92 | 106 | 119 |

During DST#2a roughly 1.1 MM$m^3$-Vn gas and 119$m^3$ liquid, with some paraffin, were produced. During testing continuous annulus losses were recorded. All together, about 25$m^3$ fluids were lost into the formation.

OMV LEP personnel collected fluid samples throughout testing. [67]

#### 5.2.4.3 Well test interpretation

For the interpretation of the bottom hole data, the full rate history was taken into account. Additional input parameter used, are summarized in Table 40.

Table 40: Input Parameter [67]

| Parameter | Unit | Value | Source |
|---|---|---|---|
| Formation Thickness | m | 73 | Log Interpretation |
| Average Formation Porosity | % | 5 | Log Interpretation |
| Water Saturation | % | 37 | Log Interpretation |
| Layer Pressure (@ gauge depth] | bar-g | 400 | Gauge Reading |
| Layer Temperature (@ gauge depth) | °C | 120 | Gauge Reading |
| Gas Specific Gravity (air=1) | - | 0.65 | Produced Gas Sample |
| Water Salinity | ppm NaCl | 60,000 | MDT Water Sample |
| Rock Compressibility | $bar^{-1}$ | $8.5*10^{-5}$ | Correlation |
| Total System Compressibility | $bar^{-1}$ | $1.8*10^{-3}$ | Correlation |

The PBU period of DST#1 is illustrated in Figure 22, showing that all early time effects on the log-log plot are masked by wellbore storage effects.

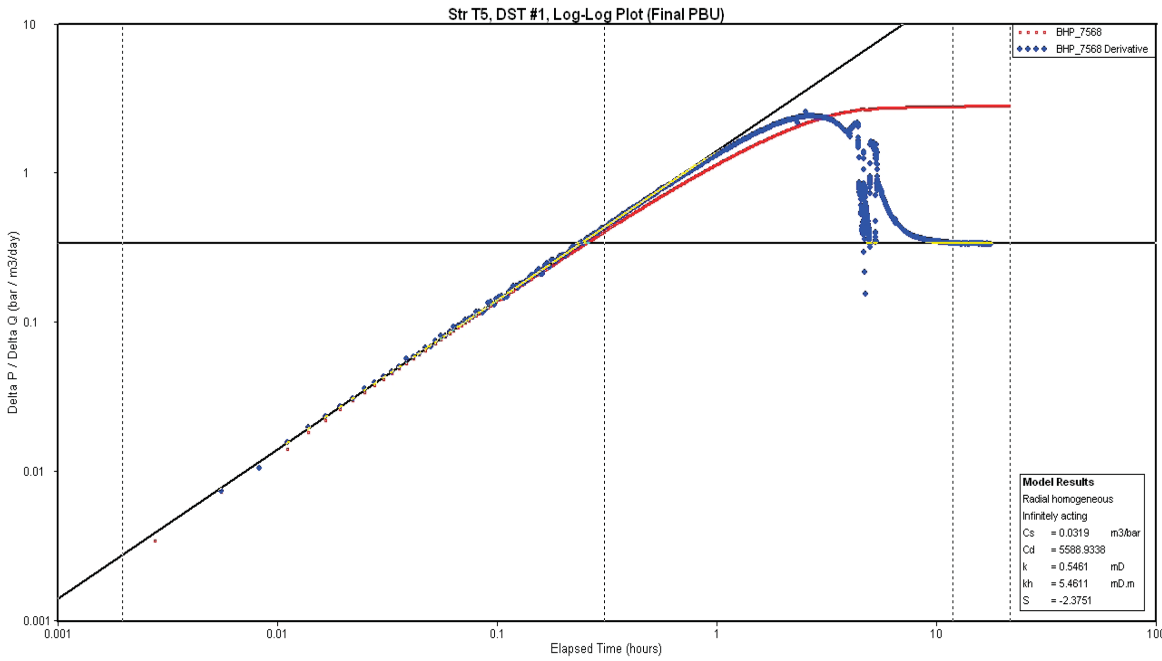


Figure 23: DST #1, Str T5 [67]

After 10 hours the pressure derivative, given by the blue line, showed a clear zero slope, indicating a radial flow regime. (The zigzag of the derivative was caused by slick line operations.)

From radial flow regime k*h was calculated and resulted in a value of 5.5md*m (based on 10m net pay). A total skin factor of -1.3 was derived. No outer flow boundaries could be identified from the Log-Log plot. A reservoir pressure (p*) of 505.5bar-g was extrapolated at a gauge depth from radial flow.

The derived permeability thickness indicated a relatively tight matrix. According to production behaviour, the flow is mainly enabled by some open fractures. However, no linear flow regime was identified within the Log-Log plot.

During DST#2a all “PBU curves” of the Log-Log Plot were nearly identical for the first 12 hours, except the initial post clean- up PBU. However, the initial PBU is not considered to be representative. Figure 23 illustrated the Log-Log plot of the final PBU.

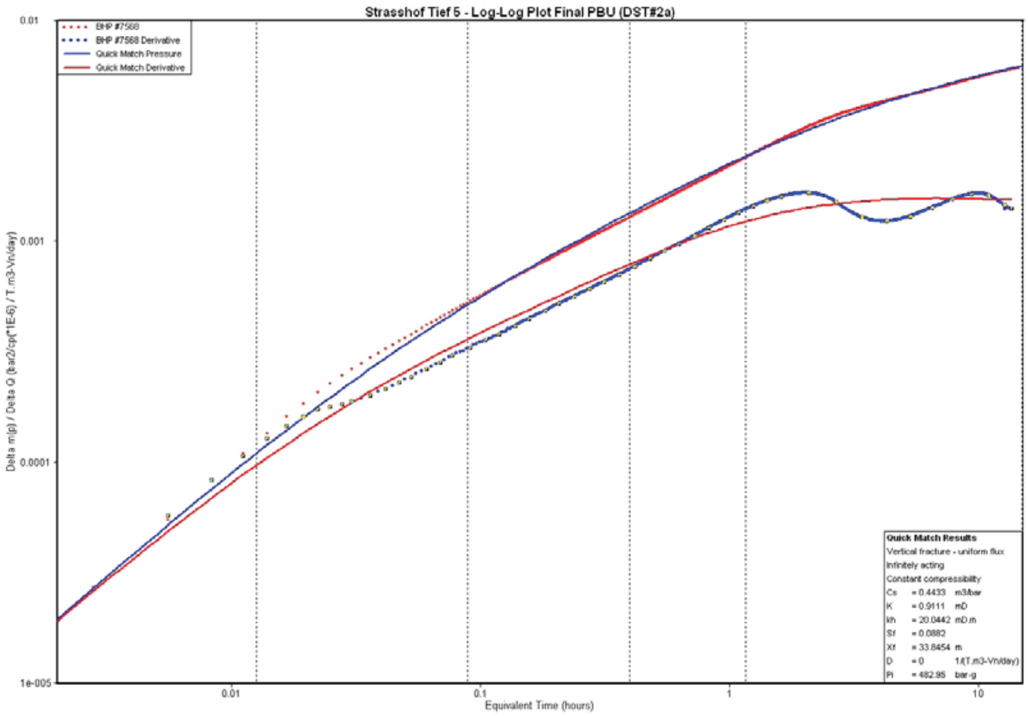


Figure 24: DST# 2a, Str T5 [67]

Within the first log cycle, wellbore storage effects are dominating. Then the trend of the pressure derivative, the blue dotted line or the red continuous line, followed a half- unit slope, indicating linear flow. After one hour, the derivative became horizontal, indicating a radial flow regime. Thereof, a permeability thickness (k*h) of 20mD*m and a total Skin Factor (S) of -4.7 were calculated. In this case, the outer flow boundaries could not be identified on the Log-Log plot.

A vertical fracture flow model fits the observed pressure response best. However, apart from the dominant natural fracture, the apparent linear flow may result from behind- pipe inflow from reservoir parts outside of the perforation.

However, with the reservoir parameter derived from the pressure match of the final PBU, the distinct constant BHP- drop is not fully reproduced. From the initial PBU, just after stimulation, a reservoir pressure of 494.1bar-g was extrapolated. From the radial flow regime of the final PBU a reservoir pressure of 481.6bar-g is extrapolated. With the pressure gradient of 0.024bar/m an extrapolated formation pressure of 496.4bar-g is calculated.

Due to the calculated Radius of investigation of 190m, the existence of flow boundaries at a further distance cannot be excluded. Stable flowing conditions could not be achieved, therefore analysis of rate-dependent skin and well deliverability do not provide valid results. Furthermore, a semi- steady state flow regime was not reached throughout testing; consequently a meaningful connected gas volume could not be derived from test data. The material balance calculation with the apparent pressure depletion resulted in an OGIP of 44.5MMm³-Vn.

Also, this test indicates a tight formation with some open natural fractures. The linear flow regime may result in a dominant frac or behind-pipe inflow. The formation was not assumed to be damaged.

The pretended pressure depletion from production indicates a possible compartmentalization of the reservoir.

Overall, the pressure response of Str T5 is similar to the one observed during testing Str T4, within the same formation. [67]

#### 5.2.4.4 Fluid Sampling and Analysis

During testing operations fluid samples were continuously collected by the OMV Laboratory for Exploration & Production. BHS were not taken during testing.

Fluid samples taken at the end of DST#1 contained formation water, diluted with mud filtrate and little amounts of completion brine. Liquid HC were not observed within the liquid samples.[67] The least contaminated sample was used for comparison with samples from Str T4, indicating that the samples originated from different reservoirs, due to the evaluated Lithium and Boron content. No specific information about salinity and ionic distribution could be gained due to the strong chemical dilution. [68]

During DST#2 and 2a several gas and liquid samples were taken at the choke manifold and separator, at the end of each flow period. The gas composition remained constant for the last four days. The content of the gas sample, taken during the final flow period, is summarized in Table 41.

The produced liquids of DST #2/2a were identified as a mixture of HC's and water, whereof the samples of DST#2a, mainly consisted of cushion fluid, spent acid, mud filtrate and minor amounts of formation water. [67]

Table 41: Sample [67]

| Sample | DST#2a |
|---|---|
| Sample: | Straßhof T5 |
| Perforation | 5050-5060, 5068-5080 |
| | Vol% |
| Hydrogen Sulphide | 2.14 |
| Carbon Dioxide | 11.62 |
| Nitrogen | 0.84 |
| Methane | 81.36 |
| Ethane | 0.53 |
| Propane | 0.14 |
| Isobutane | 0.04 |
| n-Butane | 0.07 |
| Isopentan | 0.03 |
| n-Pentane | 0.03 |
| C6+ | 0.20 |
| Density (273.15K; 101.325kPa) kg/m³ | 0.902 |
| SG. (Luft=1) | 0.6529 |

#### 5.2.4.5 Acid Stimulation

The acid stimulation during DST #2a was very successful. 25m³ of 28% HCl were pumped in, at a rate of 140l/min, with a surface injection pressure of 350 bar-g. No annulus flow was observed during the stimulation operation. A constant WHP of 160bar-g was recorded. Afterwards, the acid was replaced by 700l water and nitrogen.

The well's deliverability was significantly improved due to this acid stimulation. The gas flow rate was clearly increased during the clean-up flow period. Looking at the production and pressure data (Table 38 and Table 39) the improved productivity, caused by the acid stimulation, is obvious.

Figure 24 shows the success of the acid stimulation and the declining inflow performance during the main flow period. [67]

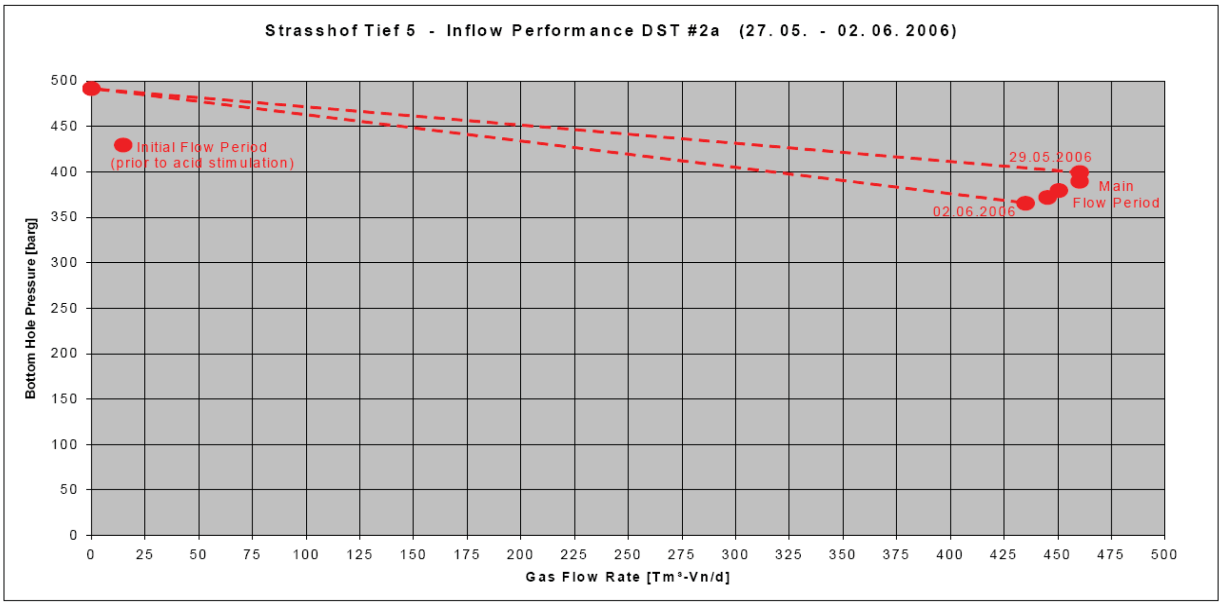


Figure 25: Inflow Performance Relationship, Str T5 [67]

### 5.2.5 Result

Overall, the well encountered 101.60m of possible HC pay within the Reyersdorfer Dolomit, Klauskalk, Hierlatzkalk, Hornsteinkalk, Rhaet and lower Rhaet, and the 2. Perchtoldsdorfer Dolomit. However, the net thickness was only 74.3m, instead of the required 100m.

Within the Reyersdorfer Dolomit additional HC were confirmed by MDT. The pressure was measured and show to be only 10bar below the initial pressure. A strong aquifer was established.

During drilling through the Hierlatzkalk/Hornsteinkalk, the secondary target, high gas readings were observed. However, it was not possible to conduct a bare foot test within this section, due to the water bearing base of the Reyersdorfer Dolomit in the test interval.

A core, taken from the Hierlatzkalk had some oil droplets in the open micro fractures. The porosities averaged approximately 0.5%. The Hornsteinkalk was confirmed to be the better reservoir part, with reservoir properties similar to the Hauptdolomit.

According to MDT and DST the primary target, the Perchtoldsdorfer Dolomit, was confirmed to be gas bearing. During testing gas rates of more than 500,000Nm³/d were achieved. However, after the well test was interpreted, it became obvious this rate would not be sustainable.

According to the Minutes of Meeting ‘Besprechungsprotokoll’, penned on May 31, 2006, the well Str T5 was planned to be a gas producer. The presence of oil should be verified with Str T6.[69]

However, the well was plugged back, due to a bad cementation job and sidetracked.

## 5.3 Realization of Strasshof T5a

Str T5a was planned to penetrate the Perchtoldsdorfer Dolomit in a structurally updip. The primary target was to assure an economical gas production. In addition the presence of HC within the Hierlatzkalk/Hornsteinkalk should be verified.

The sidetrack was already planned together with the original well Str T5. Due to experiences, while drilling the former well, the well program was modified and improved.

The well should be drilled to the bottom of the Hierlatzkalk/ Hornsteinkalk. Subsequent it should be tested, either via barefoot test or openhole test. Afterwards the drilling should be continued down to the Perchtoldsdorfer Dolomit. The logging program should be conducted as it was planned originally for Str T5. Subsequently the 7” casing should be run in and cemented according to the initial program.[ 70]

One 18m liner core with a diameter of 5 7/8” should be taken from the Perchtoldsdorfer Dolomit, about 30m below the 7” liner.

To ensure better temperature resistance adequate additives (Asphasol) should be added to the drilling mud.

