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National Cooperative for the Disposal of Radioactive Waste

TECHNICAL REPORT 95-02

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1 ABSTRACT

Boreholes SB4a/vertical (SB4a/v) and SB4a/slanted (SB4a/s) are the sixth and seventh deep investigation boreholes drilled from a single drill-site at Wellenberg as part of the Phase II investigation programme of the Wellenberg site (NAGRA, 1994). This site is under consideration as a potential location for a possible repository for L/ILW radioactive waste.

This report presents the results and describes the methods applied in the pressure transient testing of the vertical and the slanted borehole SB4a. A total of twenty three packer tests were successfully conducted in the vertical and twenty four in the slanted borehole. A primary objective of the tests was to characterise the flow properties of the formation under single and two-phase flow conditions. Of equal importance was the determination of the head distribution in the potential repository area. In general, the tests were designed and conducted in a way which allowed a flow model to be derived that accurately reflects the characteristics of the formation. Based on this flow model the effective conductivities and the heads were determined.

The downhole equipment used included single and double packer set-ups as well as special tools designed for gas injection testing and for downhole sampling. Fluid withdrawal was performed by means of a surface controlled Moineau pump system. The surface test equipment consisted of a flow control board and water/gas separation equipment. A new type of a small vertical separator was introduced. Downhole pressure data as well as surface flow and separator data were gathered by a computer-based data acquisition system.

An extended quality assurance/quality control programme was introduced and successfully applied.

Two levels of test interpretation were applied; standard and detailed test analysis. These levels were applied to both single and dual phase tests, and to gas threshold pressure tests. Test data were analysed in two steps. The first step involved using the analytical interpretation software FLowDIM and INTERPRET/2. State of the art diagnostic methods as well as careful evaluation of rate sequence and input parameters constituted the basis for an iterative analysis sequence. Based on these analysis results, consistency checks and analyses using alternative interpretation software (MULTIFIT and GTFM) were performed. For cases of two phase flow the TOUGH / ITOUGH2 codes were applied. Standard analyses were performed for all forty seven tests. Twelve tests were also analysed at a detailed level.

Interpreted hydraulic conductivities for both boreholes range from 10^{-13} m/s to 10^{-6} m/s. The head distribution confirmed the results obtained from other investigation boreholes drilled at this site. The heads were hydrostatic to slightly artesian in the upper parts of the boreholes, to about 600 m below ground level. In the lower part of the boreholes head conditions well below hydrostatic were encountered. The lowest head measured was over 600 m below ground level. The occurrence of small amount of gas in the Palfris formation and surrounding formations was again confirmed. The zones where gas was encountered were approximately between 150 m and 520 m below ground level in the vertical borehole, and between 120 m and 390 m in the slanted borehole.

2 ZUSAMMENFASSUNG

Die Bohrungen SB4a/vertikal (SB4a/v) und SB4a/schräg (SB4a/s) sind die sechste und siebte tiefe Sondierbohrung, die am Standort Wellenberg im Rahmen der Untersuchungsphase II zur Charakterisierung der geologischen und hydrogeologischen Verhältnisse niedergebracht wurden (NAGRA, 1994). Der Wellenberg ist als Standort für ein Endlager für schwach- und mittelradioaktive Abfälle vorgesehen.

Dieser Bericht liefert die Ergebnisse und beschreibt die Methoden, die bei den transienten Drucktests in der vertikalen und geneigten Bohrung SB4a angewandt wurden. Insgesamt wurden 23 Packer-Tests in der vertikalen Bohrung und 24 in der geneigten Bohrung durchgeführt. Eines der vorrangigen Ziele der Tests war die Charakterisierung der Fließeigenschaften der Formation unter Ein- und Zwei-Phasen-Fluß-Bedingungen. Von ebenso großer Wichtigkeit war die Bestimmung der Potentialverteilung im geplanten EndlagerBereich. Die Tests wurden so geplant und durchgeführt, daß es möglich war, ein Fließmodell zu bestimmen, das die Eigenschaften der Formation am besten widerspiegelt. Basierend auf diesem Modell wurden die effektive Permeabilität und die Potentiale bestimmt.

Das Untertage-Equipment bestand aus Einfach- und Doppel-Packer-Garnituren sowie Spezial-Equipment für Gasinjektionstests und für die Probennahme im Bohrloch. Die Fluidproduktion wurde mit einem Moineau-Pumpsystem durchgeführt, das von der Oberfläche aus gesteuert wurde. Die Ausrüstung an der Oberfläche bestand aus einem Flow-Control-Board und einem Wasser-Gas-Separator. Des weiteren wurde ein neuer Typ eines vertikalen Separators eingesetzt. Daten zum Druck im Bohrloch, zu Fließraten übertage sowie Separator-Daten wurden von einem computergestützten Datenaquisitionssystem erfaßt.

Ein umfangreiches Qualitätssicherungs- und -kontrollsystem wurde eingesetzt und erfolgreich angewandt.

Bei der Datenauswertung kamen zwei Interpretationsstulen zum Einsatz - eine Standard- und eine ausführliche Testanalyse. Diese Stuben wurden bei Ein- und Zwei-Phasen-Fluß-Tests und ebenso bei Gas-Schwellendruck-Tests angewandt. Die Auswertung der Testdaten erfolgte in zwei Schritten. Der erste Schritt der Analyse wurde mit Hilfe der InterpretationssoftwarePakete FLowDIM und INTERPRET/2 ausgeführt. Auswertemethoden, die dem Stand der Technik entsprechen, sowie die sorgfältige Auswertung von Ratensequenzen und Eingabeparametern bildeten die Basis für eine iterative Analysen-Folge. Auf Grundlage der so gewonnenen Ergebnisse wurden Uberprüfungen auf Folgerichtigkeit sowie ausführliche Untersuchungen mit alternativer Interpretationssoftware (MULTIFIT und GTFM) durchgeführt. Im Falle der Zwei-Phasen-Fließmodelle kamen TOUGH / ITOUGH2 zur Anwendung. Die Standard-Analysen wurden bei sämtlichen 47 Tests durchgeführt. Zwölf Tests wurden zusätzlich einer detaillierten Untersuchung unterzogen.

Die ausgearbeiteten hydraulischen Konduktivitäten für beide Bohrungen bewegen sich zwischen 10^{-13} m/s und 10^{-6} m/s. Die Potentialverteilung bestätigte die Ergebnisse, die aus anderen Sondierbohrungen an diesem Standort stammten. Die Potentiale waren hydrostatisch bis leicht artesisch in den oberen Bereichen der Bohrungen - bis ca. 600 m unter Geländeoberkante. Im unteren Bereich der Bohrungen lagen die Potentiale erheblich unterhalb von hydrostatischen Bedingungen. Das niedrigste gemessene Potential lag unterhalb 600 m unter Geländeoberkante. Die Existenz von geringen Mengen von Gas in der Palfris Formation sowie in den umliegenden Formationen konnte erneut bestätigt werden. Die Bereiche, in denen Gas angetroffen wurde, befanden sich im vertikalen Bohrloch ungefähr zwischen 150 m und 520 m, im geneigten Bohrloch zwischen 120 m und 390 m unter Geländeoberkante.

3 RESUME

SB4a/vertical et SB4a/incliné constituent respectivement le sixième et septième forage profond foncé sur le site du Wellenberg et font partie intégrante de la phase II du programme d'exploration (NAGRA, 1994). Le site du Wellenberg est prévu comme dépôt final pour déchets radioactifs.

Le présent rapport présente les résultats et décrit les méthodes d'interprétation des essais hydrauliques en conditions instationnaires effectués dans les deux forages SB4a. 24 tests avec obturateurs ont été couronnés de succès dans le forage vertical et 23 dans le forage incliné. L'un des objectifs essentiels de ces essais était la caractérisation des propriétés hydrauliques de la roche, ceci tant sous conditions mono- que biphasique. Tout aussi importante était la détermination de la distribution des potentiels hydrauliques dans la zone potentielle de dépôt. Les essais furent planifiés de manière à pouvoir déterminer dans chaque cas le modèle d'écoulement reflétant le mieux les caractéristiques de la formation. Les perméabilités effectives et les potentiels ont été déterminés sur la base de ce modèle d'écoulement.

L'équipement en forage comportait des garnitures avec obturateurs simples et doubles, ainsi que des outils spécialement conçus pour l'injection de gaz et pour le prélèvement d'échantillons in situ. Une pompe de type Moineau, dirigée depuis la surface, servit à pomper le fluide. L'équipement de surface comprenait un tableau de contrôle des écoulements et un séparateur eau/gaz d'un type nouveau (séparateur vertical). Les pressions dans le forage, le débit en surface et les données du séparateur ont été recueillies par un acquisiteur de données numérique.

Un programme minutieux d'assurance qualité a été introduit et conduit avec succès.

Deux niveaux d'interprétation des données des des essais ont été appliqués: l'analyse standard et l'analyse détaillée. Ces niveaux ont été appliqués à tous les types de test, y compris les "Gas-Threshold-Pressure-Tests". L'interprétation des tests s'est faite en deux étapes. Dans la première étape, on a eu recours aux programmes d'interprétation analytique FLOWDIM et INTERPRET/2. Des méthodes modernes d'interprétation ainsi qu'une évaluation détaillée des palliers de débit et des paramètres d'entrées ont constitué la base d'une série itérative d'analyses. En se basant sur les résultats ainsi obtenus, des tests de cohérence et des analyses basant sur des méthodes alternatives d'interprétation (MULTIFIT et GTFM) ont été effectués. Les programmes TOUGH / ITOUGH2 ont été appliqués pour les modèles biphasiques. L'analyse standard a été appliquée à l'ensemble des 47 essais. De plus, 12 essais ont fait l'objet d'une analyse détaillée.

Les conductivités hydrauliques des deux forages varient entre 10^{-13} m/s et 10^{-6} m/s. La distribution des potentiels est confome aux résultats des forages précédents sur ce même site. Les potentiels sont hydrostatiques à légèrement artésiens dans la partie supérieure des forages - jusqu'à environ 600m sous la surface. Dans la partie inférieure des forages, les conditions sont légèrement subhydrostatiques. Le potentiel le plus bas a été mesuré à plus de 600 mètres en dessous du niveau du sol. La présence d'un faible quantité de gaz dans la formation de Palfris et dans les formations environnantes a pu être confirmée. Le gaz a été détecté dans des zones se situant approximativement entre 150 mètres et 520 mètres en dessous du niveau du sol dans le forage vertical, et entre 120 mètres et 390 mètres dans le forage incliné.

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1 INTRODUCTION

The Wellenberg site has been under investigation since 1988 as one of four potential sites for the storage of low-level and short-lived intermediate level radioactive waste in Switzerland. Since then the Swiss National Cooperative for the Storage of Radioactive Waste (NAGRA) has obtained a series of permissions for several stages of comprehensive siting programmes. The scope of site investigations includes the determination of the geologic and hydrogeologic characteristics of the potential host rock and adjacent formations. The investigations are intended to provide data required for the safety assessment of the site. The Wellenberg site was chosen for its large thickness of potential host rock and for its favourable exploration conditions. Seven investigation boreholes (Sondierbohrungen - SB) have been completed in this area: SB1, SB2, SB3, SB4, SB4a/v, SB4a/s and SB6. Figure 1.1 shows the locations of these boreholes.

The boreholes SB4a/v and SB4/s were part of the most recently completed campaign. The drilling and investigation of this boreholes started in the fall of 1994 and completed in November of 1995. This report documents hydrogeologic investigations conducted by Golder Associates GmbH, Celle (Germany) under contract to NAGRA. Golder Associates subcontracted Baker Service Tools, Celle (Germany) to provide test equipment and personnel for hydraulic testing. The technical work reported herein concerns the hydraulic testing in borehole SB4a vertical and slanted. The vertical borehole, referred to as SB4a/v, was drilled to a total depth of 735.0 m bGL; the slanted borehole, SB4a/s, was drilled at a nominal deviation of 45° from the vertical with a measured depth of 858.20 m.

1.1 Background

The investigations conducted in the SB4a borehole constitute a continuation of in-situ investigations of the Palfris formation. This formation mainly consisting of marls has been considered as a potential host rock formation for a low and intermediate level radioactive waste repository.

The first investigations in the Palfris formation were performed in 1987 at the Oberbauenstock site (KENNEDY et al. 1988) about 10 km NE from the Wellenberg site in the vicinity of lake Lucern. The Wellenberg, site is located in the Engelberg Valley. Five deep boreholes (SB-1/2/3/4/6) were drilled and tested between 1989 and 1992. The results of these investigations are included in OSTROWSKI et al. (1992) for SB-3/4/6 and in ADAMS & WYSS (1994) for SB-1/2.

The deep borehole investigations in general are part of an extensive site investigation programme (NAGRA, 1989; NAGRA, 1991; NAGRA, 1994). The purpose of the hydraulic investigations are:

- hydraulic parameters of the host rock and the adjacent formations;
- hydraulic head and state conditions (free gas, dissolved gas);
- two phase flow parameters;
- chemical composition of the different formation waters.

The programme includes other investigations at the surface like 2-D seismic survey, further shallow boreholes and groundwater monitoring wells, as well as long term monitoring and field studies. The objectives and scope of the work presented herein (concerning borehole SB4a/v and SB4a/s) are described in the Wellenberg investigation programme Phase II (NAGRA, 1994).

Hydraulic packer testing was planned in both boreholes to characterise the vertical distribution of hydraulic properties. The most permeable features are considered to be the potential groundwater-transport pathways for radionuclides which may escape from the repository. The main objectives of the packer testing were the determination of equivalent freshwater heads and hydraulic conductivities. A secondary objective was to investigate the characteristics of flow and determine the two phase flow parameters of the formation. Also, obtaining low contaminated water samples was included as objective for several discrete test zones over a range of depths for chemical and isotope analysis.

A total of 47 tests were conducted in the SB4a boreholes; 23 were in the vertical borehole and 24 in the slanted borehole. Thirty three tests were carried out with a single packer and 14 with double packer configuration, with 7 straddle tests in each part of the borehole.

This report summarises the results of both standard and detailed field analyses for all 47 tests. The detailed interpretations were performed for 12 test sequences.

In addition to the hydraulic packer testing a standard fluid logging programme was conducted (CROISE et al., 1995; RIVERA et al., 1995a, 1995b). The results were used to help identify discrete zones for straddle packer testing.

1.2 Objectives and Outline of the Report

The overall objective of this report is to present and summarise the results of packer testing and sampling conducted in the SB4a boreholes. The specific objectives as well as the structure of the report are presented below:

- Description of both downhole and surface equipment used during the investigation programme (Chapter 2);
- Discussion of general testing strategies and test methods with respect to specific objectives of testing of the SB4a borehole (Chapter 3);

- Presentation of advanced and new test analysis approach and interpretation methods. This approach builds on many years of experience in well test analysis for siting programmes gathered during comprehensive test campaigns. Type of analyses, analysis tools as well as selected aspects of well test interpretation are presented (Chapter 4);
- Two tests representative of the range of hydraulic conditions at Wellenberg have been chosen to present the current analysis approach and typical interpretation procedures for the SB4a borehole (Chapter 5);
- The results of testing in both parts of the borehole are summarised in Chapter 6. The representative formation parameters, hydraulic conductivity and equivalent freshwater head, are presented in both graphical and tabular form in Chapters 6 and 7 for the vertical and slanted boreholes, respectively;
- A newly developed Quality Assurance and Quality Control System is described in Chapter 8 which documents each stage of the testing program;
- Conclusions and recommendations complement this report and are included in Chapter 9.

All text figures are presented in Appendix A. A summary for each test is provided in Appendices B and C which documents both data acquisition and the derivation of hydraulic parameters.

1.3 Related Documents

There are fifteen NAGRA Internal Reports (ENACHESCU et al., 1995a-h; ENACHESCU et al., 1996a-f; DOMSKI et al., 1995) which contain all test analysis results performed in the SB4a boreholes. These reports include both "Quick-Look" Reports, containing preliminary field analysis and documentation of data acquisition, as well as the results of detailed analyses conducted on selected test sequences.

Two additional types of reports, as compared with previous test campaigns were added:

Data Transfer Reports (WOZNIEWICZ & ENACHESCU, 1995; 1996) were produced. Its main objective is to document the transfer of test data from the consulting company to NAGRA and to provide a detailed description of the format for the data files. This report will provide a basis for any additional interpretations performed in the future.

Quality Assurance Report (FRIEG & MARSCHALL, 1998) documents the quality system applied for hydraulic testing and reporting for the SB4a boreholes.

The results of geological sampling, mud service, tracer service, and hydrochemical borehole service are included in two borehole summary reports (STEIGER et al., 1995a; 1995b). This report also includes the detailed borehole history.

Other useful information about related field investigations in Wellenberg area between June 1993 and November 1995 can be found in NAGRA (1995a; 1995b).

The original hydrogeologic exploration program is included in NAGRA (1994).

2 TESTING EQUIPMENT

Experience from 5 years of nearly continuous testing at Wellenberg helped in optimising and refining the equipment used for collection of data and water samples in the SB4a boreholes. The tools have been extensively described in several NAGRA Technical Reports (e.g. LEECH et al., 1984; OSTROWSKI & KLOSKA, 1989a; OSTROWSKI et al., 1992; ADAMS & WYSS, 1994) and in a series of unpublished internal reports. The following sections overview the entire system with more attention on the new parts not described in previous reports. The test equipment is classified into two general categories: downhole and surface components.

2.1 Downhole Test Equipment

The major refinements to the downhole equipment for the SB4a testing campaign were as follows:

- zero displacement shut-in tool;
- encapsulated bundle containing more hydraulic lines then previously available;
- downhole sampler tool;
- gas threshold pressure tool.

2.1.1 SCI Hydrologic Test Tool

A Baker/Lynes Surface Controlled Inflation (SCI) Hydrologic Test Tool (HTT) was used in two sizes: $3^1/_2$" and $4^5/_8$", depending on the borehole diameter. It was deployed either in a straddle configuration or as a single packer (Figures 2.1 to 2.3). The tool consists of the following main components:

- Hydraulically inflatable packers to isolate the test interval from the rest of the borehole;
- Multiple pressure/temperature sensor (Lynes Triple Conductive Wireline - TCWL) placed in a sensor carrier;
- Pressure activated zero displacement shut-in tool (SIT) to establish communication to, or to isolate the test interval from, the tubing string;
- Encapsulated bundle (quadruple pack) containing three hydraulic lines for independent inflation of the packers in addition to an independent line and a single conductor wireline cable to transmit data from the TCWL to the surface.

The latter two items, zero displacement tool and quadruple pack, are improvements on previous testing campaigns and detailed below. A common problem in the past was the distortion of the early time data at the start of shut-in periods. The closing of the downhole shut-in tool (SIT) typically resulted in a change in the interval volume. This change conceals the formation response, especially in low transmissivity environments, resulting in a larger uncertainty in derived hydraulic parameters. To resolve this problem, a zero displacement hydraulic shut-in tool was developed. This tool is activated by the pressurisation of a hydraulic line and results in virtually no change in the interval volume. To accommodate the new shut in tool and still allow for separate inflation of packers in a straddle arrangement, an additional hydraulic line was added to the triple pack used in the previous campaigns. This extra line also allows more options when the determination of gas threshold pressure is a primary test objective.

The packer elements are steel-reinforced, rubber-impregnated units with sealing length of 1.27 m. To reduce the compliance effects of the packers, constant pressure was maintained on the inflation lines during most of the hydraulic tests. The pressure was monitored during the tests to check for possible leaks. In the straddle configuration the packers are separated by interval mandrels. The distance between the packers can be any length from 1.5 m upwards.

With the shut-in tool closed the fluid in the tubing string can be swabbed or gas-lifted, without influencing the pressure in the test interval. However, disturbances caused by mechanical impact of these actions on the test tool were recorded in some of the smaller interval volumes with a low transmissivity. The volume of liquid within the test tool below the shut-in valve is estimated to be 0.01 m^3.

Downhole pressures and temperatures were monitored with the Lynes Triple Conductive Wireline (TCWL) tool with three separate sensors (Fig. 2.1). The TCWL was located in the test tubing between the shut-in tool and the upper packer. Sensors P1 and P3 were attached to a 0.25 inch hydraulic line, whilst P2 measured conditions adjacent to the sensor. The P2 sensor monitored conditions in the test interval, whilst the P1 sensor monitored conditions in the zone below the lower packer and the P3 sensor measured conditions in the annulus above the upper packer. In a single packer configuration, both P1 and P2 monitored the test interval. A thermistor is coupled with each pressure transducer. It should be noted that the temperature recorded by all three gauges monitored the environment adjacent to the sensor.

The gauges were calibrated by the manufacture prior to mobilisation to be better than 0.05% of the full scale value with a resolution of 0.005%. The pressure transducers used during the Wellenberg tests were 1000 psi (6895 kPa) and 2000 psi (13790 kPa). Prior to each test, the sensors were function checked against the overlying fluid column in the borehole. In addition, measurements were taken at the surface prior to and after testing to document the magnitude of drift. The accuracy and resolution of temperature measurements are $\pm$1.8°C and 0.1°C, respectively.

The pressure and temperature information is multiplexed as frequency data and transmitted to the surface data acquisition system through a single conductor cable attached to the tubing string. The minimum sampling interval in normal mode is 7.5 seconds. A burst model was periodically used which records P2 pressure in 0.5 second increments.

2.1.2 Downhole Sample Tool

A new tool (Figure 2.4) was developed to optimise the performance of pulse phases while simultaneously obtaining a groundwater sample from the test interval. There are two major advantages when testing with this tool; first, the withdrawn volume can be measured directly after the tool has been run out of the borehole, and second, water sampling can be performed under sealed-off downhole conditions. This tool was used during tests T6 and T7 (see pages B-42 to B-45) in the vertical borehole.

A pulse test is normally carried out by opening the downhole shut-in tool for a brief period to induce a disturbance (e.g. 30 s) and then closing in the interval to monitor the recovery under shut-in conditions. An assumption in the analysis is that the applied pressure difference is instantaneous with no flow from the formation prior to closing the shut-in tool. However, this flow period can not be avoided as the shut-in tool does not close or open instantly. The longer this flow period the more uncertainty is introduced for derivation of hydraulic parameters. Therefore, there was a need for an improved tool design to eliminate this flow period during pulse events.

Several modifications were made to the standard tool set-up described in the previous section (Fig. 2.4). First, the shut-in tool used to isolate the interval was mechanically operated and located above the top packer. Secondly, the hydraulic zero displacement shut-in tool was located on the string within the interval and concealed an empty (atmospheric pressure conditions) chamber the volume of which is 2.225 dm^3. The volume of the chamber was designed based on an assumed wellbore storage coefficient and anticipated pressure difference at the start of the pulse. The opening of the hydraulic shut-in tool imposes a truly instantaneous drawdown on the test interval. In addition, closing of the shut-in tool isolates a groundwater sample which may be retrieved at the surface.

2.1.3 Gas Threshold Pressure Tool

At the completion of drilling for both boreholes, tests were performed to determine the gas threshold pressure. The first part of these tests were optimised to derive accurate hydraulic parameters and flow model. In the subsequent gas threshold pressure detection phase of the test, the majority of the water in the interval needed to be displaced with gas. Further, gas injection and recovery phases were conducted. In the past and also for a few tests in this campaign, the displacement was carried out through the tubing (Figure 2.5). In this method, gas is injected into the interval through a ¼ inch hydraulic line with the shut-in tool open. Water is displaced through a screen located at the bottom of the interval. After the majority of the water is displaced, the shut-in tool is closed and the interval is ready for gas injection. This procedure induces pressure disturbances in the interval during displacement. This disturbance is not ideal for the accurate derivation of the threshold pressure in the subsequent injection period. Therefore, a new tool was designed to reduce the pressure disturbance during the gas displacement phase of the test.

The new gas threshold pressure tool (Figure 2.6) contained several modifications to the old design. First, a mechanical shut-in tool was used to isolate the interval from the tubing pressure. Secondly, a hydraulically operated shut-in tool was positioned in the string below the bottom packer and concealed an empty chamber. A ¼ inch hydraulic line connected this chamber to the interval when the shut-in tool was opened. Like the design above (chapter 2.1.2), the injection line into the interval contained check valves which stayed closed until the pressure in the line equalled the pressure in the interval. After equalising the pressure in the line with the interval pressure, the procedure was to then open the hydraulic shut-in tool. This allowed the fluid in the interval to drain into the underlying chamber without causing significant pressure disturbances. In reality, the ¼ inch hydraulic line connecting the chamber with the interval, periodically blocked resulting in pressure spikes. Therefore the use of a $^3/_8$“

line is recommended in the future. The gas threshold pressure chamber tool was used for tests VM13 and VM14 in the vertical borehole (see pages B-48 to B-51).

2.1.4 Downhole Pumping Equipment

Similar to preceding testing a Moineau pump system was chosen again as the main production system for the hydraulic test program in the SB4a borehole. The downhole equipment was described in detail in OSTROWSKI et al. (1992) and ADAMS & WYSS (1944). The reasons for using this type of pump system are summarised below:

- ability under most circumstances to function under two-phase, liquid-gas, conditions
- ability to pump highly viscous drilling fluid
- smooth and precise adjustability of the flow rate in the low range
- small outer diameter
- no electric cable is required, which simplifies the run-in / run-out operation

For a detailed description reference should be made to the document cited above.

2.2 Surface Test Equipment

The surface equipment used during the SB4a testing campaign at Wellenberg was designed for conducting and controlling a wide variety of injection and withdrawal test phases under one and two phase flow conditions. The present section describes the components of the surface equipment structured into the following modules:

- water-gas separation equipment
- flow control and metering equipment
- injection test equipment
- surface components of the pumping equipment
- data acquisition system.

The individual components of the system were designed to cover formation transmissivities ranging between approx. 1E-5 m^2/s and 1E-13 m^2/s with special emphasis on the low to very low transmissivity spectrum. Figure 2.7 is a schematic presentation of the construction and functionality of the surface flow control system.

2.2.1 Water-Gas Separation Equipment

One of the most important functions of the surface equipment when testing under two phase flow conditions is the liquid-gas separation of the fluid produced from the test interval. The fluid produced during withdrawal events conducted under two phase flow conditions is typically a mixture of gas (mainly methane) and water. An important parameter to be determined from such a test is the produced gas-water ratio during the respective test event. This parameter can easily be calculated from the measured gas and water rates, when ideal conditions of phase separation without delay and buffering effects are realised. The phase separation was conducted using one of two liquid-gas separators, specifically designed and constructed for the Wellenberg project.

The two separators used at Wellenberg were designed to optimise measurements over the range of expected flow rates. A high volume horizontal separator (see Fig. 2.8) was constructed for rates between 1 l/min and 25 l/min. The incoming liquid-gas flow is led against a deflector. This first stage separation occurs at higher flow rates. Further separation occurs in the settling section. The final filtering is performed in the demister section. The vertical barrier ensures that the liquid level is maintained constant and that the float of the level control valve is not disturbed by the liquid stream entering the separator. In order to displace fluid from the separator, an overpressure is kept at a constant value by a pressure control valve placed at the end of the gas outlet line. If this overpressure is exceeded due to gas flow, the gas outlet valve opens. The separator operating pressure is set according to the flow rate and the related friction resistance in the outlet lines. The operating pressure was usually set to values around 3 bars. This has also the positive effect of stabilising the flow rate coming from the Moineau pump. The separator was constructed for a maximum pressure of 10 bar. The maximum pressure is secured by a built-in safety valve. Before the production test is started, the separator is filled with water and pressurised, using an air compressor, to the desired operation pressure, as set at the pressure control valve. Provided downhole conditions are stable, it is possible to maintain constant rates for both the liquid and the gas phase during the test. The system behaviour was controlled during the production test phases by continuously recording the pressure and the liquid and gas temperatures in the separator. The water level in the vessel was monitored visually using a site glass. Figure 2.9 presents a principle drawing of the separator flow circuit.

The second phase separation device used (see Fig. 2.10) was a small volume vertical separator. This separator was designed for flow rates lower than approx. 2 l/min. It was designed to operate at atmospheric pressure conditions. The water level in the vessel was monitored using a sight glass and was kept constant using a u-tube construction. The gas outflow was directed through a gas drying unit before measuring the rate with a mass flowmeter. Figure 2.11 presents a principle drawing of the separator flow circuit.

The use of surface phase separation devices for hydraulic testing purposes has certain limitations, because it is not clear to what extent the measured liquid and gas flow rates are representative of the downhole flow rate conditions. Figure 2.12 illustrates the phase segregation processes in the downhole and surface system. As presented, there are several sections in the system where phase separation occurs. Therefore, while cumulative measurements over longer time periods are likely to yield realistic gas-water ratios, the result of instantaneous measurements of both phases are still problematic to interpret.

There are three ways of influencing the water and gas production rate of the Moineau pump:

- modifying the revolution rate of the pump
- applying a pressure cushion at the separator, which operates as a pump-backpressure and has the function of stabilising the flow
- choking the pump outlet using a needle valve or a ball valve.

Each of the three methods has its limitations under two phase flow conditions. The main difficulty is given by the fact that, once gas flow has been established, there is an air-lift component in the production mechanism, which causes the water to flow in slugs. Under such circumstances it is nearly impossible to influence the water production rate and the only way to control the pump is by maintaining the interval pressure in certain limits.

2.2.2 Flow Control and Metering Equipment

The flow control and metering equipment used at Wellenberg is shown schematically in Figure 2.7. The flow control board was designed to allow conducting constant rate and constant pressure, injection and production tests under one and two phase flow conditions. All devices were calibrated off site prior to mobilisation. In addition, relevant meters were function checked prior to running the respective test phases and documented in the testing log book. Also, measurements were periodically checked against manual measurements.

The flow meters were grouped into three functional modules. The first module was composed of three mass flowmeters calibrated for water. It was used for measuring both the liquid-gas mixture flow rates coming from the Moineau pump during production tests and the water flow rates during injection tests. Two of the three flowmeters were covering a range of flow rates between 0.2 and 120 l/min (see Fig. 2.7 for technical details). The third flowmeter, calibrated for water flow rates of up to 100 g/h and intended for constant pressure injection tests in very tight formations, was, however, never used. The second metering module was composed of three mass flowmeters calibrated for water. It was used to measure the water rates flowing out of the phase separation equipment during production tests. The flowmeters used for the second module were covering a range of flow rates between 0.1 and 18 l/min (see Fig. 2.7 for technical details). The third metering module was used for measuring gas flow rates during production tests and gas injection tests. The flowmeters used in this module were calibrated for methane or for nitrogen (see Fig. 2.7 for details) and were covering a range of flow rates between 0.2 and 50 ln/min. For the needs of constant rate gas injection tests (gas threshold pressure tests) a second flow control board was built (see Fig 2.13).

Whenever possible the water and gas rate measurements were backed up by manual flow rate measurements using a bucket and stop watch.

The water flow rates during production tests were controlled using two methods. The first method was to regulate the production rate by changing the revolution speed of the Moineau pump. This could be done both manually or using an automated computer supported system. The second rate regulation method was changing the back-pressure of the pump by manually choking the flow line with a needle valve. Generally speaking, the water production rate regulation functioned well when producing under single phase conditions. The rate regulation under two phase flow conditions however, proved to be difficult.

The rate regulation during constant rate water injection phases was usually conducted using a bypass-choke system as schematically presented in Figure 2.14. At injection rates smaller than 150 ml/min a self-regulating HPLC pump was used.

The injection rates during the gas threshold pressure tests were automatically controlled by means of a magnetic needle valve system, part of the mass flowmeters. In such cases two gas flowmeters were used to provide both the automatic rate regulation and a backup rate measurement (see Fig. 2.13).

2.2.3 Injection Test Equipment

The choice of injection system at Wellenberg depended on the test objectives and the hydrological conditions in the test zone. In zones with high transmissivity a Flottweg spiral pump was used for a broad range of water injection rates. The constant rate conditions were controlled manually using a bypass-choke system as described in the previous section.

A Shimadzu HPLC-8a pump was used in some tests where extremely low injection rates were required. This pump can be controlled to produce flow rates between 1 and 150 ml/min in a pressure range up to 8000 kPa.

For constant pressure water injection tests, a high pressure vessel with a working pressure range of up to 2000 kPa was present on site. However, this device was never used. In one case (test VM2 in SB4a/v) the horizontal separator was pressurised at 1000 kPa and used to conduct a constant pressure injection test . However, due to the relatively high friction losses along the long (approx. 40 m) 1/2“ injection line the test worked at a constant rate instead of constant pressure.

For gas injection tests, nitrogen bottles were used as source. The injection rate was automatically controlled by means of a magnetic needle valve system, part of the mass flowmeters.

2.2.4 Surface Components of the Pumping Equipment

Hydraulic top drives for the downhole Moineau pump systems were used during all pumping events. A Baker hydraulic top drive and a Nagra-owned hydraulic drive (described in ADAMS & WYSS, 1994) were applied. The first one was coupled to a hydraulic power pack. The Nagra-own drive was connected to the hydraulic system of the drilling rig.

Also, a new developed electric drive was tested. However, diverse technical difficulties, as for instance missing screening of the system did not allow for the proper use of this system (see also Section 2.3)

2.2.5 Data Acquisition System

The data acquisition used during testing of borehole SB4a at Wellenberg was a modular, computer based multi-channel system (see Fig. 2.15). All physical parameters measured in the downhole and surface system were recorded and visualised in real time using the data acquisition program BASYS version 2.0. The data acquisition program features enhanced graphics and multi-tasking capability. Depending on the type of test, different meters were monitored. Typically, the downhole pressures and temperatures (P1/T1, P2/T2, P3/T3) and the pressure in the test string (PTX) were monitored during the tests. Depending on the system components used, further parameters were monitored such as: the pressure in the flow control board, the total flow rate, the water flow rate, the gas flow rate, the pressure in the horizontal separator, the water and gas temperatures in the separator.

For data safety reasons, the system was battery buffered. The data was recorded on the computer's hard disk. Additional data backups on a floppy disk were made regularly in order to increase safety. As a last safety procedure all data was printed out when recorded.

The data sampling interval could be adjusted to the needs of the test whenever appropriate. The minimum sampling interval was 7.5 seconds. In this mode the system present on site was able to measure up to 22 hardware chanels. The number of software chanels was practically unlimited. In burst mode, the sampling interval could be decreased down to 0.5 seconds, but was limited to recording the test interval pressure (P2).

A second computer was used as part of the data acquisition system for automatically controlling the production rate of the Moineau pump. This computer was used as well for high speed monitoring of different gauges that were critical for the testing procedure. A special program was allowing the user to visualise one channel with a sampling rate of 16 MHz without recording it. This feature was typically used during pumping phases for visualising the total production rate or during gas threshold pressure tests to visualise the gas injection rate. A further computer used for test design and analysis, was permanently present at the test site as well.

2.3 Equipment Related Conclusions and Recommendations

The testing equipment used on the Wellengerg SB4a site generally functioned satisfactorily, allowing tests of high complexity to be conducted.

For future similar testing projects, several recommendations for further tool development can be made:

- Major improvements are possible in the area of two phase flow control and measurement under very low flow rate conditions. In such cases the use of downhole phase separation devices is recommended. An alternative is the use of pressurised small volume surface separators with precise fluid level control.

- The control of production rates lower than approx. 0.2 dm^3/min proved to be problematic. Difficulties occurred when the Moineau pump was run at lower than approx. 15 rpm. In case of the NAGRA-owned Moineau top drive the problem was usually related to the inability to control the hydraulic motor of the rig at the low pressure end. The BOT-owned Moineau top drive was activated by its own hydraulic power-pack. Due mainly to the long (approx. 40 m) hydraulic connections, this configuration was unable to activate the pump at a speed below 50 rpm. A specially developed electric top drive did not operate properly due to technical problems. It is not clear whether the problem of producing very small rates under constant rate conditions can be best solved by improving the Moineau top drive, by changing the dimensions of the downhole components of the Moineau-pump or even by using different pumping techniques.

- The use of automated rate control techniques may also be improved. Both bypass and choking techniques can be combined with direct pump control in order to achieve optimal results.

- Pulse tests proved to be of crucial importance for characterising very low transmissivity formations. A better control of the pulse initialisation would improve the early time data and allow better model characterisation. In particular, the ability to define and reproduce the duration of flow phases of pulse events is important when using wellbore-storage normalisation techniques in the analysis.

- Further development and standardisation of tools for downhole sampling and for gas threshold pressure tests is recommended. Experience was gained in using the different forms of the chamber tool. Further developments of the downhole valves and possibly the use of coiled tubing units could enable a more flexible use to be made of the chamber tool technique.

3 GENERAL TESTING STRATEGY AND TEST METHODS

This chapter describes the objectives of the testing campaign in the borehole SB4a at Wellenberg as well as the testing strategy and the test design implemented to meet the objectives. Special aspects and test design considerations concerning tests conducted under one and two phase flow conditions are also discussed. The original hydraulic investigation programme for boreholes SB4a/v and SB4a/s is described in NAGRA (1994).

3.1 Objectives of Testing

The objectives of testing in borehole SB4a at Wellenberg, as described in NAGRA (1994) and subsequently implemented at the test site, were aiming at the characterisation of the one and two phase flow behaviour of the geological formation in the wellbore vicinity. One of the main objectives of the slanted borehole (SB4a/s) was to asses the presence and hydraulic character of steep, sub-vertical major water conducting features in the host rock formation.

The main hydraulic parameters to be quantified were the distribution of the equivalent freshwater head and of the formation transmissivity. The general conceptual model describing flow phenomena in the Palfris formation at Wellenberg is mainly characterised through the presence of a heterogeneous, low transmissive, poorly connected fracture network embedded in a matrix with a very low transmissivity. The generally accepted assumption postulates, that the formation in the wellbore vicinity exhibits altered properties induced by the drilling process. Therefore, the flow model mainly used for the analysis of the Wellenberg test data, was describing a radial composite infinite acting system with wellbore storage and skin. This implies that the hydraulic properties of the undisturbed formation can only be determined at some distance from the borehole, or in other words, that the outer composite zone formation properties were considered representative.

A few tests were designed for the determination of the two phase flow parameters of the formation. These parameters are required by the safety analysis to assess the problem of gas release from the cavern of a repository after closure. The two phase flow conceptual model (i.e. BROOKS & COREY, 1966; GRANT, 1977; VAN GENUCHTEN, 1980) and its parametrisation were to be determined. One of the main parameters of interest was the gas threshold pressure. This was measured in four specially selected intervals by means of constant rate gas injection tests.

In some tests a quite significant gas flow was measured. The primary objective was to determine it's source; i.e. wether from free gas in the formation or evolution from dissolved gas in formation water due to the lowering of the pressure in the borehole itself or the rock formation. The occurrence of free gas under static pressure conditions has strong implications for the groundwater flow in the water conducting features, because it will lead to a reduction of the relative permeability value of the liquid phase.

Finally, a further objective of the testing campaign was the procurement of fluid samples (groundwater and gas), from a few relevant intervals.

3.2 Choice of Test Intervals

In the boreholes SB4a, a testing while drilling strategy was applied to minimise drilling history effects on the measured pressure response. Drilling was interrupted after a pre-determined length (usually approx. 100 m). A series of two to three tests were performed in the newly drilled interval. These tests conducted under these circumstances were usually conducted as single packer tests and were designed as follows:

- The first test was located in the lowest 5 to 20 m of the newly drilled borehole section. The main test objectives were the determination of the interval transmissivity, the equivalent freshwater head and eventually the procurement of a water sample.

- The second test was aiming the determination of the transmissivity and equivalent freshwater head of a larger lower section of borehole (approximately 50 m).

- The main objective of the third test was the determination of the total transmissivity of the entire newly drilled section. A subsidiary objective was the determination of the equivalent freshwater head.

Drilling was also interrupted when mud losses or major fractures in the core indicated that a zone had been intersected offering the chance to get a water sample of low contamination with drilling fluid after a acceptable time of pumping. By immediately interrupting the drilling, contamination induced by mud infiltrating in the formation could be minimised. This was of particular importance in the low head zones, where high pressure differentials at the interval to be sampled resulted in relative big mud losses.

After reaching casing depth or total depth, fluid logging measurements were conducted. On the basis of the fluid logging results, discreet zones of special interest were selected to be tested using a straddle packer configuration.

3.3 Test Sequence Strategy and Test Design

The test sequence strategy was developed for each individual case, considering the expected formation conditions, the test objectives and the time allocated. Generally, constrains induced by the hardware limitations are an important factor to be considered as well.

The different test situations encountered can be classified as tests running under one or two phase flow conditions. Gas occurrence was only observed in the moderate to high transmissivity environments. Further, depending on the test objectives, different test strategies have been adopted in order to achieve them. It should be mentioned, as well, that the testing strategy was not static. It always had to be adapted in real time through the test and, it permanently changed during the testing campaign, as a result of the additional experience gained.

3.3.1 Single Phase Tests

The general test strategy followed when testing under presumed single phase flow conditions was to conduct a test composed of four stages (see Fig. 3.1):

- Test Initialisation Stage: The main purpose of this stage was to create well defined inner boundary conditions, which would allow to continue the subsequent test stages in a controlled fashion. Typically, the Test Initialisation Stage included the packer inflation (INF), the compliance phase (COM) and the static pressure recovery phase (PSR). The individual steps undertaken were aiming to isolate the test interval from the rest of the borehole (INF), to allow the temperature in the interval to equilibrate, to measure the formation flow rate under hydrostatic conditions (COM) and to allow the pressure in the wellbore vicinity to equilibrate towards initial conditions (PSR).

- Diagnostic Stage: After the Initialisation Stage, the active part of the test is started. However, at this stage, there is relative few information available about the formation behaviour. The goal of the Diagnostic Stage is to run one or more test phases, which do not need any special design, and which would allow the test engineer to adjust the test strategy for the main part of the test. Typically, the Diagnostic Stage would include, depending on the expected formation transmissivity, a slug withdrawal (SW) followed by a shut-in phase (SWS), or a pulse withdrawal phase (PW). These phases would allow the engineer to derive a first estimate of the near borehole transmissivity and, eventually to constrain the static formation pressure to an acceptable range. The identification of a base case flow model is another goal of this stage. Based on this information, the test engineer can develop the strategy to be followed during the Main Test Stage.

  Main Stage: The main goal of this stage is to derive reliable parameter values characterising the formation, such as transmissivity, static formation pressure, flow model a.o., while increasing in the same time the radius of investigation of the test. At this stage, the main emphasis is set on constraining the number of possible test analysis realisations and narrowing the confidence limits of the derived parameters. The phases conducted in the Main Stage of the test are strongly dependent on the formation transmissivity. Ideally, a long lasting constant rate withdrawal phase followed by a long lasting shut-in phase would be conducted (RW & RWS). These phases would allow for a good quality test analysis with a relatively wide radius of investigation. The RW phase would allow as well, the procurement of a groundwater sample. However, the feasibility of conducting a production test is constrained to transmissivities generally higher than approx. 1E-9 m^2/s. For cases when the formation transmissivity did not allow pumping, the next preferred choice was to conduct a constant rate injection phase (RI) at a very low injection rate, using the HPLC-pump. The injection phase was usually followed by a shut-in period (RIS). However, the use of injection phases proved to have disadvantages, which will be discussed in this section, further below. In cases of very low interval transmissivity and very low static formation pressure (these two parameters were typically correlated at Wellenberg), the main test stage included a series of pulse withdrawal (PW) events, aiming to lower the test pressure stepwise towards the expected initial formation pressure and determine using this method the upper limit of the static formation pressure. The PW series was usually concluded with a SW-SWS sequence that would allow the static formation pressure determination using the extrapolation method (see Fig. 3.2).

- Final Stage: The Final Stage of the test was usually including a brief pulse event (PW or PI), designed to allow the measurement of the compressibility of the test interval. This value could be compared to earlier measurements to evaluate any changes in the water saturation of the test section or the test equipment due to gas accumulation.

Depending on the test objectives, on the preliminary information available and on the time allocated, the test was conducted through all stages described above or was reduced to a more efficient subset.

A few aspects of test design were derived during the campaign and proved to have general character. The first one was to recognise that injection phases have disadvantages, as compared with withdrawal phases. These disadvantages can be summarised as follows:

- The injection of mud filtrate or chemically different water is likely to build a skin zone, clog the formation and alter the properties in the wellbore vicinity.

- The water injected, specially at high rates, cools the formation and induces non-isothermal effects.

- The injection pressure can cause rock mechanical phenomena, such as changing the aperture of fractures or creating new ones, which alters the properties of the tested zone.

It was also recognised that sudden pressure drops induced during slug and pulse withdrawal tests are likely to alter the formation transmissivity in the wellbore vicinity, when these were exceeding certain values of around 100 m. Therefore, whenever it was necessary to move the test pressure towards vary low values, this was done stepwise, in order to avoid formation damage. It has been recognised as well, that driving the formation pressure towards low values can induce gas segregation and transform a single phase test in a two phase one. This issue had to be considered and, depending on the test objectives, was used to provoke this effect or to avoid it.

There is often a subject of discussion, whether the allocated test time should be invested in a few long lasting test events or in a stepwise adapted design involving a relatively large number of events. No general answer can be given to this question. The general approach of minimising the number of test events conducted in a given time certainly has an important practical value. However, it is good practice to test the formation, using different inner boundary conditions (i.e. test types). This procedure bases on the fact that different test types are differently sensitive for different aspects of the system's flow behaviour. In the same time the dimensionles duration of a test phase decisively influences the amount of information and the level of certainty that can be derived from this phase.

3.3.1.1 Determination of Transmissivity

The general conceptual model describing flow phenomena in the Palfris formation at Wellenberg is mainly characterised through the presence of a heterogeneous, low transmissivity, poorly connected fracture network embedded in a very low transmissivity matrix. Due to the low transmissivities of the potential host rock the radius of investigation is generally small (in the range of meter to deka-meter) and therefore, network effects are negligible. The conceptual wellbore model assumed that the formation in the test interval vicinity exhibits altered properties induced by the drilling process. Therefore, the flow model mainly used for the analysis of the Wellenberg test data, was describing a radial composite infinite acting system with wellbore storage and skin.

However, the flow model used for test interpretation was not applied a priori, it had to be identified for each individual test prior to deriving the formation transmissivity. The general approach was to derive the formation transmissivity from active flowing events such as SW or RW or their subsequent shut-in phases.

In cases of very low formation transmissivity (< 1E-10 m^2/s) when flow rates would have been below the measurable and/or controllable limit, the determination had to be based on pulse events. This method has the disadvantage of assuming the wellbore storage coefficient as known. Further, the use of pulse events proved to be less sensitive for the determination of the outer composite zone properties.

3.3.1.2 Determination of Head

One of the main goals of the Wellenberg testing project was the determination of the equivalent freshwater head distribution of the drilled sections.

Generally, the test design is optimised based on the available analysis tools. Essentially, two different methods were used to derive the initial pressure of the formation:

- The first method of deriving the static formation pressure was to extrapolate the shut-in periods of the test in semi-logarithmic coordinates towards infinite elapsed time, using the matched flow model type curve (e.g. radial composite infinite acting).