The possibility of an Open Hole completion was considered, due to the high savings and the high production rates. [70]

Due to the test results of the well Str T4, an oil test of the Hierlatzkalk/Hornsteinkalk was recommended.[71]

### 5.3.1 Drilling and Drilling Mud

According to the report ‘Bohrabschlussbericht- Technischer Teil’ spud in date was the 26 of May in 2006.

An overview of the completion scheme and the comparison of plans and realization are listed in Table 42.

Before, the well has been plugged back. The top of cement was at 4360m, about 38m above the casing shoe of the 9 5/8” casing. The initially planned kick off point (KOP), at a depth of 3200m, was adjusted downwards to a depth of 4435m.

Unfortunately, several tries to kick off did not succeed. Therefore an open hole whip stock was set at 4521m and cemented. Finally the operation was successful and the sidetrack was drilled down to 4747m MD. Subsequently the well was logged, before reaching the instable shale zone, known from the prior well.

Table 42: Completion and Cementing Scheme of Str T5a

| Completion | | Planned before Str T5 | Planned after Str T5 | Realized |
|---|---|---|---|---|
| KOP | [m] | ~3200 | 4434 | 4520 (whip stock) |
| TD | [m] | 4500 | 5525 | 5400/ 5140 |

| Liner | | 7" | 7" | 7" |
|---|---|---|---|---|
| bit | [in] | 8 ½" | | 8 3/8" |
| MD | [m] | 3150-4500 | bis 4900m | 4243-4985 |
| **Cement** | | | | |
| cement | | | | |
| Spec. Weight | [kg/l] | | | 1,98 |
| Cement amount | [m³] | | | 14 |
| Plug pumped | [bar] | | | 143 |
| cement elevation | [m] | | | 4243 (TOC: 4585) |
| Date | | | | |

| Liner/OH | | 4 ½" | OH | |
|---|---|---|---|---|
| bit | [in] | | | 5 7/8" |
| MD | [m] | 4800-5550 | 4800-5550 | 4987- 5400 |
| **Cement** | | | | |
| cement | | | | |
| Spec. Weight | [kg/l] | | | |
| Cement amount | [m³] | | | 4 |
| Plug pumped | [bar] | | | - |
| cement elevation | [m] | | | 5144 |
| Date | | | | |

| 7"Tie back liner | | 7" (alternativ) | | 7" Tie back |
|---|---|---|---|---|
| bit | [in] | | | - |
| MD | [m] | 0-3150 | | 0-4243 |
| **Cement** | | | | |
| cement | | | | |
| Spec. Weight | [kg/l] | | | 1.98 |
| cement elevation | [m] | | | |
| Date | | | | |

Afterwards it was decided to conduct an drill stem straddle-test of the supposed Hornsteinkalk (DST#1) in the open hole section. (The tested formation was later on geologically revised to Rhaet Dolomit- the Hornsteinkalk was not encountered within this well.) To test Str T5a the well was opened to flow for about 5 hours. A gas rate between 7,000 to 8,000m³/h was achieved. Afterwards the well was killed with a drilling mud with a density of 1.18kg/l. When pulling out the test string it was observed that a piece of a centralizer was missing. (Furthermore information about the test is reported below.)

However, drilling was resumed and the well was drilled to 4984m MD without unforeseen occurrences. Subsequently the liner was run into the hole and the liner hanger was set at 4251m. The casing was cemented according to completion scheme. However, several attempts to pull out the drill string failed. Hence, the decision was made to pull out the liner. During this operation the liner was loosened from the kick over tool and fall back on the cement head (4585m MD). The liner could not be pulled out until a 7" releasing spear was used. After that the cement was drilled through down to 4,987m. To ensure that the 9 5/8" casing was free of cement a flat-bottom mill with a scraper was run into the hole to 4345m MD.

A new 7" liner was run into the hole down to 4,985m and was set at 4243m MD (liner top). During the following cementation the plug was bumped with 18bar above the last pumping pressure. The drill string and the kick over tool were pulled out without any incidences.

After the Blow Out Preventer (BOP) was pressure tested, cement, plug and landing collar were drilled out and a FIT (EMW of 1.60kg/l) was conducted.

At 5020m MD the drill string was run out of the hole for coring. During core drilling the circulating pressure suddenly dropped by 100bar. Thereupon the coring assembly was run out of the hole. About 20m formation had been drilled. The core catcher was broken and showed mechanical deformation.

Prior to drilling the 5 7/8" section, a CBL tool was run into the hole to evaluate the cement quality and to locate the top of cement. Subsequently, drilling proceeded. At 5045m MD the total weight of the string was set on the bit due to a defect of the drilling control. Three stands were pulled out to control the Feed-off, the elevator and the bail. Afterwards the whole string was pulled out of hole to flux. After inspection the BHA was reinstalled and the well was drilled down to TD of 5400m. During the following circulation caving was recognized within the mud.

Wireline logging was conducted next. When running in the MDT, it got stuck at 5295m MD. Several attempts to free the tool failed and therefore the wire was released and pulled out of hole. The MDT remained in the hole; even several fishing operations with overshot did not meet success. Fishing operations were terminated after the fishing neck of the MDT tool broke (Top Fish at 5286m MD). During fishing significant amounts of clay were observed. Between 5250-5237m MD a clay zone was encountered which was assumed to create wellbore stability problems, as in Str T5. [72] A back up tool was used to measure the last, outstanding reading points. As a last run, a VSP measurement was conducted.

The MDT measurement showed gas from the casing shoe down to 5140m. Below that point a transition zone from gas to water was assumed. Therefore the well was plugged back to 5140m and a completion for the open hole section was proposed. Top of cement was found to be at 5144m.

Afterwards the 7" Tie back liner was run into the hole and cemented. On September 22, 2006 the well Str T5a was completed. [73]

#### 5.3.1.1 Drilling Mud

The used mud system was a $K_2CO_3$-Glycol mud, as it is already known from prior drilled wells. The used mud density is reported within the 'Well Test Report, Strasshof Tief5a (DST#1)' and equalled 1.17kg/l.

### 5.3.2 Formation Evaluation while Drilling

#### 5.3.2.1 Cuttings

Washed and dried samples and an additional set of wet samples (unwashed and not dried) were collected with a spacing of 5 m from 4520 m to 5400 m MD.

#### 5.3.2.2 Coring

One core was cut from 5020 – 5024.70 m MD. The recovery of the core of the Perchtoldsdorfer Dolomit was only 8.5% (0,4m), due to a total damage of the coring tool.

The used coring equipment was a Coremaster with an inner barrel of aluminium and a jam buster- Anti Jamming System. In general, the used bottomhole assembly consists of two components- the outer barrel and the inner barrel assembly. The inner core barrel, where the core material is recovered, consisted of two sections. When dismantling this barrel, the upper section was found completely empty, only containing mud. The lower barrel is made up by the core catcher sleeve, containing the core catcher, a connecting tube and the lower barrel itself. The core catcher was found broken into several pieces. Its bulk was pushed inside the connecting pipe. A solid piece of dolomite of 13cm length was removed from the core catcher sleeve, together with one large piece of the core catcher. Several dolomite chips and mud have been removed together with the core catcher from the connecting pipe. On top of the chips an aluminium piece (6x 4cm) was found, which shaped the top of the core.

It was assumed that the aluminium piece originated from the liner assembly. A similar piece was removed from the PDC bit, prior to coring.

**<u>Interpretation</u>**

The analysis of these "minor formation samples" showed that there was no $H_2S$ present. A visually detectable porosity was not observed. The sample pieces are made up of 100% dolomite. Its colour is dark grey and it is very hard. The grain size reaches from cryptocrystalline to fine crystalline. Sucrosic to waxy calcite veins and hypidiomorph calcite crystals on open fracture surfaces were observed. [64]

### 5.3.2.3 Well logging

The conducted well logs are illustrated in Figure 25.

The following cut off values were defined:

| | |
|---|---|
| Porosity | - |
| Water Saturation | 50% |
| Shale volume | 30% |

The interpretation of the logs, denoted in the 'Final Well Report, Strasshof Tief 5' is listed in Table 43.

According to the presentation 'Preliminary Loginterpretatation' 6 different horizons were mentioned, including the Neokom, Calpionella Kalk, Klauskalk, Riffkalk, Dolomit and the Perchtoldsdorfer Dolomit.

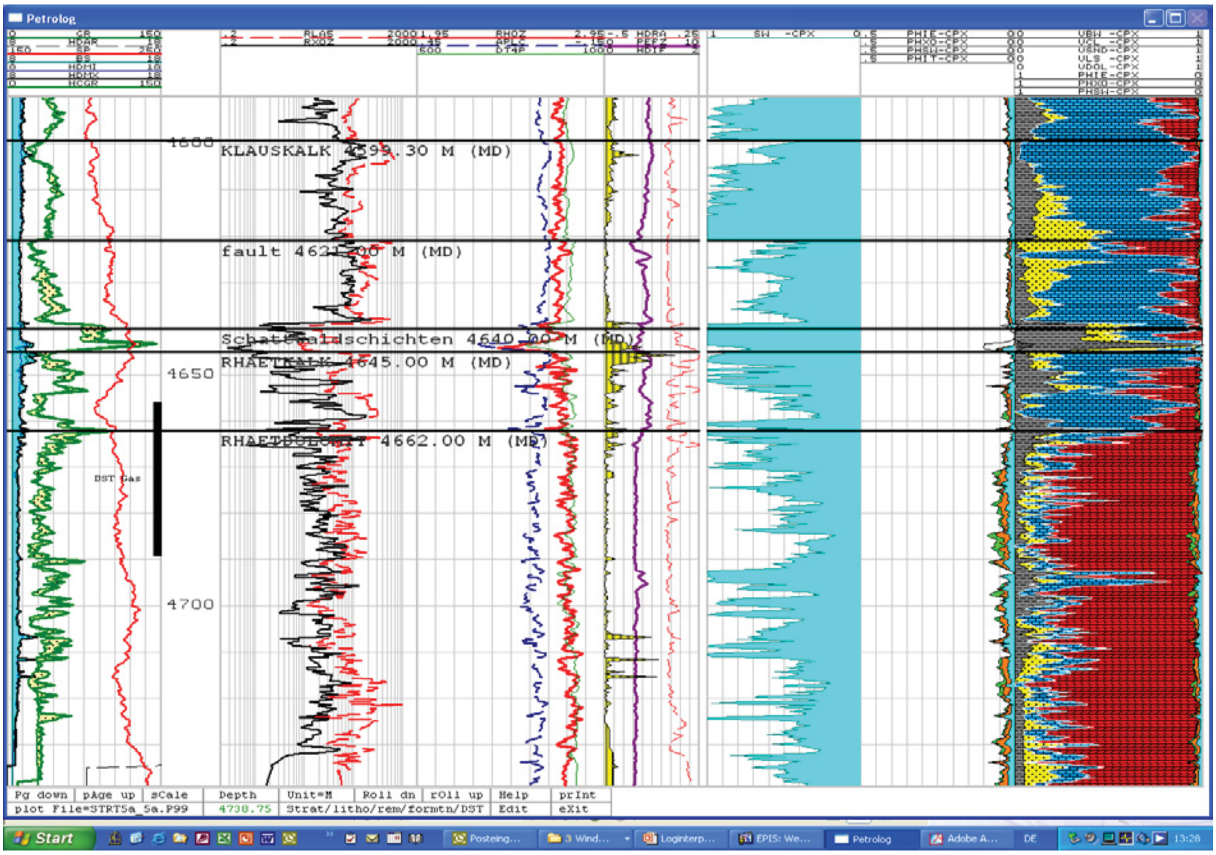


Figure 26: Well Log of the 8 3/8" section of Str T5a [28]

Table 43: Well Log Interpretation Results of Str T5a [28]

| Horizon | MD | | Cut off Values | | |
|---|---|---|---|---|---|
| | Top (m) | Bottom (m) | Net pay (m) | Phie (%) | Sw (%) |
| **Riffkalk** | 4645 | 4658 | 5 | 3 | 29 |
| **Rhaet Perchtoldsdorfer Dolomit** | 4668 | 4733 | 23 | 4 | 31 |
| **Nor Perchtoldsdorfer Dolomit** | 4992 | 5354 | 104 | 3 | 34 |

### 5.3.2.4 MDT in 8 3/8" section

When drilling the 8 3/8" section an MDT was run in the well Str T5a to obtain representative formation pressures in the Hornsteinkalk for fluid gradient determination.

A temperature gradient of 2.5°C/100m TVD was calculated from the mud temperature.

The recorded mud pressures showed a constant density of 1.19kg/m³, resulting in a mud overbalance of more than 40bar. A slightly over-hydrostatic formation pressure gradient was calculated from all pressure points obtained in the supposed Hornsteinkalk.

During testing only four pressure points showed fully stabilized formation pressure build-ups. From the two most representative points a pressure gradient of 0.0215bar/m was determined, indicating the formation to be clearly gas bearing.

A comparison of the formation pressures recorded in Str T5 and 5a did not evidence a cross-communication of these two dolomite bodies. [74]

During the second MDT within the 5 7/8" section the same temperature gradient, as determined in the former section, was calculated.

The representative formation pressures are illustrated in Figure 26, in green. For comparison also previously obtained formation pressures from the first MDT of the Sidetrack (red) and the original well (blue).

Within the lower Perchtoldsdorfer Dolomit a pressure gradient of 0.027bar/m was determined from the top three pre-test points. This gradient is 3bar higher than in the upper Perchtoldsdorfer Dolomit and equals the one observed in Str T5.

From the four lowermost points a gradient of 0.091bar/m was calculated, indicating a water bearing formation.

The two pressure points within the black ellipse are considered as representative, indicating that permeability barriers may be present. Hence a clear determination of the fluid contact is impossible. However, a gas- liquid contact was assumed to be at 5,088m TVD (5140m MD), illustrated in Figure 27.

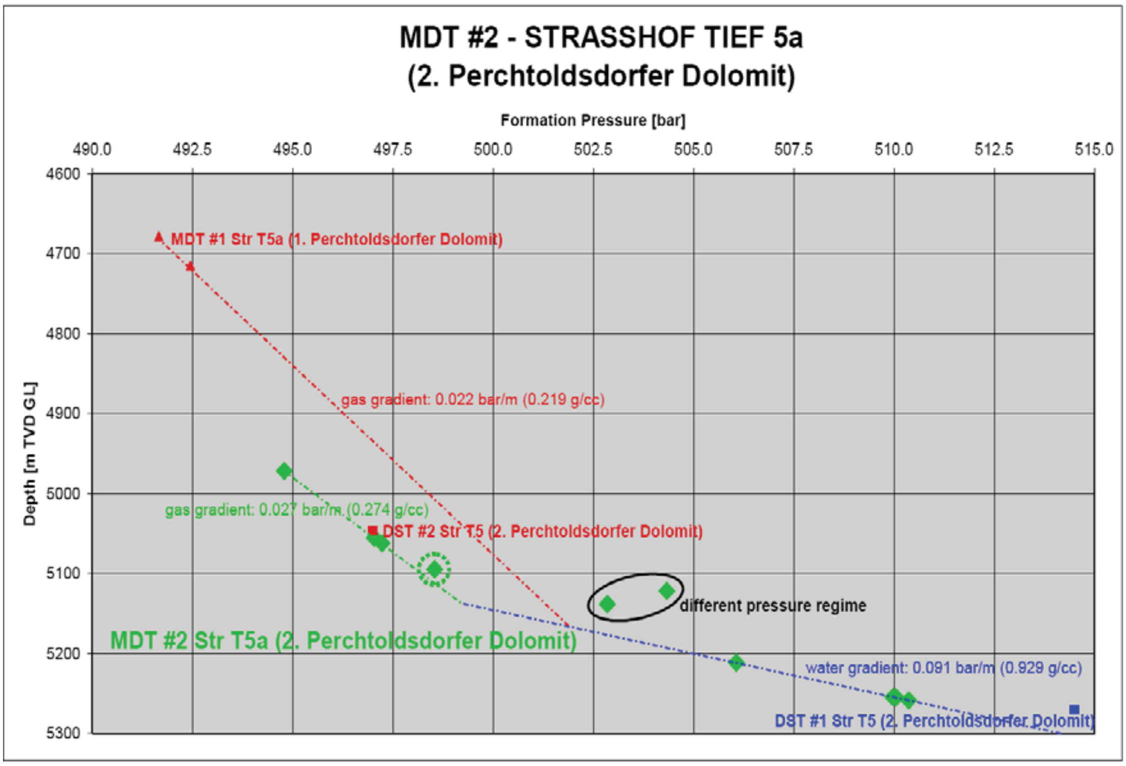


Figure 27: Comparison of MDT's of Str T5 and 5a [75]

#### 5.3.2.5 Pumping Pressure Tests

One FIT with an equivalent Mud Weight of 1.60kg/l was conducted. [64]

### 5.3.3 Completion and Testing

#### 5.3.3.1 Testing

Only the 'Well Test Report, Strasshof Tief5a (DST#1)' and the 'Presentation Short Test Overview Strasshof Tief, Reservoir Characterization, Meeting 15$^{th}$ of June 2007 at OMV Vienna' were available.

However, one Open-Hole Straddle Test (DST) with Side Wall Anchor, of the supposed Hornsteinkalk, was successfully conducted between August 12 and 17, 2006. The test interval extended over a depth of 4656 to 4689m MD, evaluated from well logs, conducted on August 9, 2006. The tested interval was later geologically revised to be Rhaet Dolomit. After testing operations the well was drilled to TD and completed as a production well in the Perchtoldsdorfer Dolomit.

Prior to opening the well, a 50bar under balance was created with a partial water and nitrogen cushion.

During the 5 hour flow period initially a gas flow rate of 8,000m³-Vn/h was measured. This rate decreased to less than 7,000m³-Vn/h at the end of the test. A WHP of approximately 185bar-g was recorded at the choke manifold. The cumulative gas production equalled 35,000m³-Vn. At the end of the flow period almost stabilized conditions were achieved, with an applied pressure draw down of 209bar. The collected gas samples showed an H2S content of 0.4%.

During testing small liquid slugs, mainly mud, were occasionally measured. Overall, 2m³ liquids were recovered.

After the main test objectives were achieved the well was shut in. A dual CIP valve was cycled into the circulation position, shutting-in the well downhole. Thereafter the test string content was reversed-out. The packer was loosened without significant over pull, the open hole section was circulated clean and the test string was pulled out of the hole.

The wellhead pressure (green) the bottomhole pressure (grey), the liquid rate (blue) and the gas rate (red) are illustrated in Figure 27.

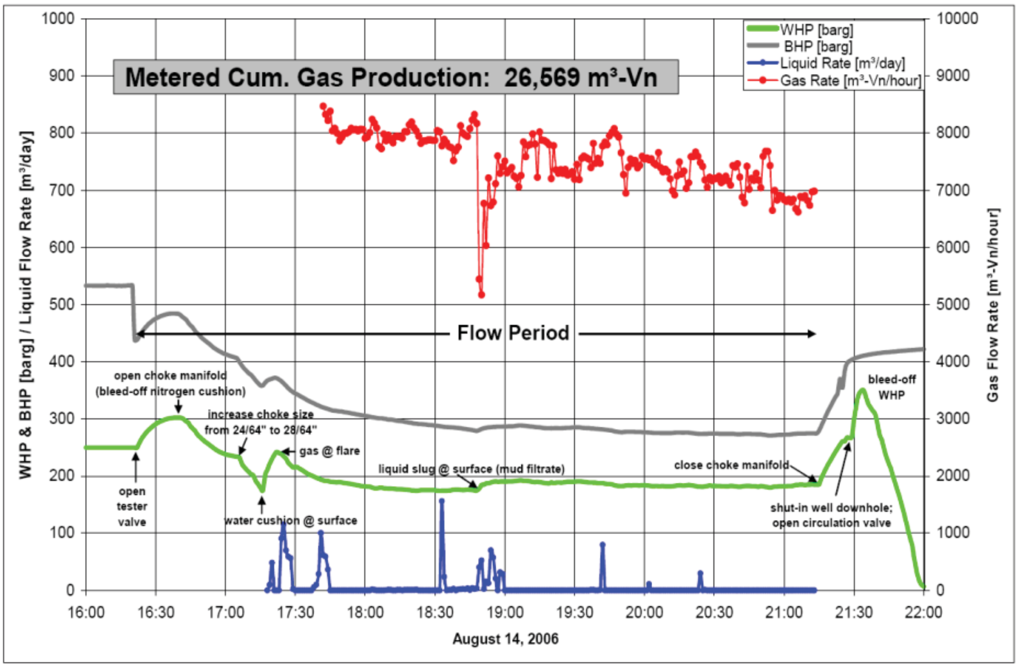


Figure 28: Pressure and Rate history of Str T5a during DST#1[76]

Bottom Hole Data were recorded by two electronic memory gauges at 4666.42m MD. A comparison of the absolute pressure readings of the gauges showed nearly identical measurements throughout the test. The main BHP's recorded by the memory gauges are listed in Table 44.

Table 44: Bottom Hole Pressures of Str T5a during DST#1, at 4666.42m MD [76]

| Key Tubing Pressure | [bar-g] |
|---|---|
| Initial Hydrostatic BHP prior opening the Tester Valve | 533.15 |
| Initial BHP after opening the Tester Valve | 435.25 |
| Final BHP prior to opening the well | 484.73 |
| Final BHP after flowing period | 274.76 |
| Final BHP of the shut in period | 426.78 |
| Final Hydrostatic BHP prior well kill operations | 531.93 |

Although the BHP was still rising by 0.165bar/min at the end of the PBU period, it remained 52bar below the initial formation pressure of 485bar-g. Via MDT a pressure of 490bar-g was measured at gauge depth.

The inflow performance of the tested interval, at the end of the flowing period, when almost stabilized flowing conditions were achieved, is illustrated in Figure 28. [76], [ 77]

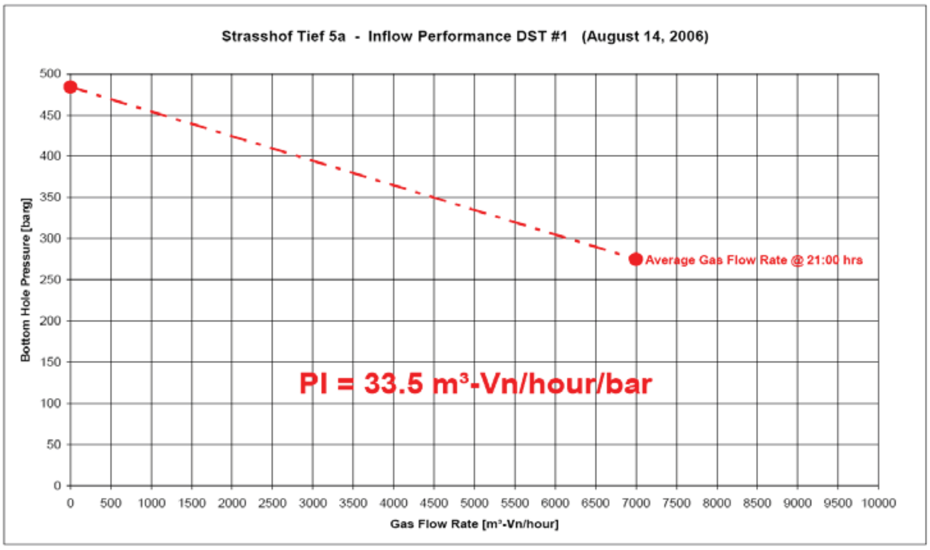


Figure 29: Inflow Performance Str T5a- DST#1[76]

According to the presentation 'Short Test Overview Strasshof Tief, Reservoir Characterization, Meeting 15th of June 2007 at OMV Vienna' an additional OHT was conducted in Str T5a. The OH section extends from 4985m to 5144m. The extrapolated reservoir pressure decreases continuously from 484bar-g to 481bar-g at gauge depth (4643m MD). A production of approximately 1.2MMm³-Vn might be possible from the Perchtoldsdorfer Dolomit.

The analysis of the PBU period showed the following values:

The BHT equalled 145.5°C. The well flowing pressure reached for 455bar-g and a production rate of 485,000m³-Vn/d was achieved. The shut in pressure after 12hours of PBU was 476bar-g. The reservoir pressure was extrapolated to 481bar-g. The evaluated permeability thickness was in the range of 150-230mD*m. [77]

**Well test Interpretation**

To interpret the PBU period again the diagnostic Log-Log plot was used as illustrated in Figure 29.

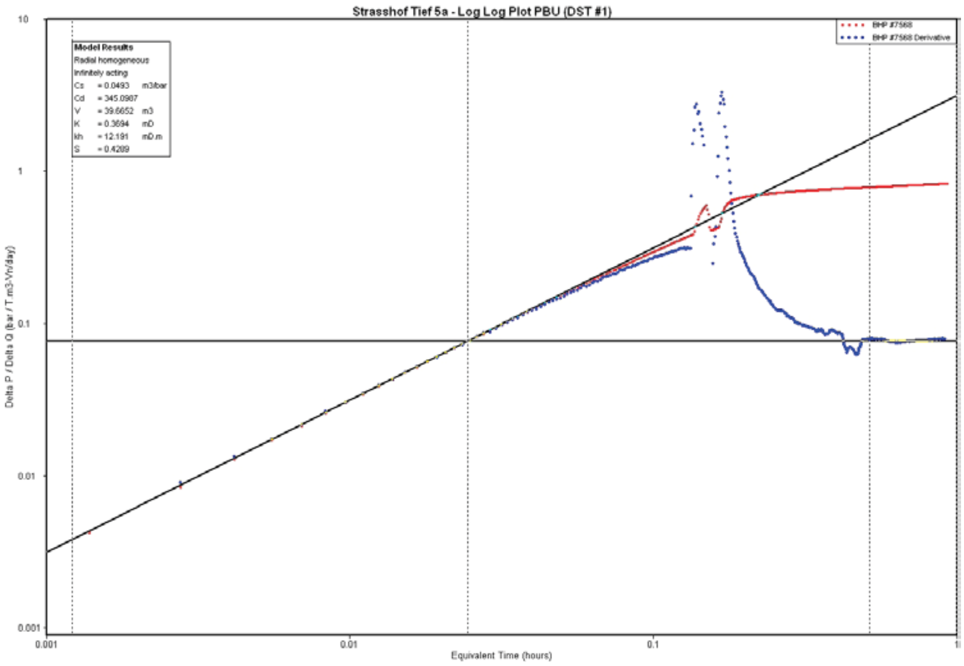


Figure 30: Log- Log Plot of the PBU period, Str T5a [76]

Due to the initial surface shut- in, distinct wellbore storage effects dominated the first 10min of the PBU period, until the Dual CIP valve was cycled into the well.

The permeability thickness (k*h), calculated from the apparent radial flow regime, resulted in a value of 12mD*m and the total skin factor was 0.4.

However, with the reservoir parameters used the PBU could not be matched satisfactorily, except by slightly adjusting the reservoir parameters. Type curves did not match the observed pressure response. As no reliable radial flow regime had developed, valid reservoir parameters could not be derived.

The semi-log plot of the PBU at the end of the DST is illustrated in Figure 30.

A reservoir pressure of 449bar-g at gauge depth was extrapolated from the radial flow plot. This pressure is 36bar below the initially extrapolated formation pressure. This may indicate pressure depletion from production during testing, which in turn could indicate a compartmentalized reservoir.

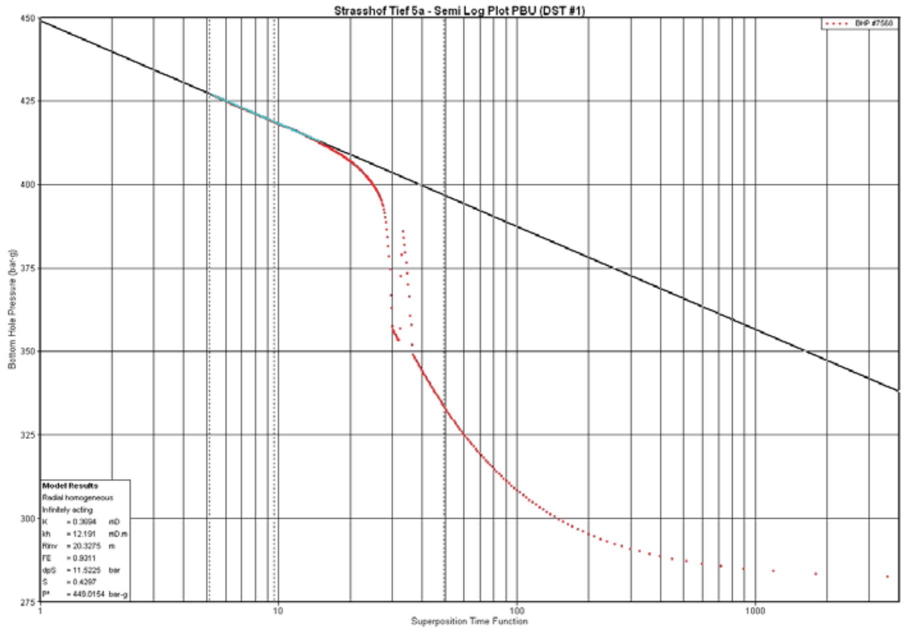


Figure 31: Radial Flow Plot, Str T5a [76]

Given a calculated radius of investigation of just 20m, the existence of flow boundaries at a further distance cannot be excluded. Stable flowing conditions were achieved for only one rate, therefore analysis of rate-dependent skin and well deliverability do not provide valid results. Furthermore, a semi- steady state flow regime was not reached throughout testing; consequently a meaningful connected gas volume could not be derived from test data. The material balance calculation with the apparent pressure depletion resulted in an OGIP of 0.5MMm$^3$-Vn.

The derived reservoir parameter should be used with caution, as the identified radial flow regime might not be reliable. However, this test indicates a tight and undamaged formation.

A prediction on the long-term production behaviour of the well was not possible. [76], [77]

#### 5.3.3.2 Fluid Sampling and Analysis

During testing operations fluid samples were continuously collected by the OMV Laboratory for Exploration & Production. BHS were not taken during testing. A comparison of the analyzed gas samples showed that the composition remained constant during the last two hours of the flow period. The composition of the last samples is listed in Table 45. Its content differs from gas samples from DST#2/2a taken in Str T5.

Table 45: Composition of the last evaluated Gas Sample of Str T5a

| Sample | DST#1 |
|---|---|
| Sample: | Straßhof T5a |
| Test interval | 4656-4689 |

| | Vol% |
|---|---|
| Hydrogen Sulphide | 0.64 |
| Carbon Dioxide | 4.32 |
| Nitrogen | 0.64 |
| Methane | 93.37 |
| Ethane | 0.59 |
| Propane | 0.14 |
| Isobutane | 0.03 |
| n-Butane | 0.06 |
| Isopentan | 0.02 |
| n-Pentane | 0.03 |
| C6+ | 0.16 |

| | |
|---|---|
| Density (273.15K; 101.325kPa) kg/m³ | 0.795 |
| SG. (air=1) | 0.615 |

The produced liquids were identified as cushion water and mainly mud. Some light liquid HC were detected. Formation water was not present within the samples.

#### 5.3.3.3 Stress Corrosion Cracking

$H_2S$, an extremely toxic, corrosive and flammable component in HC reservoirs, is one of the leading causes of equipment failure in oil and gas reservoirs. High-strength steel under residual or applied tensile stresses may crack under the influence of $H_2S$ gas and water. Only minor concentrations, as low as one ppm, and traces of water, may induce sulphide stress corrosion cracking. Material selection of equipment for such wells is especially critical. The materials of choice must be corrosion resistant, cost-effective, reliable, and provide the required strength. [ 78]

However, two core catchers used in the wells Str T5 and 5a did not meet these demands. When recovering the second core of the well Str T5 and the first core of Str T5a a failure of the core catcher led to the loss of both cores.

According to the report 'Schaden am Kernfänger, Bohrung Strasshof T5' some debris of the core catcher, used for the second core in the well Str T5, were sent to the Labour for analysis.

Additional metal pieces were found within the core taken from 3280 -3280.2m. (Just before initializing coring, a minor H2S content was discovered within the drilling mud.)

The visual examination showed no plastically deformation of the breaking edge. To some extent fissures were visibly to the naked eye.