- The second method was based on the total test simulation, including the pre-test history, in Cartesian coordinates and determining the initial pressure as a best fit parameter. Parameters and flow models derived with the first method were typically used as starting values for the initial simulation.

Usually a multiple head determination from the analysis of all shut-in phases of the test was conducted (i.e. PSR, SWS, RWS etc.). Specially, in cases of low head and low transmissivity, the approach was to lower the test pressure stepwise, using a series of pulse withdrawal events towards the expected initial formation pressure and run a SW - SWS sequence at the end of the test, in order to allow for head extrapolation. In such cases, rollover behaviour of pressure recovery phases such as PW's was interpreted as an indication that the static formation pressure is lower than the measured pressure at the end of the respective phase. Hence, the final pressure of the respective event provides an upper limit for the freshwater head.

It should be noted that the accuracy of the derived static formation pressure is strongly dependent on the accuracy of the history description. Generally, the longer and the more complicated the historical period, the larger the uncertainties due to difficulties in accurately representing this period in the analysis. Lower transmissivities are more strongly influenced by uncertainties in the historical period. A common approach to partly overcome the historical influence is the general assumption that phases early in the test will have a stronger historical influence than phases towards the end of the sequence. Therefore it has been tried to place a relatively long lasting shut-in following a well defined flow period as one of the last phases of the test.

In borehole SB4a/v, a few intervals have been isolated for long term monitoring. The measurements maybe used to calibrate the test results.

3.3.2 Two Phase Flow Tests

Another main objective of the SB4a testing campaign at Wellenberg, was to evaluate the occurrence of free gas at static formation pressure as well as the characterisation of the two phase flow behaviour of the Palfris formation. Preliminary test design calculations concerning these subjects were conducted by FINSTERLE (1995) and SENGER et al. (1997) using the two phase flow numerical code TOUGH.

The two phase flow conceptual model of the wellbore system, describes a zone around the borehole, where the initial saturation conditions were altered during the drilling process, due to flow of degassed mud filtrate into the formation. Further, it has been recognised that the amount of gas flowing during a test sequence, is influenced by the pressure level of the respective sequence.

Based on these facts, a general design for tests conducted under two phase flow conditions has been developed. They are briefly presented in the following two sections.

Two test types with different objectives have been defined. The Gas Evidence Tests were designed to characterise the provenience of the gas phase observed during production test events. Three distinct possibilities were recognised:

1. A free gas phase is existent under static formation pressure conditions.

2. A free gas phase in the formation induced by borehole history and production test events.

3. No free gas phase in the formation, gas segregation in the test interval or in the test string.

Only the case when a continuos gas phase is present in the host rock (case 1) is relevant for the performance assessment. The second type of test was the Extended Gas Threshold Pressure Test (EGTPT), which was conducted with the objective of determining the two phase flow parameters of the formation for the case of gas release from the repository.

3.3.2.1 Gas Evidence Tests

The ideas incorporated in the design of test proving gas occurence can be described as follows:

- Characterise the formation under single phase conditions. The initial phases of the test, typically including SW, SWS and PW events, are designed to derive the flow model around the wellbore, the static formation pressure and the in situ transmissivity. Another objective was to determine the system compressibility under single phase conditions by running a compressibility check (usually a PW phase). The test phases were usually conducted in a relatively small pressure range in order to avoid phase segregation.

- Induce gas segregation and test the formation under two phase flow conditions. In this stage the pressure level of the test was dropped gradually using a constant rate withdrawal phase (RW). If necessary the production rate was adjusted during the early times of the phase in order to achieve the drawdown needed. Below a certain pressure gas production occurs. One of the main parameters to be determined during the two phase flow production period was the stabilised gas-water ratio produced. The measured gas-water ratios could be compared to the solution gas-water ratios under downhole conditions. The production phase would normally be used to conduct groundwater and gas sampling as well. A pressure recovery period would typically follow the production phase. A high wellbore storage coefficient would indicate significant gas content in the interval and would be evidence for two phase flow in the formation under the conditions of the production phase. A low wellbore storage coefficient would indicate that no, or an insignificant amount of gas is present in the interval, which is an indication that the gas produced during the RW phase has segregated in the test pipe above the interval. The final proof of gas presence in the interval was usually provided by a compressibility check (i.e. a brief pulse injection event) that followed the RWS phase.

- Re-inject degassed water in the unsaturated formation. The goal of this test sequence was to re-saturate the formation surrounding the borehole and compare the test results with the results derived from the previous two stages. This stage would typically include a RI - RIS sequence. The test would be concluded with a final compressibility check (PI phase).

A representative example of this type of test (VM11 / SB4a/s) is included in ENACHESCU et al. (1996e). The theoretical background is provided in FINSTERLE (1995) and FINSTERLE & PRUESS (1997).

3.3.2.2 Gas Threshold Pressure Tests

The determination of the gas threshold pressure of the formation demanded a specialised test design (SENGER et al., 1997). The test was to be divided into two parts. A first part, the standard hydraulic test, during which the single phase formation flow parameters (transmissivity, head, flow model) were to be determined and a second phase, consisting of constant rate gas injection events with a final recovery, during which the gas threshold pressure and the two phase flow parameters were to be derived.

The design of the hydraulic part of the test consisted of an initial diagnostic phase (typically a PW) followed by a series of production and recovery or injection and recovery periods (typically SW or RW). The final goals of the hydraulic part of the test were threefold:

- derive the formation flow geometry

- derive all relevant formation flow parameters

- end the hydraulic part of the test at relatively stable pressure conditions.

The gas threshold pressure test was divided into three phases. The test was planned to be started with relatively stable initial pressure conditions and 100% water saturation. During the first phase the water in the test interval was to be displaced with nitrogen while maintaining constant pressure conditions in the system. Once the water was displaced and equilibrium conditions were achieved, a series of extended constant rate injection phases was planned, with the objective of measuring the gas threshold pressure and determining the formation two phase flow parameters. A second check of the two phase flow parameters was to be derived from the third part of the test, the pressure recovery.

The duration of the individual periods was to be determined whilst the test was in progress; analysis of real time data ensures that these periods can be set to a length that is sufficient for the derivation of a reliable set of hydraulic parameters.

The test design was usually supported by preliminary and real time GTFM and TOUGH simulations, as well as by real time test data analysis.

Representative examples of this type of tests are included in ENACHESCU et al. (1995g) and DOMSKI et al. (1995).

3.4 Sampling Activities

The procurement of groundwater and formation gas samples was an important part of the SB4a field campaign at Wellenberg. The sampling of groundwater was usually preceded by a long lasting constant rate production phase. The quality of the produced water was monitored by measuring the tracer content of control samples, periodically taken at the well head during the pumping phase. The first sample collected at start of pumping was used as a reference and the concentration of all subsequent samples was compared with the first one. The target that described an acceptable groundwater sample was defined at 1% tracer concentration of the reference sample. The sampling activity was additionally monitored with a flow cell measuring temperature, pH, Eh, and oxygen contents of the produced water.

Finally, the procurement of the groundwater sample was conducted directly at the well head while continuing pumping. In one case a wireline downhole sample chamber was used to collect the groundwater sample (e. g. Test VM9 / SB4a/s).

Gas sampling was usually performed towards the end of the constant rate production event at the gas outflow of the separator. In one case, a vacuum extraction unit was used to collect gas samples used for groundwater age determination with isotopes (^{39}Ar) (Test RM1 / SB4a/v).

4 TEST ANALYSIS

This chapter describes the main aspects of test interpretation as applied in the testing campaign SB4a at Wellenberg. The initial two sections of this chapter describe, respectively, the short and long term objectives of the analyses as well as the conceptual model for flow circulation globally within the host rock and locally around the borehole. The three subsequent sections 4.3, 4.4 and 4.5, describe the general interpretation procedure, the input parameters and the interpretation software packages used. The different levels of analysis applied in the project are described in sections 4.6. Finally, some selected aspects of the analysis approach are detailed in section 4.7.

4.1 Objectives of the Analysis

The main objectives of the analysis are first to derive:

- a flow model that accurately characterises the hydraulic properties of the formation
- the transmissivity in the vicinity of the interval
- the equivalent freshwater head

In addition the analyses serve for evaluating other hydraulic rock properties, such as the storativity and in some cases, the two-phase flow properties. The results are usually presented as a set of profiles, illustrating the results of all test interval (often overlapping) results. The packer test results are later combined with complementary data, such as the fluid logging results, in the hydrogeological synthesis of the borehole data (VINARD & LAVANCHY 1994, LAVANCHY & TAUZIN, 1996). These synthesis reports include integrated and consistent profiles of transmissivity and head, which are reported at the depth of the corresponding water-conducting feature (WCF). For modelling purposes, the WCF transmissivity profiles of each borehole are transformed into block permeability profiles at a given scale. This upscaling procedure is performed via geostatistical and numerical methods (JAQUET & al., 1997). The permeability profiles obtained constitute the data set for the 3-dimensional geostatistical model of the permeability used as input for groundwater flow modelling at the Wellenberg site (VOBORNY et al., 1996).

4.2 Conceptual Model

The general conceptual model describing flow phenomena in the Palfris formation at Wellenberg is mainly characterised through the presence of a heterogeneous, low transmissivity, presumably poorly connected fracture network embedded in a very low permeability matrix. The formation in the wellbore vicinity exhibits altered properties induced by the drilling process and characterized by enhanced flow properties. Therefore, the flow model mainly identified from the analysis of the Wellenberg test data was a radial composite system with an inner zone being more permeable than the outer zone. This implies that the hydraulic properties of the undisturbed formation can only be determined at some distance from the borehole.

The two phase flow conceptual model, describes a zone around the borehole with the initial saturation conditions that can be altered during the drilling process, due to flow of degassed mud filtrate into the possibly unsaturated formation. In several cases, the test behaviour changed drastically after long lasting production periods with gas occurrence, due to the changed saturation distribution around the wellbore (e.g. VM4 in SB4a/s). In fact this change might be either due the recovery to undisturbed unsaturated conditions, or in contrary to the depletion induced by the production, which can lead to degassing process.

4.3 General Procedure

In this subsection, a brief summary on the general interpretation approach is provided, as used for the data analysis during the SB4a testing campaign at Wellenberg. The preliminary step in the analysis is to determine a best estimate for each input parameter and decide on the appropriate pressure or rate borehole history. Once this has been achieved, the test is divided into discrete phases. In a first approach each of the relevant test phases is subsequently analysed. The next phase consists in simulating the entire test sequence with a consistent set of parameters. The different steps in the analysis procedure can be summarized as follows:

- Identification of the flow model by evaluation of the superposition derivative on the log-log diagnostic plot. Initial estimates of the model parameters using conventional straight line analysis.

- Analysis of each relevant test phase using superposition type curve matching in log-log and semilog co-ordinates. Non-linear regression in semi-log co-ordinates (superposition HORNER plot) is used to determined improved parameter estimates. Refinement of the parameter set using non-linear regression.

- Simulation of the entire test sequence in Cartesian co-ordinates using the optimised parameter set obtained from the analysis of the individual phases. This final step is used to check the consistency of the model to the entire data set.

- Consistency check of the previously estimated parameters by an independent interpretation team using alternative well test simulators.

- Determination of the recommended flow model and parameter values, as well as evaluation of the confidence intervals.

Two consecutive test analysis approaches were combined in the interpretation of the SB4a test data. First the single events of the entire test sequence were separately matched using specialised plotting techniques (i.e. log-log plot, semi-log derivative etc.). Secondly the entire test sequence was considered for matching the flow model in Cartesian coordinates. The two methods were regarded as complementary and the combination of the two methods was considered to provide a superior interpretation quality.

Sensitivity analysis using alternative parameters (transmissivity, formation head, storativity, wellbore storage coefficient, duration and water level during borehole history, etc...) are applied at various level of the simulation, including during the consistency check.

4.3.1 Flow Model Identification

The flow model identification was mainly based on the log-log derivative plot of the main test events. The reliability of the derived parameters depends on the ability of characterizing all components of the model; in case of a two shell composite flow model, the presence of late time test data is relevant for the outer zone transmissivity determination. For high transmissivity environments, all components of the modell can be easily recognised. In moderate to low transmissivity intervals, transitional data between inner and outer zone, is extrapolated for the undisturbed formation properties. This transitional data may be influences by uncertainties in the representation of the wellbore history. Only the inner zone response is recognised in the individual test phases. In cases of very low transmissivity, the inner composite zone response is additionally masked by wellbore storage phenomena. In this case the model recognition had to rely on the overall test behaviour, which was mainly characterised by poor late time recovery of the pulse events, indicating a leaky closed system with a very low outer zone transmissivity (see Fig. 4.1).

Typical indications for fracture dominated flow such as fractional dimension responses, or for interaction between fractures and matrix (i.e. dual porosity) were relatively seldom. In one or two cases (e.g. tests VM8 and possibly VM13 in SB4a/v), sub-cylindrical flow geometries could be identified.

4.3.2 Single Event Analysis

The use of single event specialised plotting techniques such as the superposition log-log derivative plot provides a very good means of diagnosing the flow model during a test phase. Once an appropriate flow model was identified, an automated non-linear regression matching technique in log-log coordinates was used for determining the best fit parameter set of the specific test event. The use of log-log coordinates and derivative provides a good parameter sensitivity for the regression method. This method has also the advantage of identifying parameter changes from one test phase to another, such as hydraulic conductivity changes due to the opening or closing of fractures or changes in the wellbore storage coefficient due to phase redistribution phenomena. It also provides a means of establishing confidence in the derived parameters by interpreting test phases conducted under different inner boundary conditions. The main limitation of the method is the fact that the pressure history of a particular event influences the shape of the superposition function and, implicitly, the flow model identification. In other words, the method is as exact as the description of the pressure history. It should be emphasised that the lower the transmissivity of the test interval, the stronger the historical influence is.

4.3.3 Simulation of the Entire Test Sequence

The parameter sets from the single event interpretation are subsequently checked for validity on the entire test simulation in Cartesian coordinates. The main advantage of the entire test sequence matching technique, as applied at Wellenberg, is that it provides an improved and more accurate handling of the historical events. This feature mainly becomes important when testing very low transmissive formations. In particular, the entire test simulation allows for improved sensitivity study and uncertainty analysis for the assumptions related to the borehole history duration and pressure conditions. It also has the advantage of making the entire test time available for analysis, including the parameter sensitivity study, which provides an improved overall understanding of the formation penetrated by the test. The main disadvantage of the method is its relatively poor sensitivity when applied in Cartesian coordinates. However this is compensated by a better control of the parameter estimates by simulating the entire test sequence with a consistent set of parameters.

4.3.4 Consistency Check

As a final step, a fast check of the parameter estimates is completed to verify the consistency of results. The test results obtained from the preceding steps are used by an independent interpretation team as input to two different borehole simulators to verify whether the recommended parameter values can reasonably match the measured pressure of the entire test sequence. The consistency check applied in the Wellenberg program considered only the simulation of the entire test sequence, with the purpose of checking or determining the most representative formation parameter set, as well as determining the uncertainty ranges of key parameters (e.g. transmissivity and static pressure). Finally, the results of all preceding analyses including sensitivity studies are used for determining the recommended parameter values and confidence ranges. The most probable flow model is identified as well.

4.4 Assumptions and Definition of Input Parameters

The input parameters used in the test analysis often have different provenience and are subject to different degrees of uncertainty. Several of the parameter values used have to rely on assumptions or have to be estimated. Other parameters are calculated based on standard Pressure-Volume-Temperature (PVT) correlation's. A comprehensive list concerning all input parameters used in the analysis, their definition and their provenience, was attached to the documentation of all tests conducted at Wellenberg. The list of physical analysis input parameters include rock and fluid properties as well as the test tool and test interval characteristics. The complete list of input parameter as well as their definition are listed at the end of this report.

4.5 Analysis Tools

A series of analytical and numerical analysis packages was used in the SB4a test interpretation. The tests were usually analysed using several of the packages in the same time. The different strong parts of the programs were used alternatively in order to detail different aspects of the respective test. The general goal of the interpretation was a thorough understanding of the physical phenomena and a consistent interpretation of the entire test sequence.

The subsequent sections describe the capabilities of the programs used:

- FLOWDIM

- INTERPRET/2

- MULTIFIT
- GTFM
- TOUGH2/ITOUGH2

4.5.1 FlowDim

The GOLDER ASSOCIATES test analysis software package FLOWDIM V 2.14 is used to provide a comprehensive interpretation of the Wellenberg data. FLOWDIM is a modular well test interpretation program which can be used to analyse constant rate, constant pressure and slug/pulse tests in both source and observation zones. It can handle several flow models of any flow geometry between linear (dimension = 1) and spherical (dimension = 3). Changes in the flow dimension and in the transmissivity of the formation can be handled as well as matrix fracture interaction. Other features include two-step superposition of constant rate events (i.e. flow period followed by a build-up) and automatic curve fitting using a non-linear regression algorithm.

Further, the new analysis method of slug and pulse test deconvolution (see Section 4.7.3) was implemented in the latest program version, and widely used during the SB4a testing campaign.

4.5.2 INTERPRET/2

The main software package used for analysis was INTERPRET/2 (Windows version 1.5) developed by SCIENTIFIC SOFTWARE INTERCOMP Ltd.. INTERPRET/2 is an interactive program that uses a constant rate solution to provide optimised hydraulic parameters for a wide range of potential reservoir models. Some of the features of INTERPRET/2 include extensive superposition of constant rate events, non-linear regression and multi-event validation plots. Additionally, it can accommodate changing wellbore storage and skin between the test periods. Another useful feature is the calculation of equivalent drawdown responses to reduce some of the ambiguity in identification of the flow model.

4.5.3 MULTIFIT

The analytical simulator MULTIFIT (Multiple Test Inverse Fitting Simulator) was designed by COLENCO for low-permeability formations as an inverse modelling program to fit a sequence of pulses and slug tests preceded by a variable pressure history. A test sequence resulting from any combination of pulses/slugs can be matched to provide parameter estimates and uncertainties for the entire sequence. Temperature effects on the pressure response in the wellbore can also be included with MULTIFIT. Because MULTIFIT is analytical in nature, it does not suffer from numerical dispersion/near wellbore effects and can be used to fit any flow model that has a closed form constant rate solution (i.e. complex boundary conditions and formation flow models can be incorporated). Currently, three formation flow models are analysed: homogeneous, fractional dimension and composite. The outer boundary conditions for the homogeneous model can be either no flow or constant pressure, whereas the inner boundary conditions for all three flow models can include wellbore storage and infinitesimal skin.

4.5.4 GTFM

A further test analysis tool used at Wellenberg was the numerical borehole simulator GTFM (Graph Theoretical Field Model) specifically designed by INTERA for simulating tests in low-permeability media, where conventional well-test analyses methods are not applicable. Because GTFM is a numerical simulator, it can easily incorporate a wide range of wellbore boundary conditions and can handle varying parameters input from "look-up" tables. GTFM is able to model variable rate or pressure histories, shut-in tests, slug tests, pulse tests, constant head and constant rate tests. A test sequence resulting from any combination of these events can be modelled as one test sequence. GTFM is currently able to model one-dimensional radial flow for three basic formation flow models: homogeneous, double porosity, and composite. The outer boundary can either be no flow or constant head/pressure, whereas the inner boundary can include wellbore storage. Temperature effects on the pressure response in the wellbore are accounted for with GTFM. GTFM is equipped with a user-friendly interface in which conventional diagnostic and semi-log/superposition plots can be made.

4.5.5 TOUGH2/ITOUGH2

The two-phase flow analysis of some of the SB4a tests was conducted using the numerical code TOUGH2 (PRUESS, 1991). TOUGH2 simulates two-phase flow of water and gas, accounting for mutual interference between phases owing to relative permeability and capillary pressure. Thermophysical properties of water are represented by steam-table equations, while the gas is treated as ideal gas. Dissolution of gas in water is modelled with HENRY's law. The phase relationship between gas and water is based on a local thermodynamic equilibrium assumption. The equation-of-state module describing the thermophysical properties of air and water (EOS3) is used for the simulation of the GTP test sequence. For the two-phase analysis of the hydrotest sequence in WLB SB4as-VM11 the equation-of-state module describing the thermophysical properties of methane and water (EOS13) is used.

The governing equations are discretized using first-order backward finite difference in time and integral finite differences in space (NARASIMHAN & WITHERSPOON, 1976). All flux terms are evaluated implicitly at the new time level for numerical stability. Local thermodynamic equilibrium is assumed to exist so that each volume element of the integrated finite difference grid is characterised by a set of primary thermodynamic state variables (e.g. pressure and saturation). The coupled set of non-linear equations is solved by NEWTON-RAPHSON iteration and either a sparse GAUSSIAN matrix solver or a conjugant gradient solver. For more information on theory and background behind TOUGH2, the reader is referred to PRUESS (1987; 1991).

In combination with TOUGH2, the code ITOUGH2 (FINSTERLE, 1993) was used to estimate two-phase flow parameter through inverse modelling. In addition to the parameter estimates, ITOUGH2 also calculates the sensitivity- and correlation coefficients of different parameters, which give a measure of the uncertainty in the parameter estimates for a given flow- and two-phase parameter model.

4.6 Analysis Levels

The present chapter documents the levels of analysis as applied during the SB4a testing campaign at Wellenberg. The interpretation procedure defined two level of analyses, which included parts or all of the analysis steps included in the general procedure presented in Section 4.3.

- The standard analysis corresponds to the field analysis, including the flow model identification and the simulation of individual relevant test phases, the consistency check, and the determination of the recommended parameters and confidence intervals (steps 1, 2, 4 and 5 in section 4.3). The purpose of the standard analysis was a reliable estimation of the formation parameters based on relatively simple assumptions. At this level, no particular effort was devoted to restrict the confidence interval. Further information about the standard analysis in section 4.6.1.

- In addition to the analysis steps described above for the standard analysis, the detailed analysis procedure includes the simulation of the entire test sequence and an extensive sensitivity and uncertainty analysis (see section 4.7.5). Furthermore two-phase flow conditions are considered in the detailed analysis. Additional information about the detailed analysis is provided in section 4.6.2. The main purposes of the detailed analysis are to assess the flow model, improve the parameter estimates and restrict the confidence interval.

Within the two levels of analysis, additional classification is considered for instance to define if the test was conducted in single or dual phase conditions or if a fast simulation is required for a given interval selected only for a standard analysis (section 4.6.3). This additional depth of interpretation is described by an interpretation procedure reference numbered from 1 to 6 (Tab. 4.1; FRIEG & MARSCHALL, 1998). The following table (Tab. 4.1) presents a comprehensive description of the individual analysis levels.

Tab. 4.1: Types of analysis

Interpretation Type	Specific Objectives	Proced. Ref. #	Interpretation Procedure	Downhole Phase Cond.	Product Expected	Methodology Applied	Docu-mentation
standard single phase (hydrotest)	– head profile – interval transmissivity	1	simple interpretatio n without fast GTFM-simulation	single phase assumed	– reliable estimation of formation parameters – uncertainty range based on qualitative criteria or based on a few sensitivity runs	– review of QLR results – estimation of uncertainties based on „expert opinion" (flow model as in QLR)	included in IR
		2	simple interpretatio n with fast GTFM-simulation			– review of QLR results – estimation of uncertainties based on simulations (flow model as in QLR)	
detailed single phase (hydrotest)	– detailed characterisation of flow system – identification / delimitation of hydrological units (mainly B, C & D)	3	detailed interpretatio n	single phase verified	– flow model verified – accurate estimation of formation parameters – quantitative uncertainty study	– diagnostic and specialised plots – parameter refinement (inverse mode) – quantitative evaluation of uncertainty ranges	main body of IR
detailed dual phase (hydrotest)	– free / dissolved gas – dual phase parametric model – dual phase formation parameters	4	detailed interpretatio n	dual phase assumed	– flow model verified – source of gas estimated – reliable estimation of formation single phase and dual phase parameters	– same procedure as for detailed interpretation in single phase medium	main body of IR
standard dual phase (GTPT)	– gas threshold pressure	5	fast ITOUGH simulation	initially single phase	– reliable estimation on gas threshold pressure	– review of QLR results – check result with fast ITOUGH simulation	included in IR
detailed dual phase (GTPT)	– gas threshold pressure – evaluation of dual phase model	6	detailed interpretatio n	initially single phase	– reliable estimation of gas threshold pressure and dual phase model	– same procedure as for detailed interpretation in dual phase medium	main body of IR

4.6.1 Standard Analysis

The standard analysis procedure was usually based on the Quick Look Report interpretation. The Quick Look Report was reviewed as part of the Quality Assurance / Quality Control program (FRIEG & MARSCHALL, 1998). During this procedure, open questions and eventual interpretation ambiguities were defined. Basing on the outcome of the Quality Control review, further specifications and, if necessary, further analysis steps were implemented.

The standard analysis procedure was usually characterised by the use of a single flow model and a single interval history scenario. No sensitivity analyses were conducted and the confidence ranges of the parameters were usually based on expert opinion. However, in several cases, additional fast GTFM and MULTIFIT analyses were carried out. During this type of analysis, simple sensitivity studies were conducted by varying the transmissivity and the static formation pressure, one parameter at a time. This analysis was used as a means of providing improved parameter confidence limits. For tests including a gas injection period in a water saturated formation, the analysis was restricted to an evaluation of the threshold pressure, without considering further two-phase flow analysis. The recommended parameters are usually based on the results of the most reliable test phase(s) and the confidence limit is estimated by expert judgement, using the range of individual test phase results as well as a comparison with other test intervals results conducted in the same borehole section.

4.6.2 Detailed Analysis

The detailed test analysis procedure was applied on tests of special interest in respect of their contribution to the overall program objectives. In comparison to the standard analysis, a considerable amount of effort was put into the detailed interpretation.

The central issue of the detailed test interpretation was the sensitivity analysis of the results. Issues such as the choice of the flow model, the characterisation of the interval history and the quantification of the input parameters were carefully inspected. The impact of uncertainties on the analysis results was quantified and, on this basis, parameter confidence limits were derived. Additionally, MULTIFIT non-linear regression analyses of the entire test sequence were conducted, to derive uncertainty ranges of the main test parameters (transmissivity and static formation pressure). Finally, the parameter consistency was verified by means of numerical GTFM simulations.

Whenever appropriate, the issues related to the two phase flow behaviour of the formation were addressed. Tests considered for two-phase flow analysis concerned either cases where both water and gas flow was detected during withdrawal events or cases where gas was forced into the water saturated medium (threshold pressure test), to mimic the impact of waste produced corrosion gas in gas-free natural environment. The two-phase flow analyses were conducted using the specific numerical simulation package TOUGH2/ITOUGH2. The two phase flow analysis procedure is briefly presented in Section 4.7.4. The detailed test analysis was presented in the main body of the Nagra Internal Reports.

4.6.3 Classification

The tests were subsequently evaluated in respect of their contribution to the overall program objectives. On the basis of a criteria list, NAGRA decided on the level of detail to which tests are to be analysed (FRIEG & MARSCHALL, 1998). An Example of the criteria list used by NAGRA in this project is presented in the Appendix A (Fig. 4.2 and Fig. 4.3).

4.6.4 Documentation

Both types of analyses were documented in a series of Nagra Internal Reports. The test analyses from the vertical borehole (SB4a/v) are documented in the report series (ENACHESCU et al., 1995a-g; DOMSKI et al., 1995). The test analyses from the slanted borehole (SB4a/s) are documented in the report series (ENACHESCU et al., 1995h; ENACHESCU et al., 1996a-f).

The standard test analysis was usually presented in the Appendices of the Nagra Internal Reports. Only the test analysis results were presented in executive summaries.

4.7 Special Aspects of Test Analysis

This section describes a few selected aspects of the analysis approach as used during the SB4a testing campaign at Wellenberg. The list of aspects considered is not intended to be comprehensive. In order to avoid redundancy with NAGRA technical reports describing previous testing campaigns at Wellenberg, only a few new analysis aspects were selected for a detailed description. Further, the presentation was mainly concentrated on the procedural aspects and on describing the advantages and the limitations of the new concepts used. For a thorough theoretical appraisal the reader is referred to the literature.

Following subjects were discussed:

- handling unknown or poorly defined input parameters such as the borehole history, the wellbore storage coefficient or the formation storativity,
- the generalised flow model concept of flow dimension,
- slug and pulse test analysis based on deconvolution,
- the analysis of test conducted under two phase flow conditions and
- the sensitivity analysis

4.7.1 Influence of Input Parameters

Generally speaking, test analysis results are always subject to uncertainties induced both by the input parameters used and by the matching procedure. The parameters that have to be quantified before starting the matching procedure can be summarised as follows:

- description of the wellbore history,
- quantification of the disturbance induced by the wellbore (i.e. wellbore storage coefficient) and
- quantification of the physical input parameters.

Strongly correlated model parameters represent an additional source of uncertainty. For example the correlation between skin factor and formation storativity is often a source of ambiguity and misinterpretations.

The present section describes the procedures used, whenever handling of unknown or poorly defined input parameters was required in the analysis process.

4.7.1.1 Borehole Pressure/Rate History

Borehole history characterisation is of crucial importance for correct interpretation of the data. Because this effect is difficult to measure, it must be estimated, which introduces an additional degree of uncertainty into the analysis.

The typical borehole history for the Wellenberg tests can be best described as a series of constant pressure events. Both drilling and inactive sequences can be approximated by events where the interval pressure is quasi constant.

Depending on the tools used to analyse the tests, the interval history can be weather described as a constant pressure event (GTFM, MULTIFIT) or has to be approximated to one or more constant rate phases (INTERPRET/2, FLOWDIM). Two methods are basically available for deriving estimates of the flow rates during the historical period.

The first method relies on direct flow rate measurements conducted at start of the test, during the compliance period (COM). After the packer or packers are inflated the downhole shut-in valve remains open and the flow rate during this phase is measured. An additional goal of this phase is to allow the temperature in the interval to stabilise, so the test can be started at isothermal conditions. The rate measured during the COM phase is a measure of the flow rate of the interval under hydrostatic conditions and is usually used as a first estimate of the historical rate. In the case when the interval was exposed to severe and long lasting pressure changes during the pre-test history, the equivalent rates can be estimated by scaling the flow rate measured under hydrostatic conditions for the appropriate pressure differences.

The rates derived using the method descried above are used as a first estimate to start the analysis. The second step in deriving the equivalent historic flow rate bases on the assumption that events conducted later in the test are less influenced by the poorly defined history than events conducted at the beginning of the sequence. Using this assumption, the pressure static recovery (PSR), which is conducted at start of the test, is matched against a shut-in phase conducted towards the end of the test sequence, by adjusting the equivalent historical flow rate (see Fig. 4.4) on a rate normalised log-log plot.

The uncertainties in the borehole history and their impact on the analysis results, were subsequently quantified in a sensitivity analysis.

Finally, the results of the constant rate superposition analysis were used as an initial guess for the subsequent GTFM and MULTIFIT analysis, where the historic period is described as one or a series of constant pressure events.

4.7.1.2 Wellbore Storage

One of the most sensitive parameters when testing in low transmissivity formations is the wellbore storage coefficient. It controls the length of the wellbore storage dominated period of constant rate and pressure recovery test events and, in the case of slug and pulse events, it directly scales the derived transmissivity.

The wellbore storage coefficient is defined as the volume of fluid additionally stored or released by the interval while changing the pressure in the system by one unit (i.e. 1 Pa). Several methods of determining the wellbore storage coefficient are available. Since the results of the calculations can vary by several orders of magnitude, depending on the method used, a separate section was included in this report in order to discuss these methods in more detail. In parallel, a typical test sequence, as usually conducted in very low transmissivity test sections at the Wellenberg site, was simulated, using a black oil numerical simulator (ECLIPSE 100), in order to illustrate the use of the methods. The parameters used to simulate the test presented in Figure 4.5 are listed below:

Tab. 4.4: Parameter set used for ECLIPSE test simulation example

formation compressibility	:	5.00E-09	1/Pa
water compressibility	:	5.00E-10	1/Pa
test zone compressibility	:	2.00E-09	1/Pa
inner composite zone porosity	:	2	%
outer composite zone porosity	:	1	%
inner composite zone storativity	:	2.16E-05	-
outer composite zone storativity	:	1.08E-05	-
inner composite zone transmissivity	:	8.00E-11	m^2/s
outer composite zone transmissivity	:	1.60E-12	m^2/s
skin factor	:	0	-
interval length	:	20	m
wellbore radius	:	0.079	m
test string radius	:	0.025	m
composite discontinuity radius	:	0.4	m
initial pressure	:	500	kPa
duration of history	:	500	h
pressure during history	:	5000	kPa

The simplest method of estimating the wellbore storage coefficient is to calculate it directly from the definition:

$$C = V_i \, c_{tz}$$

where V_i is the interval volume expressed in m^3 and c_{tz} represents the test zone compressibility expressed in Pa^{-1}. In the case of the simulated test example, the theoretical value of the wellbore storage coefficient can be directly calculated from the input parameters listed in the table above and is 8E-10 m^3/Pa. In reality, the value of the test zone compressibility (c_{tz}) is a relatively or defined parameter. Its lower limit is given by the water compressibility (approx. 4E-10 1/Pa). The upper limit can be set around 5E-71/Pa equal to gas compressibility. The tool compressibility is expected to play an important role in the determination of the c_{tz}-value as well. So-called casing tests, carried out at the Oberbauenstock site (KENNEDY & DAVIDSON, 1989), resulted in tool compressibility values between 5.7E-10 1/Pa and 1.5E-09 1/Pa. Therefore the calculated wellbore storage coefficient can only be regarded as a first estimate.

The next method of calculating the wellbore storage coefficient is based on measuring the volume difference in the test string (ΔV) after applying a pressure pulse of known magnitude (ΔP) to the test interval. In this case the wellbore storage coefficient is calculated as:

$$C = \Delta V / \Delta P$$

A third method of determining the relative change of the wellbore storage coefficient during a test is by plotting the slug and pulse events of the test sequence on a wellbore storage normalised log-log deconvolution plot (see also next Section for details). By changing the wellbore storage coefficients of the individual phases one can match the phases with each other and determine the trend of the change in wellbore storage coefficient from one test sequence to another. Figure 4.6 presents a wellbore storage normalised deconvolution plot of the PW1 and SW phases of the simulated example. In this case the wellbore storage coefficient of 2E-7 m^3/Pa for the SW phase was assumed as known, and the wellbore storage coefficient of the PW phase was matched to a value of 4.4E-10 m^3/s. Under open shut-in valve conditions (i.e. during a slug test) the wellbore storage coefficient is known as long as the density of the fluid in the test string is known:

$$C_f = \frac{\pi r_u^2}{\rho g}$$

whereby	C_f	: wellbore storage coefficient during a slug test	$[m^3/Pa]$
	r_u	: test string radius	[m]
	ρ	: density of fluid in the test string	$[kg/m^3]$
	g	: gravitational acceleration	$[m/s^2]$

Finally, the wellbore storage can be matched in the superposition analysis when using a wellbore storage and skin flow model. Figure 4.7 presents the superposition analysis of the simulated test example, conducted with the test analysis program INTERPRET/2. The wellbore storage coefficient was matched to 6E-10 m^3/Pa. However, the reliability of the derived C-values is tightly related to the reliability of the rate sequence used for analysis (measurements, calculations or assumptions).

Depending on the method used, the calculated wellbore storage coefficients usually differ in a range of approx. one and a half orders of magnitude. Sources for this inconsistency could be inaccurate volume change measurements or limitations of the methods of calculation. It is also possible that the wellbore storage coefficient changes during a test. This phenomenon can often be observed and is probably caused by changing system behaviour at different pressure levels or by the presence of gas.

4.7.1.3 Storativity and Skin

The formation storativity and the skin factor are highly correlated at middle and late test times. The two parameters can be lumped in the correlation group $C_D e^{2s}$ which is usually used as a type curve matching parameter. The correlation group is defined as:

$$C_D e^{2s} = \frac{C}{2\pi r_w^2 S} e^{2s}$$

whereby:	C_D	: dimensionless wellbore storage coefficient	[-]
	s	: skin factor	[-]
	C	: wellbore storage coefficient	$[m^3/Pa]$
	r_w	: wellbore radius	[m]
	S	: formation storativity	[m/Pa]

The matched correlation group can be used to calculate the formation storativity while assuming a zero skin factor:

$$s = 0 \quad (assumed)$$

$$S = \frac{\left(C_D e^{2s}\right)_M 2\pi r_w^2}{C}$$

Another strategy to solve the matched correlation group is to calculate the formation storativity from the definition and use the value to calculate the skin factor:

$$S = \phi\, c_t\, h$$

$$s = \frac{1}{2}\ln\left(\frac{\left(C_D e^{2s}\right)_M 2\pi\, r_w^2 S}{C}\right)$$

whereby:			
	ϕ	: formation porosity	[-]
	c_t	: total compressibility expressed on a pore volume basis	[1/Pa]
	h	: interval length	[m]
	M	: as a subscript denotes a matched parameter	[-]

None of the two methods is entirely accurate and can lead to erroneous storativities and skin factors. For example, a high negative skin value can indicate that the assumed formation storativity was underestimated.

The derived value of the formation storativity has a strong impact on the distances derived in the analysis, such as the composite discontinuity radius, distances to boundaries or radius of influence. They are derived using the equation below (STRELTSOVA, 1988):

$$d = A\sqrt{\frac{T}{S}t_s}$$

It can be seen that the calculated distances, such as radius of influence, are functions of the elapsed time when the response occurs (t_s), of the matched formation permeability and of the assumed storativity. The coefficient '*A*' is a constant dependent on the definition for the radius of investigation. The '*A*' constant used in the analyses was 1.89, corresponding to a dimensionless drawdown of approximately 0.3.

4.7.2 Generalised Model Concept of Flow Dimensions

The classic well test analysis usually has to assume some sort of flow geometry *a priory* in order to derive the unknown parameters such as hydraulic transmissivity and storativity. In layered sediments with perpendicular boreholes, appropriate flow geometries are reasonably obvious. In fractured rocks, the problem of uncertain flow geometry may be solved by including the geometry as one of the unknowns (BLACK, 1984). The fractional dimension flow model (known also as Generalised Radial Flow Model; BARKER, 1988) has been used in recent studies for interpretation of single- and multi-well hydraulic tests with unknown flow geometry (DOE 1991; CHAKRABARTY, 1994). This approach does not assume a fixed geometry *a priori*; instead, it considers the flow geometry, expressed by the so-called flow dimension, to be a variable which can be determined from a given hydraulic test response.

The fractional dimension flow model is based on the idea that the area available to flow in the fracture system varies as a power-law function of distance from the source point. The form of the pressure transient with this approach is given by:

$$S_{sf}\,\frac{\partial \mathrm{h}}{\partial t} = \frac{\mathrm{K_f}}{\mathrm{r}^{\mathrm{n-1}}}\,\frac{\partial}{\partial \mathrm{r}}\left(r^{n-1}\frac{\partial \mathrm{h}}{\partial r}\right)$$

where BARKER`s (1988) terminology has been retained. K_f and S_{sf} are the uniform hydraulic conductivity and specific storage of the fracture system respectively; n is the flow dimension and can be integral (i.e., 1, 2 or 3) or non-integral (Fig. 4.8). The fractional dimension flow model therefore generalises the flow dimension to non-integral values whilst retaining the assumptions of radial flow and property homogeneity.

The assumptions inherent in the fractional dimension flow model are:

- Darcian flow in a flow medium that fills an n-dimensional space
- Constant fracture transmissivity and storativity (and hence, diffusivity)
- Small pressure gradients
- Single phase flow with negligible gravitational and thermal effects.

There are a variety of mathematical solutions to the generalised radial flow equation presented above, depending on the nature of the source wellbore condition and the formation boundary conditions. For constant rate tests in an "infinite-acting" flow medium, mathematical solutions have been developed for situations involving one or more monitoring zones (BARKER 1988; CHAKRABARTY, 1993).

Similarly, models for constant pressure and slug/pulse tests were developed. Changes in flow dimension and in transmissivity can be modelled as well as the interaction between matrix and the fracture system (i.e. dual porosity fractional dimension; see Fig. 4.9).

Several tests conducted during the SB4a campaign at Wellenberg were analysed using fractional dimension flow models. Usually, sub-cylindrical flow geometries were derived.

4.7.3 Deconvolution of Slug/Pulse Test Events

Slug and pulse test events were playing an important role during all testing campaigns at Wellenberg. Particularly in very low transmissivity formations pulse and sometimes slug tests are the only testing techniques that can be applied. During previous testing campaigns, the analysis of slug and pulse tests was usually conducted with RAMEY-type analysis techniques using homogeneous, infinite acting flow models. The use of this method usually proved to have disadvantages, specially when applied to tests conducted in very low transmissive formations. The disadvantages usually included the inability to identify the appropriate flow model. A relatively large ambiguity in the test parameters was usually the consequence. An additional analysis method was involving the use of test simulation packages such as GTFM and

MULTIFIT. This method, although very accurate in simulating complex test sequences, was disadvantageous due to the rather insensitive matching procedure in Cartesian coordinates.

During the SB4a testing campaign, a new slug and pulse test analysis technique was introduced. The new method represents a further development of the slug test deconvolution technique described by PERES et al. (1989) and is presented in BLACK et al. (1996). The method uses the fact that the inner boundary condition during slug and pulse tests is only controlled by wellbore storage. For this particular case, the wellbore storage effect can be numerically removed from the data set using a deconvolution technique. A new family of type curves was developed, describing a cylindrical source with skin and without wellbore storage. Figure 4.10 presents a type curve set for a homogeneous, infinite acting formation. Different other flow geometries were realised as well, such as: dual porosity and composite (see Fig. 4.11).

The slug test deconvolution method allows for an improved flow model recognition and proved to be a reliable tool mainly for determining the inner composite zone parameters. However, specially in very low transmissivity formations, the method is strongly influenced by the pressure gradients around the borehole during the test (i.e. the borehole history). These mainly affect the late time data, used for the determination of the outer composite zone parameters. In addition, this method allows the separate determination of storativity and skin from a single zone test. This was not possible in the past. In several cases however, the skin was set to zero due to the lack of well defined early time data.

A further application of the deconvolution method was the use of wellbore storage normalised deconvolution plots of the slug and pulse events of a test. This method allows to monitor changes in the wellbore storage coefficient from one test phase to another. Another application was to calibrate the usually poorly known wellbore storage coefficient during pulse events against the wellbore storage coefficient of slug tests. Figure 4.12 presents an example of a wellbore storage normalised deconvolution plot of a test conducted in borehole SB4a/s.

The slug test deconvolution method was usually used in combination with the other two methods described above, aiming to achieve a maximum of analysis consistency.

4.7.4 Analysis of 2-Phase Flow Tests

To better characterize the two-phase flow behavior of transport of waste-generated gas from a L/ILW repository, gas injection tests with subsequent recovery were performed in SB4a (e.g. SB4a/v-VM13 & VM14). The overall objectives of these extended gas threshold pressure tests (EGTPT) were:

- determination of the gas threshold pressure and absolute permeability of the formation to define the relationship between air-entry pressure and permeability for the host rock at the Wellenberg site.

- identification of the two-phase parameter model for relative permeability, distinguishing between the BROOKS & COREY, VAN GENUCHTEN and GRANT model.

In comparison to a standard gas threshold pressure test (GTPT), the gas injection continued significantly beyond the gas threshold pressure in order to analyze the pressure response as the gas continues to move into the formation, reflecting the two-phase flow behavior of the host rock. Several tests conducted at Wellenberg suggested that either relative permeability model (BROOKS & COREY or GRANT) could equally well reproduce the observed pressure response during the GRI/GRIS sequences.

Two-phase properties were not only analyzed from the gas injection tests, but also from hydrotests where free gas was observed. A number of tests intervals indicated gas flow from the interval during withdrawal sequences. To investigate the phase conditions in the formation, that is, if flow through water-conducting features (WCFs) is controlled by two-phase or single phase liquid, SB4a/s-VM11 was designed as a gas evidence test. The test sequence for VM11 followed the proposed set of sequences based on the design study by FINSTERLE (1995) for the purpose of estimating two-phase flow properties. The strategy for the two-phase flow analysis of VM11 was led by the following objectives:

- distinction between free gas and dissolved gas in the formation

- identification of the two-phase parameter model for relative permeability, distinguishing between the BROOKS & COREY, VAN GENUCHTEN and GRANT model.

- In case of initially free gas in the formation, the volumetric free gas content in terms of gas saturation of free gas in the formation should be determined (i.e. upper limit of free gas content).

The test sequence of SB4as-VM11 was implemented with the two-phase flow code TOUGH2/ITOUGH2 (PRUESS, 1991; FINSTERLE, 1995) to simulate flow of liquid (water) and gas (methane) accounting for mutual interference between phases owing to relative permeability and capillary pressures. In comparison, the EGTP test were simulated using air as the gas phase. Thermophysical properties of water were represented by steam-table equations, while the gaseous phase was treated as an ideal gas. Dissolution of gas in water was modelled with HENRY's law

Two-phase flow parameters are generally represented by constitutive relationships between (a) capillary pressure and liquid saturation (S_l), and (b) relative permeability and saturation (see Fig. 4.13 & 4.14). These relations are typically determined from laboratory experiments and then fitted to parametric models. The most commonly used models for capillary pressure (P_c) and relative permeability of liquid (k_{rl}) and gas (k_{rg}) are those by BROOKS & COREY (1966):

$$P_c(S_l) = P_e\left(\frac{S_l - S_{lr}}{1 - S_{lr}}\right)^{-1/\lambda}$$

$$k_{rl} = S_e^{\frac{2+3\lambda}{\lambda}}$$

$$k_{rg} = (1 - S_e)^2\left(1 - S_e^{\frac{2+\lambda}{\lambda}}\right)$$

and VAN GENUCHTEN (1980):

$$P_c(S_l) = \frac{1}{\alpha}\left[\left(\frac{S_l - S_{lr}}{1 - S_{lr}}\right)^{-1/m} - 1\right]^{1-m}$$

$$k_{rl} = S_e^{\in}\left[1 - \left(1 - S_e^{1/m}\right)^m\right]^2$$

$$k_{rg} = \left(1 - S_e\right)^{\gamma}\left(1 - S_e^{1/m}\right)^{2m}$$

where S_e is the effective saturation, given by:

$$S_e = \frac{S_l - S_{lr}}{1 - S_{gr} - S_{lr}}$$

where the residual water saturation (S_{lr}) and the residual gas saturation (S_{gr}) represent minimum values that must be exceeded before the corresponding phases become mobile.

In the BROOKS & COREY model, the parameter λ is the pore-size distribution index and P_e is the air-entry pressure (capillary-displacement or threshold pressure). The air-entry pressure is the minimum gas pressure that must exist before gas can begin to displace the liquid. P_e is related to the largest connected pore radius through which the water is displaced by gas. The parameter λ determines the curvature of the capillary pressure function and is related to the pore geometry of the rock; $\lambda = 2$ yields the widely used COREY relative permeability model (COREY, 1954), which is used as base case in the numerical simulations.