The metallographic material testing showed heavily branching cracks, which are a clear indication for stress corrosion cracking.

The hardness testing resulted in values far in excess of the hardness limit for carbon steel for usage within sour gas bearing areas. No indication for precedily material damage was encountered.

The hard material of the core catcher was known to be prone to stress corrosion cracking induced by H2S. To avoid these embrittlement processes it was recommended to use a proper material, applicable for this purpose, with hardness values being below the limit values. [ 79]

In October 2006 the same incident had already occurred during coring the well Str T5a.

Due to a defect of the scanning electron micrograph a complete material testing could not be conducted. Anyhow, the analysis of its composition showed that the material and its hardness are inappropriate for use within aqueous media with H2S content. Therefore it was recommended to use super alloy with appropriate hardness or to nickel the core catcher.

In September 2006 1.5g of metal millings were passed to the Laboratory of Exploration and Production to evaluate their origin. Furthermore, also the liner hanger was handed over to the LEP for comparison. The aim was to evaluate the chemical composition and thus evaluate the origin of the millings.

The millings consisted of an alloy containing 0.224% chrome and 0.0117% molybdenum. These contents agreed with that of the casing. The chemical composition of liner hanger differed from that of the millings. (Cr: 1.03%; Mo: 0.20%). Due to these results it was excluded that the millings originated from the liner hanger. [80]

Later on also a piece of the Casing was available. An analysis proved the initial assumption based on the inspection certificate. The millings were clearly related to the casing string.

# 6 Strasshof Tief 6 and 6a

The appraisal well Str T6 followed Str. T5/5a. Its primary target of Str T6 was the Perchtoldsdorfer Dolomit to better estimate the recoverable reserves. The 7th SH and the Hierlatzkalk were valid as secondary targets.

## 6.1 Realization of Strasshof T6

According to the report 'Bohrabschlussbericht- Technischer Teil, Erweiterungsbohrung Str T6' the well was drilled from October 28, 2006 to February 5, 2007. Before the drilling process started, a 30" conductor was dug into the ground.

An overview of the realized completion scheme is listed in Table 46.

Table 46: Completion and Cementing Scheme of Str 6[81]

| 1st Section | | Planned | Realization |
|---|---|---|---|
| surface Casing | [in] | | **18 5/8"** |
| bit | [in] | | **24"** |
| MD | [m] | | 615,2 |
| **Cementation** | | | |
| cement | | | Foam cement |
| Spec. Weight | [kg/l] | | Lead: 1,6; Tail: 1,91 |
| Cement Amount | [m³] | | Lead: 65; Tail: 21 |
| Plug pumped | [bar] | | |
| cement elevation | [m] | | 14m³ to surface |
| Date | | | |

| 2nd Section | | Planned | Realization |
|---|---|---|---|
| Intermediate casing | | | **13 3/8** |
| bit | | | **17 1/2"** |
| MD | [m] | | 3239.5 |
| This section was deviated: | | | |
| KOP | [m] | | 1015 |
| Inclination | [°] | | 15 |
| Azimuth | [°] | | 139.3 |
| EOB (MD) | [m] | | 1332 |

| Cementation | | | |
|---|---|---|---|
| cement | | | Foam cement |
| Spec. Weight | [kg/l] | | 1.76 |
| Cement Amount | [m³] | | 190 |
| Plug pumped | [bar] | | 160 |
| cement elevation | [m] | 3239,5-208 | 3239.5- 208(measured)/ Cement to surface |
| Date | | | |

| 3rd Section | | Planned | Realization |
|---|---|---|---|
| Intermediate casing | | | **9 5/8"** |
| bit | | | **12"** |
| MD | [m] | | 4622.5 |
| **Cementation** | | | |
| cement | | | |
| Spec. Weight | [kg/l] | | Lead: 1.55; Tail: 1.85 |
| Cement Amount | [m³] | | Lead: 48; Tail: 7 |
| Plug pumped | [bar] | | 200 |
| cement elevation | [m] | | 4622.5-3070m (measured) |
| Date | | | |

| 4th Section | | Planned | Realization |
|---|---|---|---|
| liner | | | |
| bit | | | 8 3/8" |
| MD | [m] | | |
| **Plug Cementation** | | | |
| cement | | | Class G Cement |
| Spec. Weight | [kg/l] | | 1.95 |
| 1. Plug | | | 5300-5200 |
| 2. Plug | | | 4675-4575 |
| 3. Plug | | | 3200-3100 |

**Limitations while Drilling**

The first section was drilled with a 24” bit, down to a depth of 618m with reduced rates, as in Str T4 and Str T5. The well logging was conducted by OMV PDS service (CSA- CAL and IC) down to a depth of 596m. There

the tool stood up.

At 2063mMD (2031m TVD) the Aderklaa Konglomerat was met. This formation was drilled without any incidents.

Within the areas between 1606 – 1000m and 840- 618m heavy discharge at the shale shakers was encountered. For the rest of this section overloads up to 10t were encountered.

In a depth of 2559.5m a sudden pressure drop occurred. Afterwards the bit was pulled with 65bar. It turned out that the downhole motor was screwed off of the stator adaptor. In total 15.26m of the borehole assembly (BHA) remained in the well. Borehole stability problems made the fishing job more difficult. Several times the fish was released and lost again.

When the fourth run was undertaken the company Schlumberger D&M informed OMV that the fishing neck-diagram was incorrect. Therefore the first trials were in vain. Finally the fishing runs led to success and the tool was freed with 100t overload.

At 2677m the bit was pulled. It showed high wear (ring out, lost cutters.) Before drilling deeper it was tried to remove the cutters, which however remained in the hole. Therefore the pumping rate was increased. With the new PDC the inclination and the direction could be hold. However, the bit performance and the inclination decreased beyond 2710m MD.

At 2739m MD the bit was pulled out of hole and an insert bit was used instead. After 127m this bit was also pulled, because the angle build up became problematic and the jar was wrongly adjusted. Once the Weight on Bit (WOB) exceeded 20t, the jar was activated and extremely high weights acted on the bit for a short term.

Another three insert bits and tow DHM were used to drill to the end of this section, to 3243m MD. Afterwards the borehole was logged and cemented.

After 24hours waiting on cement (WOC), the pressure in the annulus was bled off to 25bar. However, after 30 min the pressure in the annulus increased by 5bar. Hereupon 13m³ water were pumped into the annulus stepwise and the pressure again bled off. At the last pressure bleed off 7m³ liquid were' produced' from the annulus. Top of cement was calculated to be at a depth of 208m.

The casing could not be set into the slips because the box of the most upper casing was situated within the slip area. Therefore the casing was first shortened for 0.4m and then set into the slips with 30t.

In the 12" section a downtime of the MWD occurred. After the tool was changed the well was drilled down to 4477m MD. Due to the repair of the stand pipe it was necessary to pull the drill string into the casing shoe. The assembly showed a counter clockwise tendency during rotary drilling. In the lower part of this section deviated drilling became more difficult due to the long openhole section and the increased slip loads involved.

The total depth of the 12" section was reached at a measured depth of 4655m. A check trip was conducted down to total depth and the drill string was pulled out of hole without any further incidents. After repeated stand ups with the logging tool during wireline logging a rotary assembly was run into the hole and the well was reamed. Within the shale shakers clayish caving was observed. The MW was increased from 1.13 to 1.16SG to stabilize the borehole. However, this led to seepage losses.

While running in the 9 5/8" casing the borehole was circulated out for clean up. At 4622.5m it became impossible to get ahead. A pump rate with constant pressure was initiated, to avoid a loss of circulation during cementing.

With the 8 3/8" bit the well was drilled to TD of 5500m. Before pulling out the drill string, a check trip was conducted (down to 5020m MD). Subsequently the well was logged.

The wireline log showed that the Perchtoldsdorfer Dolomit had been met down dip, close to a possible contact. Therefore it was decided to drill a sidetrack (Str T6a) which should intersect the dolomite body within the gas bearing formation, about 300 to 400m updip. Therefore a plug cementation was conducted. At 2895m MD a bridge plug was set and the casing was pressure tested. [81]

#### 6.1.1.1 Drilling Mud

Due to the absence of the MI- Reports and the Daily Drilling Reports the actual mud losses could not be evaluated. The Mud System used is listed in Table 47.

Table 47: Mud System of Str T6 [81]

| Hole Section [in] | Mud Type | Mud Weight [kg/l] |
|---|---|---|
| 24 | $K_2CO_3$ | 1.05 – 1.11 |
| 17 ½ | $K_2CO_3$ – Glycol | 1.11 – 1.16 |
| 12 | $K_2CO_3$ – Glycol | 1.11 – 1.14 |
| 8 3/8 | $K_2CO_3$ – Glycol | 1.12 – 1.16 |

The mud additives used were:

| | |
|---|---|
| CaCO3 | as a bridging agent |
| Hostadrill and Driscal-D | to control the fluid loss and yield point of the mud under HPHT conditions |

### 6.1.2 Formation Evaluation

#### 6.1.2.1 Pumping Pressure Tests

2m below the 18 5/8" casing a FIT was conducted. The EMW equalled 1,50SG (25bars WHP at 1,09SG MW).

Again a FIT was conducted when the first meters below the 13 3/8" casing were drilled through to a depth of 3246m MD with an EMW of 1.9SG (232bar WHP at 1.15SG mud Weight).

Below the 9 5/8" casing a LOT was conducted. The WHP equalled 277bar with a MW of 1.14 SG (EMW of 1.76 SG) [81]

#### 6.1.2.2 MDT

MDT probe was set between 4329.3m and 5859m MD.

After drilling to the target formation at a total depth of 5500m at Strasshof-T6, MDT testing was carried out to assess the HC potential of the pay zone. No flow was obtained.

It was assumed that the formation had been damaged and the pore spaces had been plugged and sealed by the chemical additives in the $K_2CO_3$ – Glycol mud system, which was used while drilling the 8 3/8" hole section from 4655mMD to 5500mMD.

The use of Hostadril and Dricsal-D also came under question. The invasion of mud into the formation and the phenomena of polymer gelling up at elevated temperatures (150 deg C recorded by the logging unit) were assumed to be the causes of the plugged formation.

## 6.2 Realization of Str T6a

As the primary target of Str T6a came in deeper than assumed, the well was plugged-back and sidetracked into the Perchtoldsdorfer Dolomit.

No further information about the drilling program and the realization of Str T6a are available, except some data about wireline logging and well testing.

### 6.2.1 Formation Evaluation

#### 6.2.1.1 Well Logging

According to the Presentation 'Loginterpretation_ Str T6a' the results are summed as follows:

To calculate the HC Volumes some cut- off values were defined:

- Clay Volume <30%
- Porosity 0%
- Water Saturation <50%

The final results o the interpretation are summarized in Table 48.

Table 48: Summary of Log interpretation of Str T6a [28]

| Formation | Top | Bottom | Gross Pay | Net Pay | $V_{clay}$ | $\phi$ | $S_w$ |
|---|---|---|---|---|---|---|---|
| | [m] | [m] | [m] | [m] | [%] | [%] | [%] |
| Perchtoldsd. D. | 5154 | 5186 | 32 | 16.3 | 0.5 | 3.9 | 31.5 |
| Dolomitbrekzie | 5418 | 5496 | 78 | 41.8 | 3.1 | 4.5 | 26.5 |
| Konglomerat | 5640 | 5704 | 64 | 45.9 | 0.8 | 2.6 | 16.1 |

## 6.3 Completion and Testing

### 6.3.1 Testing

According to 'Well Test Report Str T6a a cased-hole barefoot drill stem test of the naturally fractured Hierlatzkalk/Hornsteinkalk was successfully conducted in April 2007. DST #1 was a misrun, due to equipment failure. $S_w$

Without stabilized flow conditions nor a shut-in pressure build-up, a reliable determination of reservoir parameters from the down-hole data proved unfeasible. .

The inflow performance indicated a low permeable formation without significant damage. Still a prediction of the longer-term production behaviour was not possible.

A formation pressure of 459barg is estimated for the top of the Hierlatzkalk.

Following operations, the well was drilled to TD and completed as a production well in the Perchtoldsdorfer Dolomit.[82]

# 7 Conclusion and Analysis of worst Incidents

Several unexpected incidents occurred, some showing limiting effects on results. However, most of them were improved during drilling and workover of the first and/or the following wells, e.g.:

- The coring program was increased.
- The wireline Logging was reduced. Only a few significant logs were used which performed best within the formation.
- In case of borehole imaging the problem was solved with using the electrical and the acoustic device.
- A new acid recipe with 28% HCl was successfully tested and established as a standard recipe.
- Stress corrosion cracking of centralizers and coring assembly was considered.

However, some Limitations are still subject to improvement:

- Mud losses, scaling and the related formation damage leading to a lower productivity and additional flow restrictions within the tubing and the formation.
- Often zonal isolation by cementing was not achieved.
- Seismic Imaging, conducted in the 90ties, targeted the Neogen Basin, not the area of interest.

## 7.1 Mud losses and Formation Damage

In general, the two classes of fluid loss are:

- Losses to permeable zones and/or
- Overbalance induced losses

During drilling Str T4 the predominant losses can be considered as seepage losses, which are usually associated with permeable formations or open fractures. Partial losses occurred within the lower section of the Hornsteinkalk, starting at 4209m MD, when the bottomhole pressure reached 675bar. Fluid losses of 5.4m$^3$/h were observed. They could not be eliminated until the pressure was reduced to 510bar. Table 49 puts the fluid losses of the 6" section into context with the circulating bottomhole pressures.

Table 49: Bottomhole Pressures during Drilling [12], [83]

| Date | MD [m] | Fluid loss [m³] | Hydrostatic Pressure [bar] | Circulating bottomhole pressure [bar] | Average Reservoir Pressure [bar] | Fracture Pressure [bar] |
|---|---|---|---|---|---|---|
| 22.03.2005 | 3710 | | | | | 664 |
| 27.03.2005 | 4111 | - | 458 | 649 | | |
| 28.03.2005 | 4209 | -25 | 472 | 675 | 429 | |
| 29.03.2005 | 4209 | -67 | | 558 | | |
| 30.03.2005 | 4216 | - | | 510 | | |
| 31.03.2005 | 4217 | -18 | | 522 | | |
| 01.04.2005 | 4223 | -45 | 453 | 614 | | |
| 02.04.2005 | 4268 | -10 | | 627 | | |
| 03.04.2005 | 4294 | -5,5 | 452 | 624 | | |
| 04.04.2005 | 4398 | -28 | 463 | 626 | 451 | |
| 05.04.2005 | 4499 | -17 | 472 | 641 | | |
| 06.04.2005 | 4516 | -12 | 476 | 639 | | |
| 16.04.2005 | 4516 | +15 | 474 | 541 | | |

According to the results of formation evaluation, the Hornsteinkalk shows an average porosity of 14% and a permeability of 1.14mD. Open fractures of unknown extent were observed from logs and well tests. If this formation would have provided ample permeability, a slightly higher differential pressure between the borehole and the fluids in the formation may have led to partial losses without fracturing the formation.

To evaluate if hydraulically fracturing was involved the bottomhole circulating pressure was calculated. The rheological model "Power Law" was used to calculate the frictional pressure losses within the pipes. Also the pressure losses through the bit were considered. The bottomhole circulating pressure was than calculated with the law of conservation of energy.

A comparison of pressures is illustrated in Figure 32. The pore pressure (blue), the minimum hydraulic pressure (red) and the fracture pressure (green) are illustrated in Figure 32 according to data of Halliburton. By contrast the pore pressure, evaluated within the targeting zones via MDT, is slightly higher and the fracture pressure, evaluated via formation integrity tests, is lower than assumed. However, the calculated bottomhole circulating pressure did not exceed the fracture pressure, indicating that no hydraulically induced fracturing occurred.