In the VAN GENUCHTEN model, the parameter m is related to the BROOKS & COREY parameter λ by $m = 1\text{-}1/n$ where $n = \lambda+1$, and $\alpha = 1/P_e$ (MUALEM, 1976). The parameters $\in$ and γ describe the interconnection of the pores (MUALEM, 1976) and are typically given as $\in=1/2$, and $\gamma=1/3$ (LUCKNER et al., 1989). Note, that in the VAN GENUCHTEN model the capillary pressure goes to zero for $S_l = 1$. In comparison, the capillary pressure in the BROOKS & COREY model is equal to the air-entry pressure for $S_l = 1$. The relative liquid permeability in the VAN GENUCHTEN model is generally lower than that of the BROOKS & COREY model, but the relative gas permeability is higher than that of the corresponding BROOKS & COREY model.

For air entry pressures, laboratory-determined threshold-pressure data compiled from the literature indicate a linear correlation with absolute or intrinsic permeability (DAVIES, 1991). The laboratory measurements were from core plugs of porous rocks for different consolidated lithologies. The relationship between intrinsic permeability and threshold pressure is described by the following regression equation (DAVIES, 1991):

$$P_e = 5.6 \times 10^{-7} k^{-0.346}$$

A limited number of gas-threshold pressure tests from Palfris formation at the Wellenberg site and Oberbauenstock show that the estimated threshold pressures follow the same trend as that shown by DAVIES (1991), but with somewhat overall higher pressures. This exponential relationship between k and P_e is supported by the most recent gas threshold pressure tests in WLB boreholes SB4a/v and SB4a/s (see Fig. 4.15). The measured threshold pressures at

Wellenberg and Oberbauenstock may be affected by wellbore storage and by skin effects (JOHNS, 1993), which may account for the difference between laboratory and field-test data.

In general, the model functions for relative permeability and capillary pressures were derived on the assumption of porous rocks. Hydraulic testing of the Palfris formation indicated that flow occurs primarily through relatively low-permeable fractures within cataclastic zones. In high-permeable fracture networks with constant fracture apertures, relative permeabilities typically vary linearly with saturation and the residual saturation is near zero. In fractured-porous media, it can be assumed that the relative permeability of the liquid phase is lower than that of the gas phase, because capillary effects will cause the liquid to move primarily within the matrix or small fractures, whereas gas will flow preferentially through the higher-permeable fractures. In this case, the phases tend to move independently of each other. Such a behavior is described by the GRANT model (GRANT, 1977), whereby the relative permeability of the gas phase is given by:

$$k_{rg} = 1 - k_{rl}$$

The BROOKS & COREY / VAN GENUCHTEN and GRANT curves, thus, can be considered to cover the possible range of relative permeabilities, whereby the GRANT curve is typically used for fractured-porous rocks.

The GRANT model is based on empirical data from fractured geothermal reservoirs (GRANT, 1977) and is probably more applicable for single component, two-phase flow systems (i.e. vapor and water), where phase-change processes will enable vapor flow to take place, even if there is initially no contiguous flow path. This effectively enhances the gas (vapor) relative permeability (PRUESS & TSANG, 1990).

For a two-component, two-phase flow system (i.e. gas and water), the relative permeability in a single fracture with variable aperture is characterized by significant phase interference (PERSOFF & PRUESS, 1993; PRUESS & TSANG, 1990). On the other hand, fractures commonly have long-range spatial correlation's in aperture width (i.e. channels), where the non-wetting flow preferentially occurs in the larger openings, leading to an enhancement of the gas relative permeability. Similarly, in typically complex fracture networks, gas can be expected to flow preferentially through larger fractures, whereas liquid moves through smaller fractures, further enhancing the gas relative permeability (PRUESS & TSANG, 1990).

Injection of low-viscosity gas into a fully water-saturated formation can cause viscous fingering, creating preferential gas flow paths and typically result in a smeared saturation front between injected gas and water. Viscous fingering is affected by heterogeneity of the fractured rock and generally increases the effective gas permeability.

Because no detailed information is available on fracture aperture or fracture-network characteristics for the Palfris formation at Wellenberg, both the VAN GENUCHTEN model with and without enhanced gas relative permeability and the BROOKS & COREY model with and without enhanced gas relative permeability (FINSTERLE, 1994; SENGER & JAQUET, 1994) were used to estimate the corresponding two-phase flow parameters from hydrotests.

With the exception of gas-threshold pressure measurements, no direct measurements of relative permeability or capillary pressure were available from the Palfris formation. Even when laboratory measurements of two-phase flow parameters were available, it remains questionable, if such small-scale representations are appropriate to describe two-phase flow processes on a field scale. Indirect parameter estimation through the analysis of hydrotest sequences under two-phase flow conditions in WLB SB4-VM2 did not allow to identify one preferred model over another model, because of data limitations and the often non-uniqueness of the inverse problem associated with two-phase flow in hydrotests (FINSTERLE, 1994; SENGER & JAQUET, 1994). In a different approach, continuum approximations for two-phase flow through the fractured marl were derived based on the phenomenological description of the hydrogeological conceptual model for the WCFs in the Palfris formation (SENGER & JAQUET, 1994). The approach allowed the estimation of the effective flow porosity and of the residual water saturation, but did not give an indication of the shape of the relative permeability and capillary pressure curves and of the residual gas saturation.

4.7.5 Sensitivity Analysis

Difficulties with the unequivocal identification of the flow model raise questions about the accuracy of the formation parameters which result from the test interpretation. Simple sensitivity analysis of the test interpretations were carried out to quantify the uncertainty in the results. The influence of borehole history, flow model selection and choice of input parameters on the results derived from the INTERPRET/2 analysis were conducted as part of the detailed test analysis and are described in the following sections. In addition, sensitivity studies were performed with GTFM/MULTIFIT by adjusting the transmissivity or static formation pressure and looking at impact to overall match quality.

4.7.5.1 Influence of Borehole Pressure/Rate History

Borehole history characterisation is of crucial importance for correct interpretation of the data. Because this effect is difficult to measure, it must be estimated, which introduces an additional degree of uncertainty into the analysis. The present section describes the sensitivity analysis procedure concerning the influence of the interval history on the test results.

As a first step of the sensitivity analysis, the character of the interval pressure and rate history was described, the sources of uncertainty were identified and the ranges of uncertainty were quantified. Generally, three aspects were assessed:

- the duration of history,
- the magnitude of the equivalent historical rates and
- the degree of complexity and discretisation of the historical period.

The method of quantifying the influence of the interval history on the analysis results can be summarised as follows:

- A best guess historical scenario was defined. This was the scenario used for the main test analysis.
- Subsequently, the critical parameters of the history were identified (i.e. duration, rate magnitude, complexity), together with their ranges of possible variation.

- Minimum and maximum history scenarios were defined, based on the variability of the single parameters.

- One or two test phases were reanalysed under the assumption of alternative history scenarios. Usually a phase at the start of the test sequence was chosen (e.g. the PSR phase) and the variation of the analysis results was compared with the results of a phase conducted later in the test (e.g. a SWS or a RWS phase).

An additional method of visualising the influence of the interval history on the analysis results, was to present on a plot the impact of changes in the history on the superposition function, plotted as superposition HORNER plot or as log-log derivative plot (see Figs. 4.16 and 4.17).

4.7.5.2 Influence of Flow Model Selection

The uncertainty related to the choice of correct flow model is a common problem in well testing, due to the inverse nature of the problem. Flow model identification is usually based on the superposition log-log derivative plot of the individual test events and corroborated with additional information on the geology, geophysics, general test response etc. Additional model identification was conducted, whenever appropriate, on the log-log deconvolution plots of the slug and pulse phases.

When testing in very low transmissivity environments, the early time wellbore storage dominated period usually lasts till the end of the testing phases and masks the formation response. In such cases flow model identification is difficult and uncertain. For example, it is often difficult to discern phenomena of changing wellbore storage during a test phase from composite formation behaviour. In most of the cases the transitional effects, usually occurring when switching from one flow regime to another, are difficult to identify and can be falsely described as infinite acting fractional dimension behaviour (see Figure 4.18).

Correct flow model identification is however important for the correct interpretation of the formation parameters derived. The sensitivity analysis conducted as part of the detailed analysis of the SB4a tests included aspects concerning the flow model selection. Usually a few selected, representative test events were analysed using different flow models. The analysis results were subsequently compared and the variability range of the key formation parameters (Transmissivity and equivalent freshwater head) was quantified (see example in Fig. 4.18).

4.7.5.3 Influence of Input Parameters

A common problem in transient pressure analysis is to ascertain a best estimate for each of the input parameters (total system compressibility, porosity and viscosity). Using the transformation equations of the dimensionless variables (t_D, p_D and C_D) for the case of constant rate boundary condition one can investigate the influence of the input parameters on the analysis results. Although these effects could be quantified by means of a MONTE-CARLO simulation, this does not form part of the scope of this report.

The calculation of the permeability and conductivity values can be derived from the following two equations:

$$k = \frac{qB\mu}{2\pi h} PM$$

$$K = \frac{qB\rho g}{2\pi h} PM$$

whereby:	k	: formation permeability	[m^2]
	K	: formation conductivity	[m/s]
	q	: flow rate	[m^3/s]
	B	: formation volume factor	[m^3/m^3]
	μ	: viscosity	[Pa s]
	ρ	: density	[kg/m^3]
	g	: gravitational acceleration	[m^2/s]
	h	: interval length	[m]
	PM	: pressure match	[1/Pa]

The following conclusions can be drawn from examination of the equations above:

- The derived permeability is dependent on the flow rate, fluid viscosity, effective interval length and pressure match.

- The calculated hydraulic conductivity is only dependent on the flow rate, effective interval length and pressure match.

The wellbore storage coefficient is a matched parameter, derived using the following equation:

$$C = \frac{2\pi\, k\, h}{\mu} \frac{1}{TM}$$

whereby:	C	: wellbore storage coefficient	[m^3/Pa]
	TM	: time match	[1/s]

As can be seen, the wellbore storage coefficient depends on the flow rate and on the match parameters (*TM* and *PM*).

The storativity is calculated using the following equation:

$$S = \phi\, c_t h$$

It can be seen that the formation storativity is, in most cases (see also comments in section 4.7.1.3), calculated from the definition. As shown in the equation above, it is dependent on the formation porosity (ϕ), the total compressibility (c_t) and the thickness of the tested interval (h).

The skin factor is calculated from the matched type curve parameter, as shown below:

$$C_D = \frac{C}{2\pi\, r_w^2 S}$$

$$s = 0.5 \ln\left(\frac{\left(C_D e^{2s}\right)_M}{C_D} \right)$$

It can be seen that the skin factor depends on the assumed formation porosity, total system (formation) compressibility and on the wellbore radius.

Distances derived in the analysis, such as the composite discontinuity radius, distances to boundaries or radius of influence are derived using the equation below:

$$d = A\sqrt{\frac{T}{S}t_s}$$

It can be seen that the calculated distances, such as radius of influence, are functions of the elapsed time when the response occurs (t_s), of the matched formation permeability and of the assumed storativity. The coefficient 'A' is a constant dependent on the definition for the radius of investigation. The 'A' constant used in the analyses is 1.89, corresponding to a dimensionless drawdown of approximately 0.3.

The static formation pressure, since it is directly extrapolated using the type curve, is not dependent on any of the input parameters.

5 SELECTED EXAMPLES OF ANALYSES

This Section presents a description of the analyses for two tests conducted in Wellenberg Borehole SB4a. They were chosen to cover the range of hydraulic conditions, demonstrate the uncertainty in the derived parameters and show the impact of gas flow on the measured response. In general, the uncertainty in the derived parameters is largely dependent on: 1) transmissivity of the interval and 2) duration and complexity for the borehole history. Low transmissivity intervals are typically dominated by wellbore storage effects and transitional data; this masks the true formation response. In this case a simple flow model is assumed and hydraulic parameters are extrapolated from the data set. In addition, inaccuracies in the representation of the borehole history period have a much larger adverse impact on low transmissivity intervals. Another consistent source of uncertainty is the presence of gas on the derivation of single phase hydraulic parameters.

The general analysis approach for the two examples presented can be divided into four steps:

- Identify a base case characterisation of the input parameters and borehole history;
- Analytical interpretation using INTERPRET/2 and FLOWDIM;
- Consistency check with borehole simulators GTFM/MULTIFIT conducted by independent team;
- Define recommended values and confidence limits.

The preliminary agreement on input parameters and interval history was important in order to allow results between the two interpretation approaches to be compared. The analytical approach concentrated on the analysis of individual phases within the tests. Best guess parameters and recommended flow model were then used as a starting point for the interpretation with the borehole simulators. The simulators placed emphasis on matching the entire sequence. Sensitivity studies were performed with both methods to develop confidence limits for the derived parameters. Final recommended values and confidence limits took into account both methods.

5.1 SB4a/v - Test T7

This example of a straddle packer test was selected to show the test procedure and analysis methodology used to optimise the reliability of parameters in low head and low transmissivity environments. These conditions were encountered in both the vertical and the slanted parts of the borehole below a depth of approx. 500 m bGL (true vertical depth).

The T7 interval (13.1 m from 550.5 to 563.6 m bGL) was drilled on February 8th, 1995. Some 46 days later the test was started after the total depth of the vertical part of the borehole was reached and geophysical surveys were carried out. The main objective was static formation pressure, and secondarily the interval transmissivity, using an appropriate flow model. Just over 4 days were needed to perform the test. A Quick Look Report was produced within 3 days after test completion. In addition, a detailed interpretation was performed using two different analysis approaches. This test is summarised on pages 44 and 45 in Appendix B and detailed in ENACHESCU et al. (1995f).

5.1.1 Test Description

The test (see page 44 and 45 in Appendix B) started with inflation of the packer to 8000 kPa using Nitrogen on 26th March 1995. The shut-in tool remained open for a 4.03 hour COM phase to allow the temperature in the interval to equilibrate. The T2 temperature changed from 21.24 to 22.42 °C during this time, but was relatively stable for the remainder of the test. The decreasing fluid level (equivalent rate = -3.06E-03 l/min) in the latter part of the COM phase suggested recovery to a sub-hydrostatic formation pressure. During the subsequent 12.87 hour PSR period, the pressure decreased to 5360 kPa. A pulse withdrawal phase (PW1) was then performed with an initial pressure difference of approx. 1440 kPa; this was to derive a first estimate of the near wellbore transmissivity and to obtain a direct measurement of the wellbore storage capacity (C = 3.25E-09 m^3/Pa). The pressure began to decline ('roll-over') at the end of this period, so a second pulse withdrawal phase (PW2 - 20.33 hours) was conducted to draw the interval pressure down towards the anticipated static formation pressure. The results of this phase were used to corroborate the near wellbore transmissivity and wellbore storage capacity measurements produced in the first pulse - the derived C-value of 3.24E-09 m^3/Pa was in good agreement. The pressure began to 'roll-over' for a second time; the final measured pressure of this period provides an upper limit for the static formation pressure. A third pulse (PW3) was performed (approx. 1890 kPa drawdown). This lasted 6.65 hours, during which time the pressures were continuously increasing after 4 hours, suggesting that the majority of the pressure history was dissipated. The derived C-value of 1.96E-09 m^3/Pa was slightly lower than those produced from the first two pulses.

With the majority of the pressure history dissipated, it was decided to proceed with the main test sequence. A slug withdrawal period (SW) lasting 11.19 hours was performed with a drawdown designed below the expected static formation pressure. The equivalent flow rate during this time was 2.38E-02 l/min. The subsequent build-up (SWS) lasted 30.23 hours with a pressure recovery of 764 kPa (to 2283 kPa) and no indication of a 'roll-over'. The test was concluded with another brief (0.14 hour) pulse withdrawal (PW4); this yielded a C-value of 1.29E-09 m^3/Pa.

5.1.2 Analytical Interpretation with INTERPRET/2 and FLOWDIM

The interpretation approach was to first analyse the amenable phases with full superposition. Emphasis was placed on those phases with relatively long duration, following well defined flow periods and late in test when impact of the uncertain historical rate schedule are minimised. The pulse phases were subsequently analysed with RAMEY (1975) type curves and deconvolution techniques. Because these analyses were performed with no superposition, the accent was placed on near wellbore parameters as the late time data is strongly influenced by the pressure history. The analysis was performed in a interactive fashion to optimise the consistency of parameters. Sensitivity studies were then performed to assess the impact of the uncertain borehole historical period. The recommended parameters were selected from the phase in the full superposition analysis which were considered to yield the most reliable parameters. Confidence limits incorporated analysis results of the individual phases and sensitivity study.

A very critical part of the analysis of test T7 is the accurate representation of the historical period in the rate schedule. This period is over an order of magnitude longer then the test duration and very complex. The impact on the test response is exasperated in the T7 test due to the low interval transmissivity and static formation pressure below the hydrostatic conditions in the borehole.

The borehole history was discretised into 18 constant rate periods, based on drilling and geological logs. The rates were initially estimated from a number of sources including mud balance data, measured rates and steady state approximations. Rates were subsequently adjusted interactively during the analysis. One means to check the adequacy of the historical period is the rate normalised multi-diagnostic plot (Figure 5.1). The SWS period, following a well defined flow period, is compared to the PSR phase, most strongly influenced by the historical period, on a single plot. Because the pressure and pressure derivative data is rate normalised, the radial flow stabilisation should have similar levels. One possible cause for a discrepancy is errors in the historical rates. In this case, the historical rates are adjusted to reduce this inconsistency.

The test rate schedule consists of a further 23 discretised intervals. Single constant rate events have been used to simulate the COM, PSR, and SWS phases. However, the slug and pulse events have been apportioned more than one constant rate step to ensure that changing rates are accurately reflected in the schedule. The pressure drops at the start of the PW and SW periods have been simulated using short constant rate events, with flows derived from the theoretical value of the wellbore storage constant. Prior to closing the shut-in tool for the pulse phases, there is a short flow period. The pressure change during this event was used to compute an equivalent rate. As the flow from the formation during SW period decreases with time, this phase was discretised into 4 approximately constant rate events.

The analysis was started by creating log-log diagnostic plots for the PSR (Figure 5.2) and SWS (Figure 5.3) periods. No analysis was possible on the PSR period due to the dominance of wellbore storage effects. The SWS phase was the longest period in the test and showed a heterogeneous response. The flow model chosen to analyse the data is summarised below:

- Flow Geometry: Cylindrical Flow
- Inner Boundary: Wellbore Storage and Skin
- Formation: Composite
- Outer Boundary: Infinite in Lateral Extent

In using this model, the levelling off of the pressure derivative starting at 0.1 h (Fig. 5.3) was interpreted as an inner zone radial flow stabilisation. This period is not easily recognised because it is partially masked in the early time by wellbore storage effects and in late time by increasing pressure derivative data. The late time data was interpreted to be transition to an outer zone of lower transmissivity. Parameters derived for the outer zone are more unreliable in comparison to the inner zone because: 1) the outer zone radial flow stabilisation must be extrapolated from transitional data and 2) the late time transitional data is strongly influenced by the uncertainties in historical rate schedule. The type curve is somewhat unstable due to the relatively small discontinuity radius. This flow model may be analogous to a damaged zone from drilling effects, resulting in an artificially enhanced permeability zone close to the borehole. In this case, the outer zone parameters are representative of the undisturbed formation properties.

After the analysis on the log-log plot, the interpretation is shifted to the HORNER (1951) plot (Figure 5.4). In this analysis, the parameters are fixed with the exception of the static formation pressure. The static formation pressure is obtained by extrapolation from the data set and takes into account pressure history effects. An upper bound for this pressure was set at the final pressure measured in the PW2 phase due to the 'roll-over'. Finally, the consistency of the parameters derived in this phase are compared to the entire test sequence in Cartesian co-ordinates (Figure 5.5). A poor match to the data may be attributed to: 1) incorrect flow model, 2) errors in the derived parameters, 3) inaccuracies in the rate schedule, or 4) changing conditions between phases. In the case of a poor match, the analysis iterates back to the log-log plot and the analysis process is re-started.

Following the analysis of the SWS phase, PW1, PW2 and PW3 were interpreted with a similar procedure. PW4 was too short in duration for an analysis and was performed simply to obtain a physical measurement for the C-value. The log-log plot for PW3 is shown in Figure 5.6. The diagnostic resolution of the pulse periods for model identification is poor due to the poorly defined flow period immediately preceding the phase. Therefore, the main objective of these analyses was the confirmation of the flow model and parameters derived for the interpretation of the SWS period. If there was a large discrepancy between the phases, the analysis would iterate between the periods in attempt to optimise the consistency in results, with accent placed on parameters derived in the SWS phase.

The next step in the analysis was to analyse the three pulse phases with deconvolution techniques and RAMEY type curves. A homogeneous model was used to match the test data. Although a heterogeneous response was recognised, the late time data is strongly influenced by pressure history which was not accounted for in this type of analysis. Hence, the derived parameters are considered to only represent the near wellbore properties. A very sensitive input parameter is the C-value. This parameter may vary over several orders of magnitude depending on the water saturation, and compressibility of both packer and borehole walls. Therefore, additional effort was expended to confirm the reliability of this input value. First, the consistency of the pressure match between the pulse periods and the slug phase was compared on a single deconvoluted wellbore storage normalised plot (Figure 5.7). In this plot, the C-value for pulses was derived from physical measurements during the test. The good consistency suggest that the measured C-values are consistent with the precisely known C-value from the slug phase. Secondly, the measured values were compared to the matched C-values in the analyses with full superposition; good consistency was a further confirmation for the reliability of the measured C-values. Although the measured values were larger then the theoretical value by at least a half an order of magnitude, this discrepancy is within an acceptable range.

The deconvolution log-log plot and RAMEY analyses is shown in Figures 5.8 to 5.11. The deconvoluted data is distorted in the early time data where the type curves are sensitive to skin. Therefore, the procedure was to select the 0 skin type curve to match the data. The RAMEY analysis was then performed by constraining the storativity to within typically 2 to 3 orders of magnitude of the theoretical value. The matched storativity is recognised as being highly correlated to the assumed skin value. In the RAMEY analysis, the match is limited to the early time data due to the middle and late time influence from pressure history. The adverse impact of pressure history is greater for steeper hydraulic gradients just prior to initiating the phase.

Finally, the derived transmissivity is compared to the inner zone parameters derived in the analyses with full superposition using a composite flow model. In the case with large discrepancies, the interpretations would iterate between the two methods to improve the overall consistency.

After the parameters derived from the various phases using two analysis methodologies, each containing different inner boundary conditions, were optimised for consistency, sensitivity studies were carried out. The uncertainty related to the choice of the correct flow model is a common problem due to the inherent inverse nature of the analysis process. Since the SWS period showed the most diagnostic character, a second more simple homogenous model was selected to match the data (Figures 5.12 - 5.15). A good match was obtained on the log-log plot (Figure 5.13). However, the poor match on simulation plot (Figure 5.15) suggests that this model is inconsistent with the entire test sequence.

The single most significant source of uncertainty in low transmissivity and low head environments is the borehole history. The longer and more complicated this period, the more inaccurate it is represented in the analysis; this increases the uncertainty in the derived parameters. Static formation pressure and transmissivity derived from the late time data are most significantly impacted. Sensitivity studies were conducted by adjusting the most uncertain rates in the borehole history within a reasonable range, to assess the impact of the derived parameters. The recommended confidence limits are extended to include the results of these sensitivity analyses. In this case, the rate used for the time while drilling and fluid logging were adjusted over several orders of magnitude. Figure 5.16 shows the impact of the adjusted drilling period rate on the character of the derivative data. The results from this sensitivity analysis suggested that the static formation pressure may be as much as 780 kPa lower then the values derived in the main interpretation, due solely to uncertainties in the borehole history.

5.1.3 Consistency Check with Numerical and Analytical Borehole Simulators

At completion of the analyses with INTERPRET/2 and FLOWDIM, the results were transferred to an other group of analysts (also members of the interpretation team) for a consistency check using the borehole simulators GTFM and MULTIFIT. The borehole history was simulated as a single constant head event. The initial analysis with GTFM analysis started by using the parameters derived in the PW2 phase with INTERPRET/2. The entire test sequence was matched using these parameters. Then the parameters were input into MULTIFIT and the entire sequence regressed upon; the storativity and test zone compressibility were fixed. Sensitivity analyses were also performed for static formation pressure and outer zone transmissivity (Figure 5.17). The effect of temperature variation on the test interval was found to be small. The best estimate of the static formation pressure using MULTIFIT is 2418 kPa, which is approximately some 1170 kPa below the best estimate with INTERPRET/2. The outer zone transmissivity showed good consistency with results from INTERPRET/2. The uncertainty in the static pressure was estimated to be approximately 1000 kPa.

5.1.4 Results

The recommended values and confidence limits are shown on page 45 in Appendix B. These values are based on the corroborated results of the test analysis using an analytical approach

(INTERPRET2/FlowDim), sensitivity analyses, additional analysis completed using MULTIFIT & GTFM simulations (T3 and T7) and correlation between the results of the tests encompassed in the interval 518.5 - 620 m bGL (T3, T4, T5 and T7). The confidence limits for transmissivity encompass over an order of magnitude and over 200 m for the equivalent freshwater head. For recommended values, emphasis was placed on INTERPRET/2 analyses for transmissivity, due to high resolution of pressure derivative on log-log plots, while the static formation pressure derived with MULTIFIT was accented, due to its better representation of the borehole history as a constant head event.

5.2 SB4a/s - Test VM4

This example of a single packer test was selected to show the test procedure and analysis methodology used to optimise the reliability of parameters in moderate to high transmissivity environments under changing water saturation in the wellbore and near formation. This transmissivity environment was encountered in the upper approximately 400 to 500 metres in both the slanted and vertical parts of the borehole. In contrast to the preceding example, the adverse effect of the uncertain borehole history is significantly lower, due to the higher transmissivity and static formation pressure close to the hydrostatic conditions in the borehole. Instead, the main source of uncertainty is the changing water saturation conditions as the test proceeds. In addition, this example is meant to demonstrate the complexities involved in the measurements of separate water and gas rates during a production phase.

The VM4 interval (86.5 m, from 330.5 to 417.0 m aBH; 238.2 to 301.9 m bGL) was drilled between June 13th and 25th, 1995. The drilling was interrupted to perform two tests in the recently cored interval. The first test, VM3, was performed over the bottom 21.9 m of the borehole. After the test, the packer was deflated and the equipment was removed to test the entirely recently drilled section, VM4. The time from drilling to start of the test was over 5 days. The main objective was transmissivity; the static formation pressure was also important. However, it is recognised that it may represent an average from several different hydrologic units, due to the relatively large test interval. In addition, the characterisation of the gas flow was a primary goal throughout the testing program. A Quick Look Report was produced within 3 days after test completion. In addition, a detailed interpretation was performed using two different analysis approaches. This test is summarised on pages 8 and 9 in Appendix C and detailed in ENACHESCU et al. (1995h).

5.2.1 Test Description

After moving the tools to VM4 test depth 2.5 m^3 of uranin tracered fresh water was circulated down the tubing. The packer was then inflated to 5500 kPa with water. The shut-in tool remained open for a 6.36 hour compliance period (COM). Fluid flowed from the tubing at an average rate of 0.1 l/min, suggesting a static formation pressure above the hydrostatic conditions in the borehole. Once the temperature stabilised, the shut-in tool was closed for a 5.43 hour PSR phase. In the PSR period, the pressure increased 28 kPa, with a final pressure of 2444 kPa. In preparation for the subsequent SW phase, fluid was swabbed from the tubing. Upon opening the shut-in tool, the pressure fell 323 kPa. The SW phase was terminated after 0.69 hours at a recovery of approximately 62 % of the initial drawdown. In the following 12.72 hour SWS period, the pressure recovered to almost the same end pressure as the PSR phase.

During the latter part of this phase preparations were made for production from the interval; the pump rotor and sucker rods were run into the tubing and the flowmeters were function checked.

The RW phase was started with an initial production rate of 2.25 l/min. Approximately 2.90 hours after the start of pumping, gas was detected at the surface and the produced fluid was directed through the two phase separator. At an initial gas flow rate of 0.24 l/min, the separator pressure continued to slowly increase. This suggests an unbalance between the gas volumes entering and exiting the separator. Therefore, the gas outlet rate was slowly increased to 0.35 l/min, which stabilised the separator pressure. The water flow rate increased slowly throughout the production phase, with a final rate of approximately 2.67 l/min. During the entire 13.78 hour RW period, the pressure decreased by 306 kPa. It is important to recognise that for the separate water and gas measurements to be representative for conditions at the well head, the separator conditions needs to be stabilised including fluid level, pressure and temperature. In this case, fairly stable conditions were obtained but often measurements were complicated for the case gas is produced in slugs; this suggest that gas may be trapped in isolated compartments of the downhole equipment. The various measurements may be summarised as follows:

- total (water and gas) rate prior to separator (Figure 5.18);
- pressure (Figure 5.19) and temperature (Figure 5.20) conditions in the separator with fluid level visually inspected;
- water rate after flowing through the separator (Figure 5.21);
- gas rate after flowing through the separator (Figure 5.22)

The subsequent RWS period lasted 11.28 hours with a final pressure very close to the end pressures of the previous shut-in phases. The test was concluded with a 1.18 hour pulse injection period (PI). It is likely that there was free gas in the interval at end of the RWS period; this is suggested by the large change in fluid level inside the tubing after the shut-in tool was briefly opened for the PI. This cannot be solely accounted for by the compressibility of the interval under 100 % water saturated conditions.

5.2.2 Analytical Interpretation with INTERPRET/2 and FLOWDIM

A critical aspect of the analysis was to identify test phases which were most adversely effected by gas in the wellbore and the near formation. Those phases least impacted would be stressed for derivation of single phase hydraulic parameters. Generally, single phase conditions are likely to be present at the start of the test. During drilling, the injection of fluid into the formation may have displaced the gas component near the wellbore. After the production phase with gas measured at the surface, the formation response is typically dominated by changes in water saturation away from the borehole. An important issue is the source of the measured gas. If the gas is partially attributed to free gas in the formation, then it is more likely that all phases will be strongly impacted. However, if the gas was originally dissolved in the water and later released due the lowering of the pressure near the wellbore, then reliable parameters may be obtained from the test periods prior to production, as long as the drawdown was minimised.

The approach was to compare the formation response of the different phases on a single, rate normalised multi-diagnostic plot, using full superposition. The flow model used to analyse the responses would be obtained from the period which is suspected to be less impacted from gas effects. The pulse and slug phases would be analysed with deconvolution techniques and

RAMEY type curves. After the consistency between the phases was optimised taking into account potential adverse effects from gas flow, sensitivity studies would be conducted.

In the analyses with full superposition, the historical period was simplified to a single period of 238 hours; the time from drilling through the upper most water-conductive feature in the interval, identified through fluid logging, to packer inflation. The historical rate was set at 0.10 l/min, measured during COM phase, and confirmed with rate normalised multi-diagnostic plots. The test rate schedule was discretised into a further 15 discretised intervals. The SW phase was discretised into 9 approximately constant rate events. The rate used for the RW phase was taken from the total flowmeter measuring both water and gas phases.

Several rate normalised multi-diagnostic plots (Figures 5.23, 5.24, 5.25) were examined with only two periods on each plot and each successive plot showing later parts of the test. The following conclusions can be drawn by examining all three plots together:

- the pressure changes in the PSR and SWS (Fig 5.23) are consistent to confirm that the assumed historical rate is reasonable;
- the wellbore storage increases with each successive phase in the test, i.e. the unit slope in early time of successive period is shifted to the right;
- the size of the 'hump' in the pressure derivative data in mid to late time increases with each test phase;
- the derivative data in the RW period is very noisy and influenced by fluctuations in the total rate and gas flow;
- the RWS data and derivative is shifted parallel, downwards compared with the SWS data (see Fig. 5.24). This suggests that the mobility conditions around the wellbore changed due to the altered saturation conditions.

In summary, the plots show that the assumed historical rate, taken from measurements during the COM period, is reasonable. This assessment is based on the good consistency with phases which are largely dependent on rates measured during the test. Secondly, the increase in wellbore storage throughout the test suggests that there was an increase in gas concentration in the wellbore with each successive phase. Thirdly, the 'hump' in the derivative data in mid to late time may be attributed to a reduction in storativity away from the borehole. This reduction in storativity may be controlled by gas near the borehole, with a decrease in concentration with increasing distance from the borehole.

As mentioned above, it is important to identify the phases that may have been significantly impacted by gas flow. The evidence suggests that in both the RW and RWS periods there was gas in the wellbore and the near formation: relatively large wellbore storage values were matched in both the RW and RWS periods, there was a measured gas rate during the RW phase, the large matched storativity ratio and the large change in the fluid level for PI suggest gas was still present in the wellbore at the end of the RWS period. It is difficult to assess which periods preceding the RW phases were impacted by gas flow. This depends on the source of the gas flow and the absence or otherwise of degassed drilling fluid near the wellbore at the start of the test. In the SW phase, the anomalous recovery may be attributed to gas rising in the tubing. Therefore, it can be concluded only that the increasing wellbore storage and storativity matched with each successive period indicate that the effects of gas increase with time and that the concentration of gas was first significant in the RW period.

A composite flow model was selected to analyse the build-up data using full superposition. The diagnosis of the PSR phase is shown in Figure 5.26. This period was considered to yield the most reliable parameters due to the least impact from gas effects. In the subsequent SW phase the anomalous recovery suggested gas rising in the tubing. However, the PSR phase is most strongly influenced by uncertainties in the historical rate. Therefore, this uncertainty was investigated through a sensitivity analysis, discussed later in the section.

The log-log, HORNER and entire simulation plots for the PSR phase are shown in Figures 5.27, 5.28 and 5.29, respectively. The match in Cartesian co-ordinates is poor starting with the production period. This suggests that the water saturation conditions may have significantly changed at this time. Although the reliability of parameters derived in latter phases is very uncertain, the confidence limits conservatively included results from all the analyses. The derived static formation pressure from the various phases shows good consistency within a range of 16 kPa; this is attributed to a relatively simple and small duration for borehole history period that could be accurately represented in the rate schedule and relatively small impact of its uncertainties on the results in the later test phases.

After the superposition analysis of the PSR, SWS, RW and RWS periods, the slug and pulse phases were analysed with RAMEY type curves. It was typical to include a PI phase at the end of a test to enable a direct measurement of the C-value; this could be compared to earlier test phases. In this case, the large change in volume of 33 l suggested that gas escaped the interval while the shut-in tool was briefly opened. As the derived transmissivity is directly dependent on this very uncertain wellbore storage coefficient, results from this analysis were not included in the recommended confidence limits.

The RAMEY analysis and deconvolution log-log plot for the SW period is shown in Figures 5.30 to 5.33. A composite model was used to analyse the response but it is recognised that the outer zone parameters are significantly influenced by pressure history, not accounted for in the analysis. On the deconvolution plot (Figure 5.33), the general character of the derivative data is consistent with the PSR phase; hence, it shows the superior resolution of this method to diagnose the flow model. The kink in the middle of the recovery may be attributed to gas rising in the tubing.

Sensitivity studies were performed to asses the impact of unequivocal flow model and uncertainties in the historical rate on the derived parameters. In the analyses, it was recognised that the storativity ratio and mobility ratio were highly correlated; i.e. the ratios could be varied concomitantly over a range without detracting from the quality of the match. Therefore, the storativity ratio was increased by an order of magnitude to assess the relative impact on the derived parameters. The match quality was also very good. Static formation pressure was virtually unchanged. The impact on transmissivity for inner and outer zones was less then an half an order of magnitude. In the sensitivity for the borehole history, both the rate and the duration were varied. In both cases, the PSR phases was most significantly effected. The impact on the SWS phases were considered minimal. Parameters derived in the sensitivity studies were included in the recommended confidence limits.

5.2.3 Consistency Check with Numerical and Analytical Borehole Simulators

At completion of the analyses with INTERPRET/2 and FLOWDIM, the results were transferred to an other group of analysts also members of the interpretation team for a consistency check using the borehole simulators GTFM and MULTIFIT. The initial analysis with MULTIFIT started by using the recommended parameters and flow model derived with INTERPRET/2. Only the PSR-SW-SWS sequence was simulated as the subsequent events were disturbed by two phase flow conditions. Results are consistent to those parameters derived with INTERPRET/2 and FLOWDIM. The relatively low storativity ratio may show there is no free gas in the undisturbed formation. Sensitivity analyses were also conducted for static formation pressure and transmissivity, shown in Figures 5.34 and 5.35.

5.2.4 Results

The results between the two analysis approaches show good consistency. A composite flow model was used to match the formation response. The inner zone parameters are thought to represent a zone adjacent to the borehole damaged from drilling activities while the outer zone is considered equivalent to the undisturbed formation response.

The recommended transmissivity was selected from the outer zone transmissivity from the MULTIFIT/GTFM results and consistent with the parameters derived in the analysis of the PSR and SWS (sensitivity interpretation) phases. The PSR period is considered to be least impacted by gas effects and shows a well defined outer zone radial flow stabilisation on the log-log plot. Although the results are dependent on the historical period, the assumed rate was taken from measurements during the COM period and shown to be consistent with the rates measured during the test. The confidence limits for transmissivity take into account both INTEPRET/2 / FLOWDIM and MULTIFIT/GTFM, for both the main and the sensitivity analyses. The only exceptions were that the parameters derived for the inner zone from the RWS and outer zone values obtained from the PI were excluded, as these phases are significantly impacted by gas effects. The recommended static formation pressure was taken from the analysis results of the SWS period which shows a pseudo-stabilisation for both the inner and outer zones and preceded by a well defined rate. The confidence range for the static formation pressure includes results using both MULTIFIT / GTFM and INTEPRET/2, and also includes the sensitivity analyses.

As mentioned above, the characterisation of gas flow was also a test objective. The composite formation response was most likely due to both changing hydraulic properties and changing gas saturation away from the borehole. The increase in both the wellbore storage and storativity as the test proceeded suggests that the gas concentration was also changing with time. The mechanism controlling the gas flow is uncertain. Based on the gas-water ratio measured in the main production period, the concentration of gas is sufficiently low to be dissolved under static formation pressure and temperature conditions. Therefore all the gas measured at the surface can be dissolved into the formation water. However, from the measured ratio, it is difficult to make definitive statements on whether there was a free gas phase in the formation under undisturbed in situ conditions or if it originates from de-gassing when the pressure is lowered in vicinity of the borehole. The pumping system contains several 'pockets' which may trap gas during production. As a result, the measurements at the surface may not be representative of the downhole conditions. In sum, the test periods following the SWS phase are significantly impacted by changing gas saturations in vicinity of the borehole as the test proceeds, whether from free gas or gas from de-gassing or a combination of both mechanisms.

6 SUMMARY OF RESULTS BOREHOLE SB4a/v

This section summarises the interpretation results of the hydraulic tests conducted in the vertical borehole SB4a/v at Wellenberg. A total of twenty-three tests were conducted, of which sixteen were performed using a single packer test assembly and seven were using a double packer tool. Three of the double packer tests were conducted as gas threshold pressure tests, two of them were successful. Groundwater and/or gas samples were obtained from three intervals. Results of the sampling activities are presented in STEIGER et al. (1995a). Brief summaries of the conducted tests are presented in Appendix B of this report.

The first section of this chapter briefly presents the general borehole information, the second section summarises the testing results. Each of the main test parameters (i.e. the equivalent freshwater head, the formation transmissivity and the temperature profile) are discussed in separate subsections. Finally, a subsection is discussing the gas occurrence observed during the tests.

6.1 General Borehole Information

Wellenberg borehole SB4a/v is located in Canton Nidwalden at a geographical longitude of 673 249.3 and a latitude of 192 218.2. The elevation of the reference point (ground level) is 942.3 m asl. Drilling of the borehole was started on October 22nd 1994. The final apparent depth of 735 m bGL was reached on February 28th 1995. The upper 71.3 m of the borehole were drilled using a 12 $^{1}/_{4}$" drill bit. The transition of the superficial slope sediments to the Rutschmasse sediments was encountered at approx. 50 m bGL. After casing the borehole with a permanent 9 $^{5}/_{8}$" casing and a temporary casing of 7" down to 71.2 m bGL, drilling continued using a 6 $^{1}/_{4}$" (159 mm) core bit. The transition to the lower Cretaceous sediments of the Palfris-Formation (Valanginien Mergel) was encountered at a depth of 104.4 m bGL (for details on geology see ISLER et al, 1995a). The next permanent casing (7") was set at 112.5 m bGL. Subsequently, the borehole was drilled with 6 $^{1}/_{4}$" core bit down to the final depth (see also GASSLER & KASCH, 1996). Following table presents a brief summary of the geology encountered (ISLER et al., 1995a; NAGRA, 1997):

Tab. 6.1: Geological units encountered in borehole SB4a/v

Apparent Depth [m aBH]	Geological Formation
0.00 - 50.00	Slope Sediments (Quaternary)
50.00 - 104.40	Rutschmasse (Quaternary)
104.40 - 426.14	Palfris-Formation (lower Cretaceous - Drusberg-Nappe)
426.14 - 441.53	Vitznau-Mergel & Palfris-Formation
441.53 - 461.60	Mélange (Schimberg-Schiefer & Vitznau-Mergel & Palfris-Formation)
461.60 - 500.30	Schimberg- Schiefer (Tertiary - Axen-Nappe)
500.30 - 630.40	Globigerinenmergel (Tertiary - Axen-Nappe)
630.40 - 630.52	Mélange
630.52 - 735.00	Palfris-Formation (lower Cretaceous - Drusberg-Nappe)

The deviation of the borehole was approximately 1.5° from vertical.

6.2 Hydraulic Packer Test Results

In Table 6.2 the geological characterisation of the test intervals and the main objectives of the hydraulic packer tests are summarised.

Tab. 6.2: Summary of information on hydraulic tests conducted in borehole SB4a/v

Test	Type	Measured [maBH] Top	Bottom	True Vertical [mbGL] Top	Bottom	Objectives	Events	Geology	Page
RM1	S	85.49	114.00	85.46	113.96	T, H, M, WS	INF, COM, PSR, RW1, RW2, RW3, DEF	Rutschmasse & Palfris-Formation	B6
VM1	S	145.00	149.90	144.97	149.87	T, H, M, WS	INF, COM, PSR, SW, SWS, RW1, RW2, RW3, RWS, PW1, PW2, DEF	Palfris-Formation	B8
VM2	S	109.96	149.90	109.94	149.87	T, H, M, WS	INF, COM, PSR, RW1, RWS1, RW2, RWS2, RI, RIS, DEF	Palfris-Formation	B10
VM3	S	260.05	295.00	260.00	294.94	T, H, M, WS	INF, COM, PSR, SW, SWS, RW1, RWS1, RW2, RWS2, RW3, RWS3, PW1, PW2, DEF	Palfris-Formation	B12
VM4	D	152.46	207.68	152.43	207.64	T, H, M	INF, COM, PSR, SW, SWS, RW1, RW2, RW3, RWS3, RW4, RWS4, PI, PW, DEF	Palfris-Formation	B14
VM5	D	203.53	258.75	203.49	258.70	T, H, M	INF, COM, PSR, SW, SWS, RW1, RW2, RWS2, RI, RIS, PW1, PW2, DEF	Palfris-Formation	B16
VM6	S	389.50	400.00	389.43	399.93	T, H, M	INF, COM, PSR, PW, RI, RIS, DEF	Palfris-Formation	B18
VM7	S	345.90	400.00	345.84	399.93	T, H, M	INF, COM, PSR, SW, SWS, RW1, RW2, RWS, PI1, PI2, DEF	Palfris-Formation	B20
VM8	S	295.84	400.00	295.78	399.93	T, H, M	INF, COM, PSR, RW, RWS, PW, DEF	Palfris-Formation	B22
T1	S	501.57	520.00	501.35	519.77	T, H, M, WS	INF, COM, PSR, PW, SW, SWS, PI, DEF	Globigerinenmergel	B24
T2	S	460.00	520.00	459.80	519.77	T, H, M	INF, COM, PSR, SW, SWS, RW, RWS, PI, DEF	Mélange & Schimberg-Schiefer & Globigerinenmergel	B26
VMT1	S	397.69	520.00	397.51	519.77	T, H, M	INF, COM, PSR, RW, RWS, PW, DEF	Palfris-Formation & Vitznau-Mergel & Mélange & Schimberg-Schiefer & Globigerinenmergel	B28
T3	S	601.49	620.00	601.16	619.66	T, H, M	INF, COM, PSR, SW, SWS, PW, PI, DEF	Globigerinenmergel	B30
T4	S	518.05	620.00	517.77	619.66	T, H, M	INF, COM, PSR, SW, SWS, PI, DEF	Globigerinenmergel	B32
T5	S	569.28	620.00	568.97	619.66	T, H, M	INF, COM, PSR, SW, SWS, PI1, PI2, DEF	Globigerinenmergel	B34
VM9	S	726.50	735.00	726.37	734.86	T, H, M	INF, COM, PSR, SW, SWS, PW, PI1, PI2, DEF	Palfris-Formation	B36
VM10	S	618.33	735.00	618.22	734.86	T, H, M	INF, COM, PSR, PW!, SW, SWS, PI1, DEF	Globigerinenmergel & Mélange & Palfris-Formation	B38
VM11	S	676.16	735.00	676.04	734.86	T, H, M	INF, COM, PSR, PW, SW, SWS, PI, DEF	Palfris-Formation	B40
T6	D	460.73	472.34	460.53	472.13	T, H, M, WS	INF, COM, PSR, PW1, RW1, RWS1, RW2, RWS2, PW2, RI, RIS, PW3, DEF	Mélange & Schimberg-Schiefer	B42
T7	D	550.45	563.56	550.15	563.25	T, H, M	INF, COM, PSR, PW1, PW2, PW3, SW, SWS, PW4, DEF	Globigerinenmergel	B44
VM12	D	647.13	650.00	647.02	649.88	T, H, M, GTP	INF, COM, PSR, PW1, PW2, PW3, SW, SWS, DEF	Palfris-Formation	B46
VM13	D	433.00	435.87	432.92	435.97	T, H, M, GTP	INF1, COM1, PW1, PSR1, SW1, SWS1, SI1, SIS1, INF2, COM2, SW2, SWS2, PI1, SI2, SIS2, DIS2, GRI1, GRI2, GRIS, PW2, PW3, DEF2	Vitznau-Mergel & Palfris-Formation	B48
VM14	D	329.70	332.57	329.64	332.51	T, H, M, GTP	INF1, COM1, PSR1, PW1, SW1, SWS1, DIS1, GRI1, DEF1, INF2, COM2, PSR2, PW2, DIS2, GRI2, GRI3, GRI4, GRIS, PI1, DEF2	Palfris-Formation	B50

S	Single packer test configuration	H	Equivalent freshwater head
D	Double packer test configuration	M	Flow model
T	Formation transmissivity	WS	Water sample
		GTP	Gas threshold pressure

The reader should keep in mind that the results presented in this section are subject to different degrees of uncertainty due to their different levels of analysis. Seven of the twenty-three tests conducted were analysis following a detailed analysis procedure, the rest of sixteen tests were subject to a standard analysis procedure. All tests conducted in the vertical borehole SB4a/v are documented in NAGRA's Internal Reports (ENACHESCU et al., 1995a-g; DOMSKI et al, 1995). The next subsections are discussing in detail the results of the testing campaign as far as the equivalent freshwater head, the formation transmissivity and the formation temperature are concerned.