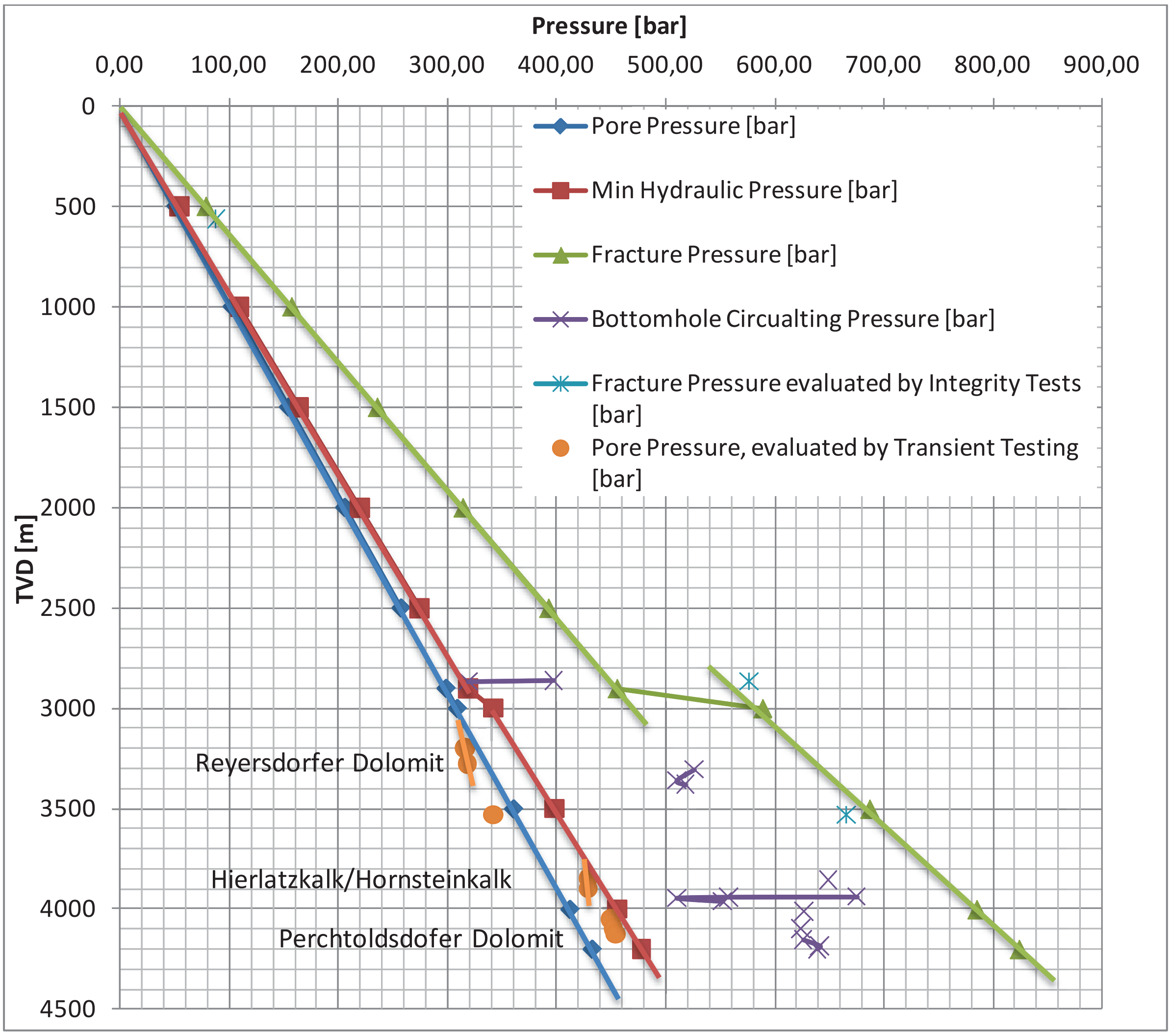


Figure 32: Fracture-, Pore- and Bottomhole Circulating Pressure of Str T4 [12], [34], [35], [36]

Unfortunately, no information about fluid loss during workover was available, except the amount of fluid loss into the Hierlatzkalk/Hornsteinkalk.

## Calcium Carbonate Scaling

Within the Strasshof Tief wells carbonate scaling was a recurring problem, as discussed previously. Inorganic scale was observed in wells, separators, and flow lines. A reduction of tubing diameter of 40% was observed during testing.

Calcium carbonate scales or calcite scale is frequently encountered in oilfield operations. The formation of carbonate scale is complex dependency on pressure, temperature, water composition and carbon dioxide ($CO_2$).

In general, calcite forms from reaction of calcium with either carbonate or bicarbonate according to the reactions:

$$Ca^{2+} + CO_3^{2-} \rightarrow Ca\,CO_3$$

Under typical pH conditions of oilfields carbonate ions are very rare. Therefore the following equation represents the principal reaction:

$$Ca^{2+} + 2(HCO_3^-) \rightarrow CaCO_3 + CO_2 + H_2O$$

Bicarbonate ions being in equilibrium with $CO_2$ results in the following reaction:

$$CO_2 + H_2O \leftrightarrow H_2CO_3$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-$$

$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}$$

In case the system is in equilibrium, any change in concentration, volume, pressure, or pH will push the equilibrium to partially counteract the imposed change, e.g., if $CO_2$ is removed from the system calcite scale will form if sufficient Ca is present. [ 84]

In the course of AGI project a scaling calculations for the formation brine with use of the software MultiScale® was conducted.

The first calculation was performed under the following assumptions:

1. The ambient water analysis of 15-800-91 is recombined with surface equilibrium gas.
2. It is then mixed with an infinite volume of 80:20 ratio $CO_2$-$H_2S$ gas at 325 bar and 115°C.

Due to the resulting low pH of 4.28, the software predicts no precipitation of $CaCO_3$.

In a second computation, a simulation was tried to show the effect of flashing formation water enriched in Ca up to the solubility limit:

1. Increase Ca in steps until the stability index reaches 1.
2. Flash water of this composition from 325 bar/115 °C down to surface conditions 3 bar/20 °C.

For that case, the Ca concentration was limited by the solubility product of $CaSO_4$ hemihydrate. Again, no precipitation was predicted upon reduction of pressure/temperature.

This indicated that even by assuming the most unfavourable situation of complete gas saturation at highest possible pressures and temperatures combined with maximum theoretical amount of $Ca^{++}$, no carbonate/sulphate scaling will be observed neither in the reservoir upon injection nor in surface facilities during water production.[ 85]

However, the solubility of calcium carbonate is decreased if the pressure decreases, temperature and pH increase. The invasion of high alkaline and $CO_3^{2-}$ rich drilling mud will result in pressure, temperature and pH changes and will provide $CO_3^{2-}$ (dissolved in water) which in turn may have led to the precipitation of carbonates. Past Str T6a the drill in fluid into the reservoir was changed. KCl mud was used as the new drill- in fluid. Henceforward, carbonate scaling was not observed anymore.

However, if the drilling mud caused the precipitations, carbonate scaling might have occurred during drilling. To analyse if carbonate scaling might have taken place during drilling, the changes in carbonate and bicarbonate concentrations were compared with the potassium concentration of the drilling mud.

Two methods were performed to calculate the carbonate and bicarbonate concentration of the mud filtrate, the Pf/MF and the pH/Pf method.

The Phenolphthalein (Pf)/methyl orange (Mf) alkalinities are historically the first method used to calculate the concentrations of hydroxyl ($OH^-$), carbonate ($CO_3^{2-}$) and bicarbonate ($HCO_3^-$) ions in the filtrate of the drilling mud. As these calculations are only estimates of the concentrations, due to its inaccuracy in the presence of weak acids, the pH/Pf method was calculated for comparison. However, also this method is only used as guideline within the total context of what is happening to the fluid, the hole and the drilling operation, as it is not without margin of error. [86]

Furthermore, the concentrations of carbonate and bicarbonate, evaluated via solid analysis, were also used for comparison.

The illustration of this comparison can be found in Appendix C. Theoretically, the concentration of twice the potassium ions should equal the concentration of carbonate ions as the chemical formulation is $K_2CO_3$, if the $CO_3^{2-}$ did not convert to $HCO_3^-$. Down to 2985m MD (Point 58) it can be observed that twice the potassium concentration is similar to the $CO_3^{2-}$ concentration. This is followed by a change in concentrations. Figure 32 shows the concentrations of carbonates and bicarbonates when drilling the 7” section (2807-3707m MD). It shows that the carbonate ions, evaluated via the pH/Pf method, exceed the $K^+$ concentration, while the carbonate concentration, calculated via the Pf/Mf method is lower. The carbonate concentrations evaluated from the solids, conducted by MI Swaco equal the values achieved via pH/Pf method. However, the mean values of the $CO_3^{2-}$ concentrations are similar to the $K^+$ concentration, while the bicarbonate concentration, evaluated from solids, exceeds the one, calculated form pH/Pf method. An illustration of the mean values of $CO_3^{2-}$ and $2*K^+$ can be found Appendix C.

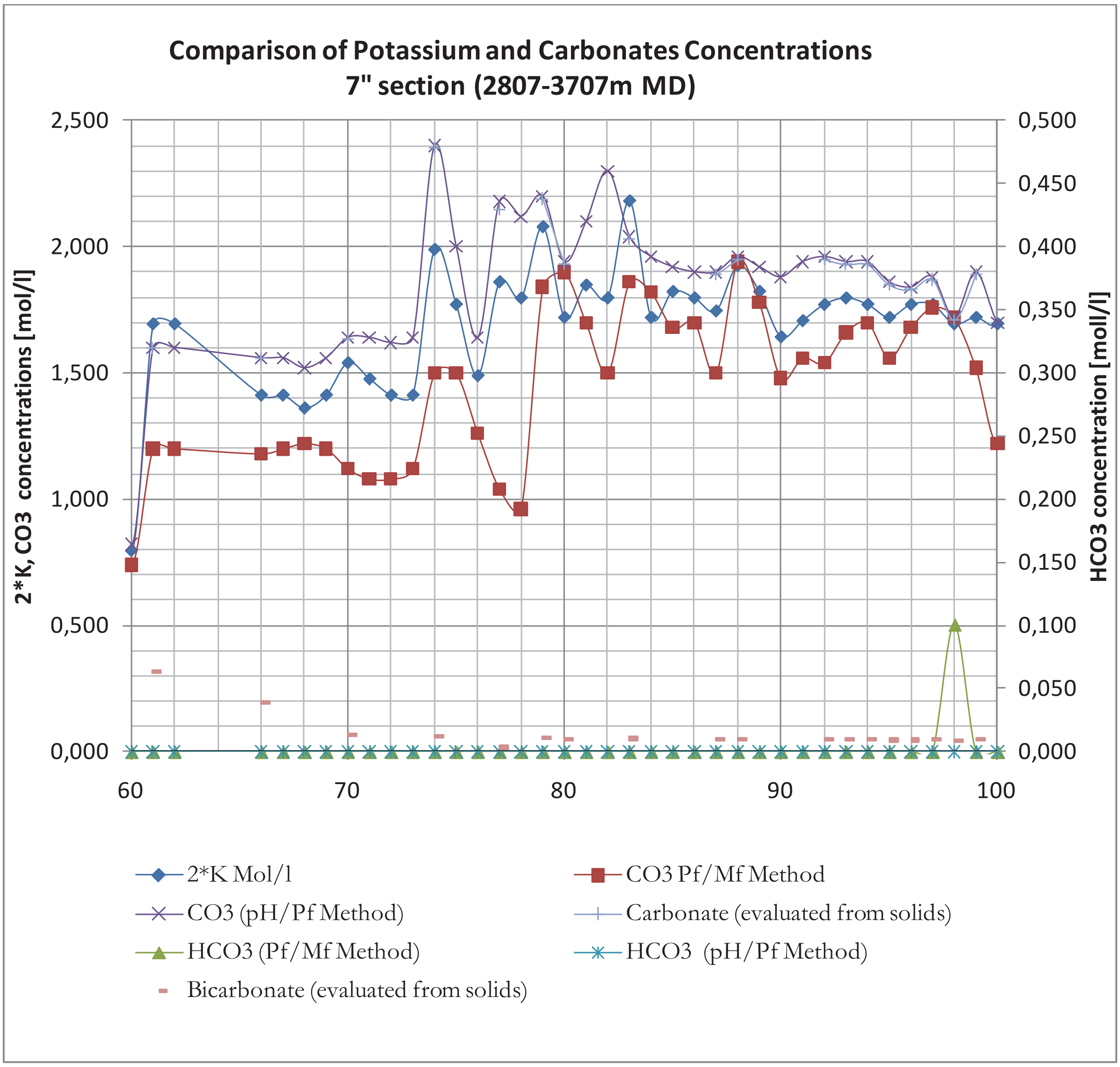


Figure 33: Comparison of $K^+$, $CO_3^{2-}$ and $HCO_3^-$ concentration of the 7" section, Str T4 [83]

In Figure 33 a change in concentrations can be observed. Both carbonate concentrations are decreasing below the potassium concentration, indicating that less carbonate was available within filtrate and solids. The presence of bicarbonate within the solids was slightly increased, due to a decreasing pH- value. However, the additional bicarbonate content is relatively less compared to the amount of carbonate missing, indicating that the carbonate content decreased below the potassium content.

When drilling through the Hierlatzkalk/Hornsteinkalk, (point 122-127), when the major mud losses occurred, all three measured carbonate concentrations are equal and still being less than potassium.

At point 142 the carbonate content, evaluated via pH/Pf method again starts to increase. At point 153 the potassium content becomes the lowest and the bicarbonate content of the solids increases, indicating the imminent kick, which occurred at point 162, on April 16, 2005.

However, this evaluation if carbonate precipitation occurred during drilling is only a rough estimate, as a continuous measurement of the total mud composition was not performed. Furthermore, it would have been interesting to compare the $CO_3^{2-}$ concentration to the $Ca^{++}$ concentration of the filtrate, though these values were not measured. Due to the continuous make up of the drilling fluid, the possibility to encounter a clear trend is provided. Additionally the contact with formation fluids occurs within the formation, and it is questionable if a clear trend can be evaluated within the actual drilling mud.

None the less, it is noticeable that the $CO_3^{2-}$content was less than the corresponding potassium content, within the lowest section.

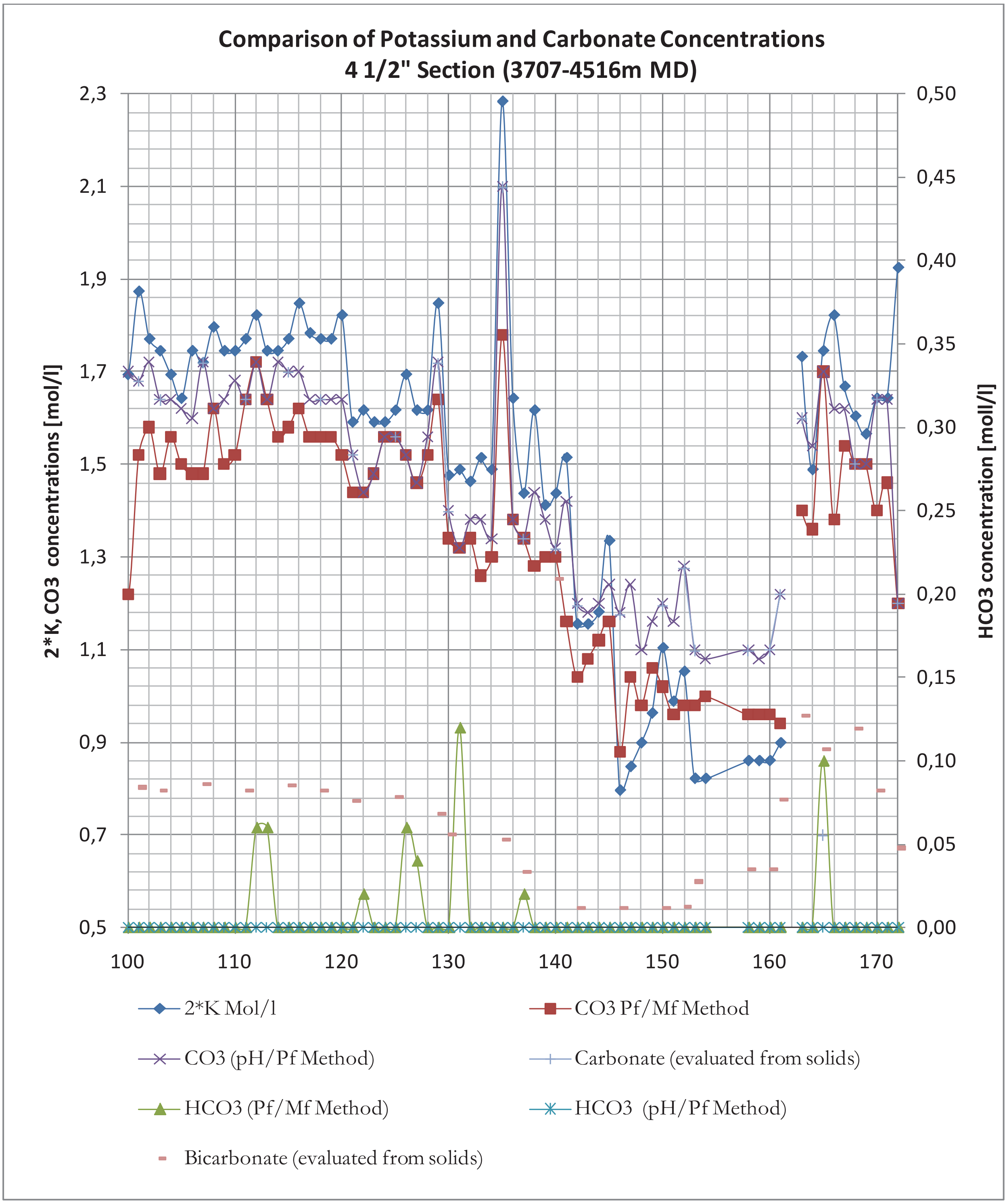


Figure 34: Comparison of $K^+$, $CO_3^{2-}$ and $HCO_3^-$ of the 4 1/2" section, Str T4 [83]

## 7.2 Cementing

In the well Str T4 a casing leak was encountered. In September 2005, during testing, slight mud losses occurred. To solve this problem an inflatable packer was set at 4120m and subsequent pressure tested. Rapidly it turned out that it was leaking. Several attempts to tighten the packer at different heights failed. Only when setting the packer above 3610m, between the XN- landing nipple and the liner seal assembly, did it become tight. Two further trials with new inflatable packers led to the same result. It was assumed that the liner seal assembly was leaking.

Figure 32 illustrates the cementing process of the 4 ½” liner. At stage 1 the spacer was pumped in and at the second stage the cement. The displacement process started at stage 3. Noticeable problems are not observable from the plot.

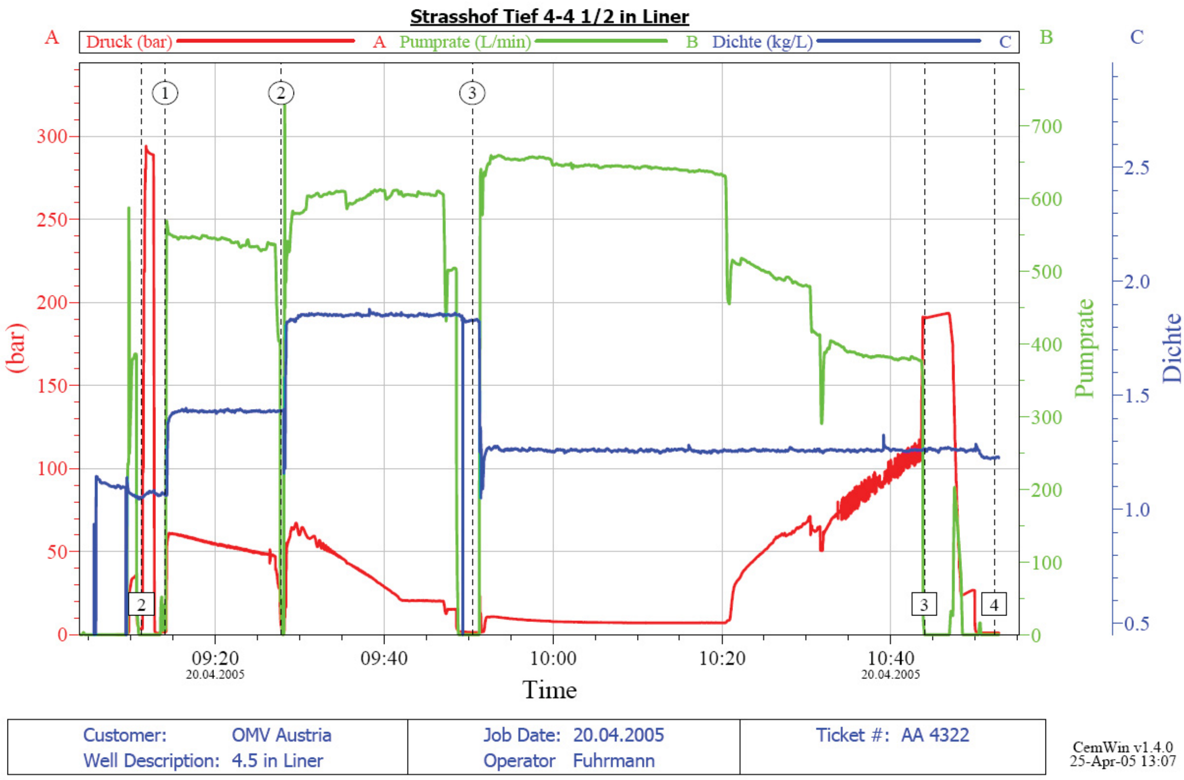


Figure 35: Cementing the 4 1/2" Liner in Str T4 [87]

TOC was planned to be at 3550m MD, about 60m above the 4 ½” liner top. The used cement amount, including the safety factor would have elevated the TOC up to 3373m, resulting in an excess of 2.3m³ of cement. (Table 50).

Table 50: Calculated TOC [88]

| | | | |
|---|---|---|---|
| 1. DP | OD | 5 | in |
| | ID | 4.25 | in |
| | MD | 1890 | m |
| | Volume | 9.16 | l/m |
| 2. DP | OD | 3.5 | in |
| | ID | 2,59 | in |
| | MD | 1446 | m |
| | Volume | 3.4 | l/m |
| 3. DP | OD | 3,5 | in |
| | ID | 2.08 | in |
| | MD | 280 | m |
| | Volume | 2.2 | l/m |
| 4 ½“ Liner | OD | 4.5 | in |
| | ID | 3.92 | in |
| | Top | 3609 | m |
| | Bottom | 4514 | m |
| | Volume | 10.26 | l/m |
| OH | ID | 6 | in |
| | Top | 3710 | m |
| | Bottom | 4516 | m |
| 7“ Casing | ID | 6.184 | in |
| | Top | | m |
| | Bottom | 3710 | m |

| Volume calculated for TOC at 3550m | | |
|---|---|---|
| Float Collar | 0.19 | $m^3$ |
| OH-4,5" liner | 7.78 | $m^3$ |
| 7"liner/4,5" Casing | 0.92 | $m^3$ |
| sum | 8.89 | $m^3$ |
| 12$m^3$ mud were pumped: | | |
| Mud volume left: | 3.11 | $m^3$ |
| Fluid height in 7" liner/3,5" DP annulus | 236 | m |
| Therefore the TOC is calculated: | 3373 | m |

| According to Halliburton’s Cementing Report: | | |
|---|---|---|
| Cement lost | 4 | $m^3$ |
| Excess Volume | 2.3 | $m^3$ |
| TOC | 3710 | m |

According to the Cementing Report of Halliburton, it was assumed, that about 4$m^3$ of slurry were lost. Subtracting this amount from the total height which could have been achieved (3373 m MD) would result in a calculated TOC at 3710m; this depth equals the setting depth of the last casing shoe.

Assuming that the TOC is at 3550m MD, as it was planned, the pressure difference between the annulus and the pipe equals 65bar. This in turn is the pressure required to balance the hydrostatic pressure in the annulus. However, this pressure was exceeded by 45bar, caused by the applied pressure of the pump. (Table 51)

Table 51: Comparison of the Hydrostatic pressures during Cementing Str T4

| Hydrostatic Pressure in the annulus | | | |
|---|---|---|---|
| | density [kg/l] | TVD [m] | $P_{hyd}$ [bar] |
| Mud | 1.21 | 0 | 289 |
| Spacer | 1.4 | 2432 | 133 |
| Cement | 1.8 | 3400 | 141 |
| | | 4198 | |
| $P_{hyd}$, annulus | | | 563 |

| Hydrostatic Pressure in the pipes: | | | |
|---|---|---|---|
| | density [kg/l] | TVD [m] | $P_{hyd}$ [bar] |
| Mud | 1.21 | 4198 | 498 |

| | | |
|---|---|---|
| Pressure Difference: | 65 | bar |
| Pump Pressure: | 110 | bar |

The hydrostatic pressure difference of the fluid columns indicates the necessary pumping pressure to bring the cement in place. However, as the pumping process is dynamic, the frictional pressure losses have to be taken into account. The bottomhole pressures were calculated via the law of conservation of mass. The results are listed in Table 52.

Table 52: Comparison of the dynamic pressures

| Pressure in the pipes | | |
|---|---|---|
| p hydrostatic mud | 498 | bar |
| p friction | -51 | bar |
| p cement | 4.4 | bar |
| Pressure applied by the pump | 110 | bar |
| total | 562 | bar |

| Pressure in the annulus: | | |
|---|---|---|
| p hydrostatic mud | 351 | bar |
| p hydrostatic spacer | 61 | bar |
| p hydrostatic cement | 141 | bar |
| p friction cement | 19 | bar |
| bottom hole pressure in the annulus | 572 | bar |

The pressure required to elevate the cement to 3550m MD equals 572bar. The pressure applied through the pipes was 10bar too small. As the cement is replaced by mud, the TOC is 173m below the anticipated TOC. Hence it is calculated to be at 3723m MD, 13m below the 7” casing shoe.

This in turn would indicate that about 1.8m³ of cement were lost. Adding the excess volume of cement results in a loss of cement of 4.1m³, similar to the volume of cement Halliburton assumed to be lost.

However, to evaluate the actual cement quality, a Cement Bond Log (CBL) measurement should have been conducted. According to the Daily Drilling Report of April, 20, 2005 the top of cement was planned to be measured by OMV PDS. Though, the measurement could not be performed, as the tool stood up at the top of the 7" liner when running it into the hole. Therefore the actual top of cement (TOC) is unknown. To define if cementing was successful and zonal isolation is achieved, more precise measurement of the cement should be conducted.

# 8 Proposal for optimization for future projects

The Str T wells dealt with the consistently emerging main issue of mud losses, being worse in Str T4. Str T5 was planned with the risk of fluid loss within the Hornsteinkalk already being taken into consideration. The basic density used in the Hornsteinkalk was 1.12kg/l and was significantly less when compared to the MW from the Str T4 well in the same layers, being 1.23kg/l. Also in Str T5 slight inflow was observed. As a result, the MW was increased by 0.02 kg/l to 1.14kg/l. Furthermore, the 9 5/8" casing setting point was set above the troublesome formation. Nevertheless, formation porosities increased within the well Str T5 accompanied by the beginning of seepage losses in the lower Reyersdorfer Dolomit.

In the case that the Hornsteinkalk had been intersected at a higher depth than expected, one method to provide a proper cementation would have been to sand up the troublesome formation. The sand will provide fluids entering the high permeable formation and the casing can be run into the hole and cemented.

Another option might be to set an external casing packer (ECP) to prevent further losses. ECPs are often used to achieve zonal isolation in OH completions. Once the liner hanger has been set, the packer is inflated via the wash pipe. Once a certain inflation pressure is reached the inflation valve closes. The ECP can be inflated either with mud or cement [84]

To work around the issue of fluid loss and depending formation damage, other options than conventional overbalanced drilling (OBD) need to be considered:

The alternative with the best chances of improvement would be underbalanced drilling (UBD). Due to open fractures being present in Str T wells it was difficult to generate uniform, stable filter cakes to prevent mud filtrate and solids invasion into the formation. The fluid loss may have increased the water saturation near the wellbore and therefore reduced the ability of the wells to produce HC. The damage, caused by OBD, may extend further into the formation than stimulation treatments can correct. However, in UBD, the wellbore pressure is set to be lower than the pressure of the drilled formation. Reservoir fluids are now able to enter the wellbore due to the underbalanced pressure condition and therefore avoid fluid loss and thereby formation damage.

Underbalanced drilling offers several other significant benefits that are superior to conventional drilling techniques. The reduction in hydrostatic head and the differential between pore pressure and hydrostatic head both contribute to a substantial improvement in ROP. When drilling hard rock formations, the penetration rate can be up to 10 times higher. Furthermore, the life of the bit can be significantly increased. Both factors are reducing drilling time and the associated costs.

As well, when drilling underbalanced, the chance of drill string sticking downhole is reduced and superior formation evaluation while drilling is possible.

UBD was already successfully supplied in wells containing sour gas. Exxon Mobile drilled two wells into the Zechstein formation, using a sour gas resistant CT. The drilling fluid was a mixture of nitrogen and water. The main issue, when drilling into sour gas bearing formations is to prevent sour gas to surface. Therefore Exxon Mobil used more water and nitrogen, accepting not being constantly underbalanced. For $H_2S$ detection a redundant sensor system was used as well as two flares to torch the $H_2S$ when necessary.

However, UBD is not without challenges. Potential problems and concerns include safety and control, wellbore stability, hole cleaning, completion and workover issues. Incremental expenses are necessary due to equipment upgrades, more exotic MWD procedures, gas costs and loss of produced gas, increased corrosion risks in some cases, special personnel and design generally required. Failing to maintain the UBD conditions on a constant basis eliminates the benefit of UBD.

Another method to reduce the formation damage is Managed Pressure Drilling (MPD). It is an adaptive drilling method which is used to exactly control the annular pressure profile given within the wellbore. Ideal would be to determinate the downhole pressure environment limits and react accordingly by regulate the annular hydraulic pressure profile. MPD differs from conventional drilling in banking upon a closed circulating system and ability to control flow and pressure in the wellbore.

MPD offers more exact control of wellbore pressure compared to conventional drilling. Its design limits the inflow of hydrocarbons. Mud losses are reduced by using a lower mud weight compared to conventional drilling. [88]

Both techniques, UBD and MPD, are variable ones, having been applied in lots of formation types, with different reservoir fluids, wells and hole sizes.

Formation damage is minimized most with UBD, therefore, enabling characterization of the reservoir or finding productive zones which could not be found with OBD. If it is the desire to mitigate drilling problems, MPD is the first choice because of its equal effectiveness to UBD and adding the benefit of economic superiority in cases of viability. If wellbore instabilities occur, MPD is chosen as well as if high $H_2S$ release rates are present and endanger the safety. When flaring is forbidden or the production while drilling is regulated, MPD might be the most effective solution.

MPD takes most effect when used to remove problems that are related to drilling, but there are also some benefits regarding reservoir activities. The impact that drilling fluid has on virgin formations is reduced, due to the lower degree of overbalance. Experience showed that UBD is best in offering solutions to problems occurring with both drilling and reservoir.

MPD often applies simpler compared to a full UBD operation. Non-reservoir sections frequently only need simple equipment to meet the safety standards for the well. Therefore, a full UBD compares less effective concerning the day rate.

Equipment requirements change with the parameters of the designed project. It so happens that both UBD and MPD need the same set-up of equipment. The main difference that separates MPD is that an influx of fluids is not expected while drilling. It is used as a measure of contingency or while the system is overbalanced a higher pressure zone exists which produces to the remainder of the openhole.[89]

Each technique has its place, and the best applicable solution will depend on the problems anticipated. The limits are set by the formation pressures, stability production potentials and factors that should be looked at from a technical and economic standpoint.

**Cementation and Zonal Isolation**

As mentioned in the previous chapter, casing leaks and behind pipe channelling were also problems, which had to be dealt with in Str T wells. In general Temperature logs served to evaluate the top of cement. In order to evaluate the cement quality behind the casing, Cement bond logs (CBL) were used. It provides an overall impression of the cement to formation and casing to cement bond. However, free gas and free liquids in the cement cannot be distinguished when only using CBL, as both fluids read high in the log. Identifying channelling from poor cement is rather difficult due to the lack of the azimuthally resolution.