6.2.1 Transmissivities and Equivalent Hydraulic Conductivities

The transmissivities derived from tests conducted in SB4a/v ranged between 6E-5 m^2/s and 3E-12 m^2/s. All reported values refer to the undisturbed in situ formation transmissivity, which, in most cases, was identified as the outer composite zone transmissivity. The Palfris formation with the Valanginian Marl was tested in intervals VM1 to VM14, which provided transmissivities between 3E-5 m^2/s in the upper part (VM2) and 3E-12 m^2/s in the lowest section of the borehole (test VM9). The transmissivities derived from tests conducted in the Tertiary sediments (tests T1 to T7) ranged between 4E-8 m^2/s and 3E-12 m^2/s. The results obtained in the tertiary formations do not show any different trend when compared with the behaviour of the Palfris formation. Figure 6.1 presents the interval transmissivities derived in borehole SB4a/v versus depth of test interval. Table 6.3 presents the derived transmissivities together with their confidence ranges. Values of the equivalent hydraulic conductivity of the tested intervals is presented in Table 6.3 together with the confidence ranges of these values, for completeness. A plot of hydraulic conductivity versus depth is presented in Fig. 6.2. However, the calculation of hydraulic conductivity can be misleading, when applied to a fractured formation such as the Palfris formation, without knowing the actual thickness of the flow conduits. The hydraulic conductivity (K) values are calculated by dividing the integral of the transmissivity (T_{int}) by the integral of the interval height (h_{int}). Discrete inflow points were detected in borehole SB4a/v using fluid logging. For details on this subject the reader is referred to CROISE et al. 1995.

Tab. 6.3: Transmissivities and hydraulic conductivities determined in the test intervals in borehole SB4a/v

Test	Measured [maBH]		True Vertical [mbGL]		T<	T	>T	K<	K	>K
	Top	Bottom	Top	Bottom		[m²/s]			[m/s]	
RM1	85.49	114.00	85.46	113.96	1.00E-05	6.10E-05	1.00E-04	3.51E-07	2.14E-06	3.51E-06
VM1	145.00	149.90	144.97	149.87	9.00E-08	1.30E-07	1.00E-06	1.84E-08	2.65E-08	2.04E-07
VM2	109.96	149.90	109.94	149.87	2.70E-05	2.90E-05	3.30E-05	6.76E-07	7.26E-07	8.26E-07
VM3	260.05	295.00	260.00	294.94	1.00E-07	1.90E-06	2.00E-06	2.86E-09	5.44E-08	5.72E-08
VM4	152.46	207.68	152.43	207.64	9.00E-08	7.00E-07	5.00E-06	1.63E-09	1.27E-08	9.05E-08
VM5	203.53	258.75	203.49	258.70	4.00E-07	2.53E-06	4.00E-06	7.24E-09	4.58E-08	7.24E-08
VM6	389.50	400.00	389.43	399.93	2.00E-11	8.00E-11	4.00E-10	1.90E-12	7.62E-12	3.81E-11
VM7	345.90	400.00	345.84	399.93	5.00E-11	6.40E-10	5.00E-08	9.24E-13	1.18E-11	9.24E-10
VM8	295.84	400.00	295.78	399.93	6.00E-07	1.10E-06	2.00E-06	5.76E-09	1.06E-08	1.92E-08
T1	501.57	520.00	501.35	519.77	9.00E-14	3.00E-12	1.00E-11	4.88E-15	1.63E-13	5.43E-13
T2	460.00	520.00	459.80	519.77	3.00E-10	8.00E-10	3.00E-08	5.00E-12	1.33E-11	5.00E-10
VMT	397.69	520.00	397.51	519.77	8.00E-09	3.70E-08	6.00E-08	6.54E-11	3.03E-10	4.91E-10
T3	601.49	620.00	601.16	619.66	3.00E-12	1.00E-11	7.00E-11	1.62E-13	5.40E-13	3.78E-12
T4	518.05	620.00	517.77	619.66	4.00E-11	1.40E-10	1.00E-09	3.92E-13	1.37E-12	9.81E-12
T5	569.28	620.00	568.97	619.66	2.00E-11	5.00E-11	2.20E-10	3.94E-13	9.86E-13	4.34E-12
VM9	726.50	735.00	726.37	734.86	6.00E-13	3.00E-12	5.00E-11	7.06E-14	3.53E-13	5.88E-12
VM10	618.33	735.00	618.22	734.86	1.00E-11	8.00E-11	5.00E-10	8.57E-14	6.86E-13	4.29E-12
VM11	676.16	735.00	676.04	734.86	1.00E-11	7.00E-11	2.00E-10	1.70E-13	1.19E-12	3.40E-12
T6	460.73	472.34	460.53	472.13	1.00E-10	3.60E-10	1.00E-09	8.61E-12	3.10E-11	8.61E-11
T7	550.45	563.56	550.15	563.25	3.00E-12	1.00E-11	4.00E-11	2.29E-13	7.63E-13	3.05E-12
VM12	647.13	650.00	647.02	649.88	2.00E-12	8.00E-12	2.00E-11	6.97E-13	2.79E-12	6.97E-12
VM13	433.00	435.87	432.92	435.97	1.00E-10	3.50E-08	6.00E-08	3.48E-11	1.22E-08	2.09E-08
VM14	329.70	332.57	329.64	332.51	2.00E-09	5.00E-09	2.00E-08	6.97E-10	1.74E-09	6.97E-09

6.2.2 Equivalent Freshwater Head

Table 6.4 presents the recommended values for the interval equivalent freshwater head together with the derived confidence limits of the results. The equivalent freshwater head was calculated with a water density of 1000 kg/m^3, a gravitational acceleration of 9.81 m/s^2 and an atmospheric pressure of 100 kPa.

Tab. 6.4: Formation equivalent freshwater heads

Test	Measured Depth, [maBH]			True Vertical Depth, [mbGL]			H<	H	>H
	Top	Mid	Bottom	Top	Mid	Bottom	[m asl]		
RM1	85.49	99.75	114.00	85.46	99.71	113.96	1018.0	1018.8	1035.0
VM1	145.00	147.45	149.90	144.97	147.42	149.87	940.0	942.0	945.0
VM2	109.96	129.93	149.90	109.94	129.91	149.87	943.9	943.9	944.0
VM3	260.05	277.53	295.00	260.00	277.47	294.94	922.0	934.0	942.0
VM4	152.46	180.07	207.68	152.43	180.04	207.64	935.0	938.0	941.0
VM5	203.53	231.14	258.75	203.49	231.10	258.70	933.0	937.0	939.0
VM6	389.50	394.75	400.00	389.43	394.68	399.93	944.0	960.0	976.0
VM7	345.90	372.95	400.00	345.84	372.89	399.93	870.0	948.0	950.0
VM8	295.84	347.92	400.00	295.78	347.86	399.93	930.0	936.0	940.0
T1	501.57	510.79	520.00	501.35	510.56	519.77	543.0	826.0	879.0
T2	460.00	490.00	520.00	459.80	489.79	519.77	923.0	970.0	1005.0
VMT1	397.69	458.85	520.00	397.51	458.64	519.77	916.0	923.0	938.0
T3	601.49	610.75	620.00	601.16	610.41	619.66	470.0	553.0	640.0
T4	518.05	569.03	620.00	517.77	568.72	619.66	700.0	736.0	763.0
T5	569.28	594.64	620.00	568.97	594.32	619.66	560.0	603.0	639.0
VM9	726.50	730.75	735.00	726.37	730.62	734.86	280.0	420.0	580.0
VM10	618.33	676.67	735.00	618.22	676.54	734.86	330.0	425.0	550.0
VM11	676.16	705.58	735.00	676.04	705.45	734.86	270.0	300.0	450.0
T6	460.73	466.54	472.34	460.53	466.33	472.13	929.0	979.0	1030.0
T7	550.45	557.01	563.56	550.15	556.70	563.25	530.0	650.0	760.0
VM12	647.13	648.57	650.00	647.02	648.45	649.88	392.0	492.0	624.0
VM13	433.00	434.44	435.87	432.92	434.45	435.97	930.0	942.0	971.0
VM14	329.70	331.14	332.57	329.64	331.08	332.51	930.0	951.0	971.0

The formation heads versus depth of the interval midpoint are plotted in Figure 6.3. In the upper part of the borehole, down to a depth of approximately 500 m bGL the equivalent freshwater head of the formation was showing hydrostatic conditions in a range of ± twenty meters. The only exception was test RM1 conducted in the Rutschmasse, where the head was showing relatively strong artesian conditions of approximately 75 m aGL. The tests conducted in the lowest 235 m of the borehole showed a decreasing trend of the equivalent freshwater head with the depth. The lowest head of approximately 300 m asl (approx. 640 m bGL) was derived from test VM11.

The very low hydraulic conductivity encountered in the lower part of the borehole leads to difficulties in determining the hydraulic head. Borehole history effects become very important under these conditions, which is basically reflected in the relatively wide confidence ranges of the equivalent freshwater head with decreasing formation transmissivity. A further problem encountered in determining the equivalent freshwater head is related with the difficulty of finding an unique description of the late formation behaviour (i.e. boundary effects, composite formation behaviour etc...).

After finishing the testing operations, the borehole was fitted with a long term monitoring system. The system in borehole SB4a/v was designed to monitor two zones:

Zone 1: 429.5 to 441.5 m bGL (Vitznau-Mergel & Palfris-Formation) includes the position of test interval VM13 and is included in VMT1. Zone 1 shows a stabilised water level at approximately 14.28 m bGL (GL at 942.3 m asl), which is equivalent to an equivalent freshwater head of approximately 928 m asl. This compares with a head confidence range of 930 to 971 m asl for test VM13 and of 916 to 938 for test VMT1. The measurement cited in this report was taken on September 2nd 1996.

Zone 2: 699.5 to 735.0 m bGL (Palfris-Formation) includes the position of test interval VM9 and is included in VM10 and VM11. Zone 2 shows an ongoing falling tendency. The last measurement, taken on September 2nd 1996, shows a water level of 283.2 m bGL, equivalent to a freshwater head of approximately 659 m asl. The equivalent freshwater head derived from test VM9 ranged between 280 and 580 m asl.

6.2.3 Temperatures

Temperature measured at the downhole depth of the P2 transducer (see Fig. 2.1) is presented in Tab. 6.5 and plotted versus the respective transducer depth in Figure 6.4. The values presented are stabilised temperatures measured during the respective test and rounded to 0.5 °C. No anomalous temperature characteristics were observed within SB4a/v. A linear regression of the measured values yields to a temperature gradient of approximately 3 °C/100m depth.

Tab. 6.5: Stabilised formation temperatures measured at P2 transducer depth in borehole SB4a/v

Test	Measured P2 Depth [m bGL]	T [°C]
RM1	81.82	9.5
VM1	141.33	10.5
VM2	106.29	11.0
VM3	256.38	14.5
VM4	148.79	11.5
VM5	199.86	12.5
VM6	385.83	17.5
VM7	342.23	16.5
VM8	292.17	15.0
T1	497.90	21.0
T2	456.33	20.0
VMT1	394.02	18.0
T3	597.82	24.5
T4	514.38	24.0
T5	565.61	24.0
VM9	722.83	28.5
VM10	614.66	25.0
VM11	672.49	27.0
T6	457.06	20.0
T7	546.78	23.0
VM12	643.46	26.0
VM13	429.33	19.5
VM14	326.03	16.0

6.2.4 Gas Occurrence and Gas Threshold Pressure Tests

One of the main objectives of the SB4a testing campaign at Wellenberg was to characterise on one hand the occurrence resp. evidence of free gas in the Palfris formation under formation pressure and one the other hand the two phase flow behaviour of the Palfris formation for gas release from a radioactive waste repository. Several tests in borehole SB4a/v were conducted under two phase flow conditions. Gas occurrence during production phases (RW or SW) was observed in tests VM3, VM4, VM5, VM7, VM8, T2 and VMT1. This locates a zone with gas occurrence in borehole SB4a/v approximately between 152 and 520 m bGL.

It should be mentioned however, that not all tests conducted in this section showed evidence of free gas under formation pressure conditions. The most obvious reason for this fact however, is that not all tests were designed to provide information on gas presence. In most cases, gas was observed after creating relatively large drawdowns in the test interval. This fact rises the question whether the observed gas was originating a free gas phase under in situ formation conditions or was the product of gas segregation under de-pressurised conditions in the test interval or even further above, in the test string. This question can usually be answered by back-calculating the produced gas-water ratio for the initial downhole conditions. In most cases however, it was difficult to obtain a stabilised gas-water ratio. In all cases the gas observed was proved to consist of at least 99% methane.

In two cases gas threshold pressure tests were conducted (tests VM13 and VM14) as extended nitrogen constant rate injection tests with subsequent shut-in. The derived gas threshold pressures of 500 kPa for VM13 and 5 kPa for VM14 fit reasonably well into the Pe-K correlation published by DAVIES (1991).

Further characterisation of the two phase flow behaviour of the formation (i. e. identification of the two phase flow model) was conducted using the numerical codes TOUGH2 and ITOUGH2. For details on results refer to DOMSKI et al. (1995).

7 SUMMARY OF RESULTS BOREHOLE SB4a/s

This chapter summarises the interpretation results of the hydraulic tests conducted in the slanted borehole SB4a/s at Wellenberg. A total of twenty-four tests were conducted, of which seventeen were performed using a single packer test assembly and seven were using a double packer tool. Five of the double packer tests were conducted as gas threshold pressure tests, two of them were successful. Groundwater and/or gas samples were obtained from five intervals. Results of the sampling activities are presented in STEIGER et al. (1995b). Brief summaries of the conducted tests are presented in Appendix C of this report.

The first section of this chapter briefly presents the general borehole information, the second section summarises the testing results. Each of the main test parameters (i.e. the equivalent freshwater head, the formation transmissivity and the temperature profile) are discussed in separate subsections. Finally, a subsection is discussing the gas occurrence observed during the tests.

7.1 General Borehole Information

Wellenberg borehole SB4a/s is located in Canton Nidwalden at a geographical longitude of 673 251.8 and a latitude of 192 213.1. The elevation of the reference point (ground level) is 942.3 m asl. Drilling of the borehole was started on May 10th 1995. The final apparent depth of 858.2 m aBH was reached on September 27th 1995. The upper 84.4 m of the borehole were drilled using a Tubex method and cased in the same time with 273 mm casing. The borehole section between 84.6 and 178.9 m aBH was characterised by drilling problems caused by artesian conditions and high outflow rates of up to 400 l/min. After coring a few meters using the 6 $^{1}/_{4}$" core bit, the drilling continued using a 9 $^{7}/_{8}$" drill bit. This was interrupted at 95.6 m aBH when outflow rates of 400 l/min started. Drilling down to 178.9 m was continued using the Tubex method with a casing diameter of 237 mm. After cementation, a 7" temporary casing was set at 178.9 m aBH. The transition from the Quaternary slope sediments and Rutschmasse to the Palfris-Formation sediments was encountered at 115.0 m aBH. Drilling continued using a 6 $^{1}/_{4}$" core bit down to a depth of 417.4 m aBH, where the 5 $^{1}/_{2}$" permanent casing was set and cemented. The borehole inclination was periodically controlled using single-shot measurements. The inclination in this section of the borehole was between 42 and 43 degrees. Drilling continued subsequently using a 4 $^{1}/_{2}$" core bit to the final depth of 858.2 m aBH. In the lower part the borehole inclination was approximately 45 degrees (see also GASSLER & KARSCH, 1996). Following table presents a brief summary of the geology encountered (ISLER et al., 1995b; NAGRA, 1997):

Tab. 7.1: Geological units encountered in borehole SB4a/s

Apparent Depth [m aBH]	**Geological Formation**
0.00 - 115.00	Slope Sediments & Rutschmasse (Quaternary)
115.00 - 504.95	Palfris-Formation (lower Cretaceous - Drusberg-Nappe)
504.95 - 523.47	Vitznau-Mergel & Palfris-Formation
523.47 - 569.62	Palfris-Formation (lower Cretaceous - Drusberg-Nappe)
569.62 - 579.34	Globigerinenmergel (Tertiary - Axen-Nappe)
579.34 - 599.14	Mélange
599.14 - 624.11	Schimberg-Schiefer (Tertiary - Axen-Nappe)
624.11 - 809.22	Globigerinenmergel (Tertiary - Axen-Nappe)
809.22 - 810.94	Mélange
810.94 - 858.20	Palfris-Formation (lower Cretaceous - Drusberg-Nappe)

7.2 Summary of Hydraulic Packer Results

In table 7.2 the geological characterisation of the test intervals and the main objectives of the hydraulic packer tests are summarised.

Tab. 7.2: Summary of information on tests conducted in borehole SB4a/s

Test	Type	Measured [maBH] Top	Measured [maBH] Bottom	True Vertical [mbGL] Top	True Vertical [mbGL] Bottom	Objectives	Events	Geology	Page
VM1	S	321.50	332.20	231.52	239.39	T, H, M, WS	INF, COM, PSR, SW, SWS, RI1, RIS1, RI2, RIS2, PI, DEF	Palfris-Formation	C2
VM2	S	181.61	332.20	128.90	239.39	T, H, M, GF	INF, COM, PSR, SW1, SWS1, SW2, SWS2, RW1, RW2, RWS, DEF	Palfris-Formation	C4
VM3	S	395.10	417.00	285.69	301.85	T, H, M, GF, WS, GS	INF, COM, PSR, PW, SW, SWS, RW, RWS, PI, SI, DEF	Palfris-Formation	C6
VM4	S	330.52	417.00	238.15	301.85	T, H, M, GF	INF, COM, PSR, SW, SWS, RW, RWS, PI, DEF	Palfris-Formation	C8
VM5	S	521.50	532.60	378.00	385.93	T, H, M, GF, WS	INF, COM, PSR, SW, SWS, PW, DEF	Palfris-Formation & Vitznau-Mergel	C10
VM6	S	512.62	532.60	371.64	385.93	T, H, M, GF, WS	INF, COM, PSR, PW1, SW, SWS, PW2, PI1, RI, RIS, RW, RWS, PI2, DEF	Palfris-Formation & Vitznau-Mergel	C12
VM7	S	447.00	532.60	324.00	385.93	T, H, M, GF	INF, COM, PSR, PW1, SW, SWS, RW, RWS, RI, RIS, PW2, DEF	Palfris-Formation & Vitznau-Mergel	C14
VM8	S	418.90	532.60	303.28	385.93	T, H, M, GF	INF, COM, PSR, SW, SWS, RW, RWS, PW, DEF	Palfris-Formation & Vitznau-Mergel	C16
VM9	D	437.50	443.69	317.01	321.56	T, H, M, GF, WS	INF, COM, PSR, SW, SWS, RW, RWS, PI, DEF	Palfris-Formation & Vitznau-Mergel	C18
T1	S	609.72	617.30	440.04	445.27	T, H, M, WS	INF, COM, PSR, PW, SW, SWS, PI, DEF	Schimberg-Schiefer	C20
VMT1	S	578.99	617.30	418.69	445.27	T, H, M, GF	INF, COM, PSR, PW, SW, SWS, PI, DEF	Palfris-Formation & Vitznau-Mergel & Mélange & Schimberg-Schiefer	C22
VMT2	S	534.26	617.30	387.11	445.27	T, H, M, GF	INF, COM, PSR, SW, SWS, RI, RIS, PW, DEF	Palfris-Formation & Vitznau-Mergel & Mélange & Schimberg-Schiefer	C24
T2	S	715.00	740.00	511.92	528.86	T, H, M, WS	INF, COM, PSR, PW1, PW2, SW, SWS, PI, DEF	Globigerinenmergel	C26
T3	S	672.70	740.00	483.18	528.86	T, H, M	INF, COM, PSR, PW, SW1, SWS1, SW2, SWS2, PI, DEF	Globigerinenmergel	C28
T4	S	617.11	740.00	445.14	528.86	T, H, M	INF, COM, PSR, PW, SW, SWS, PI, DEF	Schimberg-Schiefer & Globigerinenmergel	C30
VM10	S	837.41	858.20	595.36	609.56	T, H, M	INF, COM, PSR, PW1, PW2, SW, SWS, PI, DEF	Palfris-Formation	C32
VMT3	S	787.00	858.20	560.92	609.56	T, H, M	INF, COM, PSR, PW, SW, SWS, PI, DEF	Globigerinenmergel & Mélange & Palfris-Formation	C34
VMT4	S	739.02	858.20	528.19	609.56	T, H, M	INF, COM, PSR, PW, SW, SWS, PI, DEF	Globigerinenmergel & Mélange & Palfris-Formation	C36
VM11	D	448.00	457.46	324.73	331.66	T, H, M, GF	INF, COM, PSR, PW1, SW, SWS, RW, RWS, PW2, PI, RI, RIS, PW3, DEF	Palfris-Formation	C38
VM12	D	535.80	538.80	388.21	390.35	T, H, M, GTP	INF, COM, PSR, PW, SW, SWS, DEF	Palfris-Formation	C40
VM13	D	551.50	554.50	399.35	401.47	T, H, M, GTP	INF, COM, PSR, PW, SW, DEF	Palfris-Formation	C42
VM14	D	524.70	527.70	380.29	382.43	T, H, M, GTP	INF, COM, PSR, PW, SW, SWS, PI, DIS, GRI, GRIS, DEF	Palfris-Formation	C44
VM15	D	480.00	483.00	347.38	349.55	T, H, M, GTP	INF, COM, PSR, PW	Palfris-Formation	C46
VM16	D	441.50	444.50	319.95	322.16	T, H, M, GTP	INF, COM, PSR, SW, SWS, PI1, PW, DIS, GRI1, GRI2, GRI3, GRIS, PI2, DEF	Palfris-Formation	C48

S	Single packer test configuration	H	Equivalent freshwater head
D	Double packer test configuration	M	Flow model
T	Formation transmissivity	WS	Water sample
GF	Gas Flow	GTP	Gas threshold pressure

The reader should keep in mind that the results presented in this section are subject to different degrees of uncertainty due to their different levels of analysis. Five of the twenty-four tests conducted were analysis following a detailed analysis procedure, the rest of nineteen tests were subject to a standard analysis procedure. All tests conducted in the slanted borehole SB4a/s are documented in NAGRA's Internal Reports (ENACHESU et al, 1995h; 1996a-f). The next subsections are discussing in detail the results of the testing campaign as far as the equivalent freshwater head, the formation transmissivity and the formation temperature are concerned.

7.2.1 Transmissivities and Equivalent Hydraulic Conductivities

The transmissivities derived from tests conducted in SB4a/s ranged between 1E-6 m^2/s and 1E-12 m^2/s. All reported values refer to the undisturbed in situ formation transmissivity, which, in most cases, was identified as the outer composite zone transmissivity. The Palfris formation with the Valanginian marl was tested in intervals VM1 to VM16, which provided transmissivities between 1E-6 m^2/s in the upper part (VM2) and 1E-12 m^2/s in the test interval VM15. The latter value however, should be viewed with caution since the test was interrupted at a very early stage. The transmissivities derived from tests conducted in the Tertiary sediments (tests T1 to T4) ranged between 1E-11 m^2/s and 7E-11 m^2/s. The results obtained in the tertiary formations do not show any different trend when compared with the behaviour of the Palfris formation. Figure 7.1 presents the interval transmissivities derived in borehole SB4a/s versus depth of test interval. Table 7.3 presents the derived transmissivities together with their confidence ranges. Values of the equivalent hydraulic conductivity of the tested intervals is presented in Table 7.3 together with the confidence ranges of these values, for completeness. A plot of hydraulic conductivity versus depth is presented in Fig. 7.2. However, the calculation of hydraulic conductivity can be misleading, when applied to a fractured formation such as the Palfris formation, without knowing the actual thickness of the flow conduits. The hydraulic conductivity (K) values are calculated by dividing the integral of the transmissivity (T_{int}) by the integral of the interval height (h_{int}). Discrete inflow points were detected in borehole SB4a/s using fluid logging. For details on this subject the reader is referred to RIVERA et al. (1995b).

Tab. 7.3: Transmissivities and hydraulic conductivities determined in the test intervals in borehole SB4a/s

Test	Measured [maBH]		True Vertical [mbGL]		T<	T	>T	K<	K	>K
	Top	Bottom	Top	Bottom	[m²/s]			[m/s]		
VM1	321.50	332.20	231.52	239.39	3.00E-08	7.00E-08	2.00E-07	2.80E-09	6.54E-09	1.87E-08
VM2	181.61	332.20	128.90	239.39	5.00E-07	1.00E-06	4.00E-06	3.32E-09	6.64E-09	2.66E-08
VM3	395.10	417.00	285.69	301.85	3.00E-09	1.00E-08	3.00E-08	1.37E-10	4.57E-10	1.37E-09
VM4	330.52	417.00	238.15	301.85	2.20E-07	3.00E-07	4.00E-06	2.54E-09	3.47E-09	4.63E-08
VM5	521.50	532.60	378.00	385.93	2.00E-09	4.00E-09	6.00E-08	1.80E-10	3.60E-10	5.41E-09
VM6	512.62	532.60	371.64	385.93	2.00E-09	9.00E-09	6.00E-08	1.00E-10	4.50E-10	3.00E-09
VM7	447.00	532.60	324.00	385.93	1.00E-09	2.00E-08	3.00E-08	1.17E-11	2.34E-10	3.50E-10
VM8	418.90	532.60	303.28	385.93	1.00E-08	4.00E-08	2.00E-07	8.80E-11	3.52E-10	1.76E-09
VM9	437.50	443.69	317.01	321.56	6.00E-09	2.00E-08	5.00E-08	9.69E-10	3.23E-09	8.08E-09
T1	609.72	617.30	440.04	445.27	4.00E-12	1.00E-11	4.00E-11	5.28E-13	1.32E-12	5.28E-12
VMT1	578.99	617.30	418.69	445.27	1.00E-11	3.00E-11	3.00E-10	2.61E-13	7.83E-13	7.83E-12
VMT2	534.26	617.30	387.11	445.27	1.00E-09	2.00E-09	7.00E-09	1.20E-11	2.41E-11	8.43E-11
T2	715.00	740.00	511.92	528.86	1.00E-12	3.00E-11	6.00E-11	4.00E-14	1.20E-12	2.40E-12
T3	672.70	740.00	483.18	528.86	6.00E-12	3.00E-11	6.00E-11	8.92E-14	4.46E-13	8.92E-13
T4	617.11	740.00	445.14	528.86	1.00E-11	7.00E-11	1.00E-10	8.14E-14	5.70E-13	8.14E-13
VM10	837.41	858.20	595.36	609.56	1.00E-12	2.00E-12	1.00E-11	4.81E-14	9.62E-14	4.81E-13
VMT3	787.00	858.20	560.92	609.56	1.00E-12	4.00E-11	4.00E-11	3.92E-14	1.57E-12	1.57E-12
VMT4	739.02	858.20	528.19	609.56	1.00E-12	1.00E-10	1.00E-10	8.39E-15	8.39E-13	8.39E-13
VM11	448.00	457.46	324.73	331.66	2.00E-09	4.00E-09	6.00E-09	2.11E-10	4.23E-10	6.34E-10
VM12	535.80	538.80	388.21	390.35	3.00E-13	3.00E-12	3.00E-11	1.00E-13	1.00E-12	1.00E-11
VM13	551.50	554.50	399.35	401.47	6.00E-13	6.00E-12	6.00E-11	2.00E-13	2.00E-12	2.00E-11
VM14	524.70	527.70	380.29	382.43	3.00E-12	9.00E-12	4.00E-10	1.00E-12	3.00E-12	1.33E-10
VM15	480.00	483.00	347.38	349.55	1.00E-13	1.00E-12	1.00E-11	3.33E-14	3.33E-13	3.33E-12
VM16	441.50	444.50	319.95	322.16	2.00E-09	7.00E-09	2.00E-08	6.67E-10	2.33E-09	6.67E-09

7.2.2 Equivalent Freshwater Head

Table 7.4 presents the recommended values for the interval equivalent freshwater head together with the derived confidence limits of the results. The equivalent freshwater head was calculated with a water density of 1000 kg/m^3, a gravitational acceleration of 9.81 m/s^2 and an atmospheric pressure of 100 kPa. The true vertical depths were calculated using the dip measurements conducted at the end of the testing campaign.

Tab. 7.4: Formation equivalent freshwater heads

Test	Measured Depth, [maBH]			True Vertical Depth, [mbGL]			H<	H	>H
	Top	Mid	Bottom	Top	Mid	Bottom	[m asl]		
VM1	321.50	326.85	332.20	231.52	235.46	239.39	946.0	947.0	948.0
VM2	181.61	256.91	332.20	128.90	184.15	239.39	968.0	973.0	978.0
VM3	395.10	406.05	417.00	285.69	293.77	301.85	926.0	950.0	955.0
VM4	330.52	373.76	417.00	238.15	270.00	301.85	944.0	947.0	948.0
VM5	521.50	527.05	532.60	378.00	381.97	385.93	960.0	970.0	980.0
VM6	512.62	522.61	532.60	371.64	378.79	385.93	960.0	966.0	990.0
VM7	447.00	489.80	532.60	324.00	354.97	385.93	952.0	962.0	972.0
VM8	418.90	475.75	532.60	303.28	344.61	385.93	930.0	955.0	970.0
VM9	437.50	440.60	443.69	317.01	319.29	321.56	930.0	950.0	970.0
T1	609.72	613.51	617.30	440.04	442.66	445.27	930.0	950.0	970.0
VMT1	578.99	598.15	617.30	418.69	431.98	445.27	940.0	960.0	1040.0
VMT2	534.26	575.78	617.30	387.11	416.19	445.27	950.0	965.0	1000.0
T2	715.00	727.50	740.00	511.92	520.39	528.86	600.0	660.0	750.0
T3	672.70	706.35	740.00	483.18	506.02	528.86	600.0	660.0	750.0
T4	617.11	678.56	740.00	445.14	487.00	528.86	700.0	750.0	850.0
VM10	837.41	847.81	858.20	595.36	602.46	609.56	420.0	470.0	620.0
VMT3	787.00	822.60	858.20	560.92	585.24	609.56	420.0	630.0	630.0
VMT4	739.02	798.61	858.20	528.19	568.88	609.56	440.0	640.0	640.0
VM11	448.00	452.73	457.46	324.73	328.20	331.66	946.0	957.0	977.0
VM12	535.80	537.30	538.80	388.21	389.28	390.35	930.0	943.0	960.0
VM13	551.50	553.00	554.50	399.35	400.41	401.47	960.0	973.0	980.0
VM14	524.70	526.20	527.70	380.29	381.36	382.43	-	-	-
VM15	480.00	481.50	483.00	347.38	348.47	349.55	950.0	954.0	970.0
VM16	441.50	443.00	444.50	319.95	321.06	322.16	938.0	941.0	952.0

The formation heads versus depth of the interval midpoint are plotted in Figure 7.3. In the upper part of the borehole, down to a depth of approximately 430 m bGL (true vertical depth) the equivalent freshwater head of the formation was showing hydrostatic or slight artesian conditions of up to 1040 m asl (test VMT1). The only exception was test VM14, which clearly showed sub-hydrostatic pressure conditions. It is believed that the long and complicated pressure history, as well as degassing effects are responsible for this anomaly. The tests conducted below this section showed a decreasing trend of the equivalent freshwater head with the depth. The lowest head of approximately 470 m asl was derived from test VM10.

The very low hydraulic conductivity encountered in the lower part of the borehole leads to difficulties in determining the hydraulic head. Borehole history effects become very important under these conditions, which is basically reflected in the relatively wide confidence ranges of the equivalent freshwater head with decreasing formation transmissivity. A further problem encountered in determining the equivalent freshwater head is related with the difficulty of finding an unique description of the late formation behaviour (i.e. boundary effects, composite formation behaviour etc...).

The equivalent freshwater heads derived from the slanted borehole SB4a/s correlate very good with the values derived from the vertical borehole SB4a/v.

7.2.3 Temperatures

Temperature measured at the downhole depth of the P2 transducer (see Fig. 2.2) is presented in Tab. 7.5 and plotted versus the respective transducer depth in Figure 7.4. The values presented are stabilised temperatures measured during the respective test and rounded to 0.5 °C. No anomalous temperature characteristics were observed within SB4a/s. A linear regression of the measured values yields to a temperature gradient of approximately 3.1 °C/100m depth.

Tab. 7.5: Stabilised formation temperatures measured at P2 transducer depth in borehole SB4a/s

Test	Measured P2 Depth, [maBH]	True Vertical P2 Depth, [mbGL]	T, [°C]
VM1	317.83	228.92	15.0
VM2	177.94	126.30	12.5
VM3	391.43	283.09	17.0
VM4	326.85	235.55	15.5
VM5	517.83	375.40	20.0
VM6	508.95	369.04	19.5
VM7	443.33	321.40	18.0
VM8	415.23	300.68	17.5
VM9	433.83	314.41	17.5
T1	606.05	437.44	21.5
VMT1	575.32	416.09	21.0
VMT2	530.59	384.51	20.0
T2	711.33	509.32	24.0
T3	669.03	480.58	23.0
T4	613.44	442.54	21.5
VM10	833.74	592.76	27.0
VMT3	783.33	558.32	25.5
VMT4	735.35	525.59	24.5
VM11	444.33	322.13	18.0
VM12	532.13	385.61	20.5
VM13	547.83	396.75	20.5
VM14	521.03	377.69	20.0
VM15	476.33	344.78	20.0
VM16	437.83	317.35	18.0

7.2.4 Gas Occurrence and Gas Threshold Pressure Tests

One of the main objectives of the SB4a testing campaign at Wellenberg was to characterise on one hand occurrence of free gas in the Palfris formation under formation pressure and on the other hand the two phase flow behaviour of the Palfris formation for gas release from a radioactive waste repository. Several tests in borehole SB4a/s were conducted under two phase flow conditions. Gas occurrence during production phases (RW or SW) was observed in tests VM2, VM3, VM4, VM5, VM6, VM7, VM8, VM9 and VM11. This locates a zone with gas occurrence in borehole SB4a/s approximately between 120 and 390 m bGL (true vertical depth).

It should be mentioned however, that not all tests conducted in this section showed evidence of free gas under formation pressure conditions. The most obvious reason for this fact however, is that not all tests were designed to provide information on gas presence. In most cases, gas was observed after creating relatively large drawdowns in the test interval. This fact rises the question whether the observed gas was originating a free gas phase under in situ formation conditions or was the product of gas segregation under de-pressurised conditions in the test interval or even further above, in the test string. This question can usually be answered by back-calculating the produced gas-water ratio for the initial downhole conditions. In most cases however, it was difficult to obtain a stabilised gas-water ratio. Test VM11 was specially selected for a two phase flow analysis using the numerical codes TOUGH2 and ITOUGH2. In the case of this test it could be shown that the gas produced at the surface was originating a free gas phase under in situ formation conditions (ENACHESCU et al., 1996e). In all cases the gas observed was proved to consist of at least 99% methane.

In two cases gas threshold pressure tests were conducted (tests VM14 and VM16) as extended nitrogen constant rate injection tests with subsequent shut-in. The derived gas threshold pressures are presented in table 7.6. They fit reasonably well into the Pe-K correlation published by DAVIES (1991).

Tab. 7.6: Gas threshold pressures determined in borehole SB4a/s

Test	Inner composite zone		Outer composite zone	
	Gas Threshold Pressure [kPa]	Conductivity [m/s]	Gas Threshold Pressure [kPa]	Conductivity [m/s]
VM14	1342	3.2E-10	2615	3.0E-12
VM16	110	8.0E-08	240	2.3E-09

Further characterisation of the two phase flow behaviour of the formation (i. e. identification of the two phase flow model) was conducted using the numerical codes TOUGH2 and ITOUGH2. For details on results refer to ENACHESCU et al. (1996f).

8 QUALITY ASSURANCE / QUALITY CONTROL SYSTEM

This section presents the Quality Assurance (QA) and Quality Control (QC) system implemented to accompany the testing work in borehole SB4a/v and SB4a/s at Wellenberg. In order to ensure a consistent and high level work quality, a existing QA/QC system was improved or modified. This system is compatible with the QA procedure applied by NAGRA on former testing campaigns at Wellenberg.

The general concept behind the QA/QC system was to develop a structure, specially adapted to the operational needs at Wellenberg, which covers all tasks of the work and in the same time documents every stage of the project.

The general procedure of every of the tests conducted at Wellenberg (see Fig. 8.1) can generally be divided in following quality relevant tasks:

- test definition (test interval, objectives, allocated resources, etc.)
- test design
- operational test phase
- field analysis and Quick Look Reporting (QLR)
- QLR-quality control
- test classification
- Further analysis (standard or detailed) incl. sensitivity, consistency check of results
- Interval Reporting (IR)
- IR-quality control

During the progress of the project, several tests, at different stages of completeness were handled in the same time. Figure 8.2 presents as example the work schedule for a time slice of the project. In order to enable the team to handle the work, the QA/QC system had to ensure that all completed tasks of an individual test were documented. A further important function of the QA plan was to provide a maximum data security of the test and analysis data.

The need and the characteristics of the individual components of the QA/QC system is discussed in the following sections. For further details concerning the QA/QC system the reader is referred to FRIEG & MARSCHALL (1998).

8.1 Test Documentation

The aims of the test documentation system were to ensure that all physical parameters needed for the subsequent analysis and reporting were documented, to document that the meters used during the test were operating within specifications and to provide a comprehensive list of all activities undertaken during a specific test. The test documentation was prepared by the field testing group during the operational testing period and provided as an Appendix of the Quick Look Report. Finally, after following the standard quality control procedure, the test documentation of a specific test was documented in the respective Interval Report in the form of a Nagra Internal Report (NIB). The following table 8.1 provides a list of all components of the test documentation system.

Tab. 8.1: Components of the test documentation system

Name	Aims and Description
Testing Logbook	The Testing Logbook (see example in App. D-2) was designed to provide a comprehensive commented list of all test related observations, measurements and other activities conducted.
Testing Data Form 1S - Tool Configuration	The Testing Data Forms 1S and 1D are providing tool drawings of the single (1S) and double (1D) packer configuration as used for the respective test.
Testing Data Form 1D - Tool Configuration	Single tool component lengths as well as ID's and OD's were provided (see example in App. D-3). The main aim of the forms is to provide the reader with a principle drawing of the downhole equipment.
Testing Data Form 1F - Generalised Layout of Surface Equipment	The Testing Data Form 1F (see example in App. D-4) provides a generalised layout drawing of the surface equipment. The main aim of this form was to document what equipment was available on site and how the components were assembled to a metering and control unit. Calibration specifications are provided as well. The devices used for the specific test and their function are listed in the lower part of the form.
Testing Data Form 2 - Pertinent Test Information	The Testing Data Form 2 (see example in App. D-5) provides a list of all relevant information available prior to test. The main aim of this form is to ensure that all necessary information was collected.
Testing Data Form 3 - Transducer Bench Test	The bench test Data Forms 3 and 4 (see example in App. D-6 and D-7) document whether the metering equipment (pressure transducers and flowmeters) used during a specific
Testing Data Form 4 - Flowmeter Bench Test	test was functioning within specifications. All gauges were bench-tested whenever possible. The downhole pressure gauges were always checked against atmospheric pressure before running in hole and after pulling tools out at the end of the specific test, in order to document eventual drift of the gauges. Flowmeters were usually checked against manual measurements with bucket and stop watch.
Testing Data Form 5 - Tally List	The Testing Data Form 5 also called Tally List (see example in App. D-8) provided a list of all test string joints and sucker rods used to run the tool on testing depth. This list was used to calculate and document the correct depth of the test tool.

Quick reaction on the needs of every specific test event with the aim to maximise the test output and lower the test duration and costs was applied during the project. The test design was a dynamic process between the NAGRA project management and the testing teams. The decisions were documented as written field documents and correspondence. Milestones of the decision process were documented in the Testing Logbook.

8.2 Test Analysis and Reporting

The entire process, starting with the definition of a test (test zone, objectives, time allocated etc.), the field operation and the different stages of analysis and reporting was structured in tasks and sub-tasks. Each of the tests conducted was accompanied by a set of control documents called MTDF (Master Testing Data Form - see example in Appendix D-9 to D-11). The function of these documents was twofold:

- to quickly identify the stage a certain test had reached (e.g. whether analysis complete, reporting etc.)
- to record the individuals responsible for carrying out and for checking specific tasks.

The operation and checking tasks were divided between the members of the project; the Golder Associates (GA) group mainly responsible for the site work and test interpretation and the Colenco Power Consulting (CPC) group mainly responsible for quality and consistency control. Beside that each group was responsible for their own internal quality control procedures. NAGRA was responsible for project management and overall quality control. Figure 8.1 presents a detailed flow chart of the project.

The work of the entire team, this consisting of the NAGRA project manager, the GA/BOT field testing group, the CPC-QC group and the GA/CPC/INTERA interpretation teams was documented in the MTDF forms (example in Appendix D-9 to D-11).

The test documentation descripted in a previous chapter is part of the first step (Task A) of the MTDF control document. The field analysis and Quick Look Reporting (Task B of the MTDF control document) usually was a process, which had to be completed in shortest time possible after a specific test was concluded. After a QLR was produced, an independent analyst group was reviewing the work and submitting an independent quality control document (Task D of the MTDF control document). The QC report was reviewing the following aspects of the QLR:

- test objectives and test design
- hardware performance
- overall test response
- QLR-analysis
- QLR-reporting

The QC reports of all tests conducted in borehole SB4a at Wellenberg are documented in FRIEG & MARSCHALL (1998).

On the basis of the QLR results and of the QC documents each test was subject to a classification procedure (see Section 4.3) which decided on the level of further analysis (standard or detailed) and reporting for the respective test as part of the Interval Report (IR). The standard and detailed analysis procedure is described in Task H and J respectively, and divided into various subtasks.

As part of the QA/QC system and for a consistency check of the analysis results, two different analysis approaches were used for test interpretation. The two methods were applied by two independent groups within the interpretation team. Both interpretations were documented in a common report. The recommended parameters of the tested interval and the confidence ranges were accounting for the results of both analyses.

8.3 Test and Analysis Data

A data security system was implemented to accompany the project as well. The aim of the procedures implemented was to ensure a maximum level of security for the test data and for the analysis and reporting work done. The data security system was divided into field data acquisition procedures and office work procedures.

The field data acquisition security procedures can be summarised as follows:

- The entire data acquisition system, including meters, data logger and data acquisition computer were battery buffered and placed in an air conditioned container.
- A regular test data backup on floppy disks was conducted every hour while the test was running. For this purpose two floppies were rotated. In this way there was at no time more than one hour of test data without magnetic media backup.
- As an additional security procedure, the test data was continuously printed out while the test was running.

The analysis and reporting system computers in the office were linked together with the data server in a network. A complete data backup of the entire network was run every night on tape. There were 7 tapes currently in use, one tape for each day of the week. Once a month, one tape was replaced with a new one and the old tape was secured in a fireproof safe.

The final version of the project data was handed out to NAGRA in MOD tape format together with a data transfer report (WOZNIEWICZ & ENACHESU, 1995; 1996). NAGRA took the responsibility for all further data security.

9 CONCLUSIONS AND RECOMMENDATIONS

The successful field investigation programme conducted in the Wellenberg borehole SB4a led us to the following general and more specific conclusions:

- Development of the new objective-dependent test strategies led to improvements in test performance and resulted in more detailed characterisation of the tested intervals.
- Withdrawal phases proved to be better for the determination of undistorted formation properties.
- Pressure change steps of more than about 1000 kPa had negative consequences for test results and made subsequent test interpretation more difficult.
- The low transmissivities encountered in the Wellenberg borehole necessitated further modification of the surface equipment. A small vertical separator proved to be particularly useful for rates not exceeding 2 kg/min.
- The low effective permeabilities and the resulting long duration of two-phase flow experiments suggests that in future investigations more time should be invested in advance (working programmes) in order to understand fully the gas flow characteristics of a rock formation such as the Palfris at the Wellenberg site if required.
- The introduction of fractional dimension conceptual models improved the understanding of the non-ideal flow geometries encountered in the fractured, low permeability formation.
- Advances in test analysis, for example slug and pulse deconvolution and multi-rate diagnostic plots, helped in reducing the uncertainties in results by providing additional opportunity for validation.
- Finally, the close co-operation between NAGRA as customer and project manager and the two supplies Golder Associates and Colenco Power Engineering during all stages of the data analysis and interpretation process led to a new time and cost efficient way of producing final technical reports. These were agreed upon and validated in an intensive iterative analysis process.

Our recommendations, based on the experiences from this test campaign, can be summarised as follows:

- Further advances in test design should be encouraged to ensure that test objectives are reached within the shortest possible time. Advances would include the minimisation of the number of test events as well as development of new methods for on-line validation of tests and for quantification of uncertainties.
- In future investigations, it is recommended especially in the two-phase flow environment to make further equipment developments in the field of flow control in combination with very low flow rates (see also section 2.3).

- Further development of both analytical and numerical computer analysis codes is recommended. The latest advances in computer technology and software encourage further steps in the direction of automatic history matching, of fully analytical multiple event borehole simulation and of better quantification of data and analysis related uncertainties in the test results.

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NOMENCLATURE

A	Coefficient dependent on definition of radius of investigation (see Streltsova 1988)
aGL	above Ground Level, [m]
asl	above Sea Level, [m]
bGL; aBH	below Ground Level [m]; along Borehole [m]
BASYS	Baker Data Acquisition System
B_w	Formation Volume Factor, [m^3/m^3]
C	Wellbore Storage Coefficient, [m^3/Pa]
C_s	Wellbore Storage Constant, (shut-in) [m^3/Pa]
C_f	Wellbore Storage Constant, (changing fluid level) [m^3/Pa]
C_D	Dimensionless Wellbore Storage Constant, [-]
c_f	Formation Compressibility, [1/Pa]
c_t	Total Compressibility, [1/Pa]
c_{tb}	Test Zone Compressibility, [1/Pa]
c_w	Water Compressibility, [1/Pa]
c_g	Gas Compressibility, [1/Pa]
d	Distance to Boundary (Outside Grid Radius for GTFM), [m]
d_c	Distance from Reference Point (typically Ground Level) to Midpoint of Test Interval, [m]
d_{tc}	Distance from Sensor to Midpoint of Test Interval, [m]
FE	Formation Efficiency, [fraction]
g	Gravitational Acceleration, [m/s^2]
h	Interval length, [m]
H_e	Equivalent Freshwater Head, [m asl]
k ($kw_{1\ or\ 2}$)	Permeability, [m^2], (w=water, g=gas) (Subscripts denote inner or outer composite zone permeability [m^2])
K ($Kw_{1\ or\ 2}$)	Conductivity, [m/s] (w=water, g=gas) (Subscripts denote inner or outer composite zone conductivity [m/s])
$(\,)_M$	Matched Parameter in Type Curve Analysis, [-]
η	Diffusivity, [m^2/s]
P	Pressure, [kPa]
$P_{1,2,3}$	Measured Pressure of Sensors 1,2, 3, [kPa]
P_{atm}	Atmospheric Pressure, [kPa]
P_D	Dimensionless Pressure, [-]
P_{fc}	Formation Pressure at Midpoint of Interval, [kPa]
PI	Productivity Index, [m^3/D/kPa]
P_i	Initial Pressure, also $(pav)_i$, [Pa]

PM	Pressure Match for Type Curve Analysis, [1/Pa]
pwf	Final Flowing Wellbore Pressure, [kPa]
ρ	Density, [kg/m^3]
ρ_m	Density of Borehole Fluid, [kg/m^3]
ρ_w	Density of Fresh Water, [kg/m^3]
Qg	Total Volume of Gas Flow, [m^3]
Qw	Total Volume of Water Flow, [m^3]
q_g	Gas Flowrate, [l/min]
q_w	Water Flowrate, [l/min]
r	Radius, [m]
r_{eff}	Effective Wellbore Radius, [m]
r_t	Tubing Radius, [m]
r_w	Wellbore Radius, [m]
r_1	Composite Radius, [m]
r_i	Radius of Influence, [m]
r_D	Dimensionless Radius, [-]
S	Storativity, [m/Pa]
S_s	Specific Storativity, [1/Pa]
S	Storage, [-]
S_s	Specific Storage, [1/m]
s	Skin, [-]
$S_{(w)}$	Skin of the Well (comp. model), [-]
$S_{(t)}$	Equivalent Skin due to Inner Zone(comp. model), [-]
t	Time, [s]
t_D	Dimensionless Time, [-]
T	Transmissivity, [m^2/s] (w=water, g=gas)
T_2	Temperature Measurement of Sensor 2, [°C]
TDS	Total Dissolved Solids, [ppm]
TM	Time Match for Type Curve Analysis, [1/h]
x_f	Fracture Half Length, [m]
μ_w	Water Viscosity, [Pa s]
z	Elevation of Reference Point, [m]
ϕ	Effective Porosity, [-]
κ	Double Permeability Model: transmissibility ratio, [-]
Ω	Double Porosity Model: storativity ratio,[-]
λ	Double Porosity Model: flow coefficient,[-]

Ω-2	Double Porosity Model: storativity ratio, outer zone,[-]
λ-2	Double Porosity Model:flow coefficient, outer zone,[-]
$(\phi\ c_t\ h)^1/_2$	Composite Storativity Ratio [-]
$(k\ h\ /\ \mu)^1/_2$	Composite Mobility Ratio [-]
PVT	Pressure - Volume - Temperature Correlation
$T_{w1\ or\ 2}$	Subscripts denote inner or outer composite zone transmissivity [m^2/s]

GLOSSARY

COM	Compliance
DEF	Packer Deflation
EQB	Pressure Equilibration
HI	Constant Head Injection
HIR	Pressure Recovery after Constant Head Injection
HIS	Pressure Recovery after Constant Head Injection (shut-in)
HW	Constant Head Withdrawal
HWR	Pressure Recovery after Constant Head Withdrawal
HWS	Pressure Recovery after Constant Head Withdrawal (shut-in)
INF	Packer Inflation
IPI	Impulse Injection
IPW	Impulse Withdrawal
PI	Pulse Injection
PSR	Static Pressure Recovery (shut-in)
PW	Pulse Withdrawal
RI	Constant Rate Injection
RIR	Pressure Recovery after Constant Rate Injection
RIS	Pressure Recovery after Constant Rate Injection (shut-in)
RW	Constant Rate Withdrawal
RWR	Pressure Recovery after Constant Rate Withdrawal
RWS	Pressure Recovery after Constant Rate Withdrawal (shut-in)
SAM	Sampling
SI	Slug Injection
SIS	Pressure Recovery after Slug Injection (shut-in)
SW	Slug Withdrawal
SWS	Pressure Recovery after Slug Withdrawal (shut-in)
c. p. bound.	Constant Pressure Boundaries
comp.	Composite
d. por.	Dual Porosity
hom.	Homogeneous
inf. lat. ext.	Infinite Lateral Extent
n. f. bound.	No Flow Boundaries
part. pen.	Partial Penetration
wellb.stor. & skin	Wellbore Storage and Skin (assumes storativity is $\phi * c_t * h$)
wellb.stor. & stor.	Wellbore Storage and Storativity (assumes skin is equal to zero)

DEFINITIONS

With DARCY's law :

$v = \frac{k}{\mu}\frac{dp}{dL}$ or $v = K\frac{dh}{dl}$ and

$dp = \rho g dh$ results in

$\frac{k}{\mu}\rho g = K$ or $k = \frac{K\mu}{\rho g}$

$$p_D = \frac{2\pi\, k\, h\, \Delta p}{q\mu B_w} = \frac{2\pi\, T\Delta p}{q\rho\, gB_w} = \frac{2\pi\, T\Delta h}{qB_w}$$

$$tD = \frac{kt}{\phi\mu c_t r_w^2} = \frac{Kt}{S_s r_w^2} = \frac{Tt}{Sr_w^2}$$

$C_D = \frac{C}{2\mu\,\phi\, c_t r_w^2 h} = \frac{\rho gC}{2\pi\, r_w^2 S}$ or $S = \frac{\rho gC}{2\pi\, r_w^2 C_D}$

$$t_D/C_D = \frac{2\pi\, k\, h\, t}{\mu\, C} = \frac{2\pi\, Tt}{\rho\, g\, C}$$

$C_f = \frac{\pi r_t^2}{\rho g}$ (C_f Wellbore Storage for changing fluid level; C_s Wellbore Storage Shut-in)

$C_s = V_w c_w$

$S = \phi\, c_t h$

$S_s = \phi\, c_t$ (S Storativity, S_s Specific Storage)

$T = Kh$

VAN EVERDINGEN - HURST (1949)
infinitesimal skin

$$s = \frac{2\pi\, k\, h}{q\mu\, B_w}\Delta p_{skin}$$

$s = \left(\frac{k}{k_s} - 1\right)\ln\frac{r_s}{r_w}$ and $r_{weff} = r_w e^{-s}$

equivalent fluid column calculated with:

$H_e = \frac{p_{fc} - p_{atm}}{1000g} - d_c + z$ with $p_{fc} = p_{ft} + \rho_b g d_{tc}$

INPUT PARAMETERS

In the following paragraphs the physical input parameters used in the analysis are listed, and the provenience of the values used is commented:

freshwater density (ρ_w)	A freshwater density of 1000 kg/m^3 is used. The value of the freshwater density is used for head and permeability calculations.
mud density (ρ_m)	The density of the fluid in the interval at the start of the test is used, information supplied by the mud engineer. Used to correct P2 pressures to midpoint of test interval and to estimate pre test history pressures. In certain cases, also used for the C_f (slug test wellbore storage coefficient) calculation. The density of the mud column above the transducer is also calculated using the transducer readings before inflating the packer(s) and the transducer depth.
freshwater viscosity (μ_w)	Calculated by INTERPRET/2 according to the temperature and salinity conditions in the interval. The freshwater viscosity is used to calculate the formation permeability.
mud viscosity (μ_m)	The viscosity of the fluid in the interval is reported but not used in calculations. The value was assumed in most of the cases.
porosity (ϕ)	A porosity of 10% was used for the „Rutschmasse“ and of 2% for the Palfris formation. These are assumed values. The porosity is used for storativity and skin calculations.
formation compressibility (c_f)	RIVERA (1991a; 1991b) reported that the formation compressibilities from several triaxial lab measurements in the Palfris formation ranged from 3.2E-11 to 4.6E-10 1/Pa on a bulk volume basis, which translates to pore volume based values of 1.6E-09 to 2.3E-08 1/Pa (assuming a 2% porosity). Earlougher 1977 reports typical formation compressibilities calculated on a pore volume basis to be between 1.3E-10 and 1.3E-08 1/Pa. An estimated bulk volume formation compressibility of 1.0E-10 1/Pa translates to a pore volume formation compressibility of 5.0E-09 1/Pa. The formation compressibility is used when calculating the total compressibility of the formation system and the formation storativity.

water compressibility (c_w)

Calculated by INTERPRET/2 according to the PVT conditions in the test interval. A value of 4.4E-10 1/Pa is commonly used. Influences the calculation of the theoretical Cs-value and, as a part of the total compressibility, the storativity.

gas compressibility (c_g)

Calculated by INTERPRET/2 according to the PVT conditions in the test interval. A gas composition of 99% CH_4 was used for production tests with gas occurrence. During gas threshold pressure injection tests, nitrogen was used. The gas compressibility is typically three orders of magnitude higher than the water compressibility. The gas compressibility together with the gas saturation influences the total compressibility of the formation system, which goes into the calculation of storativity.

borehole compressibility (c_b)

The borehole compressibility is unknown. It is questionable if it should be set equal to the formation compressibility. Influences the calculation of the closed system wellbore storage (C_s).

tool compressibility (c_p)

So-called casing tests, carried out at the Oberbauenstock site (KENNEDY & DAVIDSON, 1989), resulted in compressibility values between 5.7E-10 1/Pa and 1.5E-09 1/Pa. This compressibility is strongly dependent on the inflation pressure and inflation fluid of the packers. Packer inflation pressures typically used in the Palfris formation are around 8000 kPa. The inflation fluid is water. The unconsolidated sediments of the „Rutchmasse" require lower inflation pressures and - depending on the quality of the borehole - sometimes nitrogen as inflation fluid. The tool compressibility influences the calculation of the theoretical closed system wellbore storage (C_s).

total compressibility (formation) (c_{tf})

The value of the formation system total compressibility can be written as:

$c_{tf} = S_w\, c_w + S_g\, c_g + c_f$

with c_f calculated on a pore volume basis. For cases of 100% water saturation a total compressibility of ca. 5.4E-09 1/Pa can be calculated. A 1% gas saturation would rise the total compressibility value by half order of magnitude (ca. 1.2E-08 1/Pa). The formation system total compressibility directly influences the theoretical value of the storativity and implicitly the skin calculation.

total test zone compressibility (c_{tz})	The value of the borehole system total compressibility can be written as: $c_{tz} = S_w c_w + S_g c_g + c_b + c_p$ The borehole system total compressibility can be determined by a short time pulse test (as described in OSTROWSKI et al., 1992). Several compressibility checks carried out at the Wellenberg site resulted in values around 2E-09 1/Pa. The value of the borehole system total compressibility influences the calculation of the closed system wellbore storage (C_s) which is important for the permeability determination during pulse tests.

APPENDIX A:
TEXT FIGURES

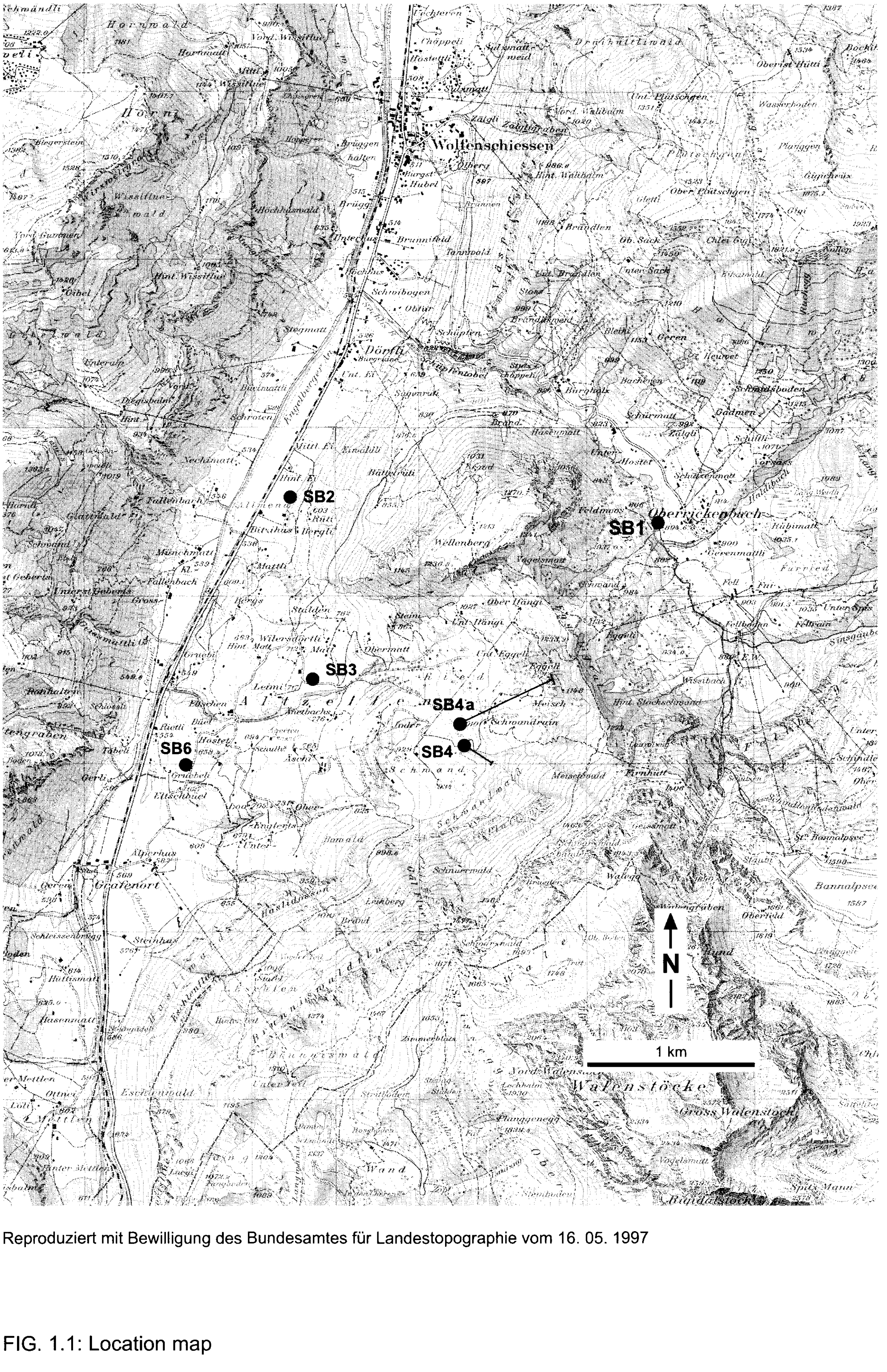
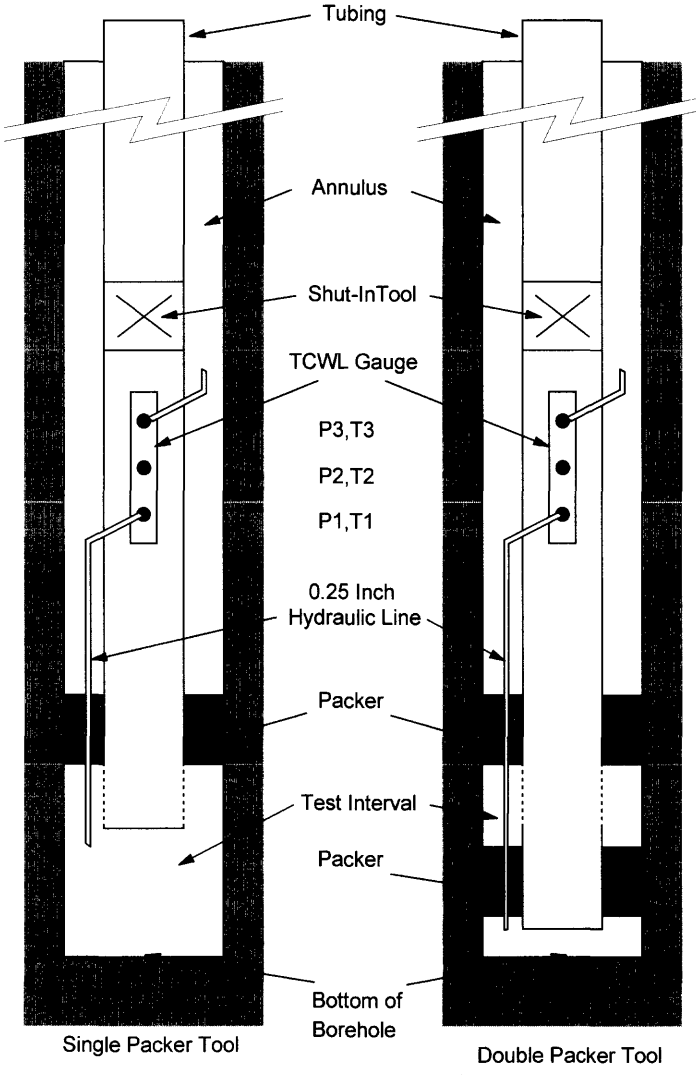


FIG. 1.1: Location map



Note: The measuring point for all temperature
and pressure measurements is at the sensor depth.

FIG. 2.1: TCWL position in single and double packer configuration

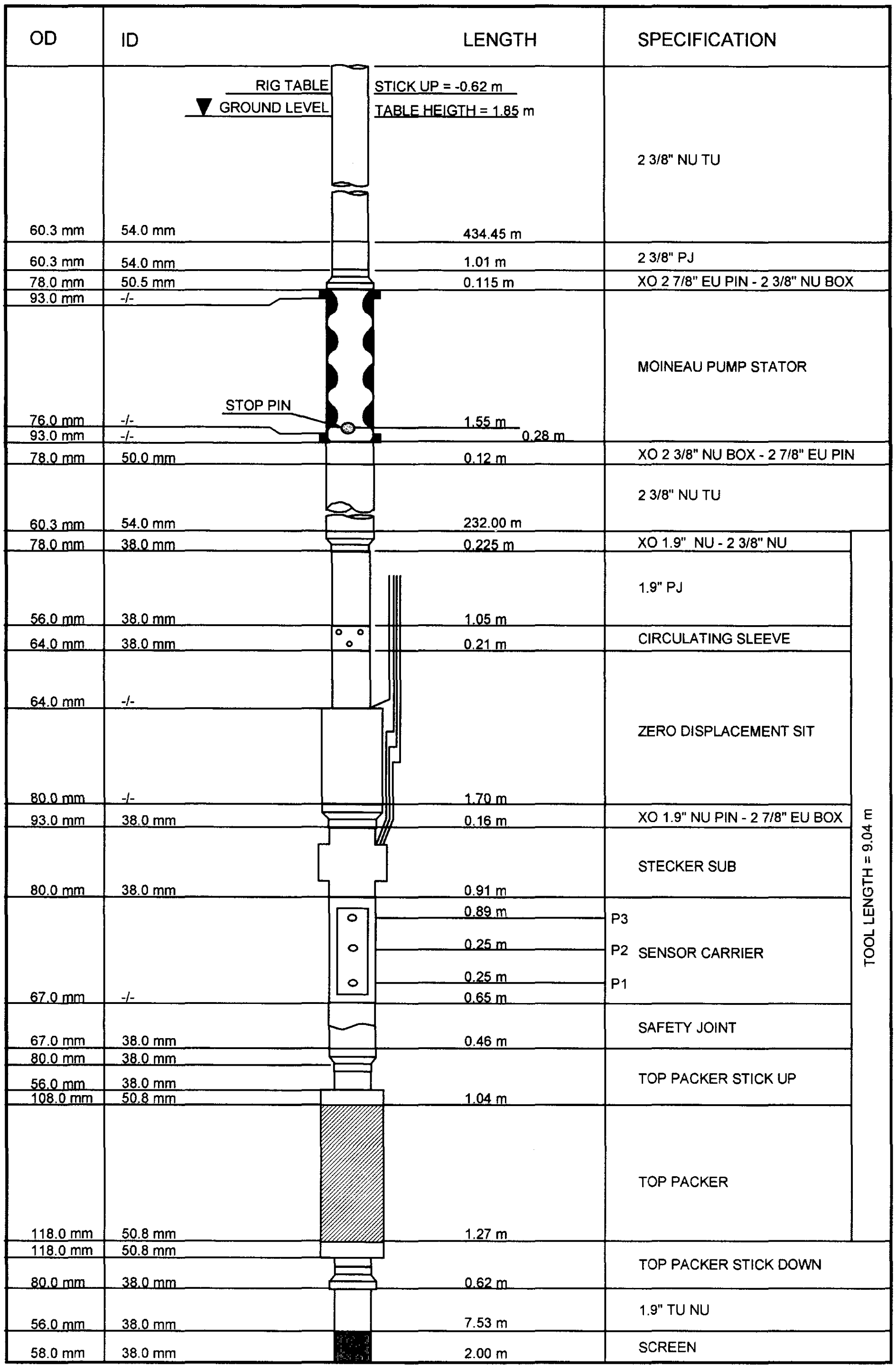


FIG. 2.2: Single packer tool configuration (e.g. Test VM11 - SB4a/v)

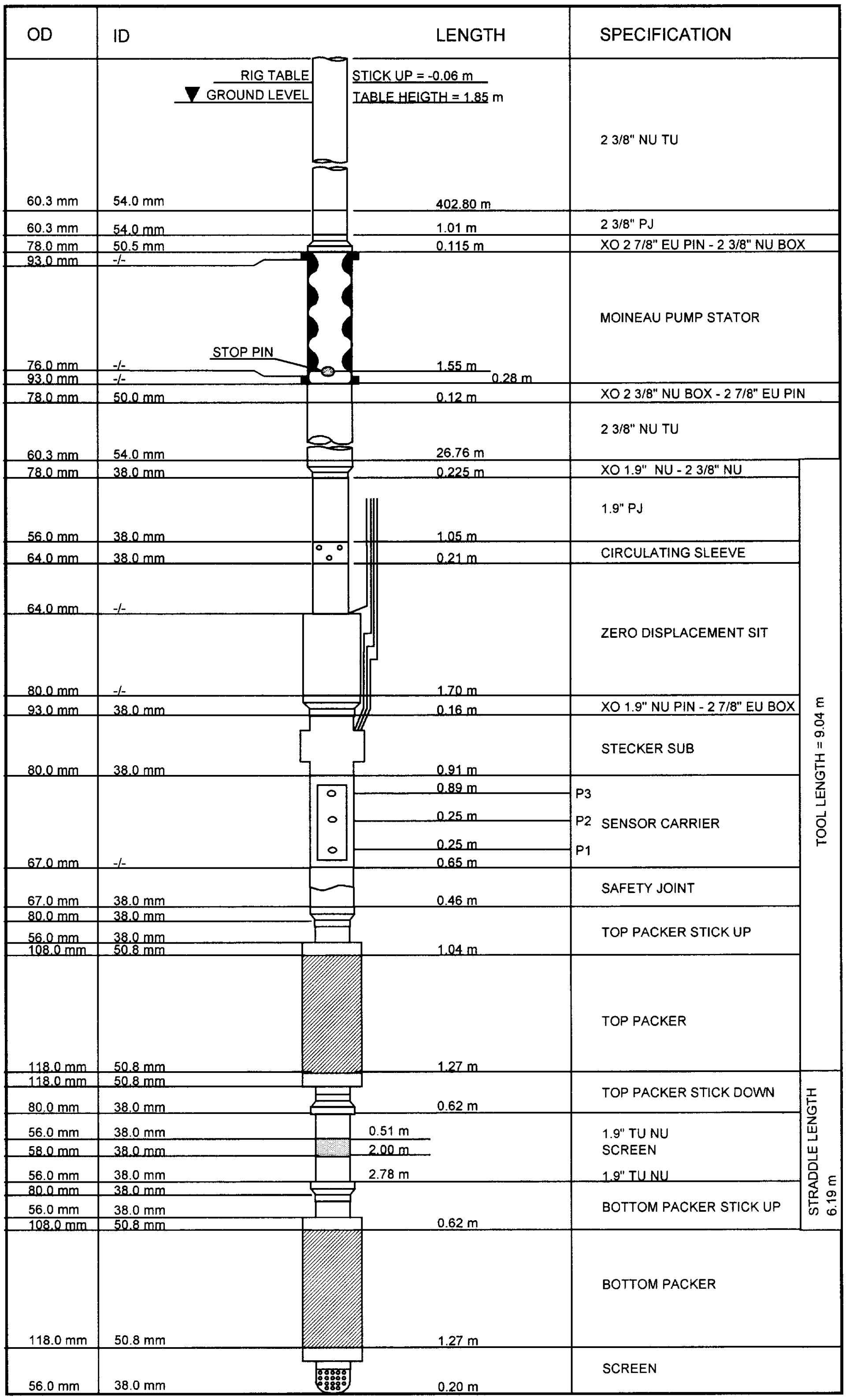
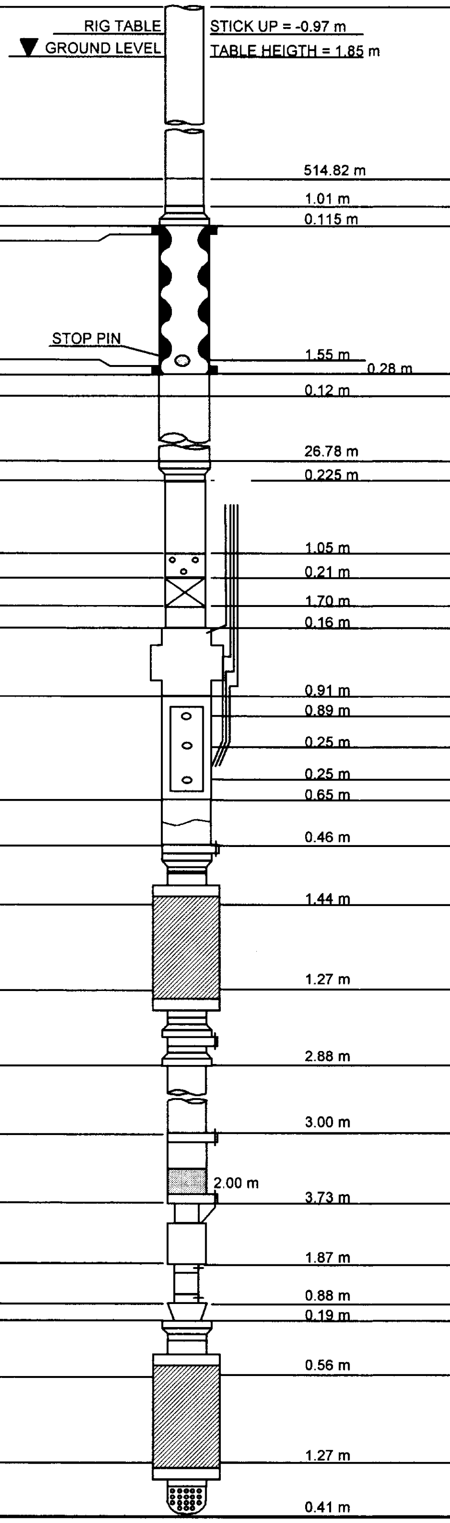


FIG. 2.3: Double packer tool configuration (e.g. Test VM9 - SB4a/s)



OD	ID	LENGTH	SPECIFICATION	
60.3 mm	54.0 mm	514.82 m	2 3/8" NU TU	
60.3 mm	54.0 mm	1.01 m	2 3/8" PJ	
78.0 mm	50.5 mm	0.115 m	XO 2 7/8" EU PIN - 2 3/8" NU BOX	
93.0 mm 76.0 mm 93.0 mm	-/- -/- -/-	1.55 m 0.28 m	MOINEAU PUMP STATOR	
78.0 mm	50.0 mm	0.12 m	XO 2 3/8" NU BOX - 2 7/8" EU PIN	
60.3 mm	54.0 mm	26.78 m	2 3/8" NU TU	
78.0 mm	38.0 mm	0.225 m	XO 1.9" NU - 2 3/8" NU	TOOL LENGTH = 8.58 m
56.0 mm	38.0 mm	1.05 m	1.9" PJ	
64.0 mm	38.0 mm	0.21 m	CIRCULATING SLEEVE	
80.0 mm	-/-	1.70 m	MECHANICAL SIT	
93.0 mm	38.0 mm	0.16 m	XO 1.9" NU PIN - 2 7/8" EU BOX	
80.0 mm	38.0 mm	0.91 m	STECKER SUB	
67.0 mm	-/-	0.89 m 0.25 m 0.25 m 0.65 m	P3 P2 SENSOR CARRIER P1	
67.0 mm	38.0 mm	0.46 m	SAFETY JOINT	
80.0 mm	38.0 mm	1.44 m	TOP PACKER STICK UP	
118.0 mm	50.8 mm	1.27 m	TOP PACKER	
80.0 mm	38.0 mm	2.88 m	TOP PACKER STICK DOWN	STRADDLE LENGTH = 13.11 m
56.0 mm	38.0 mm	3.00 m	1.9" NU TU	
56.0 mm	38.0 mm	2.00 m 3.73 m	SCREEN	
80.0 mm	-/-	1.87 m	HYDRAULIC SIT	
56.0 mm	38.0 mm	0.88 m	SAMPLER CHAMBER	
56.0 mm	0.0 mm	0.19 m	DEAD END SUB	
80.0 mm	38.0 mm	0.56 m	BOTTOM PACKER STICK UP	
118.0 mm	50.8 mm	1.27 m	BOTTOM PACKER	
56.0 mm	38.0 mm	0.41 m	SCREEN	

FIG. 2.4: Downhole chamber sample tool (e.g. Test T7 - SB4a/v)

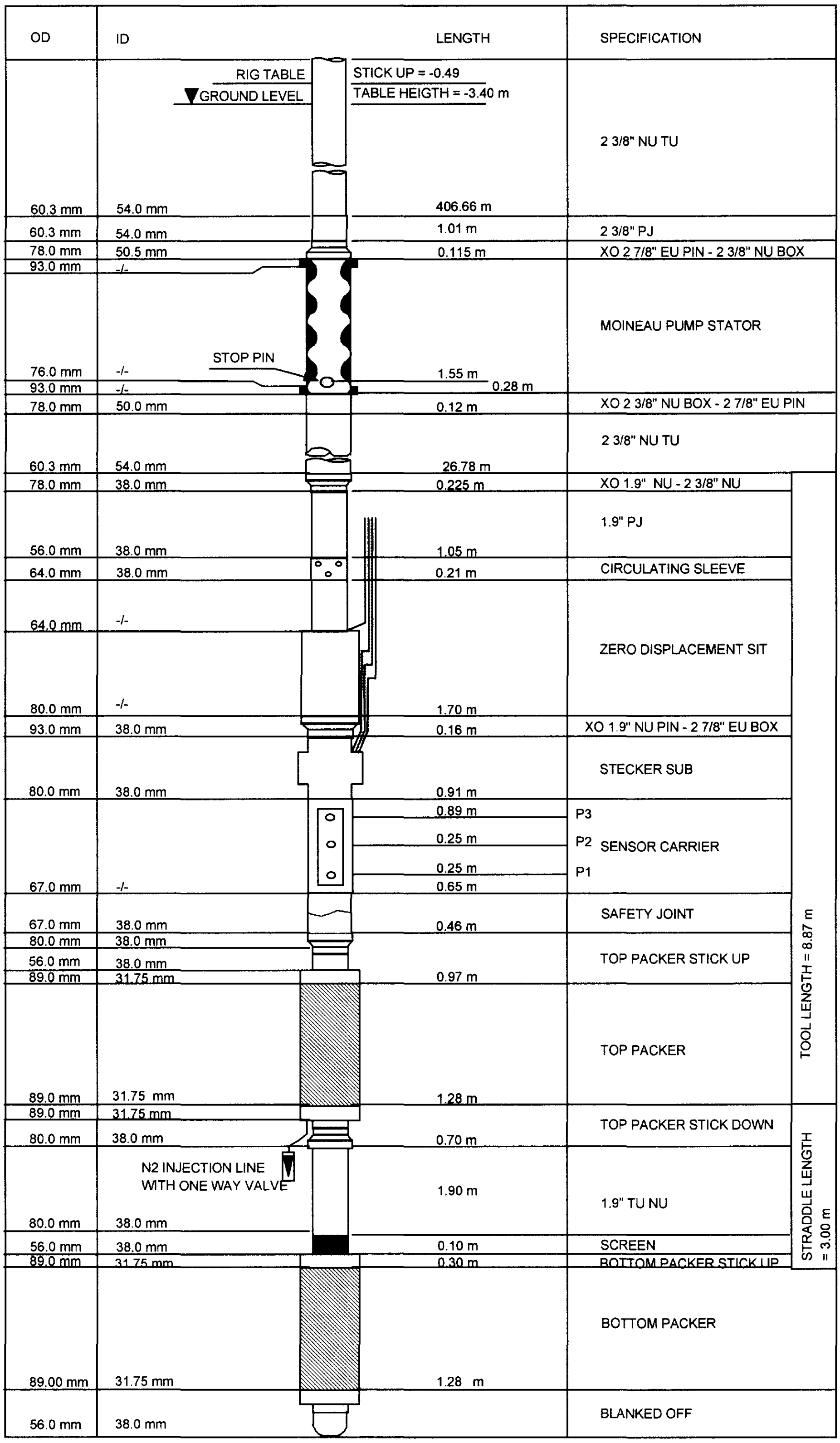
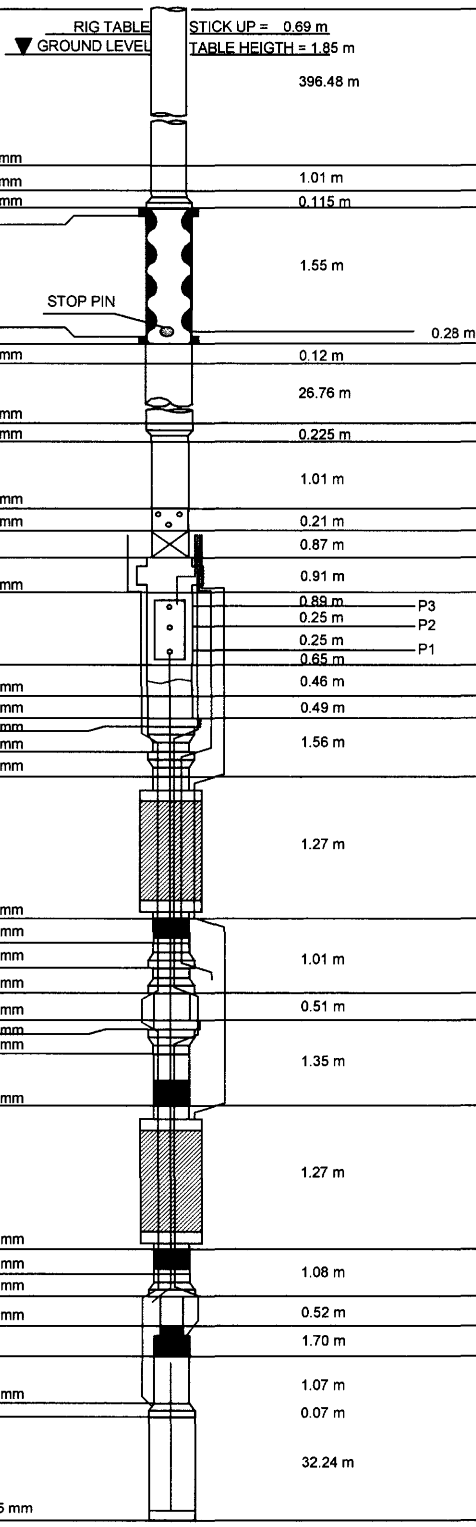
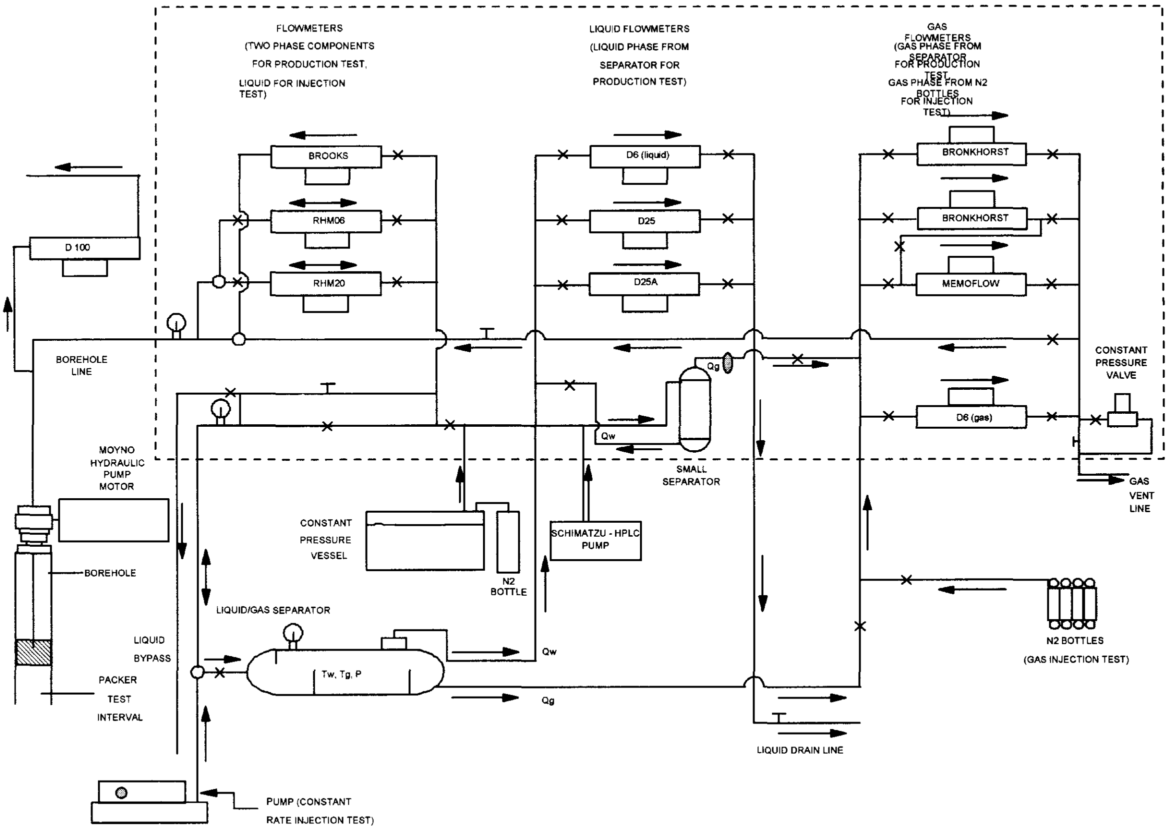


FIG. 2.5: Gas threshold pressure test tool (e.g. Test VM16 - SB4a/s)



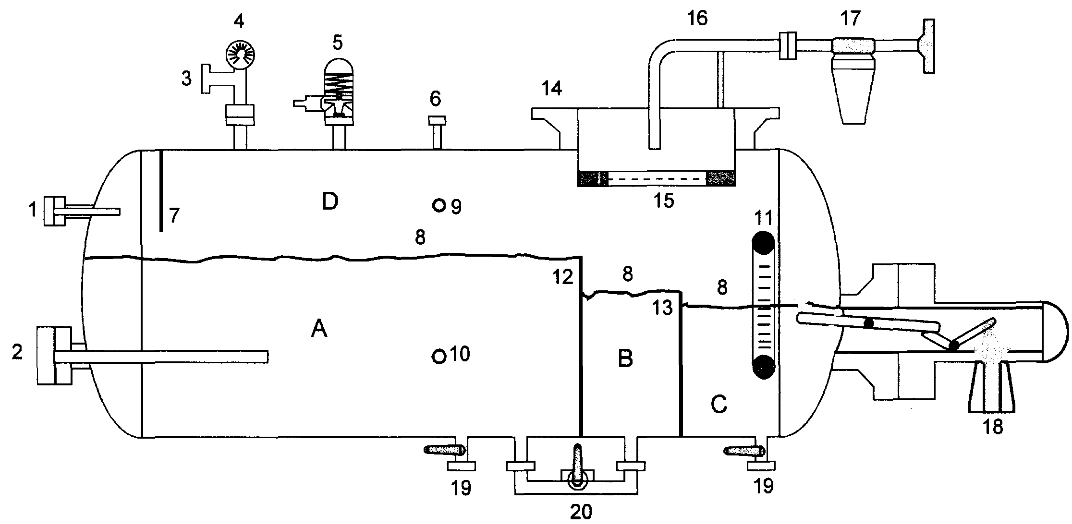
OD	ID	LENGTH	SPECIFICATION	
60.3 mm	54.0 mm	396.48 m	2 3/8" NU Tubing	
60.3 mm	54.0 mm	1.01 m	2 3/8" NU Tubing	
78.0 mm	50.5 mm	0.115 m	XO 2 7/8" EU X 2 3/8" NU	
93.0 mm 76.0 mm	-/- -/-	1.55 m	Moineau Pump Stator	
78.0 mm	50.0 mm	0.12 m	XO 2 7/8" EU X 2 3/8" NU PIN	
60.3 mm	54.0 mm	26.76 m	2 3/8" NU Tubing	
78.0 mm	38.0 mm	0.225 m	XO 1.9" NU X 2 3/8" NU	TOOL LENGTH = 9.05 m
56.0 mm	38.0 mm	1.01 m	1.9" NU Tubing	
64.0 mm	38.0 mm	0.21 m	CIRCULATING SLEEVE	
54 mm	-/-	0.87 m	MECHANICAL SIT	
80.0 mm	38.0 mm	0.91 m	STECKER SUB	
67.0 mm	-/-	0.89 m 0.25 m 0.25 m 0.65 m	SENSOR CARRIER	
67.0 mm	38.0 mm	0.46 m	SAFETY JOINT	
56.0 mm	38.0 mm	0.49 m	1.9" NU TU	
136.5 mm	38.0 mm	1.56 m	PRESSURE CTRL. SUB	
80.0 mm	38.0 mm		2 X Y-SUB	
80.0 mm	38.0 mm		1 X Y-SUB	
136.5 mm	50.8 mm	1.27 m	UPPER PACKER	
88.9 mm	38.0 mm	1.01 m	LUBRICATOR SUB	STRADLE LENGTH = 2.87 m
80.0 mm	38.0 mm		1 X Y-SUB	
80.0 mm	38.0 mm		2 X Y-SUB	
56.0 mm	38.0 mm	0.51 m	1.9" NU TU	
136.5 mm	38.0 mm	1.35 m	PRESSURE CTRL. SUB	
80.0 mm	38.0 mm		2 X Y-SUB	
56.0 mm	38.0 mm		SCREEN	
136.5 mm	50.8 mm	1.27 m	Lower packer	
88.9 mm	38.0 mm	1.08 m	LUBRICATOR SUB	
80.0 mm	38.0 mm		3 X Y-SUB	
56.0 mm	38.0 mm	0.52 m	1.9" HANDLING SUB	
80.0 mm	-/-	1.70 m	HYDRAULIC SIT	
93.0 mm	62.0 mm	1.07 m	2 7/8" JOINT	
114.3 mm	-/-	0.07 m	CROSSOVER	
132.1 mm	100.5 mm	32.24 m	4 1/2" TAIL PIPE PLUG	

FIG. 2.6: Downhole chamber tool for gas threshold pressure tests (e.g. Test VM14 - SB4a/v)



Gauge	Calibrated Range	Output Range
BROOKS	2-100 g/h	0-5 V
RHM06	0-10 kg/min	0-10 V
RHM20	0-120 kg/min	0-10 V
D6 liquid	0-900 g/min	4-20 mA / 500 Ohm
Micromotion D25	0-18 kg/min	4-20 mA / 500 Ohm
Micrmotion D25A	0-5000 g/min	4-20 mA / 500 Ohm
BRONKHORST - 1	0-10 l/min N2	0-5 V
BRONKHORST - 2	0-50 l/min N2	0-5 V
D6 gas	0-50 g/min	4-20 mA / 500 Ohm
MEMOFLO	0-10 l/min	0-5 V
D100	0-100 l/min	4-20 mA / 500 Ohm
Twater	-30 - +50 °C	0.10 V
Tgas	-30 - +50 °C	0.10 V
Psep.	0-30 bar	0-10 V
Pman.	0-34.474 bar	0-2 V
Tubing Pressure - 1	0-5 bar	4-20 mA / 250 Ohm
Tubing Pressure - 2	0-10 bar	4-20 mA / 250 Ohm

FIG. 2.7: Schematic drawing of the flow control board



Position	Component	
1	Gas / Fluid Inlet	
2	Heater	
3	Flange with connection for N2 Gas Bottle / Gas Compressor	
4	Mechanical Manometer (Max. Pressure: 16 bar)	
5	Safety Valve (Opens at 12 bar and closes at 11 bar)	
6	Flange with connection for Digital Pressure Gauge	
7	Deflector Plate	
8	Water Levels	
9	Gas Temperature Monitoring Orofice	
10	Fluid Temperature Monitoring Orofice	
11	Site Glass	
12	Weir (440 mm)	
13	Weir (350 mm)	
14	Manhole	
15	Gauze Sieve	
16	Gas outlet	
17	Pressure Control Valve (Small Valve pressure range 0 - 3.5 bar; Large Valve pressure range 2.0 - 10.0 bar)	
18	Float Valve linked to Swimmer	
19	Chamber outlets	
20	Bypass	
A	Separator Fluid Chamber	(Vol. = 307 l)
B	Separator Fluid Chamber	(Vol. = 47 l)
C	Separator Fluid Chamber	(Vol. = 69 l)
D	Gas volume in Separator	(Vol. = 284 l)