Other methods to evaluate the zonal isolation are acoustic impedance logs. The material's acoustic impedance in contact with the casings outside can be measured with a Cement Evaluation Tool (CET). Based on the same measurement physics, the Ultra Sonic Imager Tool (USIT) provides the enhanced measuring method. Improvements shown mainly in signal processing's accuracy, consistent answer of acoustic impedance and providing complete casing coverage by using a single rotating transducer and receiver. The USIT provides two measurements: the evaluation of the cement and the casing evaluation in order to detect corrosion and wear. Field tests show, that channelling, contaminated cement, light cement and gas can be diagnosed and that external hardware such as centralizers can be detected. From corrosion measurement mechanical wear, corrosion and deposits, also being problems in Str T wells, can be detected.

Combining CBL and USIT and capitalize on advantages of both, will be the best workaround if problems according to zonal isolation and corrosion are present. [90]

**<u>OH completion- Pre- drilled liner/ slotted liner</u>**

On the one hand zonal isolation is an important issue to prevent communication between the layers. On the other hand, cementing might impair the permeability and damages the formation. In order to increase the productivity of the well an OH completion should be preferred for the zone of interest. In the absence of stimulation, the highest productivity can be achieved with a barefoot, openhole completion. The sole effect on productivity is the skin damage. Competent formations, especially naturally fractured limestone and dolomite, are best candidates for barefoot completions. In Str T5a an OH completion was already considered. However, the well was completed, as the formation below 5140m MD was identified to be water bearing and hole stability problems occurred.

As an alternative, pre drilled or pre-slotted liners might be used to stop hole collapse. Pre-drilled liners are generally a better choice than pre-slotted liners, due to their larger inflow and stronger build. The pressure drop through the holes and plugging is not taken into account. Although the geometry of slots in a pre-slotted liner can be optimized to improve strength, they still compare poorly to the strength of a pre-drilled liner. [84]

**<u>Short radius horizontal drilling</u>**

Increasing the deliverability of the wells with short radius horizontal sidetracks should be taken into consideration. Sidetracking was applied in most wells in Str T for various reasons. A short radius sidetrack shows a radius from vertical to horizontal ranging from 20 to 100ft and the produced laterals in 100 to 1300ft. This method is most fitting for wells that target the Perchtoldsdorfer Dolomit. The exposure time to the troublesome Hornsteinkalk will be minimized during drilling and it will be isolated by the casing when drilling into the Perchtoldsdorfer Dolomit. [91]

However, drilling into the reservoirs in a horizontal direction has various benefits: a smaller number of wells are necessary to develop a reservoir since a horizontal well can drain a larger rock volume. In very low matrix permeability wells with large vertical fractures an increase of the production rate and the recovery factor can be achieved, as well as return on investment and total return.

Joshi (1988) developed a horizontal well deliverability relationship that was augmented by Economides et. al (1990):

$$q = \frac{k_H h \, \Delta p}{141.2 B\mu \, \{\ln\left[\frac{a + \sqrt{a^2 - \left(\frac{L}{2}\right)^2}}{\frac{L}{2}}\right] + \left(\frac{I_{ani} h}{L}\right) ln \frac{I_{ani} \, h}{[r_w (I_{ani} + 1)]}\}}$$

Where '$I_{ani}$' stands for the measurement of the vertical- to horizontal permeability anisotropy and is defined as:

$$I_{ani} = \sqrt{\frac{k_H}{k_V}}$$

'a' is the large half-axis of the drainage ellipsoid formed by a horizontal well of length L, defined as:

$$a = \frac{L}{2}\{0.5 + \left[0.25 + \left(\frac{r_{eH}}{\left(\frac{L}{2}\right)}\right)^4\right]^{0.5}\}^{0.5} \qquad for \frac{L}{2} < 0.9 r_{eH}$$

In general, reservoirs of moderate to low thickness with good vertical permeability (favourable vertical-to-horizontal permeability anisotropy) are attractive candidates for horizontal drilling. In case of very thin reservoirs this requirement is not imperative. [ 92]

**<u>Drilling mud- K2CO3- System</u>**

During drilling, potassium was used as a Base Exchange ion to stabilize drilled shales as it is an effective clay swelling/hydration inhibitor. The concentration of potassium to achieve the desired result is a function of the shale being drilled.

To accomplish maximum inhibition, potassium must be the intervening ion within the fluid phase of the drilling mud. For example, in sea water, a minimum of 50,000g/l of potassium chloride is required to be the dominant ion as opposed to magnesium, calcium, and the other cations to indigenous to naturally occurring seawater.

Furthermore, potassium carbonate has a high $CO_2$ removal capacity and efficiency. The adsorption of carbon dioxide transforms potassium carbonate into potassium hydrogen carbonate [93]:

$$K_2CO_3 + CO_2 + H_2O \Leftrightarrow 2KHCO_3$$

However, in Str T4 the Potassium concentration was strongly increased. On March 1, the $K^+$ concentration was raised from 60g/l to almost 140g/l after the 9 5/8" casing was set. Comparing the Mud sample and samples of formation brine indicates that potassium was by far the dominating ion.

From logs, the shale content in the formation was shown to be rather small. Most of the reservoir rocks consist mainly of dolomite. Furthermore, glycol was added to the lower sections to improve wellbore stability and to stabilize shale due to its ability to cloud-out. It forms a physical barrier to reduce filtrate invasion into the shale matrix.

Therefore the question arises, which potassium concentrations are necessary to maintain shale stabilization. To analyze if lowering the potassium concentration in the drilling mud would lead to borehole stability problems, a clay swelling test in the presence of drilling mud with different potassium concentrations should be conducted. Since preserved shale cores are not available, swelling tests can be performed by creating shale 'pellets' from cuttings. Therefore the cuttings are ground- up and compressed into samples. These pellets will swell more than the intact shale because the inertial fabric and especially the bonding are largely destroyed. This can be prevented by compacting the sample in such a way that it becomes similar to the intact native shale and therefore it will respond similarly. [94]

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# 10 Appendix A- Contour Map

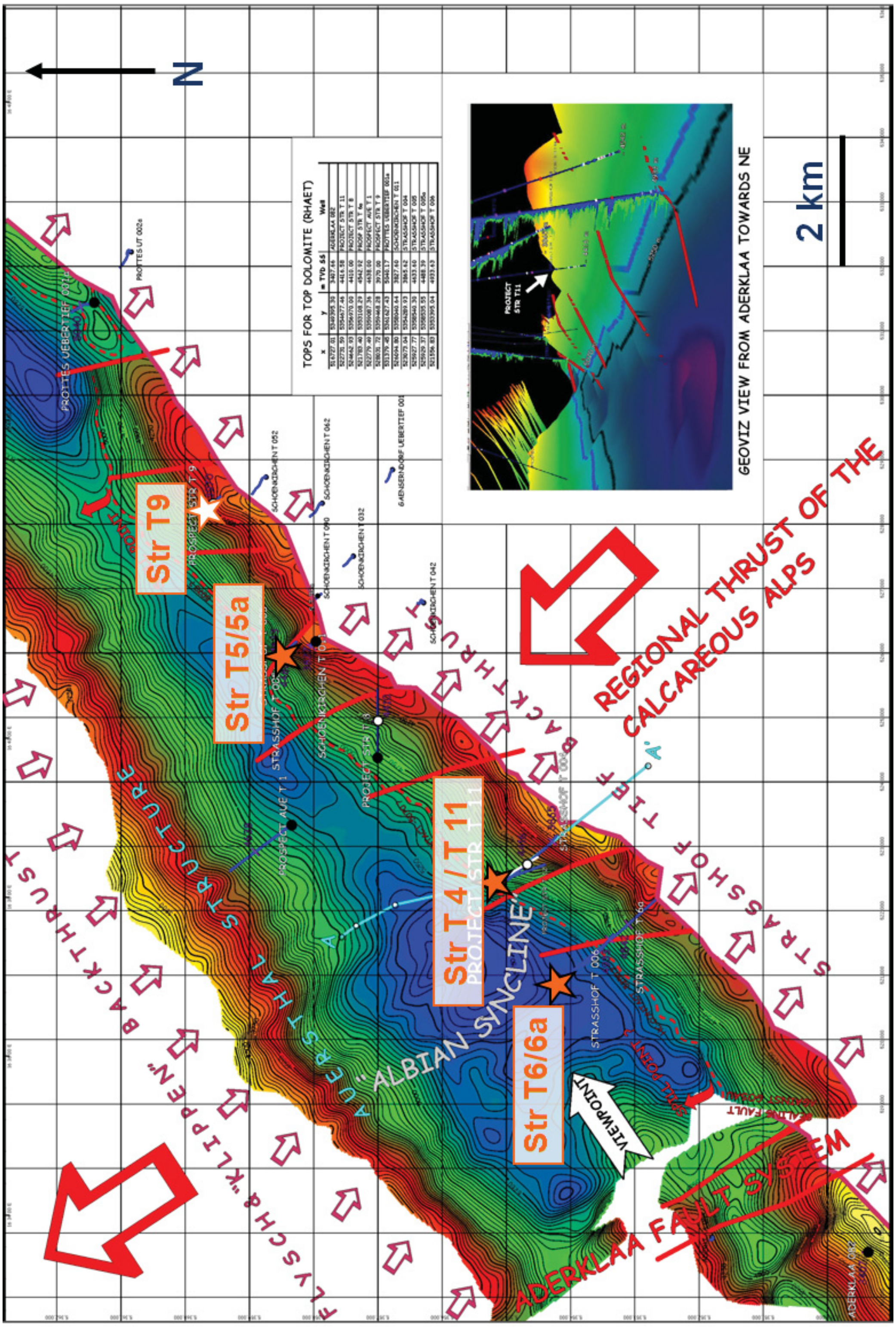


Figure 36: Strasshof Tief depicted on Top of Perchtoldsdorfer Dolomit

# 11 Appendix B- Stratigraphic Summaries

Table 53: Stratigraphic Summary of Str T4

| Strasshof T4- Stratigraphic Summary | | | | |
|---|---|---|---|---|
| **Age** | | **Horizon** | **MD** | **TVD** |
| **PANNON** | | | (m) | (m) |
| | *Mittel Pannon* | | 0 | 0 |
| | | 2.MP | 333 | 333 |
| | *Unter Pannon* | | 485 | 485 |
| | | 2. UP | 573 | 573 |
| | | 4. UP | 608 | 608 |
| | | 5. UP | 758 | 758 |
| **SARMAT** | | | 770 | 770 |
| | *Ober Sarmat* | | 770 | 770 |
| | | 3. / 4. SH | 794 | 794 |
| | | 5. SH | 819 | 819 |
| | | 6. SH | 853 | 853 |
| | | 7. SH | 900 | 900 |
| | *Unter Sarmat* | | 975 | 975 |
| | | 8. SH | 979 | 979 |
| | | 10. SH | 1059 | 1059 |
| **BADEN** | | | | |
| | *Bulim.-Rot.Zone* | | 1109 | 1109 |
| | | 8. TH | 1302 | 1302 |
| | | SANDSCHALER ZONE | 1615 | 1615 |
| | | OBERE LAGENIDEN ZONE | 1828 | 1828 |
| | | 16. TH - BULI.-ROT.Z. | 1860 | 1860 |
| **KARPAT** | | | 1915 | 1915 |
| | | ADERKLAAER KONGLOMERAT | 1915 | 1915 |
| | | ADERKLAAER SCHICHTEN | 2074 | 2072 |
| | | GÄNSERNDORFER SCHICHTEN | 2785 | 2760 |
| | | STRASSHOFER HAUPTMARKER | 2825 | 2795 |
| | | GAENSERNDORFER SCHICHTEN TL3 | 2866 | 2830 |
| | | GAENSERNDORFER SCHICHTEN TL4 | 2949 | 2900 |
| **ALB** | | THANNHEIM. SCH. BECKENUNTERGUND | 3007 | 2949 |
| **NEOKOM** | | SCHRAMBACH S. | 3059 | 2992 |
| **MALM** | TITHON | CALPIONELL. K. | 3187 | 3097 |
| | KIMMERIDGE | SACCOCOMA K. | 3224 | 3128 |
| **RHAET** | | KOESSENERSCH. | 3252 | 3151 |
| | | PLATTENKALK | 3284 | 3178 |
| **NOR** | | | 3296 | 3188 |
| | | REYERSD. DOLOMIT | 3296 | 3188 |
| **MALM** | KIMMERIDGE | BRUCH | 3400 | 3274 |
| | TITHON | CALPIONELL. K. | 3421 | 3291 |
| **NOR** | | HAUPTDOLOMIT BRUCH | 3445 | 3311 |
| **MALM** | KIMMERIDGE | SACCOCOMA K. BRUCH | 3558 | 3405 |

| | | | | |
|---|---|---|---|---|
| **RHAET** | | KOESSENERSCH. | 3572 | 3416 |
| | | PLATTENKALK | 3588 | 3429 |
| **NOR** | | HAUPTDOLOMIT | 3605 | 3443 |
| **UNTER KREIDE** | | BRUCH | 3978 | 3749 |
| **MALM** | TITHON | CALPIONELL. K. | 4075 | 3828 |
| | KIMMERIDGE | SACCOCOMA K. | 4092 | 3842 |
| | OXFORD | RADIOLARIT | 4111 | 3858 |
| **DOGGER** | | KLAUSKALK | 4132 | 3875 |
| **LIAS** | | HIERLATZKALK | 4157 | 3896 |
| | | HORNSTEINKALK | 4186 | 3920 |
| | | FLECKENMERGEL | 4226 | 3953 |
| **NOR** | | | 4316 | 4029 |
| | | HAUPTDOLOMIT | 4316 | 4029 |
| **UNTER KREIDE** | NEOKOM | BRUCH | 4433 | 4129 |
| **TURON** | | BRUCH | 4450 | 4143 |
| **TD** | | | 4516 | 4198 |

Table 54: Stratigraphic Summary of Str T5

| **Strasshof Tief 5- Stratigraphic Summary** | | | | |
|---|---|---|---|---|
| **AGE** | | **HORIZON** | **Measured Depth** | **Depth (TVDSS)** |
| | | | (m) | (m) |
| **PANNON** | | | 0 | 168 |
| | *Unter Pannon* | | 425 | 257 |
| | | 1.UP | 425 | 257 |
| | | 2.UP | 496 | 328 |
| | | 5.UP | 660 | 492 |
| **SARMAT** | | | 697 | 529 |
| | *Ober Sarmat* | | 697 | 529 |
| | | 3./4. SH | 730 | 562 |
| | | 5. SH | 764 | 596 |
| | | 6. SH | 806 | 638 |
| | | 7. SH | 851 | 683 |
| | *Unter Sarmat* | | 927 | 759 |
| | | 8. SH | 936 | 768 |
| | | 9. SH | 965 | 797 |
| | | 10.SH | 1011 | 843 |
| **BADEN** | | | 1030 | 862 |
| | *Bulim.-Rot.Zone* | | 1030 | 862 |
| | | 5. TH | 1120 | 952 |
| | | 6. TH | 1178 | 1010 |
| | | 7. TH | 1206 | 1038 |
| | | 8.Nulliporen- TH | 1220 | 1052 |
| | | 8. TH | 1235 | 1067 |
| | | 9. N.TH | 1274 | 1106 |
| | | 9. TH | 1290 | 1122 |

| | | | | |
|---|---|---|---|---|
| | | 11.TH | 1353 | 1185 |
| | *Sandschaler Zone* | | 1561 | 1393 |
| | | 16. TH | 1675 | 1507 |
| **KARPAT** | | | 1779 | 1611 |
| | *Aderklaaer Konglomerat* | | 1779 | 1611 |
| | *Aderklaaer Schichten* | | 1801 | 1633 |
| | | Marker 24 | 1821 | 1653 |
| | | M 23 | 1890 | 1722 |
| | | M 22 | 1931 | 1763 |
| | | M22/1 | 2007 | 1839 |
| | | M 21 | 2067 | 1899 |
| | | Fault | 2130 | 1962 |
| | | M 19 | 2160 | 1992 |
| | | M 19/1 | 2190 | 2022 |
| | | M 18 | 2230 | 2062 |
| | *Gänserndofer Schichten* | | 2232 | 2064 |
| | | M 17 | 2269 | 2101 |
| | | m 17/1 | 2313 | 2145 |
| | | M 17/2 | 2342 | 2174 |
| | | M16 | 2397 | 2229 |
| | | M 15 | 2421 | 2253 |
| | | M 14 | 2477 | 2309 |
| | | M 13 | 2523 | 2355 |
| **OTTNANG** | | | 2543 | 2375 |
| | *Bockfließer Schichten* | | 2543 | 2375 |
| | | B 14 | 2721 | 2553 |
| **TURON- CENOMAN** | | | 2792 | 2624 |
| | | Beckenuntergrund | 2792 | 2624 |
| **ALB** | | | 2886 | 2718 |
| **NEOKOM** | | | 2945 | 2777 |
| **CAMPAN/ FAULT** | | | 3053 | 2885 |
| **TURON** | | | 3112 | 2944 |
| **ALB** | | | 3175 | 3007 |
| **MALM** | | | 3217 | 3049 |
| **NOR** | | | 3245 | 3077 |
| | | Reyersdorfer Dolomit | 3245 | 3077 |
| **MALM** | | | 3365 | 3197 |
| **NOR** | | | 3390 | 3222 |
| | | Hauptdolomit | 3390 | 3222 |
| **KARN** | | | 3715 | 3547 |
| | | Opponitzer Schichten | 3715 | 3547 |
| **NOR** | | | 3790 | 3622 |
| | | Hauptdolomit Fault | 3790 | 3622 |
| **NEOKOM** | | | 4481 | 4313 |
| | | Fault | 4481 | 4313 |
| **DOGGER** | | | 4597 | 4429 |
| | | Klauskalk | 4597 | 4429 |
| **LIAS** | | | 4622 | 4454 |
| | | Hierlatzkalk | 4622 | 4454 |
| | | Hornsteinkalk | 4657 | 4489 |
| | | Kieselkalk | 4695 | 4527 |
| | | Kalksbuergerschichten | 4780 | 4612 |
| **RHAET** | | | 4796 | 4628 |
| **NOR** | | | 4805 | 4637 |

| | | | |
|---|---|---|---|
| | Perchtoldsdorfer Dolomit | 4805 | 4637 |
| **RHAET** | | 4854 | 4686 |
| **NOR** | | 4984 | 4816 |
| | Perchtoldsdorfer Dolomit | 4984 | 4816 |
| **TD** | | 5435 | 5267 |