FIG. 2.8: Schematic drawing of the 2-phase horizontal separator

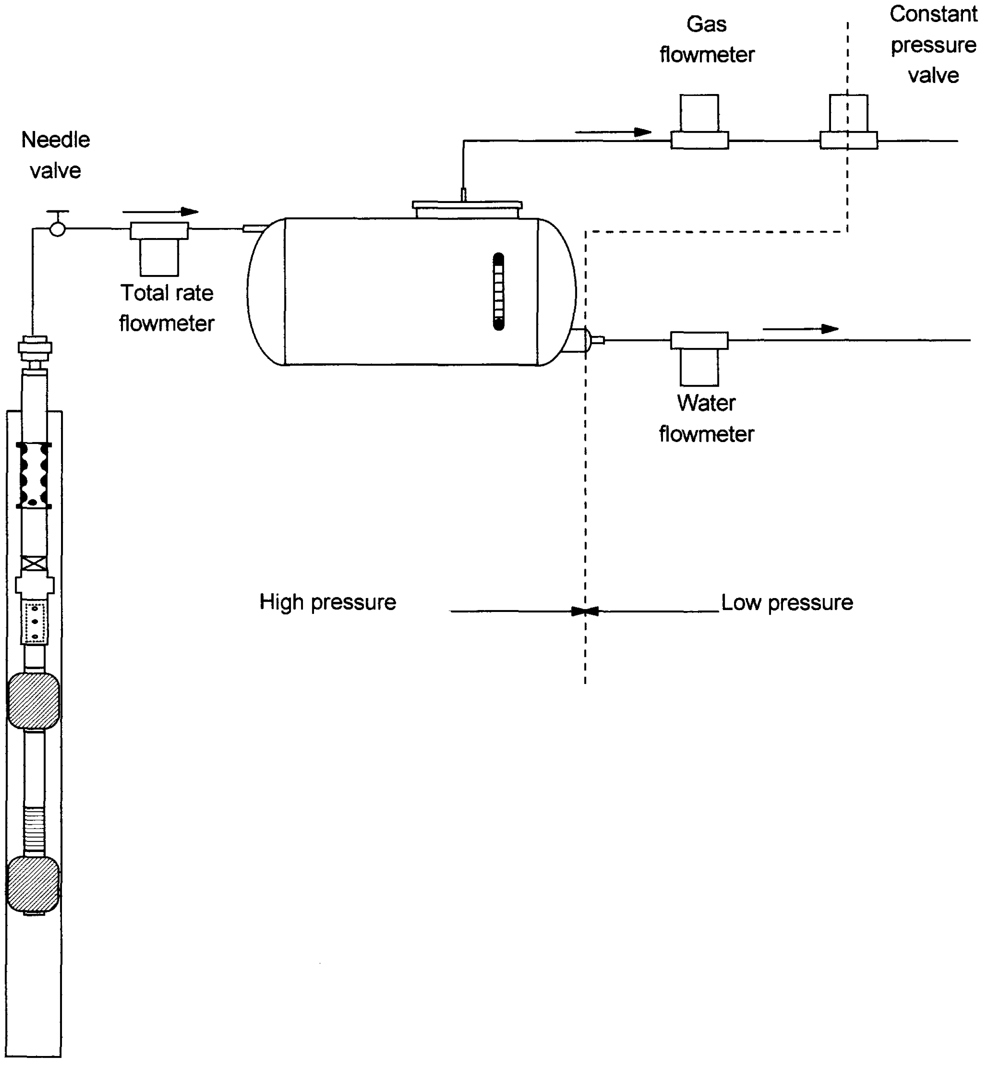


FIG. 2.9: Principle of function of the horizontal 2-phase separator

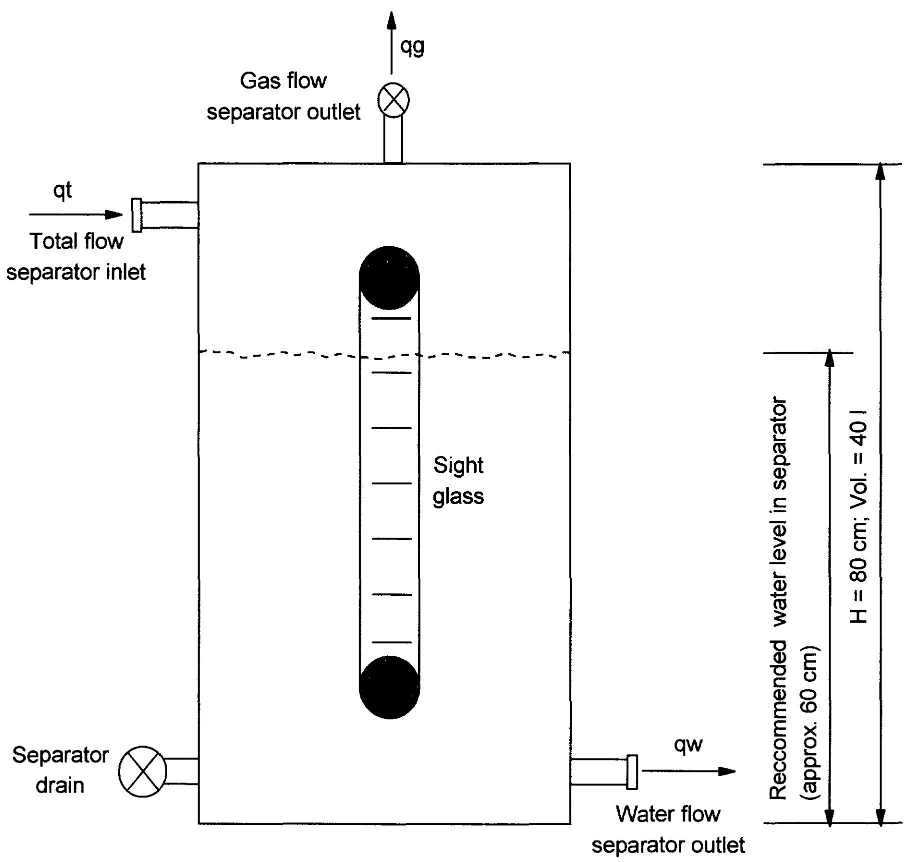


FIG. 2.10: Schematic drawing of the 2-phase vertical separator

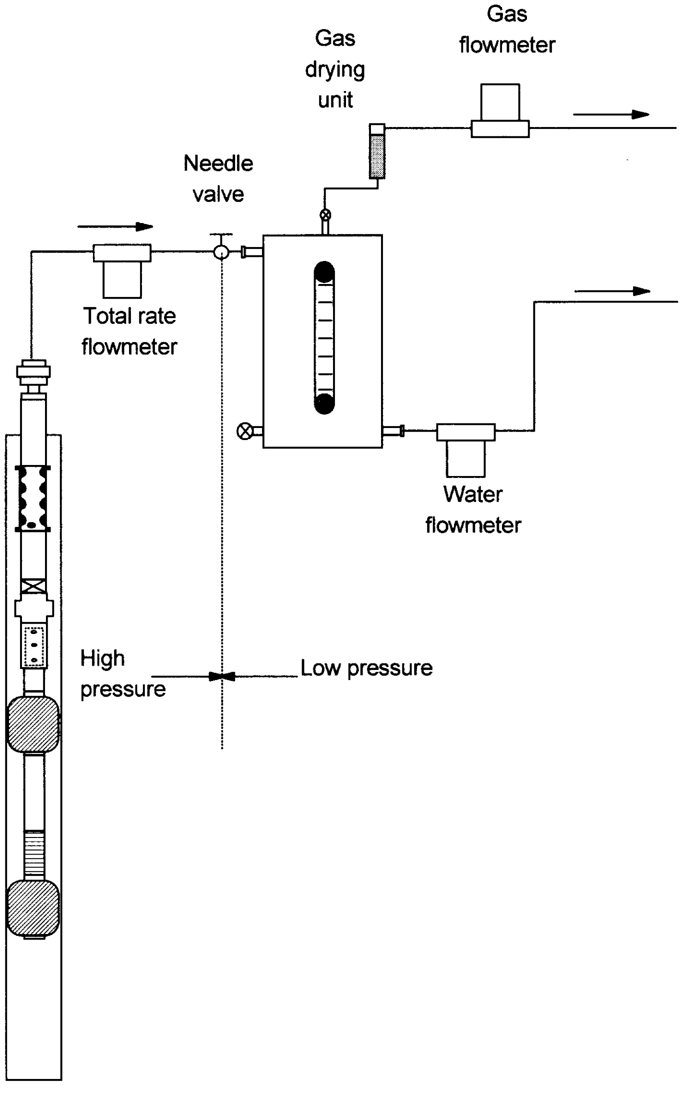


FIG. 2.11: Principle of operation for the vertical 2-phase separator

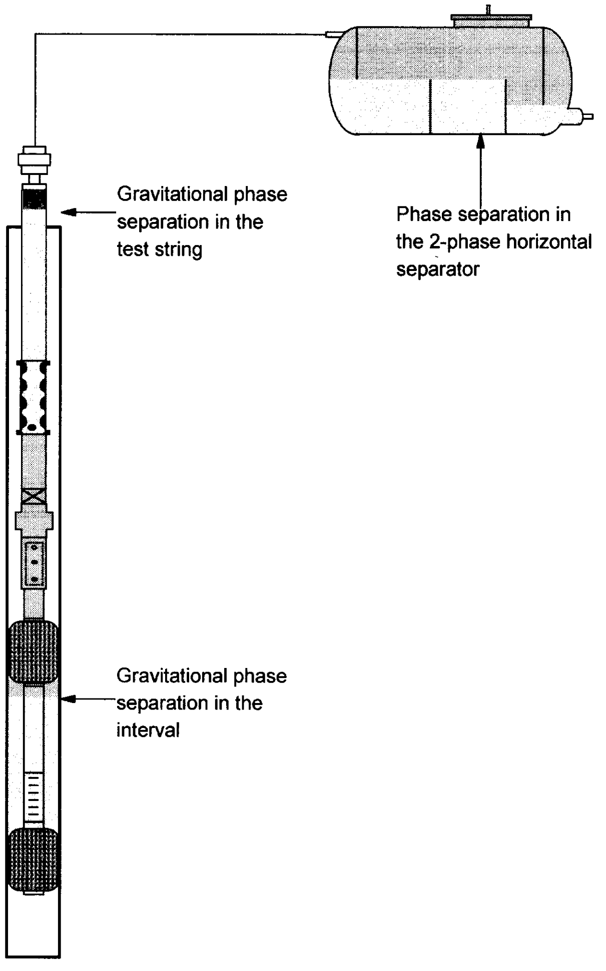


FIG. 2.12: Possible phase separation phenomena in the testing system

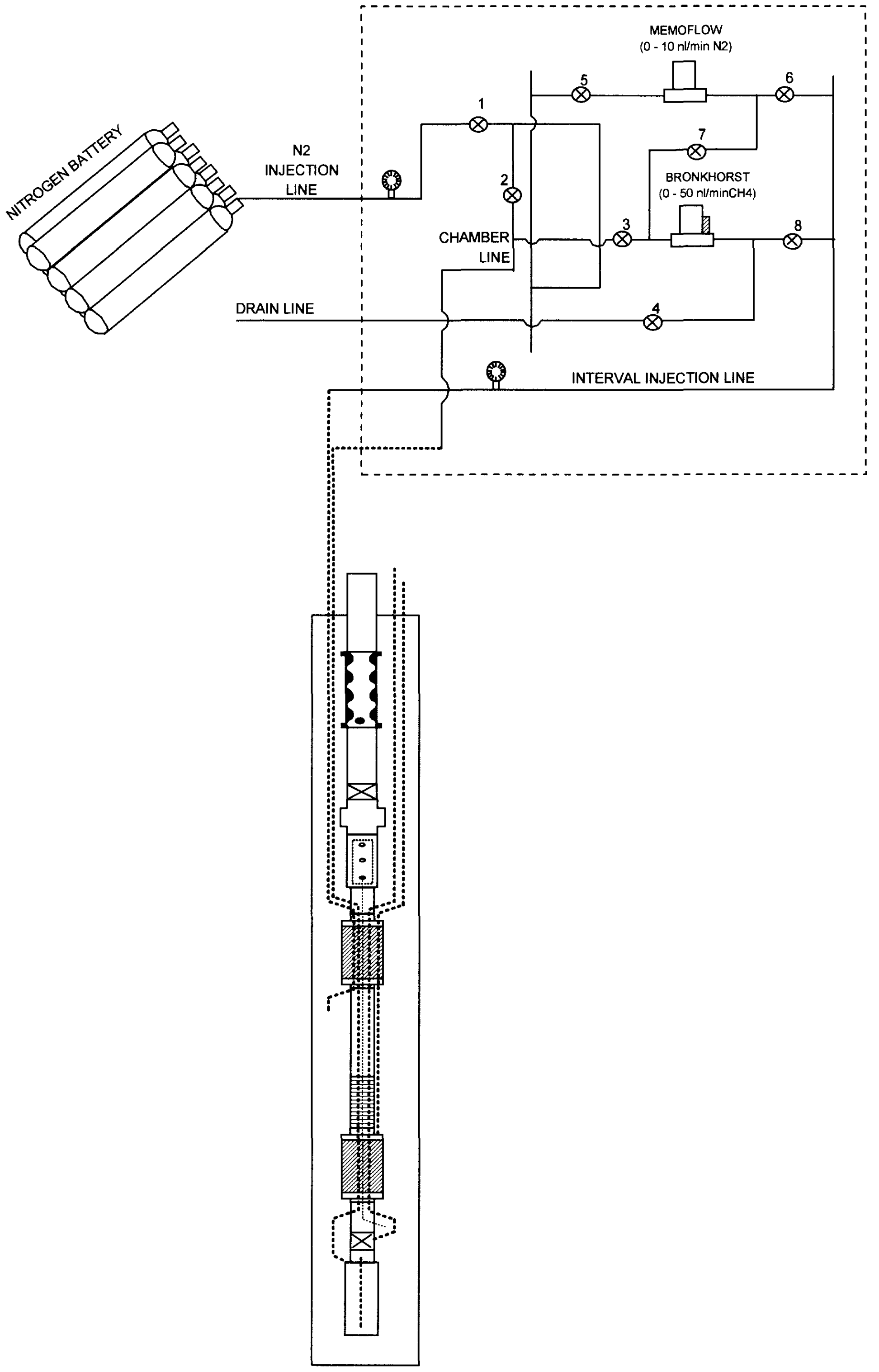


FIG. 2.13: Flow control board for gas threshold pressure tests, as used in connection with the downhole chamber tool

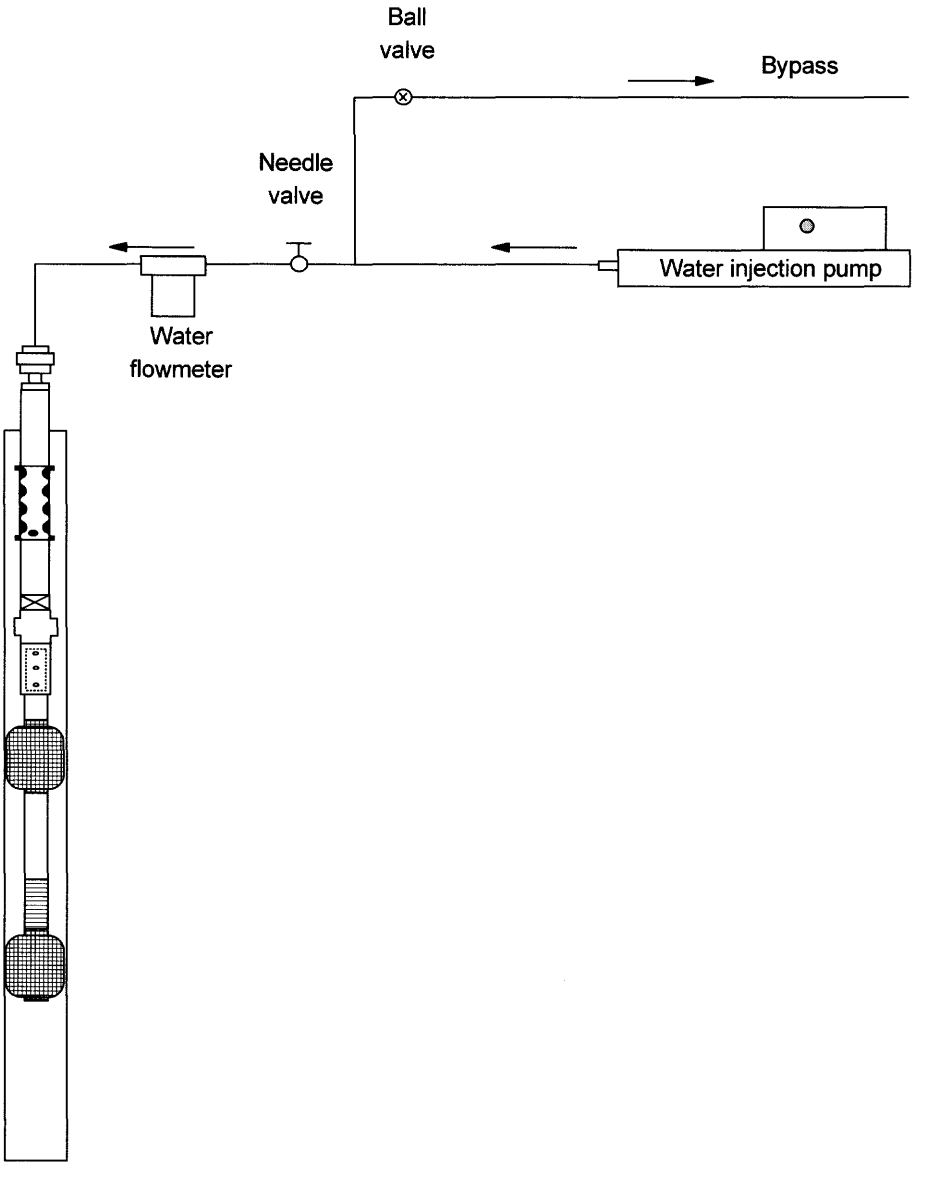
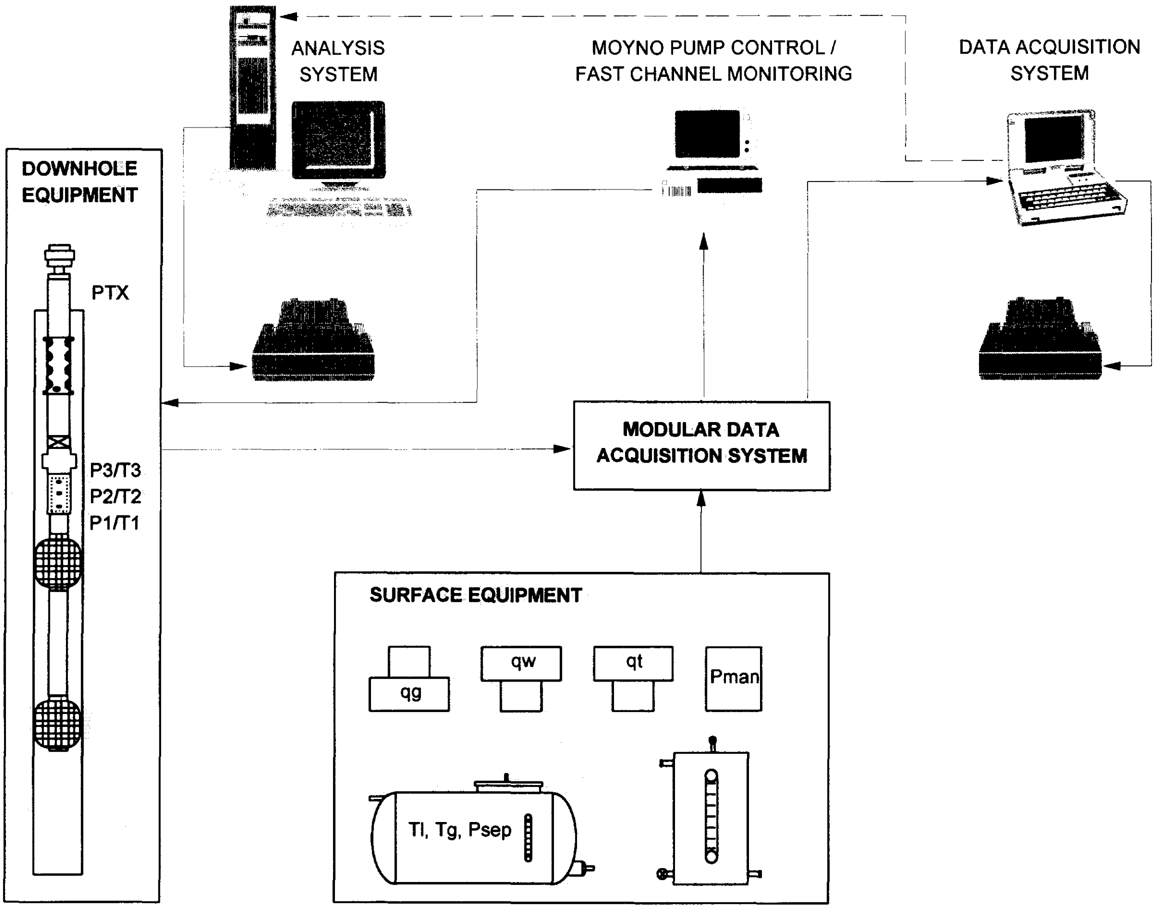


FIG. 2.14: Bypass-choke system used for constant rate injection tests



P1	Pressure in the guard zone	qt	Total flow rate
P2	Presure in the test interval	qw	Water flow rate
P3	Pressure in the annulus	qg	Gas flow rate
T1	Temperature in the guard zone	Pman	Pressure in the manifold
T2	Temperature in the test interval	Tl	Temperature in the separator (liquid phase)
T3	Temperature in the annulus	Tg	Temperature in the separator (gas phase)
PTX	Pressure in the test string	Psep	Pressure in the separator

FIG. 2.15: Schematic drawing of data acquisition system

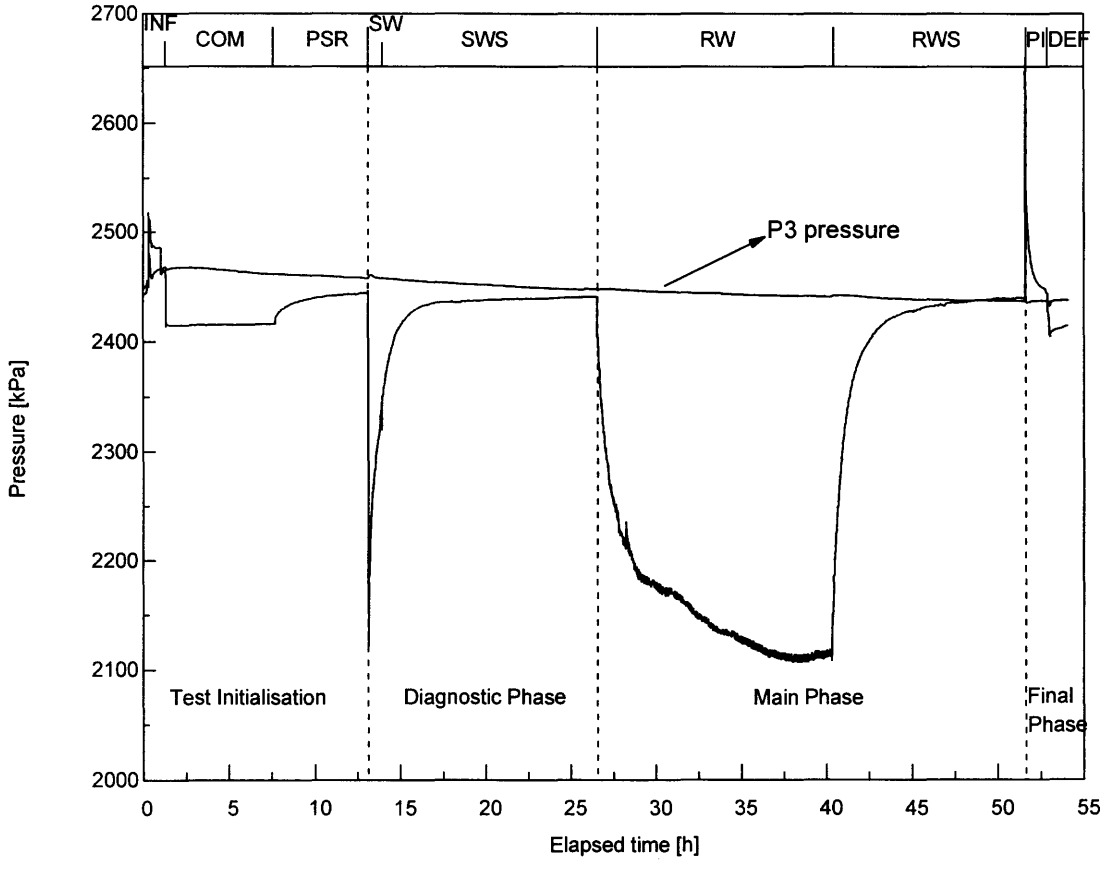


FIG. 3.1: Typical test in a test interval of medium transmissivity and hydrostatic head

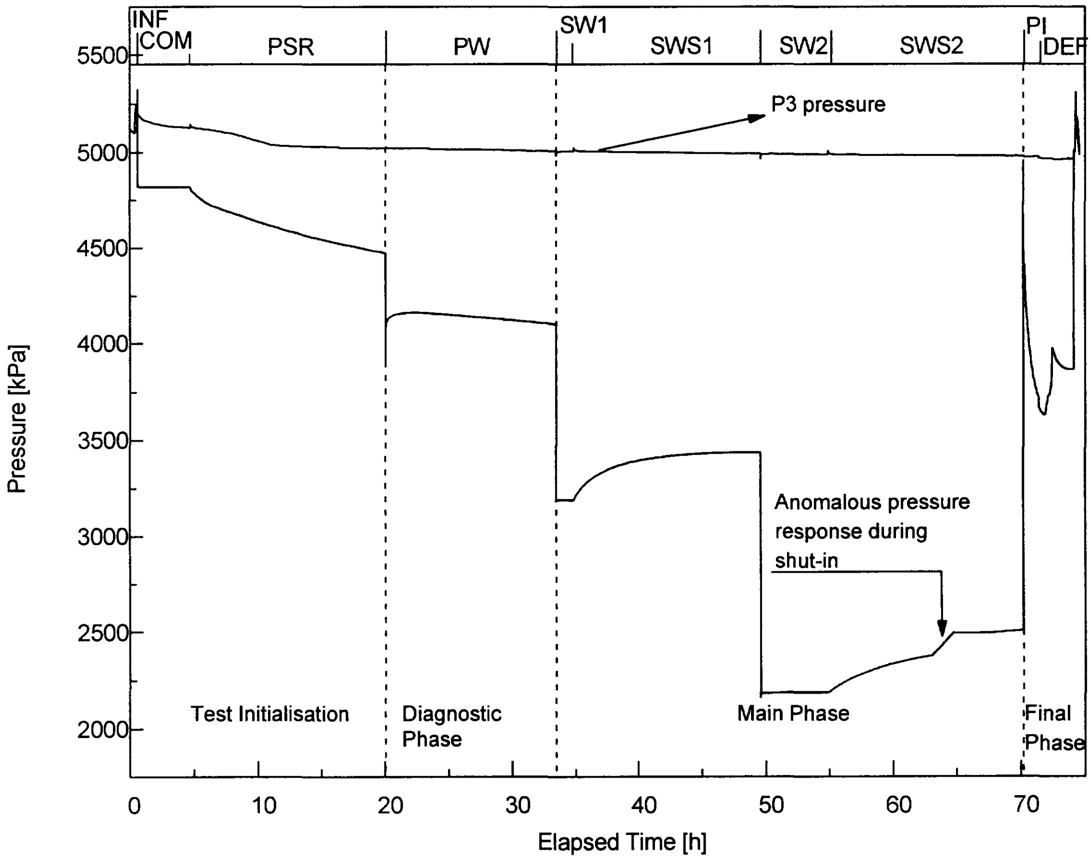


FIG. 3.2: Typical test design for a test interval with low transmissivity and low head

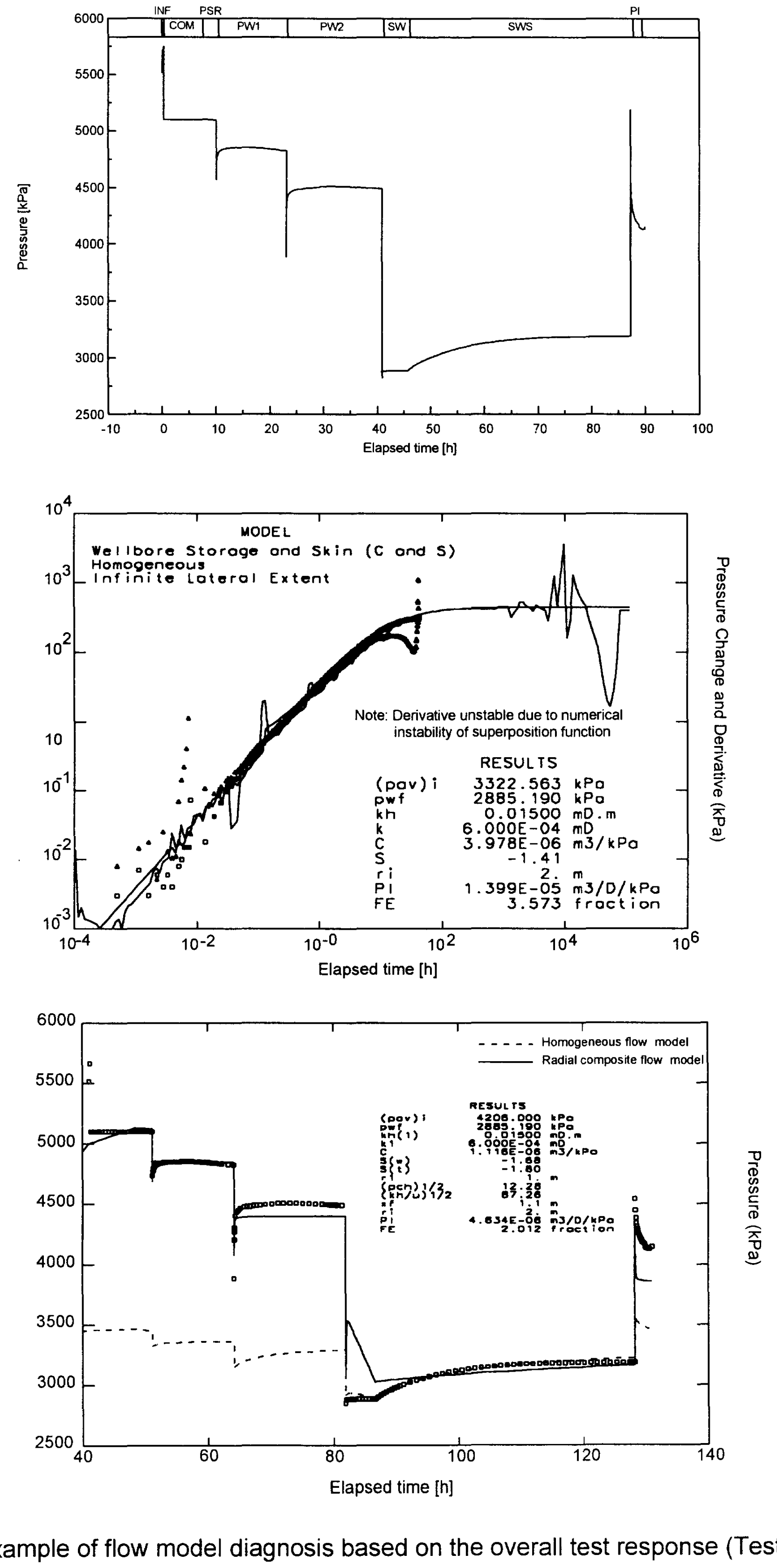


FIG. 4.1: Example of flow model diagnosis based on the overall test response (Test T2 in SB4a/s)

Criteria	Value	Legend	
Test name	VM10		
Test events	INF, COM, PSR, PW1, PW2, SW, SWS, PI		
A - LIST OF CRITERIA (by contractor)			
1. General Test Parameters			
1.1 location (H.U./repositiry)	D/1-2	- with respect to hydrogeo. units	A : Landslide B : VM - intermediate trans. C : VM - low transmissivity D : VM - very low transmissivity
		- with respect to repository level	1 : > 200 m 2 : 50 - 200 m 3 : < 50 m
1.2 length of straddle interval	2-3	1: > 60 m 2: 20 - 60 m 3: < 20 m	
1.3 duration BH	1-2	1: < 2 days (relatively simple) 2: 2 - 10 days 3: > 10 days	
1.4 complexity of BH	1	1: can be handled using 1 - 2 simple flow periods or unknown 2: can be handled using 2 - 3 flow periods 3: can be handled using a series of flow periods	
1.5 gas obs./meas./susp.	no	-	
1.6 test duration	3	1: < 24 hours 2: 1 - 3 days 3: > 3 days	
2. Test Data Quality			
2.1 pressure	3	1: data very noisy, evt. disturbances, hardly analysable	
2.2 water rate	-	2: rather noisy, still analysable	
2.3 gas rate	-	3: reliable data	
2.4 temperature effect	1-2 (PSR)	1: no significant effect of temperature 2: temperature changes might create significant pressure changes 3: certain temperature effect	
2.5 other disturbances	PSR,PW2	-	
2.6 representative events	PW1,PW2,SWS,PI		

FIG. 4.2: Test classification criteria list (Part 1)

3. Preliminary Results		
3.1 events analysed	PSR,PW1,PW2,SWS,PI	
3.2 flow model	221	111: wellbore storage, radial homogeneous, infinite lateral extent 211: wellbore storage & skin, radial homogeneous, inf. lat. extent 121: wellbore storage, radial composite, infinite lateral extent 221: wellbore storage & skin, radial composite, inf. lat. extent
3.3 uncertainty in flow model	1-2	1: no revision required or possible 2: applied model is reliable but alternative might be considered 3: applied model should be revised
3.4 T_{inner}- / T_{outer}-estimate [m^2/s]	3E-10(?) / 3E-11(?)	
3.5 T-range factor	3	1: < ± factor 3 2: ± factor 3 - 10 3: > ± factor 10
3.6 head-estimate [m asl]	610(?)	
3.7 head-range factor	3	1: < ± 15 m 2: ± 15 - 50 m 3: > ± 50 m
3.8 gas-water ratio	-	
3.9 reliability of assumptions	3(BH)	1: appropriate 2: acceptable 3: should be revised
3.10 reliability of results	2-3(BH)	1: reliable within a reasonable range 2: acceptable 3: poor
3.11 overall consistency	2/1	- with respect to adjacent tests 1 : consistent 2 : acceptable. 3 : inconsistent - with respect to hydrogeol. units 1 : consistent 2 : acceptable. 3 : inconsistent
4. Improvement of Results		
4.1 flow model	2	1: no improvement
4.2 transmissivity	2-3	2: reliable estimate
4.3 head	3	3: accurate estimate
4.4 dissolved/free gas	-	
4.5 2-phase flow par. est.	-	
4.6 gas threshold pressure	-	
B - CLASSIFICATION FOR INTERPRETATION (by NAGRA)		
1 Relevance	1	0: no relevance 1: contribution to head & transmissivity profile 2: detailed formation characterisation and/or identification of HU 3: characterisation of dual phase medium
2 Interpretation Type	standard single phase	standard, detailed single phase, detailed dual phase
3 Interpretation Procedure	1	1: standard interpretation of hydrotest without fast simulations 2: standard interpretation of hydrotest with fast simulations 3: detailed interpretation of hydrotests under single phase cond. 4: detailed interpretation of hydrotests under dual phase cond. 5: standard interpretation of GTPT with fast simulations 6: detailed interpretation of GTPT
4 Need to Revise QLR Doc.	2	1: no changes required 2: minor changes required, without additional analyses 3: additional analyses recommended

FIG. 4.3: Test classification criteria list (Part 2)

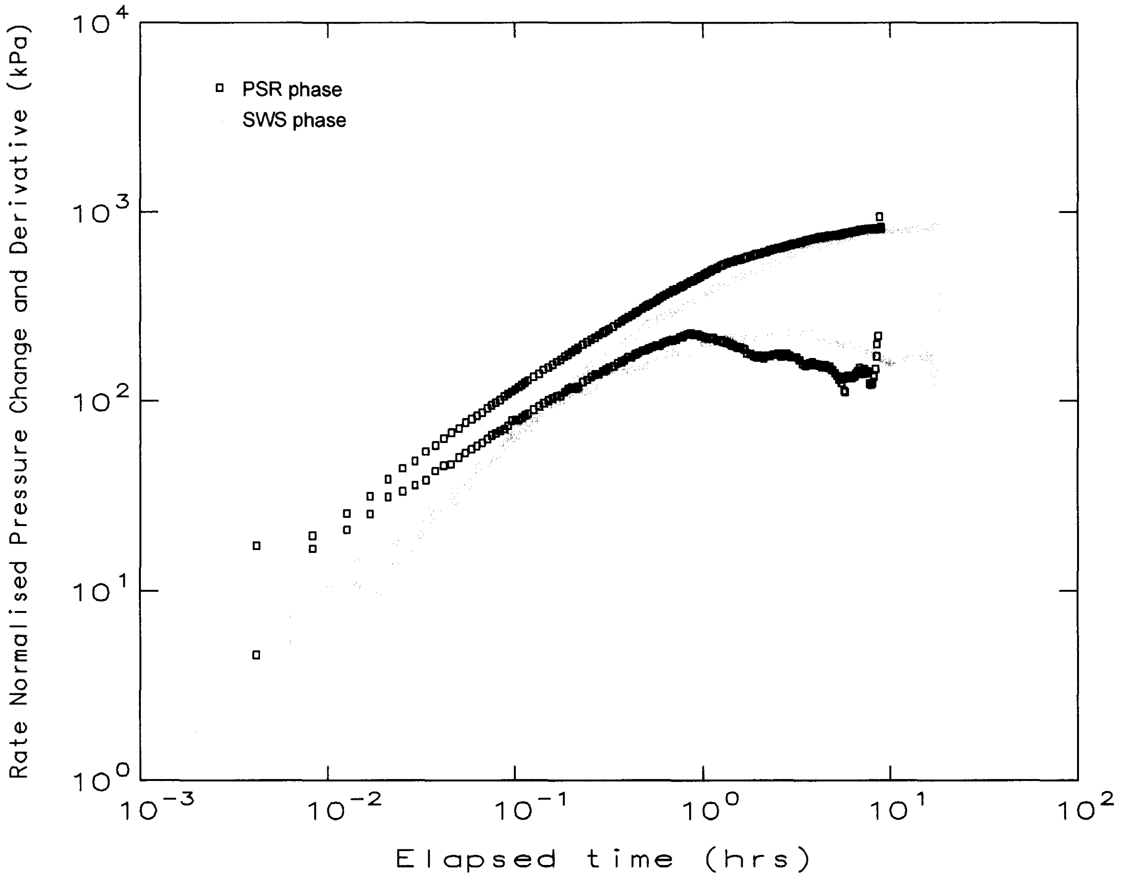


FIG. 4.4: Example of the use of a rate normalised log-log multidiagnostic plot for determining the equivalent historical flow rate (Test VM11 in SB4a/s)

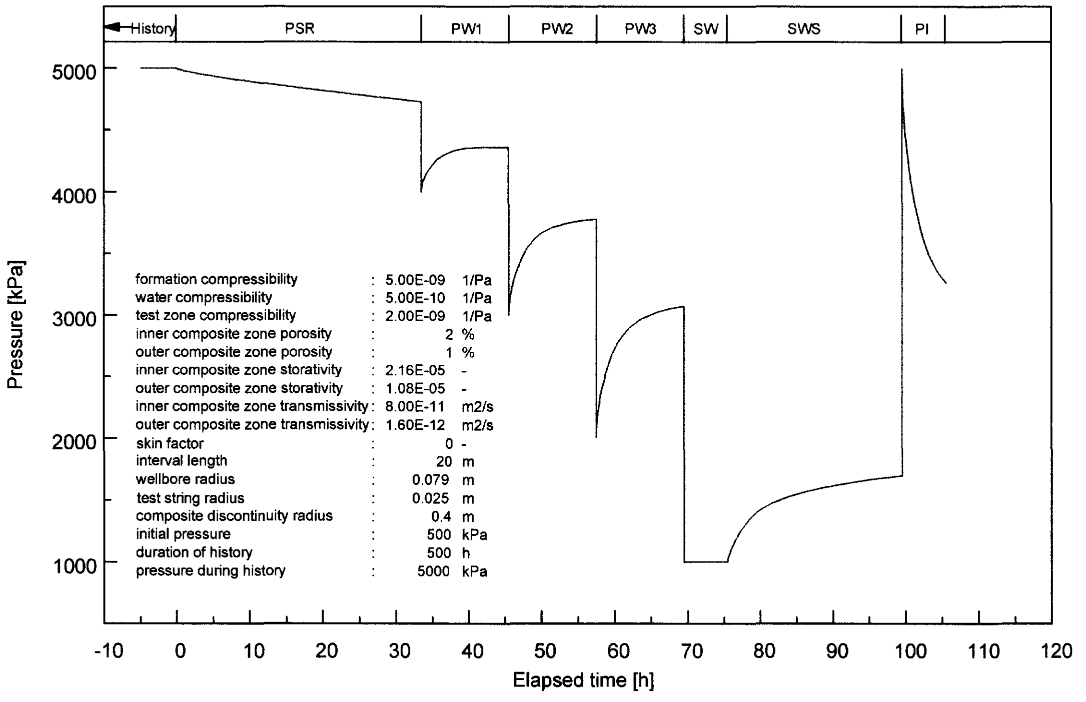


FIG. 4.5: Test example - numerically simulated

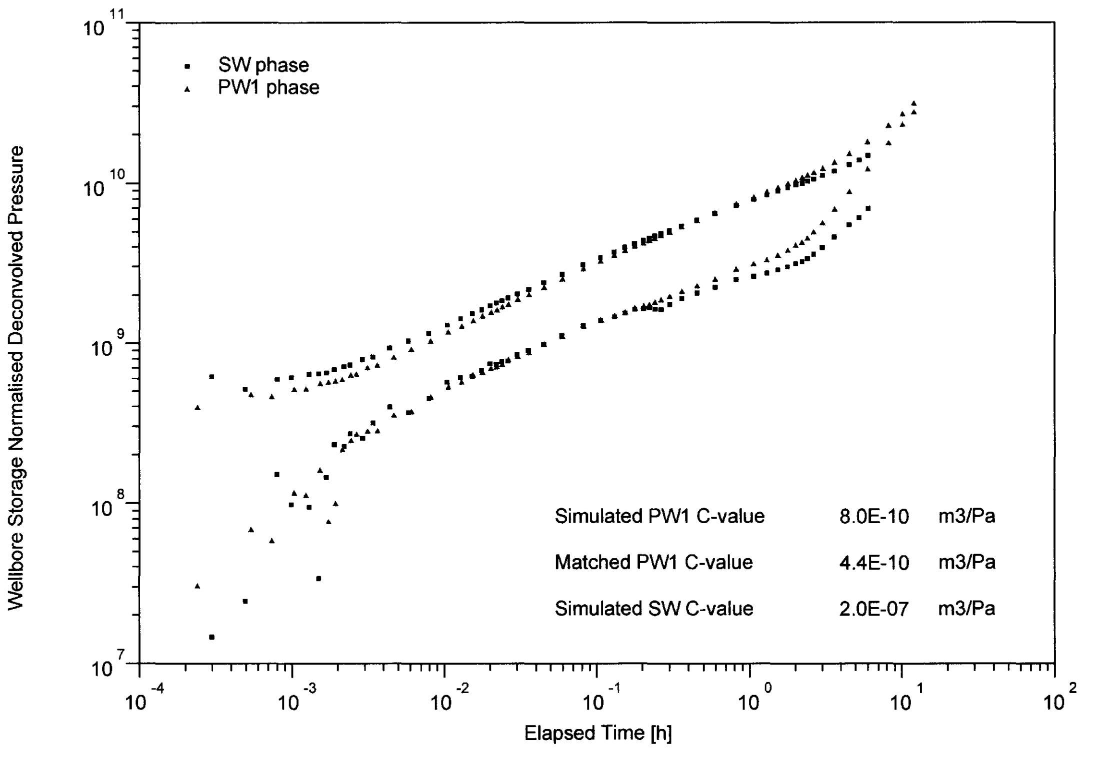


FIG. 4.6: Wellbore storage normalised log-log deconvolution plot; example for determination of the PW1 wellbore storage coefficient; test numerically simulated

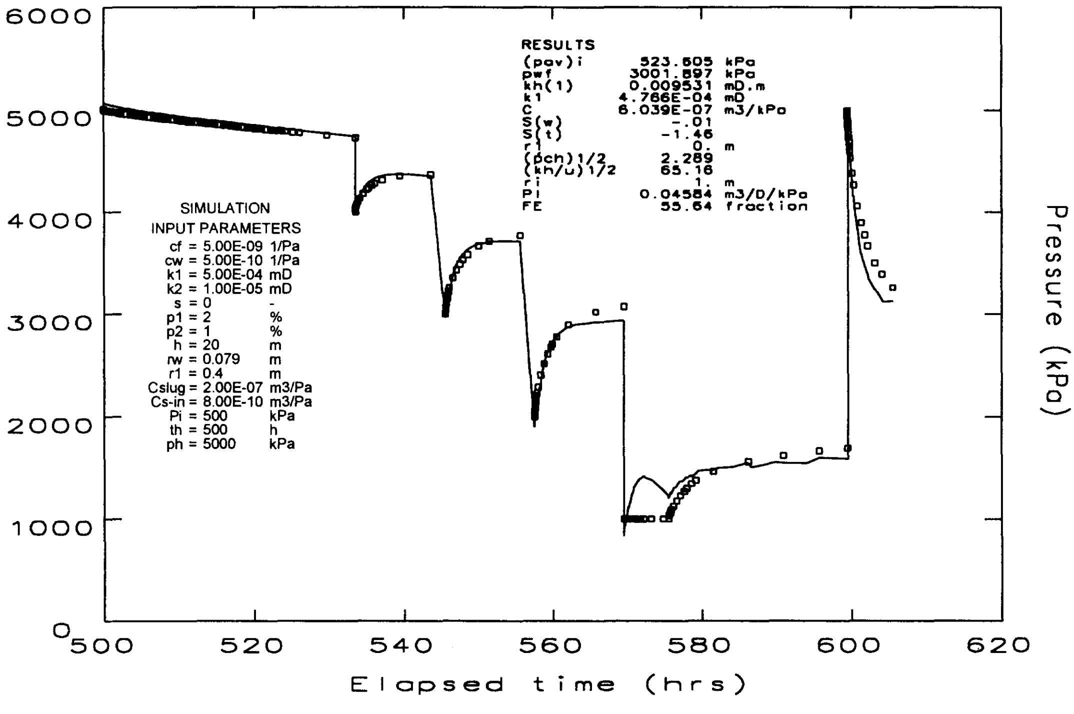


FIG. 4.7: Constant rate superposition analysis of numerically simulated test

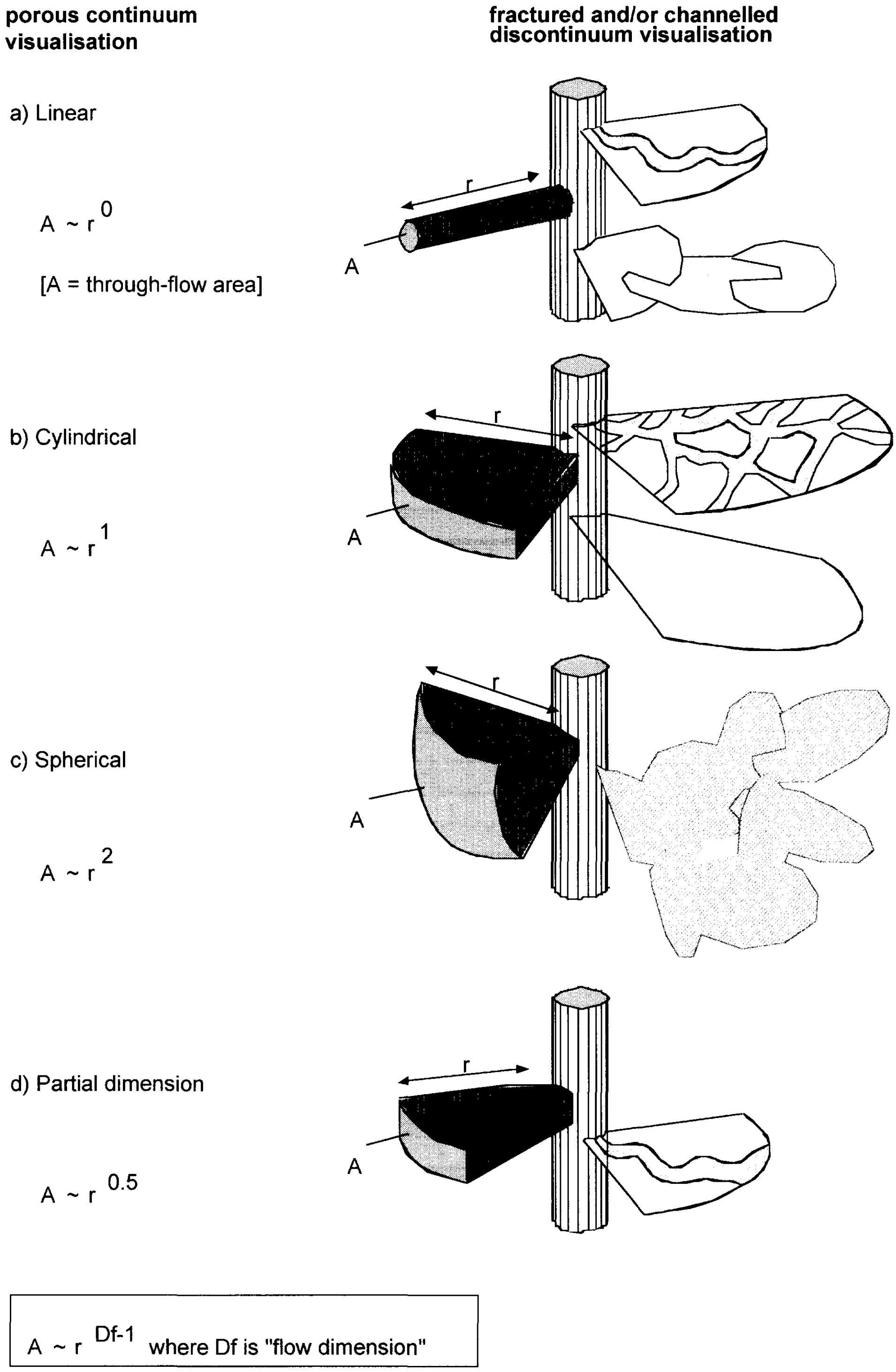


FIG. 4.8: Flow dimension definition in well testing

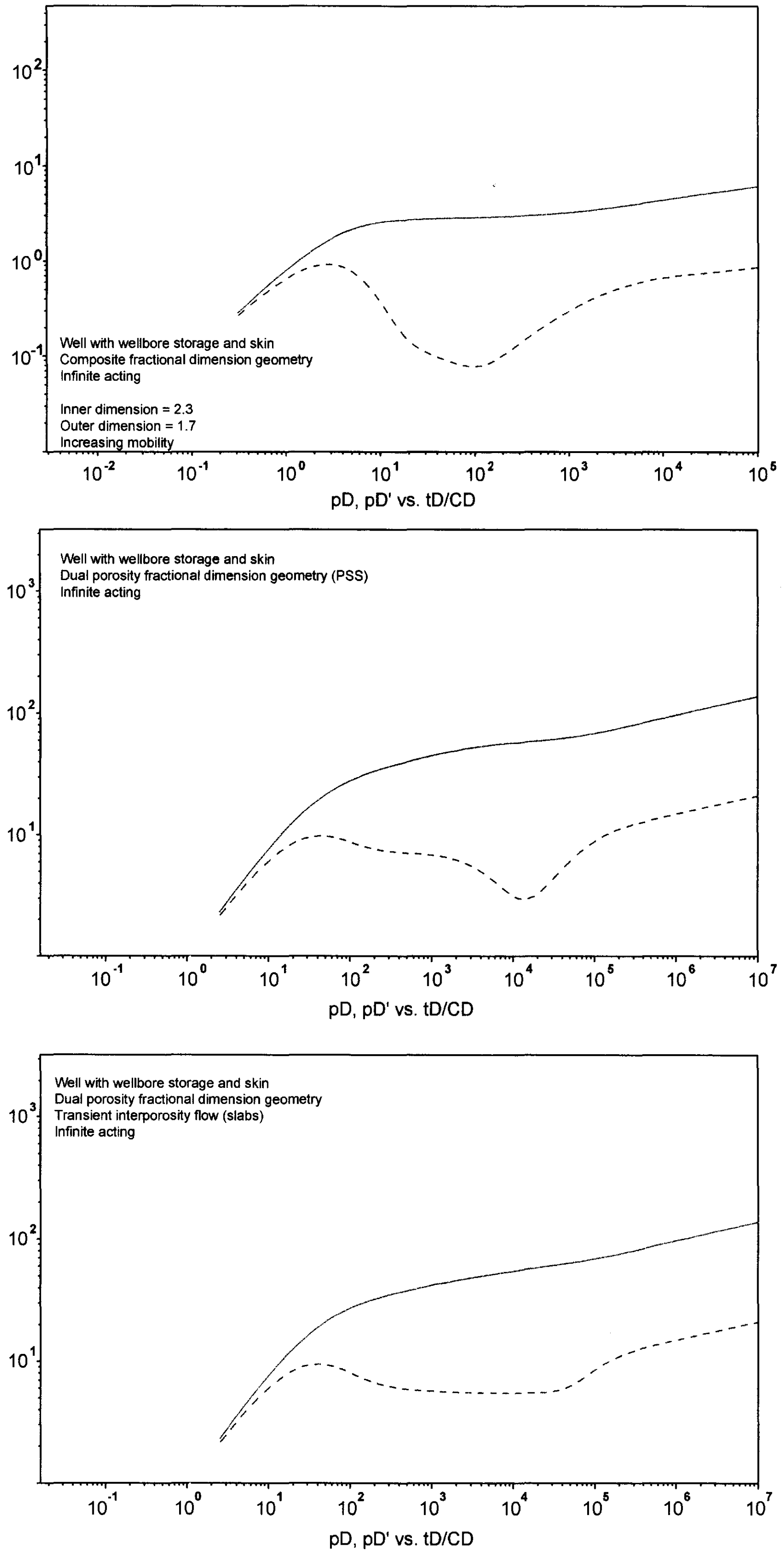


FIG. 4.9: Fractional dimension - non-homogeneous flow geometry

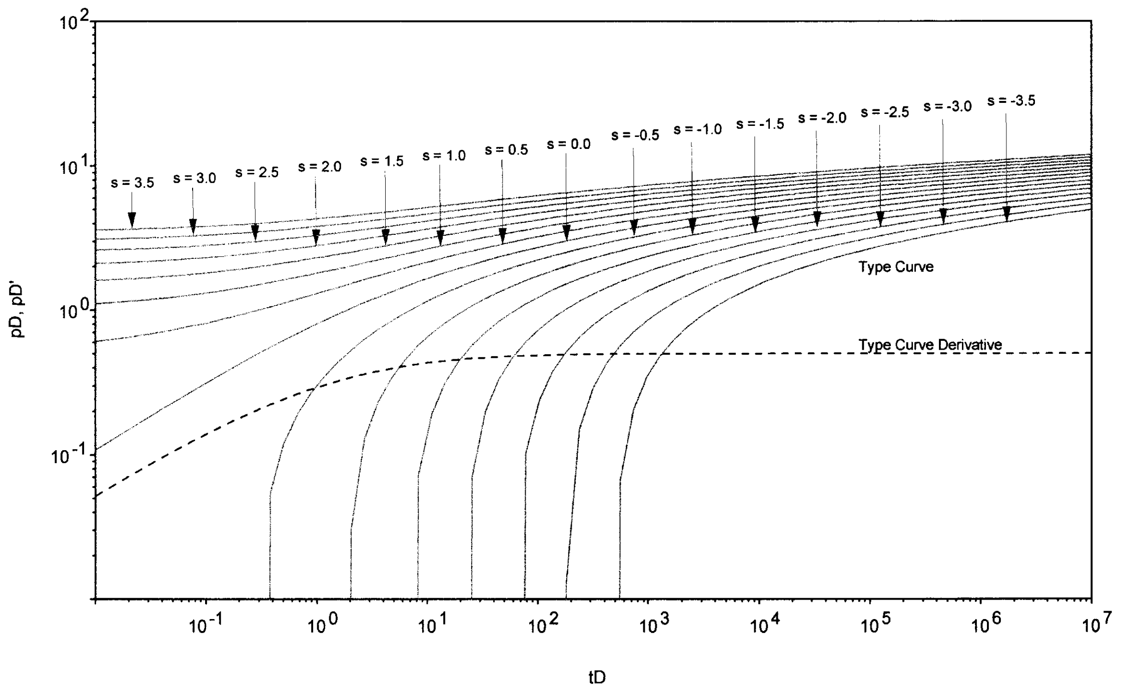
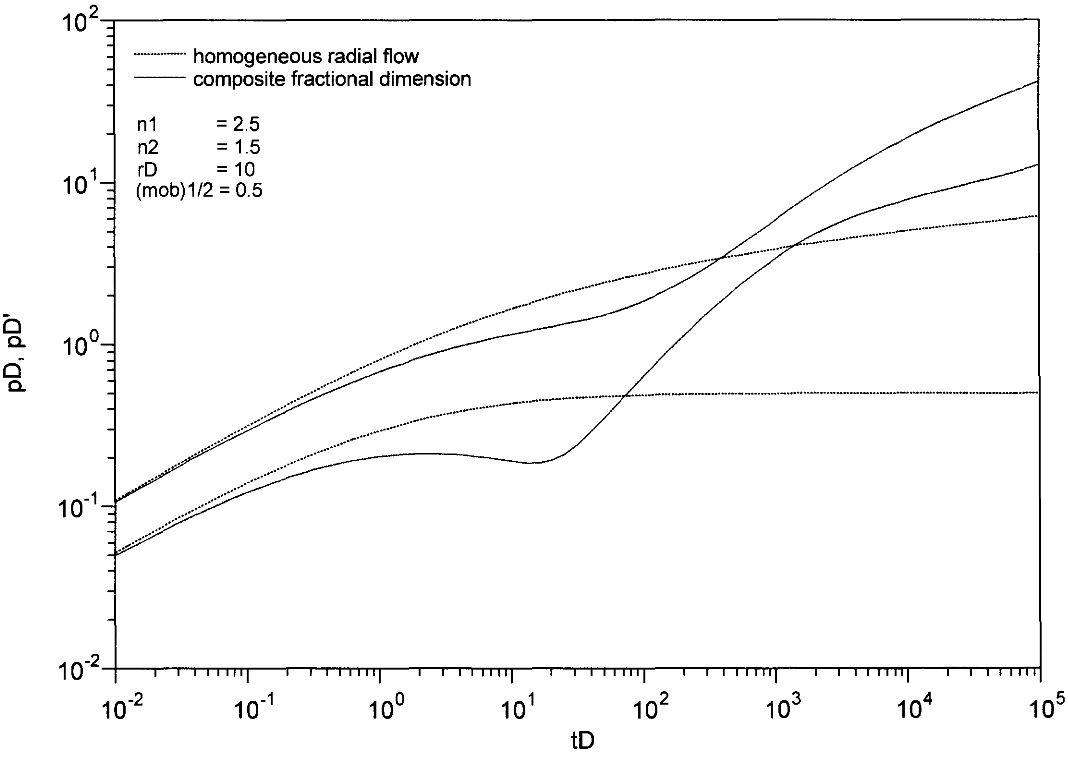


FIG. 4.10: Radial homogeneous infinite acting type curve set for slug test deconvolution analysis



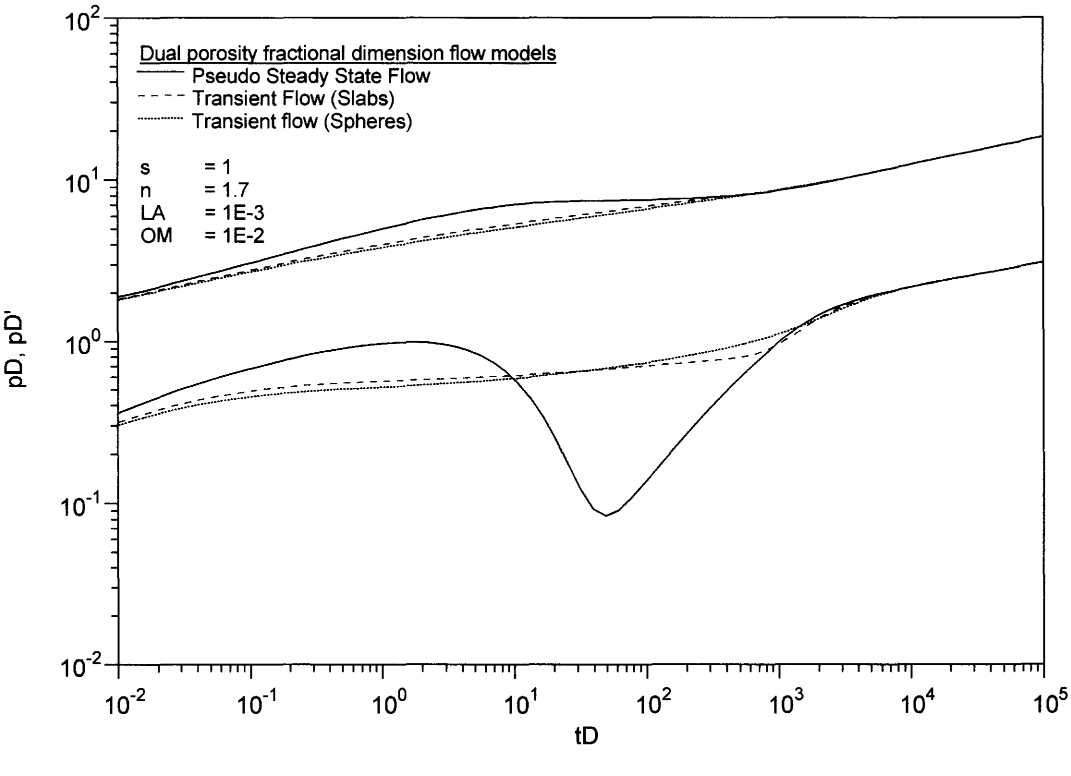


FIG. 4.11: Type curves for slug test deconvolution analysisA

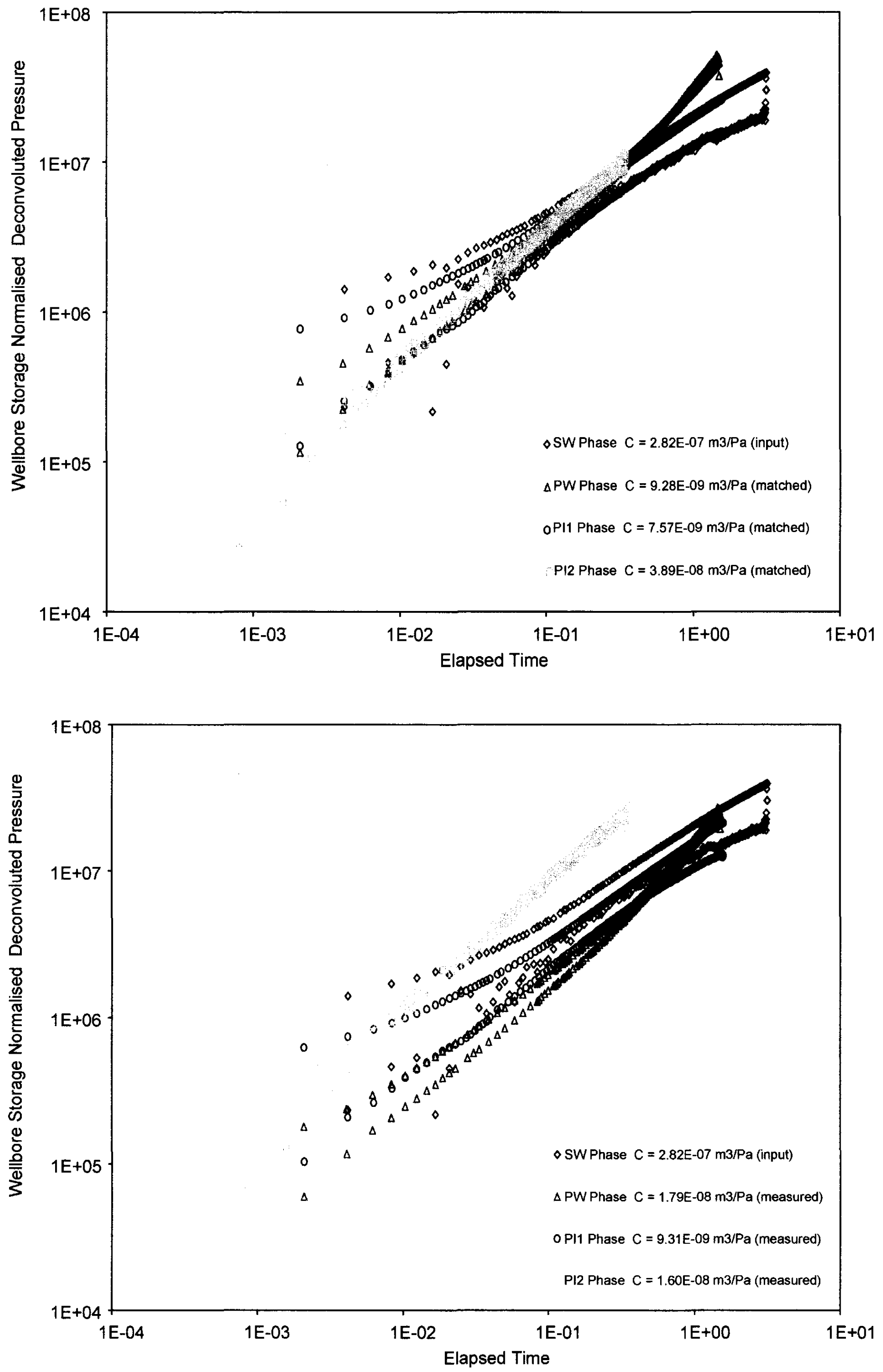


FIG. 4.12: Example of wellbore storage normalised log-log deconvolution plots using a) matched C-values and b) measured C-values (Test VM16 in SB4a/s)

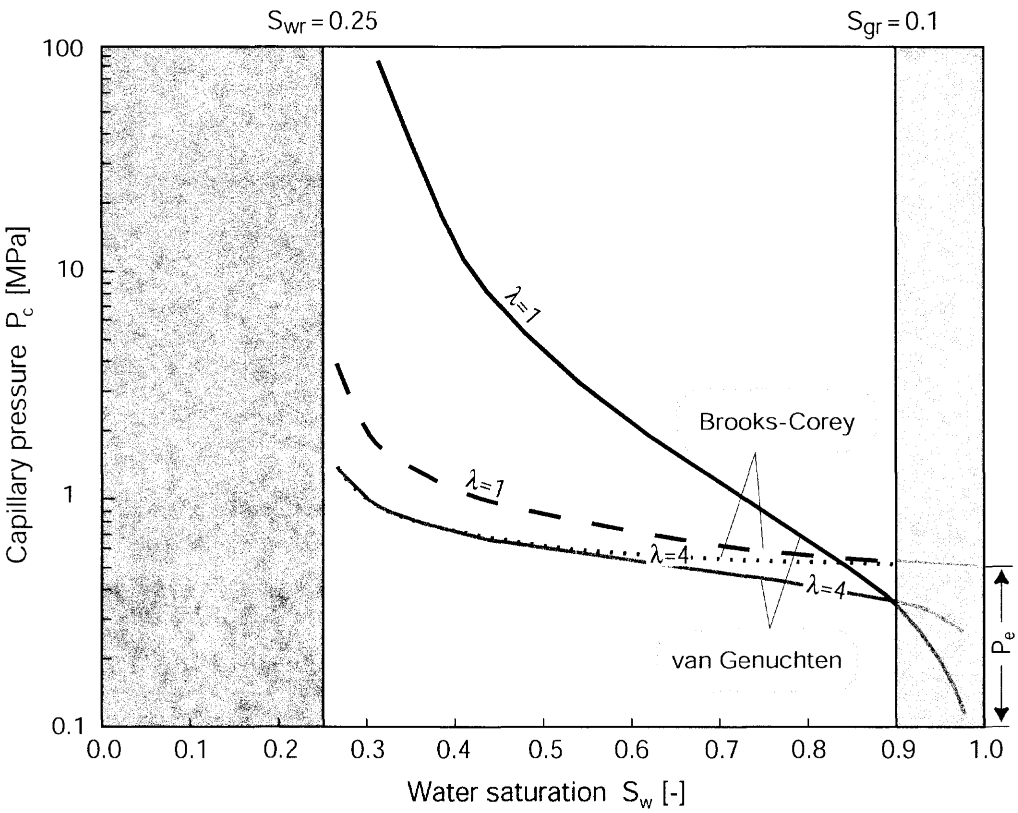


FIG. 4.13: Capillary pressure / saturation relationship - conceptual models

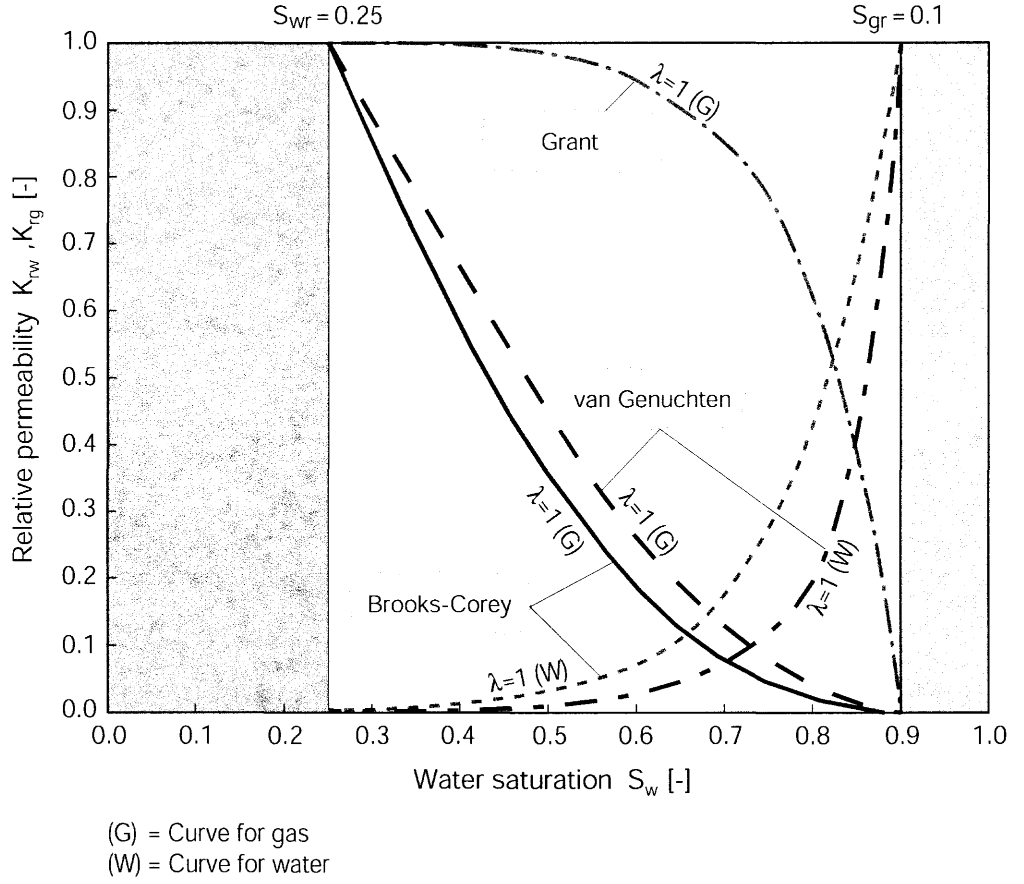


FIG. 4.14: Relative permeability / saturation relationship - conceptual models

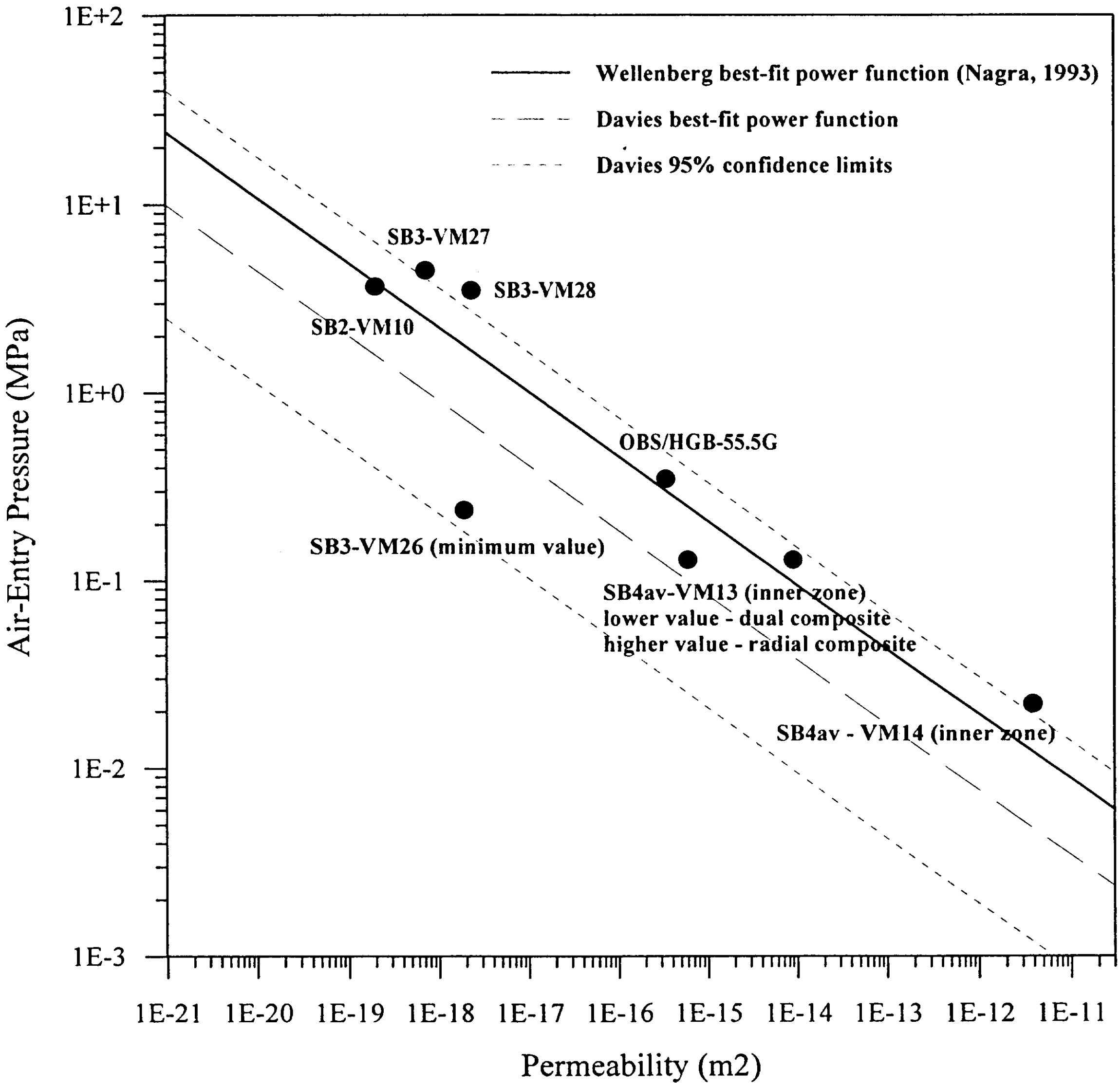


FIG. 4.15: Threshold pressure tests from SB4a and previous WLB borehole data

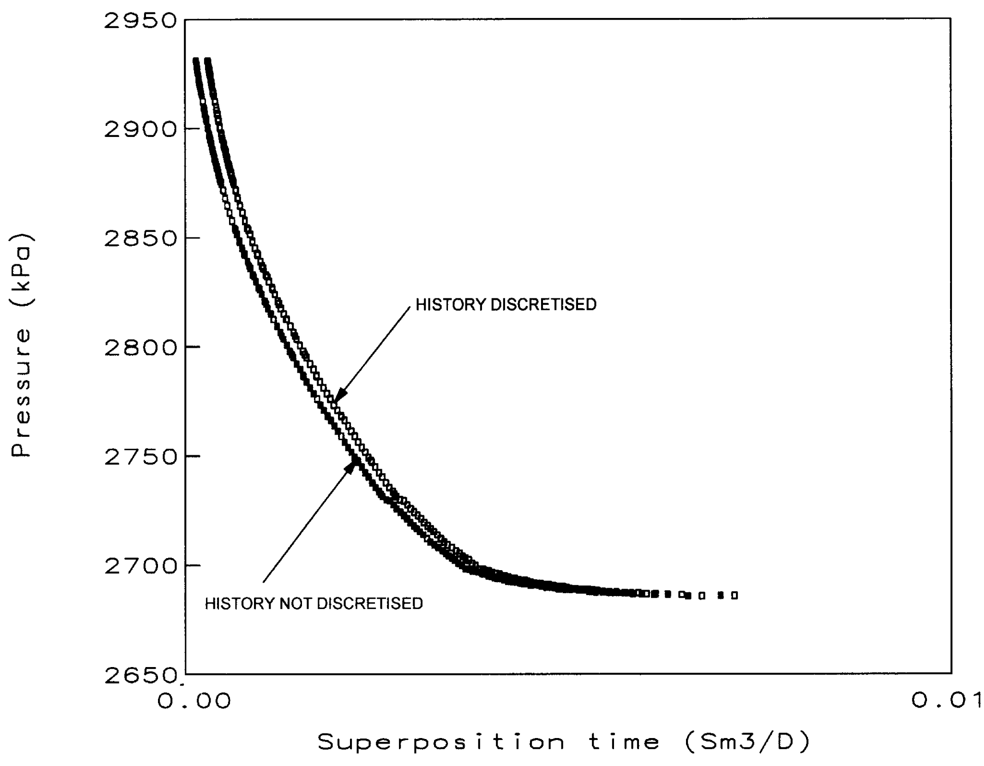
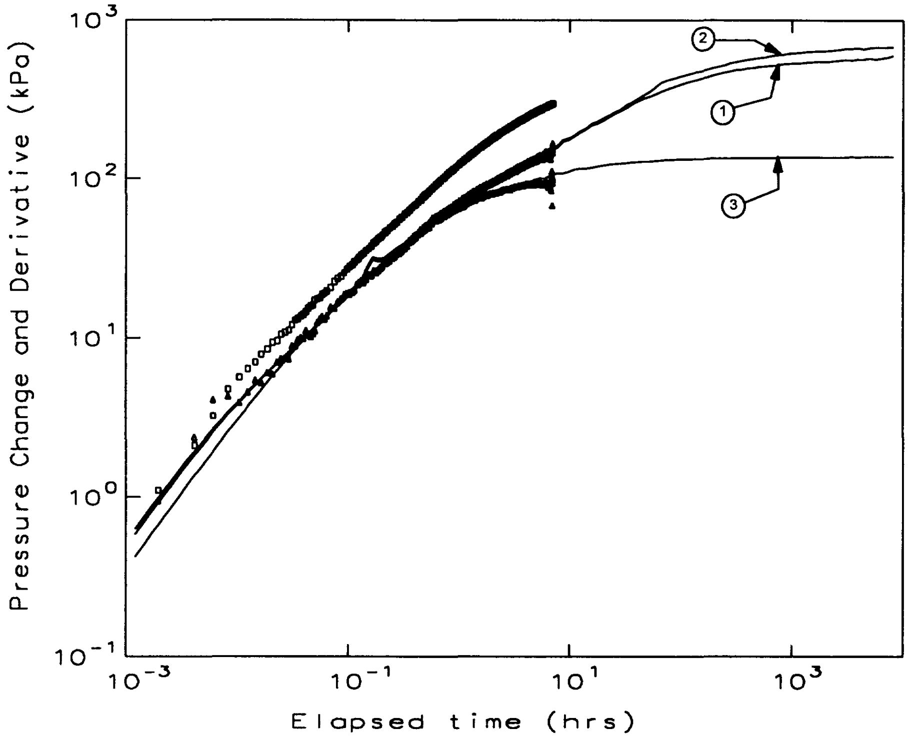
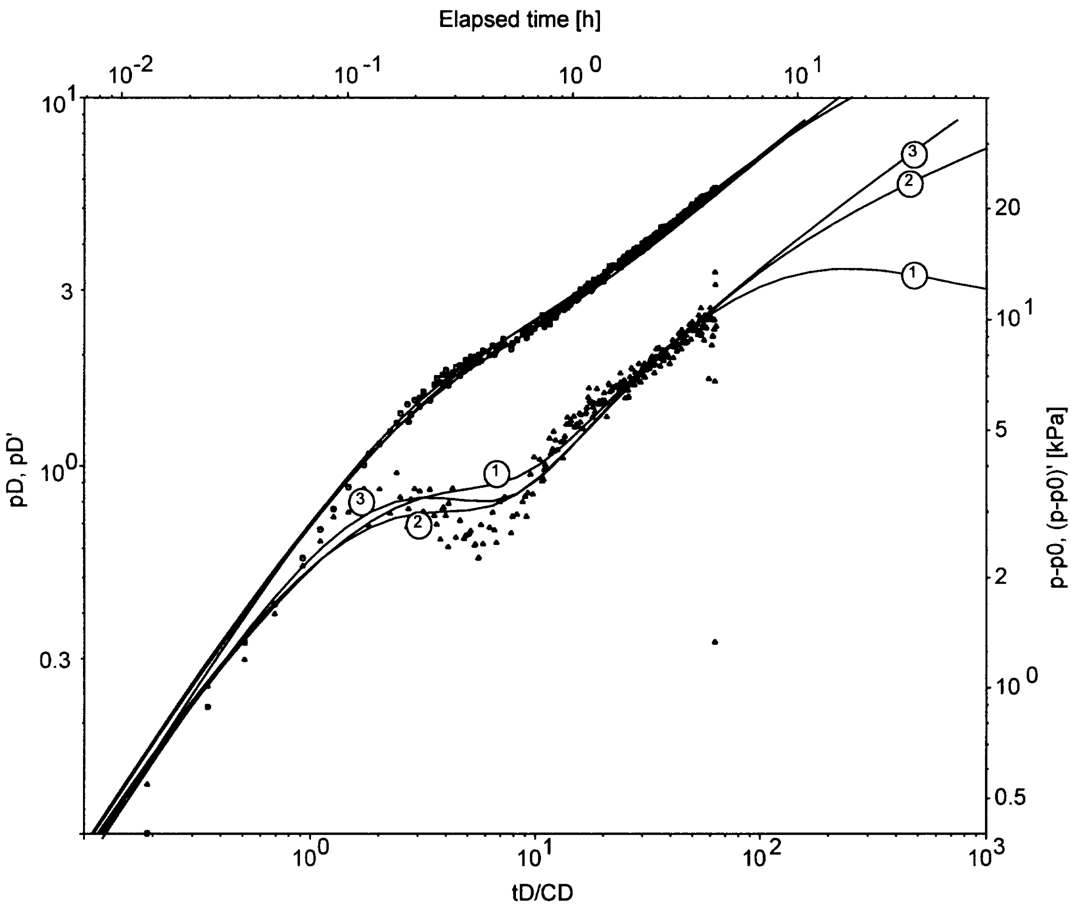


FIG. 4.16: Superposition HORNER plot, impact of history discretisation on the superposition analysis (example of the SWS phase of Test VM14 in SB4a/s)



1 - BEST GUESS HISTORICAL RATES			2 - HISTORICAL RATES * 0.1			3 - HISTORICAL RATES * 10		
(pav)i	3310.662	kPa	(pav)i	3220.344	kPa	(pav)i	3486.598	kPa
pwf	2719.850	kPa	pwf	2719.850	kPa	pwf	2719.850	kPa
kh(1)	14.01	mD.m	kh(1)	12.31	mD.m	kh(1)	14.33	mD.m
k1	4.671	mD	k1	4.104	mD	k1	4.777	mD
C	8.325E-06	m3/kPa	C	9.009E-06	m3/kPa	C	1.313E-05	m3/kPa
S(w)	-2.71		S(w)	-2.68		S(w)	-2.83	
S(t)	-3.89		S(t)	-3.92		S(t)	-3.30	
r1	3.	m	r1	3.	m	r1	2.	m
(pch)1/2	0.1029		(pch)1/2	0.1072		(pch)1/2	0.1169	
(kh/u)1/2	65.81		(kh/u)1/2	67.38		(kh/u)1/2	15.55	
ri	54.	m	ri	51.	m	ri	55.	m
PI	2.014E-04	m3/D/kPa	PI	2.377E-04	m3/D/kPa	PI	1.552E-04	m3/D/kPa
FE	1.083	fraction	FE	1.111	fraction	FE	1.066	fraction

FIG. 4.17: Influence of historical rates on analysis results (example of the SWS phase of Test VM16 in SB4a/s)



1. Match			2. Match			3. Match		
Two shell composite radial flow			Two shell composite fractional dimension			Dual porosity (Pss) fractional dimension		
T	3.57E-08	m2/s	T	3.01E-08	m2/s	T	1.39E-07	m2/s
S	2.14E-04	-	S	9.47E-05	-	S	1.25E-02	-
C	5.62E-09	m3/Pa	C	5.70E-09	m3/Pa	C	6.19E-09	m3/Pa
n1	2.00E+00	-	n1	2.17E+00	-	n1	1.02E+00	-
n2	2.00E+00	-	n2	1.37E+00	-	LA	1.81E-01	-
rD1	1.36E+01	-	rD1	1.49E+01	-	OM	1.12E-02	-
brw	5.11E+00	-	brw	2.56E-01	-			

FIG. 4.18: Example of sensitivity analysis to flow model selection (Test VM16 in SB4a/s)

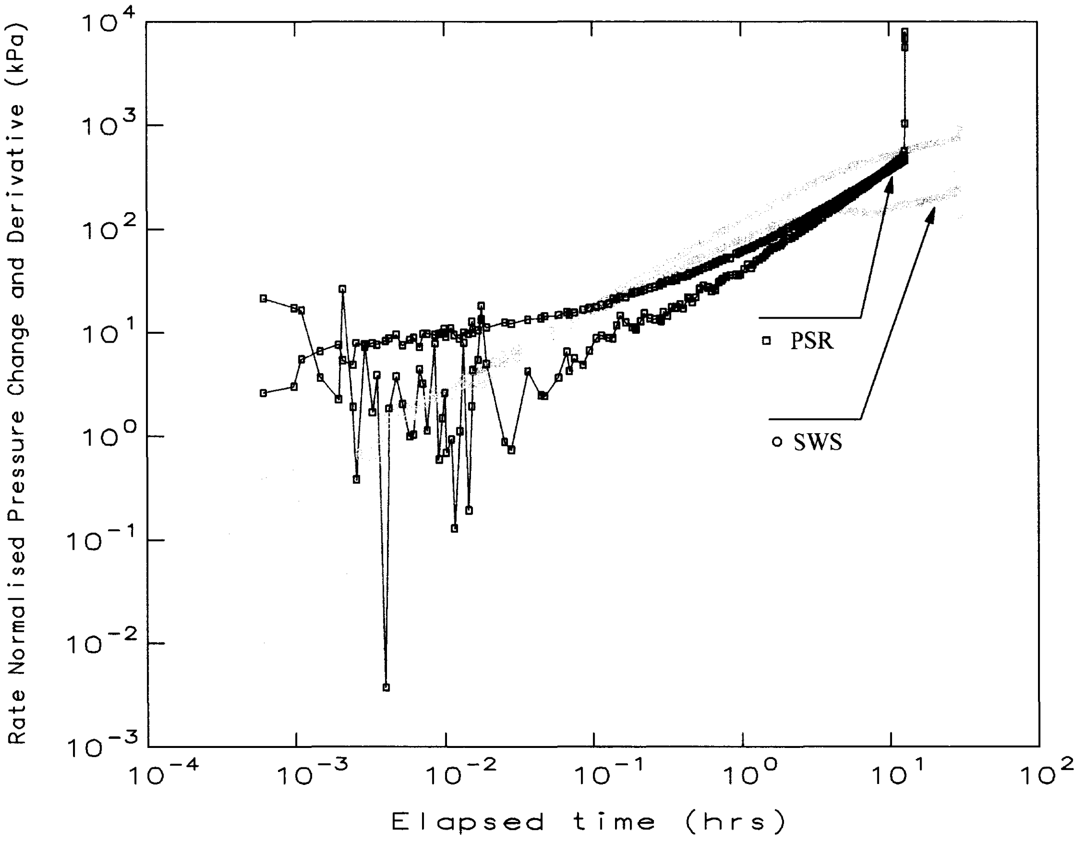


FIG. 5.1: SB4a/v - T7; Rate normalised multi-diagnostic plot

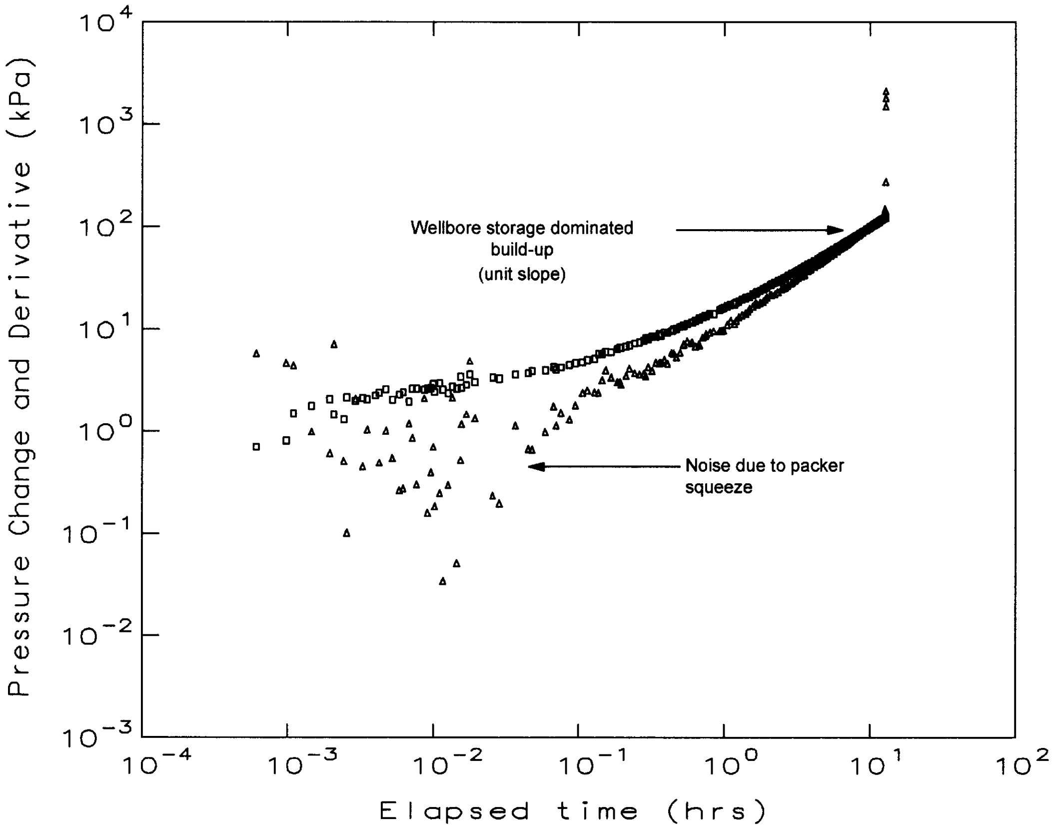
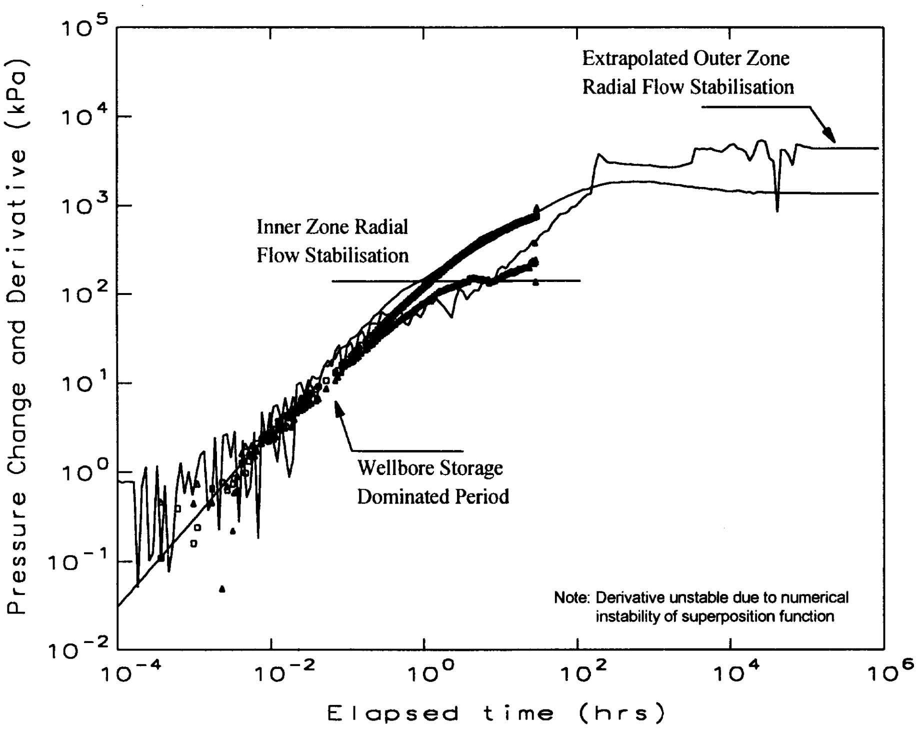