Table 55: Stratigraphic Summary of Str T5a

| **Strasshof Tief 5a- Stratigraphic Summary** | | | |
|---|---|---|---|
| **AGE** | **HORIZON** | **MD** | **(TVDSS)** |
| | | (m) | (m) |
| Neokom | | 4520 | 4350 |
| **KOP** | | 4520 | 4350 |
| **MALM** | | 4580 | 4409 |
| **UPPER JURASSIC** Tithon | | 4580 | 4409 |
| | Calpionell. Kalk | 4580 | 4409 |
| **DOGGER** | | 4597 | 4425 |
| | Klauskalk | 4597 | 4425 |
| | Fault | 4623 | 4450 |
| **LIAS** | | 4640 | 4466 |
| | Kalksbuergerschichten | 4640 | 4466 |
| **RHAET** | | 4645 | 4471 |
| | Riffkalk | 4645 | 4471 |
| | Dolomit | 4662 | 4487 |
| | Riffkalk | 4779 | 4597 |
| **NOR** | | 4788 | 4605 |
| | Perchtoldsdorfer Dolom. | 4788 | 4605 |
| | Fault | 5240 | 4999 |
| **TD** | | 5400 | 5125 |

Table 56: Stratigraphic Summary of Str T6

| **Strasshof Tief 6- Stratigraphic Summary** | | | |
|---|---|---|---|
| **Age** | **Horizon** | **MD** | **TVD** |
| **PANNON** | | (m) | (m) |
| *Ober Pannon* | | 0 | 0 |
| | 2.MP | 370 | 370 |
| *Unter Pannon* | | 492 | 492 |
| | 2. UP | 595 | 595 |
| | 4. UP | 635 | 635 |
| **SARMAT** | | 783 | 783 |
| *Ober Sarmat* | | 783 | 783 |
| | 3. / 4. SH | | |
| | 5. SH | 833 | 833 |
| | 6. SH | 864 | 864 |
| | 7. SH | 907 | 907 |
| *Unter Sarmat* | | 1001 | 1001 |
| | 8. SH | 1014 | 1014 |

| | | | | |
|---|---|---|---|---|
| **BADEN** | | | 1133 | 1132 |
| | *Bulim.-Rot.Zone* | | 1133 | 1132 |
| | | 8. TH<br>SANDSCHALER ZONE<br>OBERE LAGENIDEN ZONE<br>16. TH - BULI.-ROT.Z.<br>ADERKLAAER KONGLOMERAT | 1313<br>1635<br>1899<br>1932<br>2014 | 1309<br>1620<br>1873<br>1905<br>1984 |
| **KARPAT** | | | 2142 | 2106 |
| | | ADERKLAAER SCHICHTEN<br>GÄNSERNDORFER SCHICHTEN | 2142<br>3085 | 2106<br>3021 |
| **UNTER KREIDE** | | | 3260 | 3194 |
| **NEOKOM** | | | 3260 | 3194 |
| **OBER KREIDE** | | | | |
| **RHAET** | | | 3817 | 3649 |
| | | REYERSD. DOLOMIT | 3927 | 3841 |
| **UNTER KREIDE** | | BRUCH | | |
| **UNTER JURA** | | | | |
| | | KLAUSKALK<br>HIERLATZKALK<br>HORNSTEINKALK<br>KIESELKALK<br>ALLGÄUER SCHICHTEN<br>KALKSBURGER SCHICHTEN | | |
| **OBER TRIAS** | | | 5262 | 5098 |
| **RHÄT** | | PERCHTOLDSDORFER DOLOMIT | 5262 | 5098 |
| **NOR** | | KÖSSNER SCHICHTEN<br>PERCHTOLDSDORFER DOLOMIT | | |
| **OBERKREIDE** | | BRUCH | | |
| | GOSAU | | | |
| **TD** | | | 5500 | 5317 |

Table 57: Stratigraphic Summary of Str T6a

| Strasshof Tief 6a- Stratigraphic Summary | | | |
|---|---|---|---|
| **Age** | **Horizon** | **MD** | **TVD** |
| **PANNON** | | (m) | (m) |
| **KARPAT** | GÄNSERNDORFER SCHICHTEN | 3089 | 3027 |
| **OBER KREIDE** | | 3313 | 3221 |
| **UNTER KREIDE** | | 3554 | 3194 |
| **RHAET** | | 3643 | 3510 |
| | REYERSD. DOLOMIT | 3858 | 3697 |
| | OPPOTNITZER SCHICHTEN | - | - |
| | BRUCH | | |
| **NEOKOM** | | 4635 | 4363 |
| | KLAUSKALK<br>HIERLATZKALK<br>HORNSTEINKALK | <br>4823<br>4865 | <br>4530<br>4555 |
| **OBER TRIAS** | | 4953 | 4692 |
| **RHÄT** | PERCHTOLDSDORFER DOLOMIT | 5015 | 4692 |
| **NOR** | KÖSSNER SCHICHTEN<br>PERCHTOLDSDORFER DOLOMIT | 5110 | 4776 |
| **OBERKREIDE** | BRUCH | | |
| **TD** | | | |

# 12 Appendix C- Calculations

## 12.1 Pf/Mf Method

The calculations for using the Pf/Mf values to determine carbonate and bicarbonate concentrations are listed in Table 58.

Table 58: Pf/Mf Alkalinity Ion Concentrations, [mg/l]

| $P_f$ / $M_f$ Values | [ $OH^-$ ] | [ $CO_3^{-2}$ ] | [ $HCO_3^-$ ] |
|---|---|---|---|
| $P_f = 0$ | 0 | 0 | 1220 $M_f$ |
| $2 P_f < M_f$ | 0 | 1200 $P_f$ | 1220 ( $M_f - 2 P_f$ ) |
| $2 P_f = M_f$ | 0 | 1200 $P_f$ | 0 |
| $2 P_f > M_f$ | 340 ( $2 P_f - M_f$ ) | 1200 ( $M_f - P_f$ ) | 0 |
| $P_f = M_f$ | 340 $M_f$ | 0 | 0 |

## 12.2 pH/Pf Method

Calculate the hydroxide concentration in mg/L (OH):

$$OH^- = 17{,}000 * 10^{pH-14}$$

Carbonate concentration in mg/L ($CO_3$):

$$CO_3 = 1200\ (P_f - \left(\frac{OH}{340}\right))$$

Bicarbonate concentration in mg/L ($HCO_3$):

$$HCO_3 = \frac{\mathrm{CO_3}}{10^{\mathrm{pH}*9.7}}$$

## 12.3 Comparison of Pf/Mf and pH/Pf Method

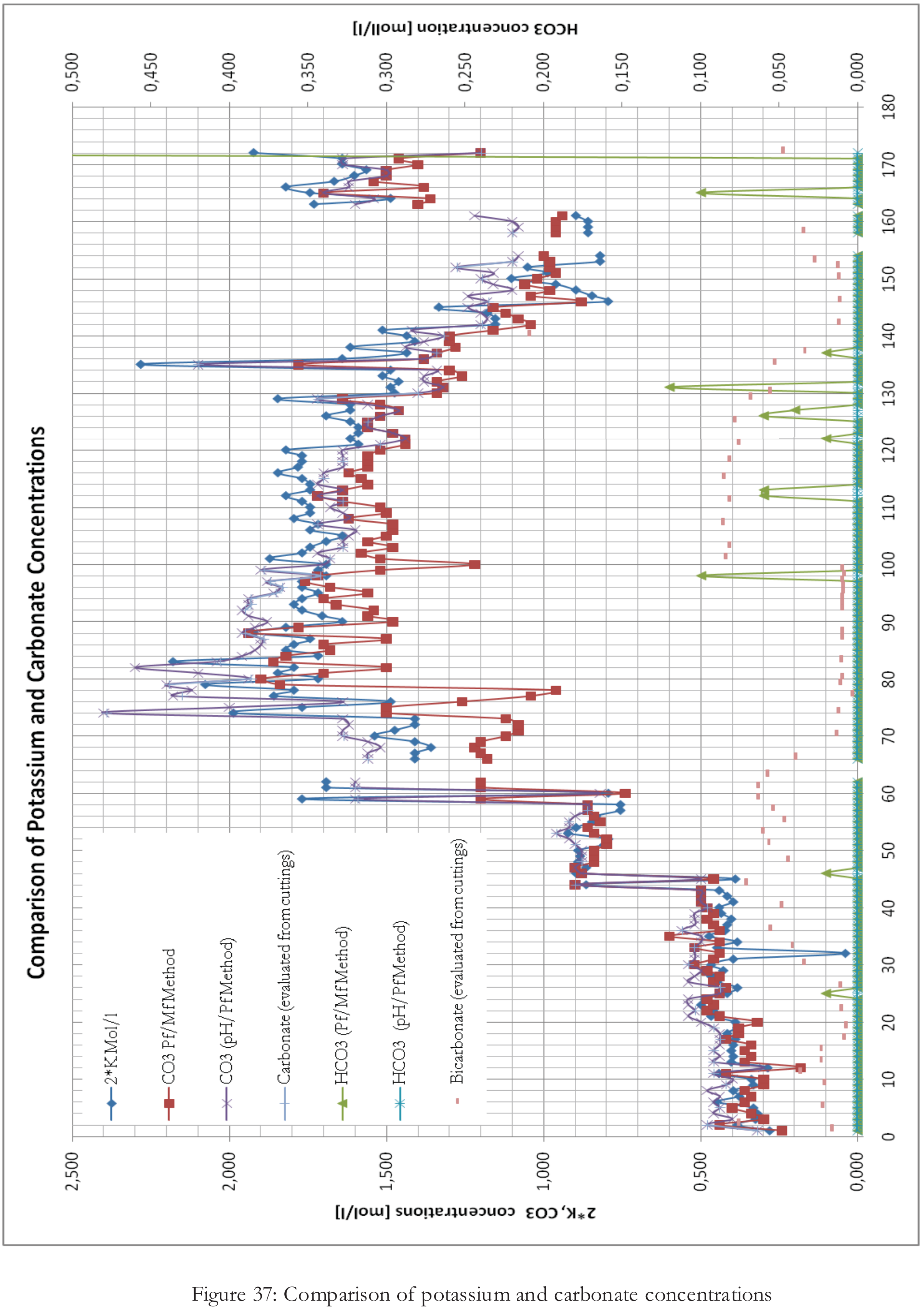


Figure 37: Comparison of potassium and carbonate concentrations

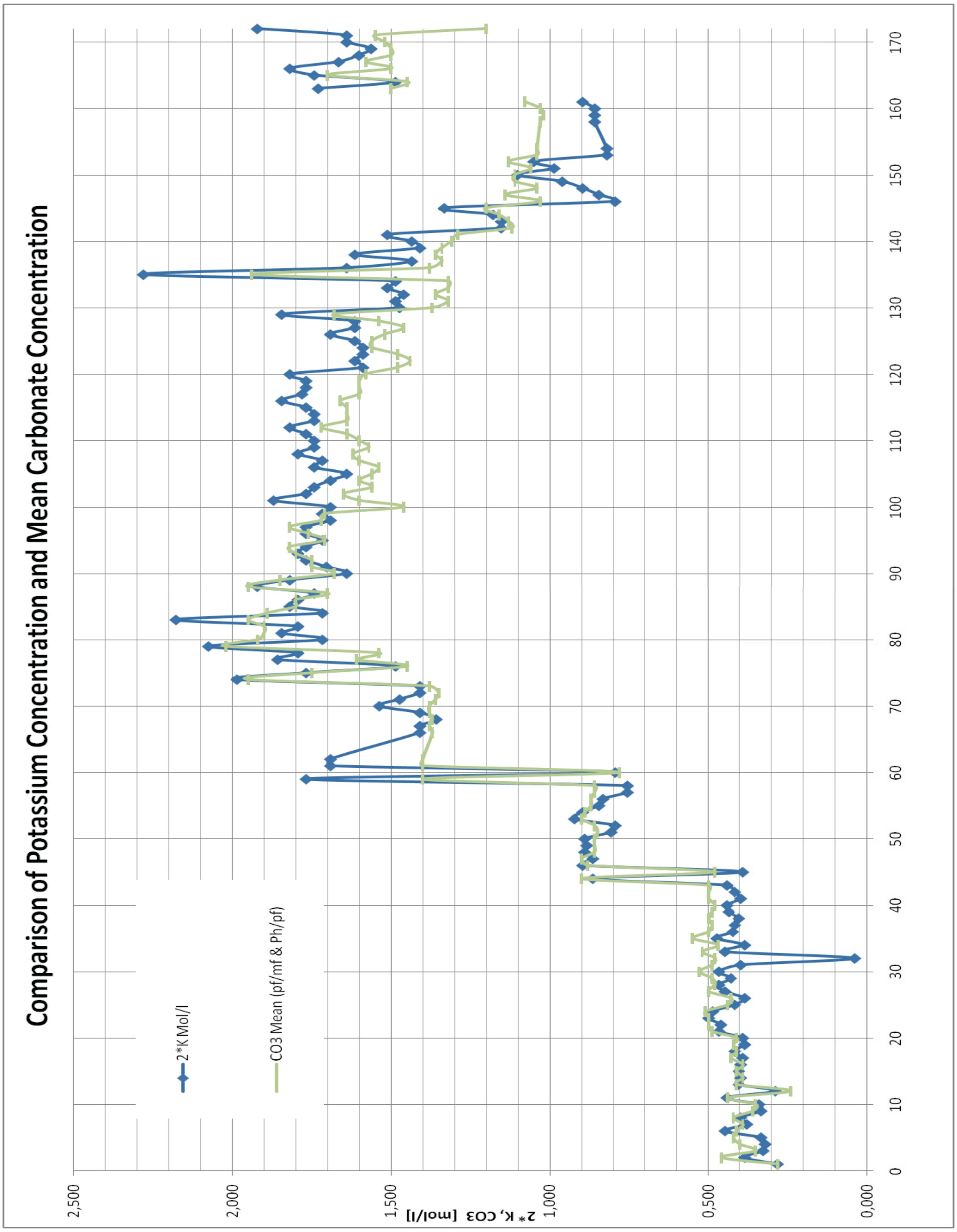


Figure 38: Comparison of potassium and mean carbonate concentrations