FIG. 5.2: SB4a/v - T7; PSR phase; Diagnostic plot

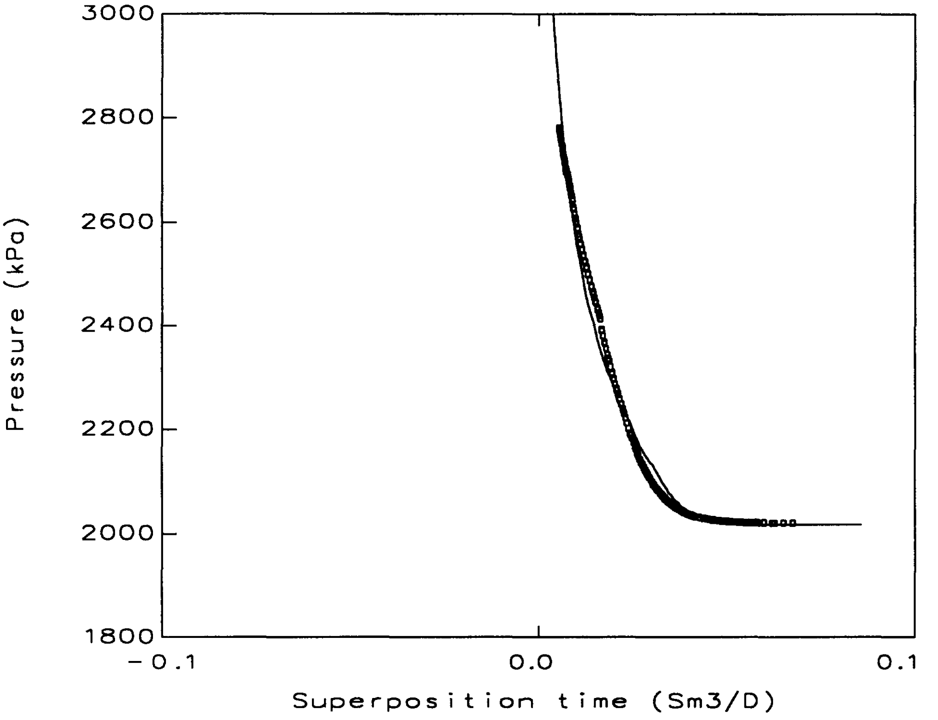


RESULTS		
(pav)i	3395.754	kPa
pwf	2020.260	kPa
kh(1)	0.1412	mD.m
k1	0.01077	mD
C	1.480E-06	m3/kPa
S(w)	-.72	
S(t)	-2.71	
r1	1.	m
(pch)1/2	1.230	
(kh/u)1/2	55.58	
ri	6.	m
PI	8.361E-06	m3/D/kPa
FE	1.082	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.3: SB4a/v - T7; SWS phase; Log-log match; composite model

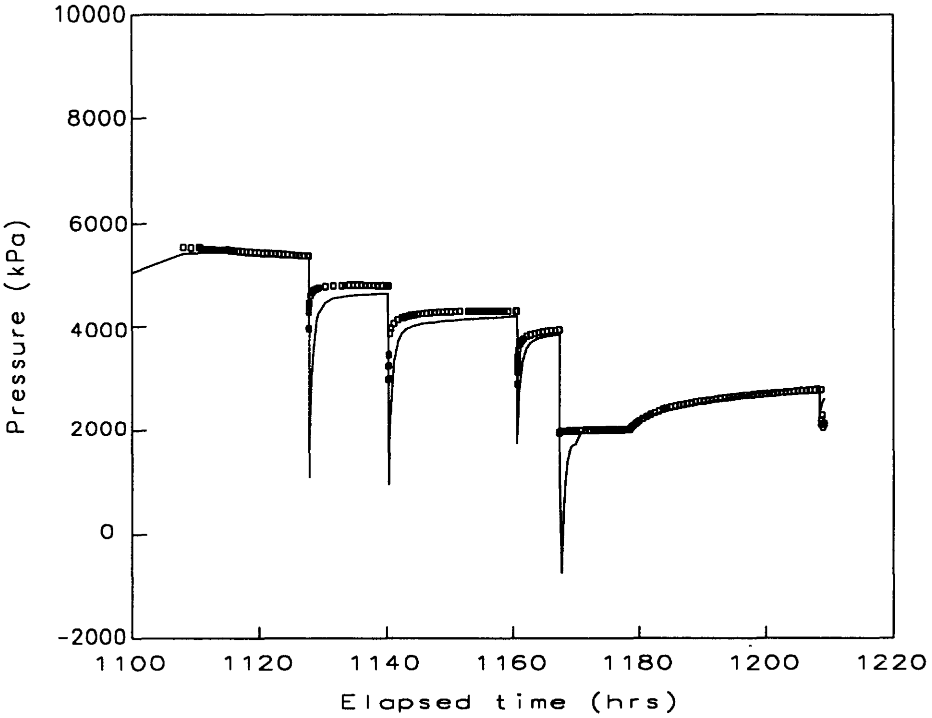


RESULTS		
(pav)i	3395.754	kPa
pwf	2020.260	kPa
kh(1)	0.1412	mD.m
k1	0.01077	mD
C	1.480E-06	m3/kPa
S(w)	-.72	
S(t)	-2.71	
r1	1.	m
(pch)1/2	1.230	
(kh/u)1/2	55.58	
ri	6.	m
PI	8.361E-06	m3/D/kPa
FE	1.082	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.4: SB4a/v - T7; SWS phase; Superposition HORNER match; composite model

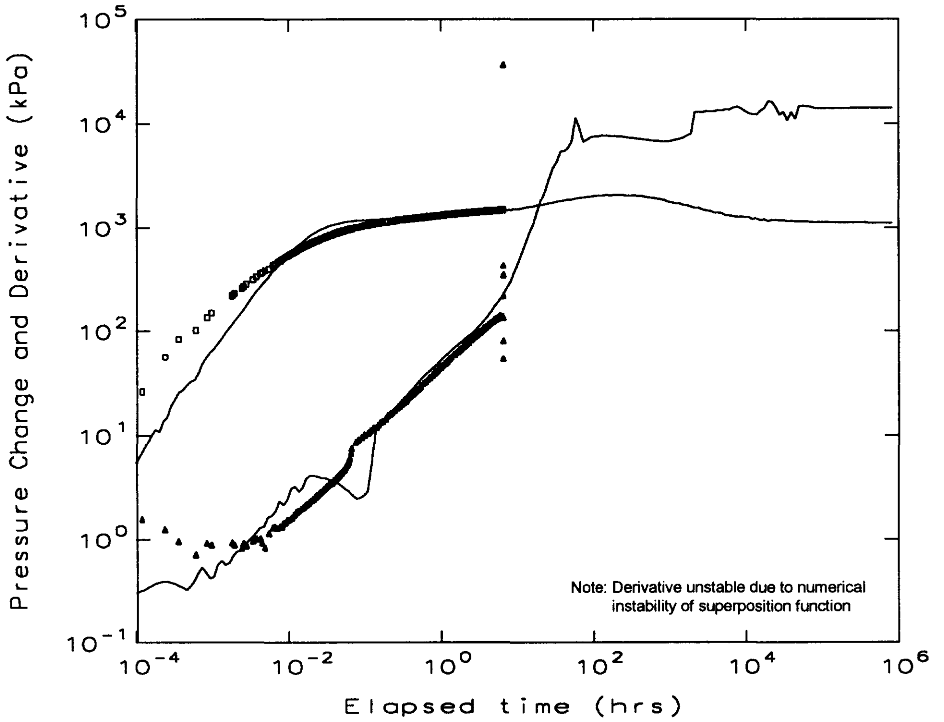


RESULTS		
(pav)i	3395.754	kPa
pwf	2020.260	kPa
kh(1)	0.1412	mD.m
k1	0.01077	mD
C	1.480E-06	m3/kPa
S(w)	-.72	
S(t)	-2.71	
r1	1.	m
(pch)1/2	1.230	
(kh/u)1/2	55.58	
ri	6.	m
PI	8.361E-06	m3/D/kPa
FE	1.082	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.5: SB4a/v - T7; SWS phase; Measured and simulated pressure response; composite model



	RESULTS	
(pav)i	3635.853	kPa
pwf	2458.621	kPa
kh(1)	3.932	mD.m
k1	0.2999	mD
C	1.718E-06	m3/kPa
S(w)	-.60	
S(t)	-2.45	
r1	1.	m
(pch)1/2	0.6214	
(kh/u)1/2	1808.2	
ri	14.	m
PI	2.698E-05	m3/D/kPa
FE	1.008	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.6: SB4a/v - T7; PW3 phase; Log-log match; composite model

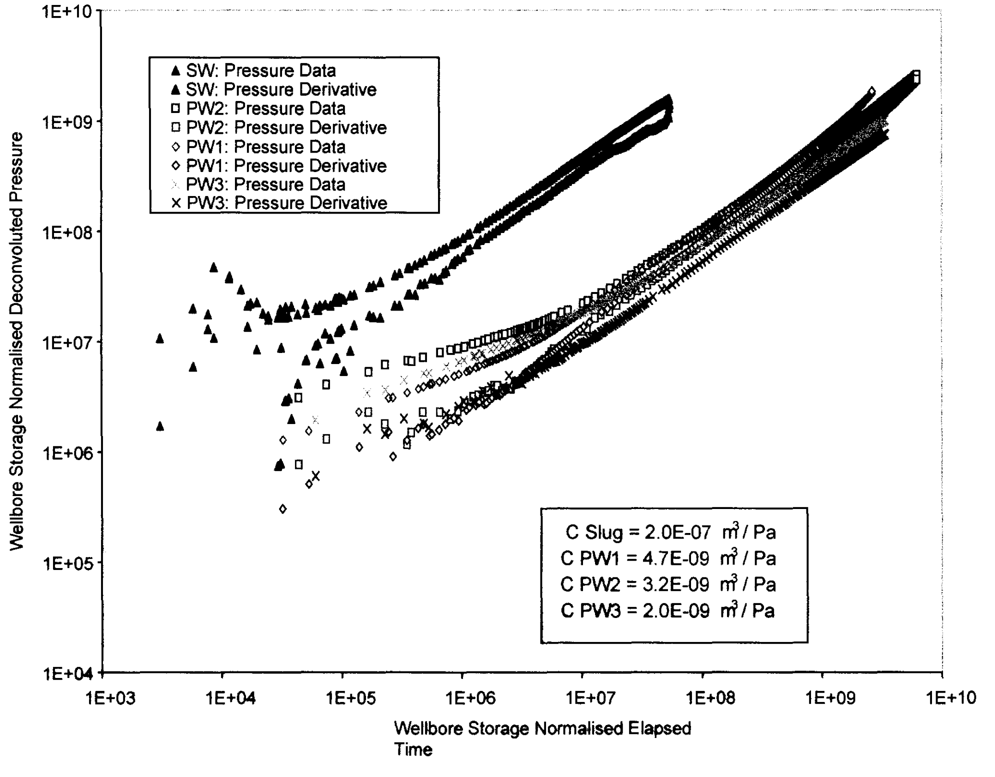


FIG. 5.7: SB4a/v - T7; Wellbore storage normalised deconvolution plot of PW1, PW2, PW3 and SW phases

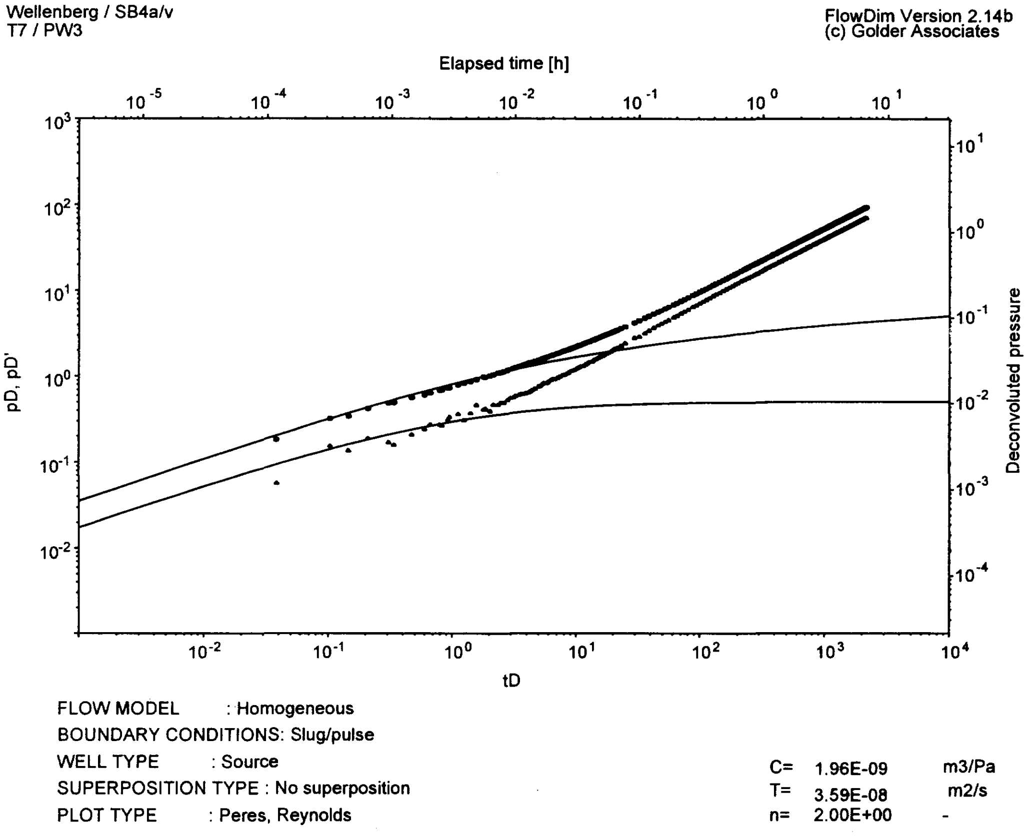
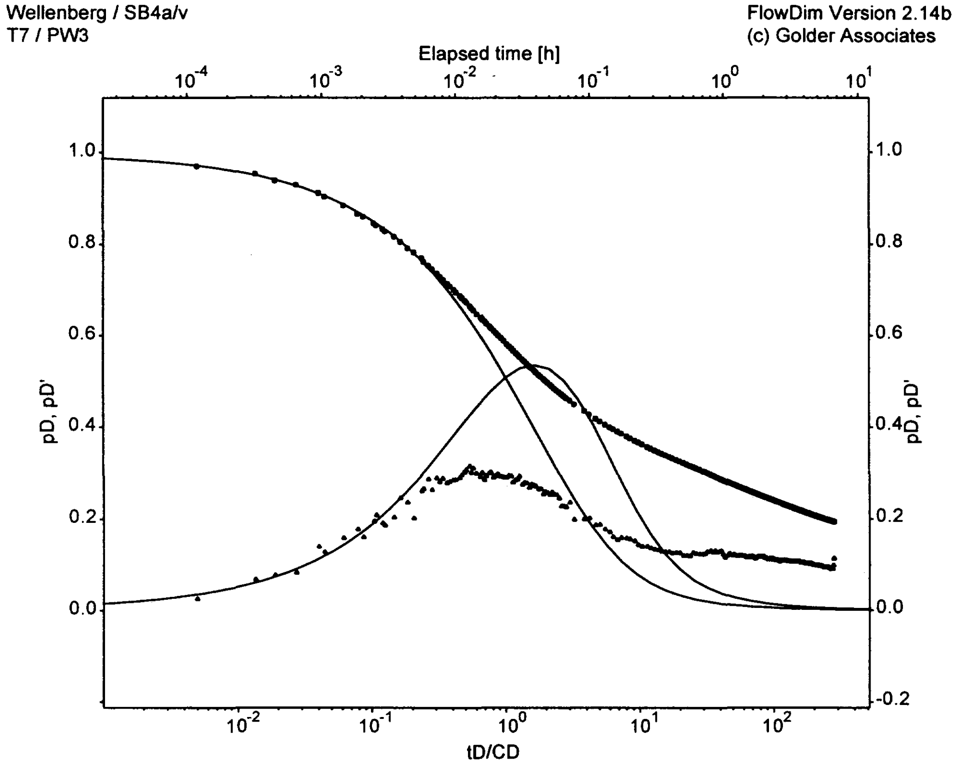
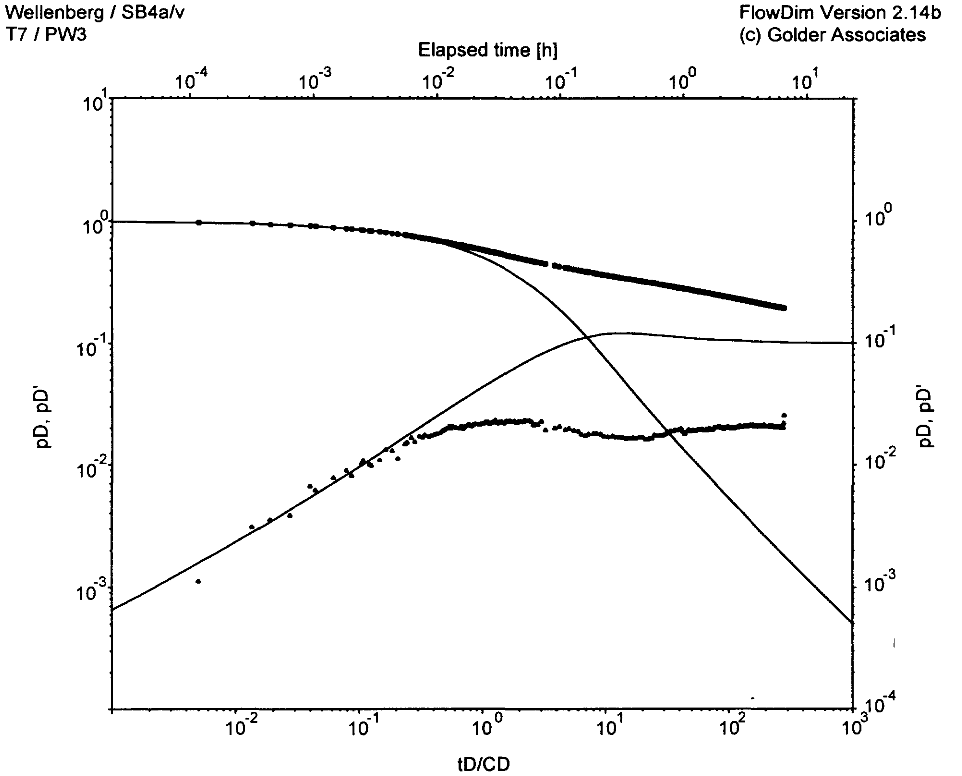


FIG. 5.8: SB4a/v - T7; PW3 phase; Deconvolution log-log match; homogeneous model



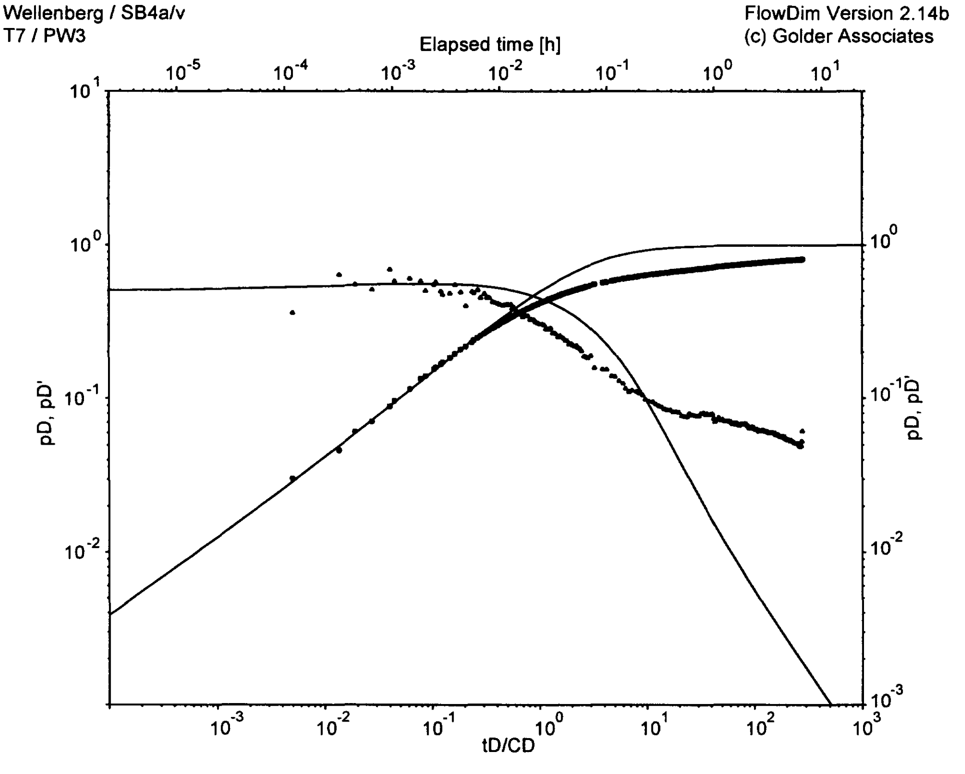
FLOW MODEL : Homogeneous	T	3.59E-08	m2/s
BOUNDARY CONDITIONS: Slug/pulse	S	5.63E-05	-
WELL TYPE : Source	C	1.96E-09	m3/Pa
SUPERPOSITION TYPE : No superposition	n1	2.00E+00	-
PLOT TYPE : Ramey A			

FIG. 5.9: SB4a/v - T7; PW3 phase; RAMEY A match; homogeneous model



FLOW MODEL : Homogeneous	T	3.59E-08	m2/s
BOUNDARY CONDITIONS: Slug/pulse	S	5.63E-05	-
WELL TYPE : Source	C	1.96E-09	m3/Pa
SUPERPOSITION TYPE : No superposition	n1	2.00E+00	-
PLOT TYPE : Ramey B			

FIG. 5.10: SB4a/v - T7; PW3 phase; RAMEY B match; homogeneous model



FLOW MODEL : Homogeneous	T	3.59E-08	m2/s
BOUNDARY CONDITIONS: Slug/pulse	S	5.63E-05	-
WELL TYPE : Source	C	1.96E-09	m3/Pa
SUPERPOSITION TYPE : No superposition			
PLOT TYPE : Ramey C	n1	2.00E+00	-

FIG. 5.11: SB4a/v - T7; PW3 phase; RAMEY C match; homogeneous model

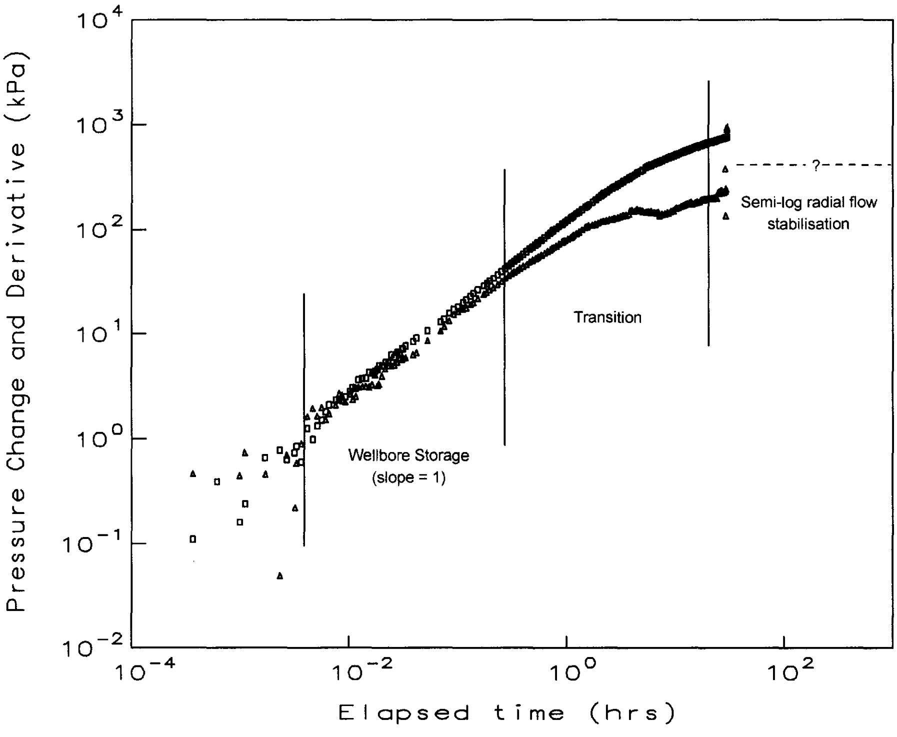
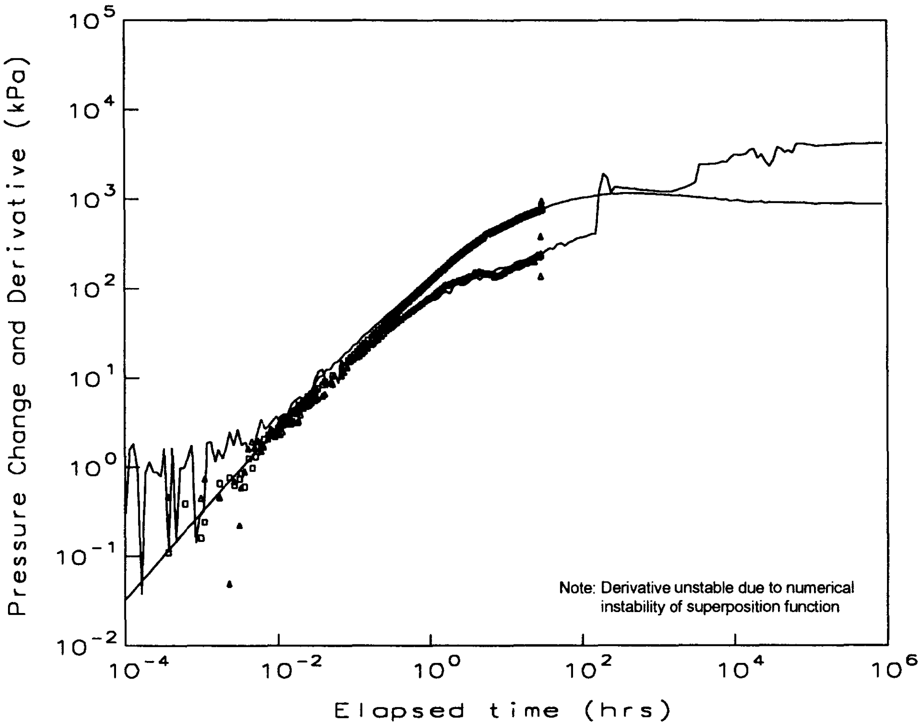
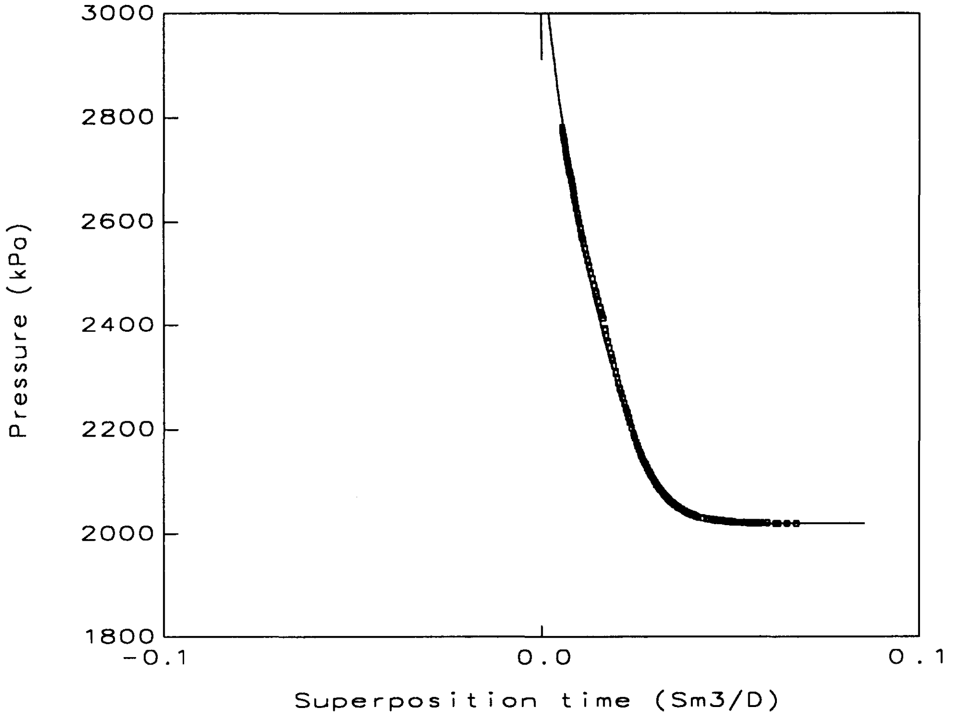


FIG. 5.12: SB4a/v - T7; SWS phase; Diagnostic plot; homogeneous model



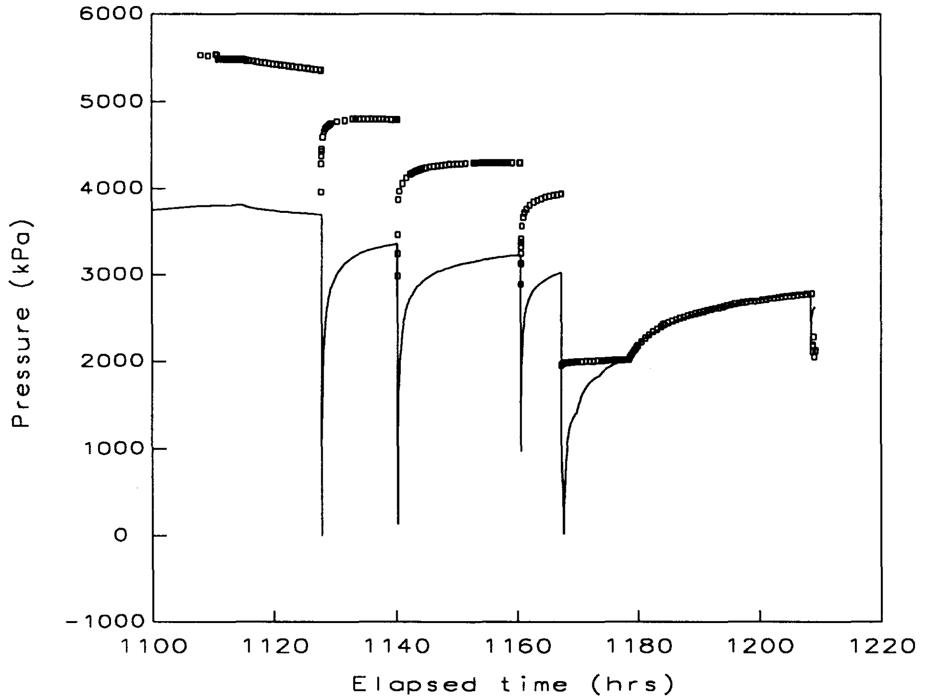
RESULTS			MODEL
(pav)i	2923.897	kPa	Wellbore Storage and Skin (C and S)
pwf	2020.260	kPa	Homogeneous
kh	0.002541	mD.m	Infinite Lateral Extent
k	1.938E-04	mD	
C	1.479E-06	m3/kPa	
S	-4.11		
xf	9.6	m	
ri	1.	m	
PI	1.273E-05	m3/D/kPa	
FE	40.52	fraction	

FIG. 5.13: SB4a/v - T7; SWS phase; Log-log match; homogeneous model



RESULTS			MODEL
(pav)i	2923.897	kPa	Wellbore Storage and Skin (C and S)
pwf	2020.260	kPa	Homogeneous
kh	0.002541	mD.m	Infinite Lateral Extent
k	1.938E-04	mD	
C	1.479E-06	m3/kPa	
S	-4.11		
xf	9.6	m	
ri	1.	m	
PI	1.273E-05	m3/D/kPa	
FE	40.52	fraction	

FIG. 5.14: SB4a/v - T7; SWS phase; Superposition HORNER match; homogeneous model



RESULTS

(pav)i	2923.897	kPa
pwf	2020.260	kPa
kh	0.002541	mD.m
k	1.938E-04	mD
C	1.479E-06	m3/kPa
S	-4.11	
xf	9.6	m
ri	1.	m
PI	1.273E-05	m3/D/kPa
FE	40.52	fraction

MODEL

Wellbore Storage and Skin (C and S)
Homogeneous
Infinite Lateral Extent

FIG. 5.15: SB4a/v - T7; SWS phase; Measured and simulated pressure response; homogeneous model

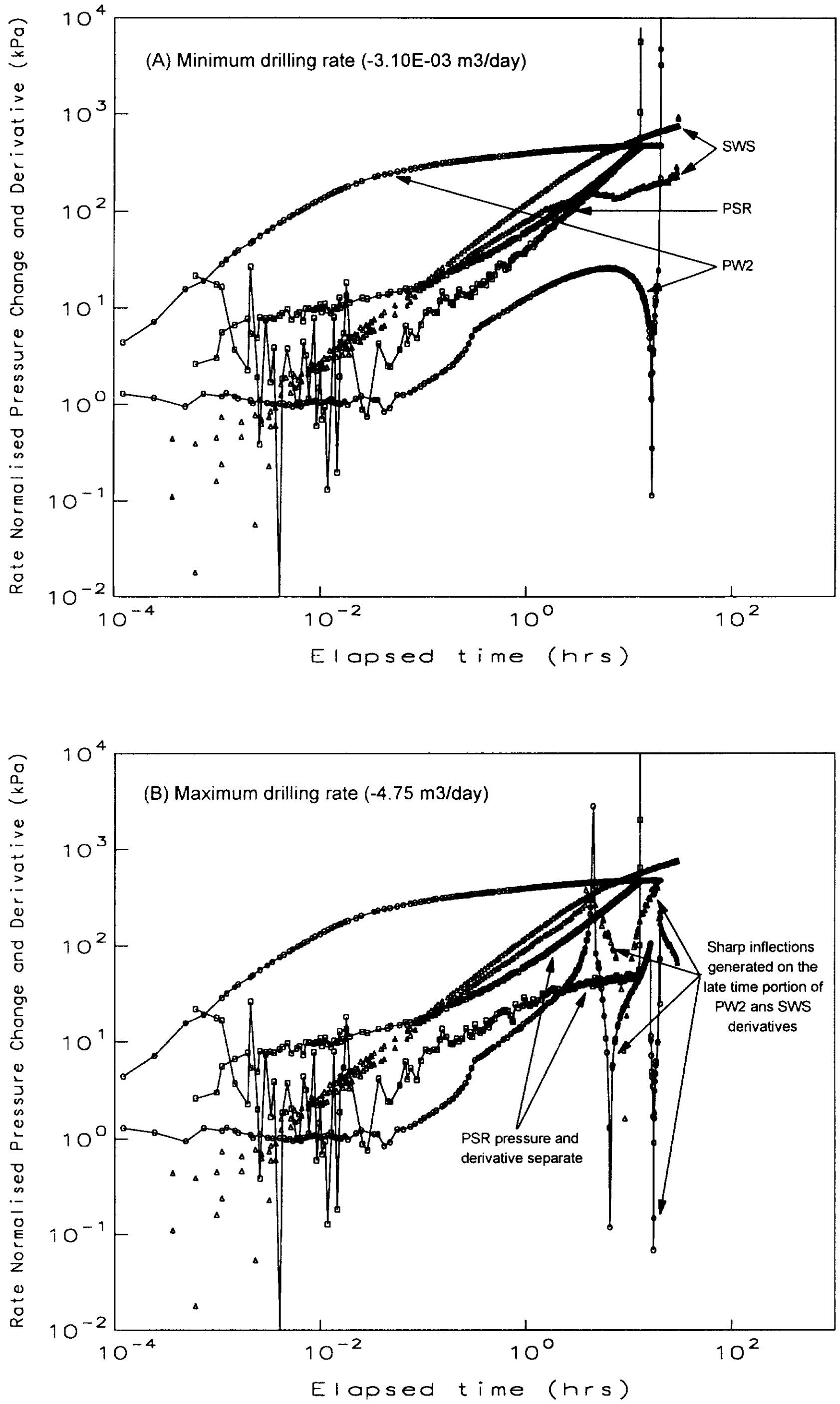


FIG. 5.16: SB4a/v - T7; Impact of minimum (A) and maximum (B) potential drilling rates compared

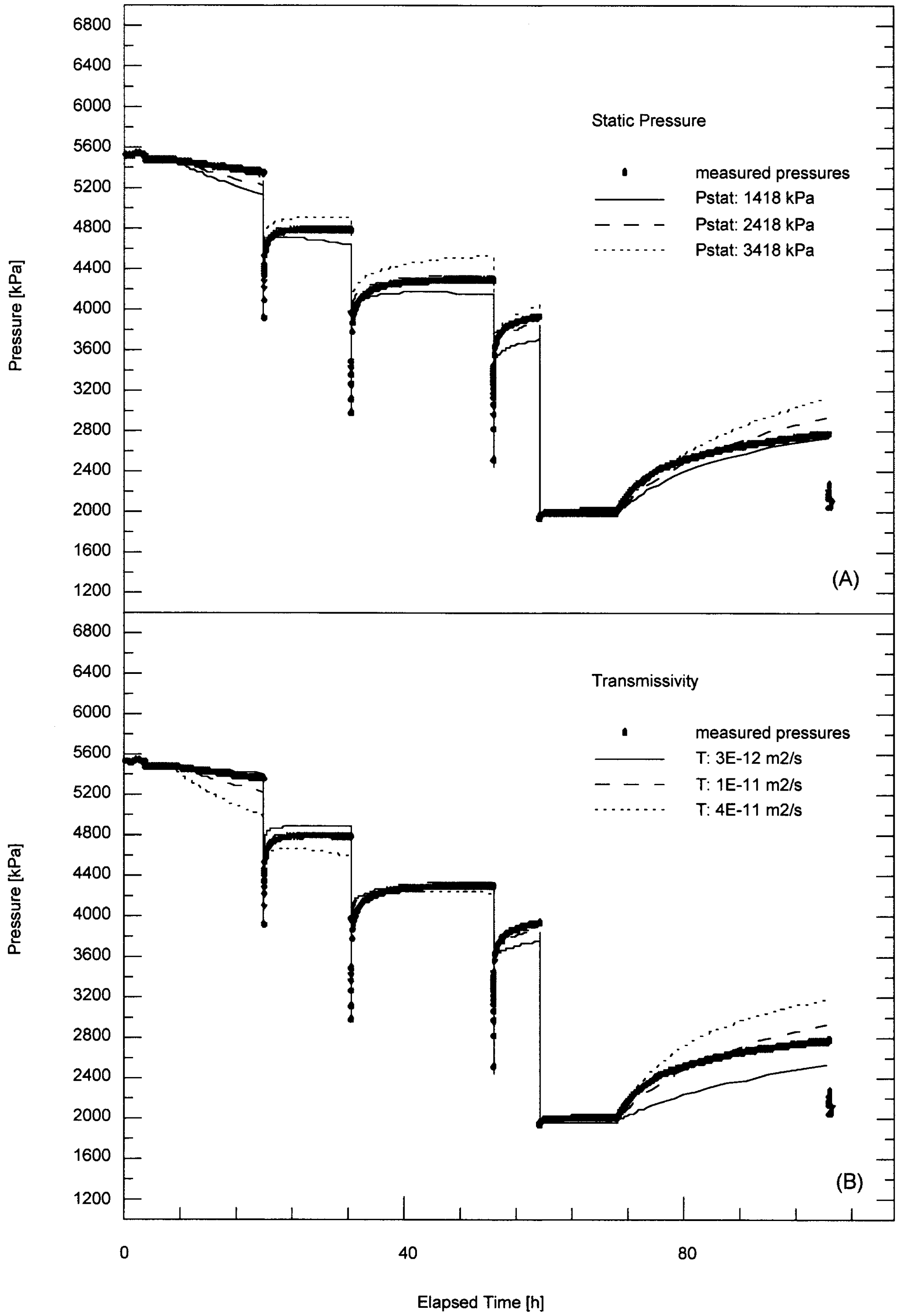


FIG. 5.17: SB4a/v - T7; Consistency check with GTFM

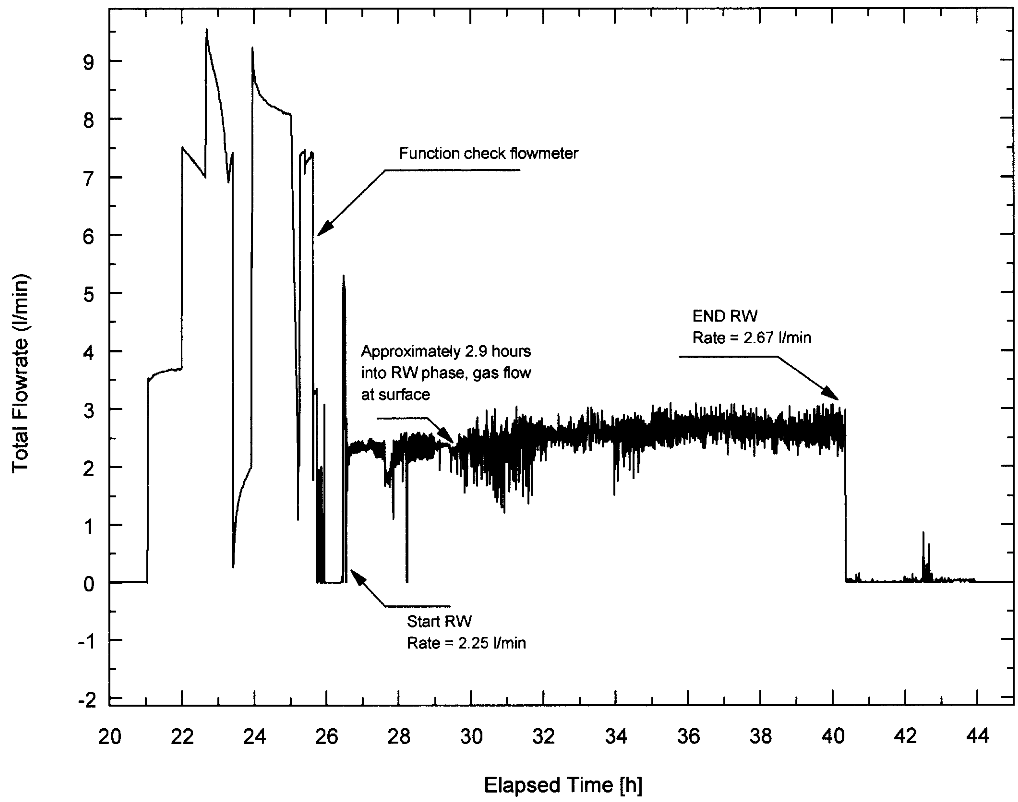


FIG. 5.18: SB4a/s - VM4; Total rate measured during RW phase prior to flow through the separator

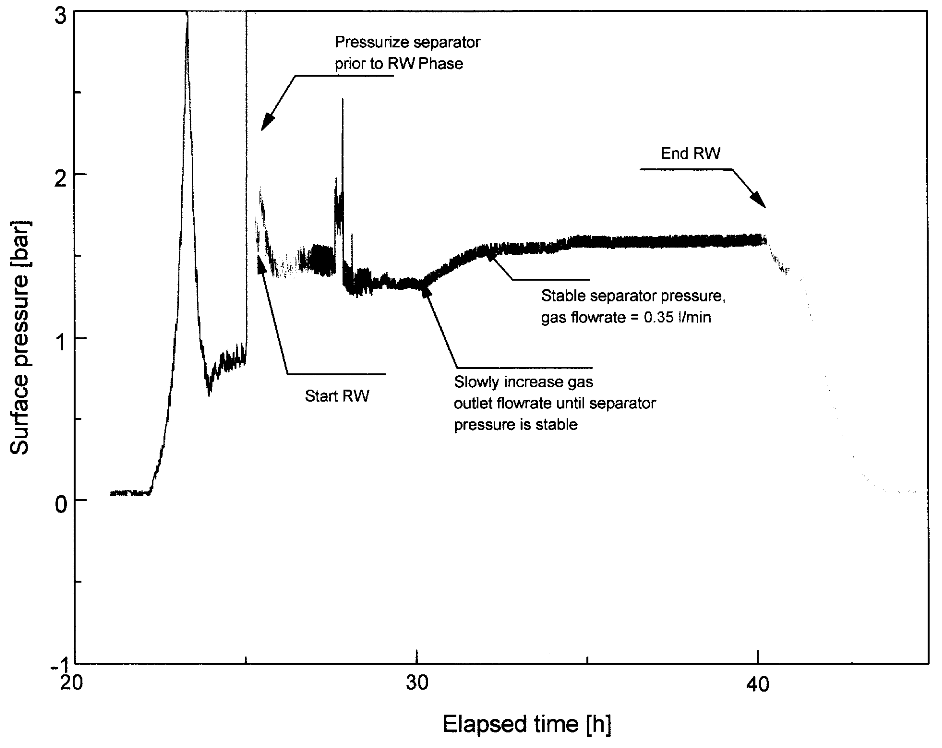


FIG. 5.19: SB4a/s - VM4; Pressure measured in the separator during RW phase

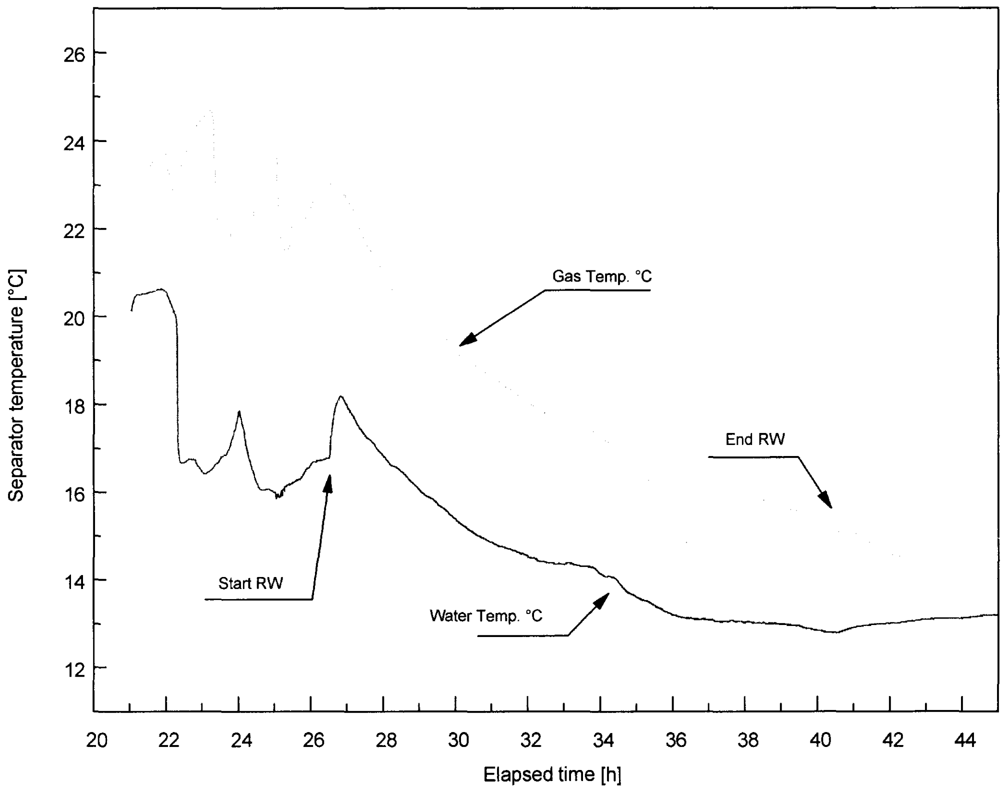


FIG. 5.20: SB4a/s - VM4; Temperature of gas and water in the separator during RW phase

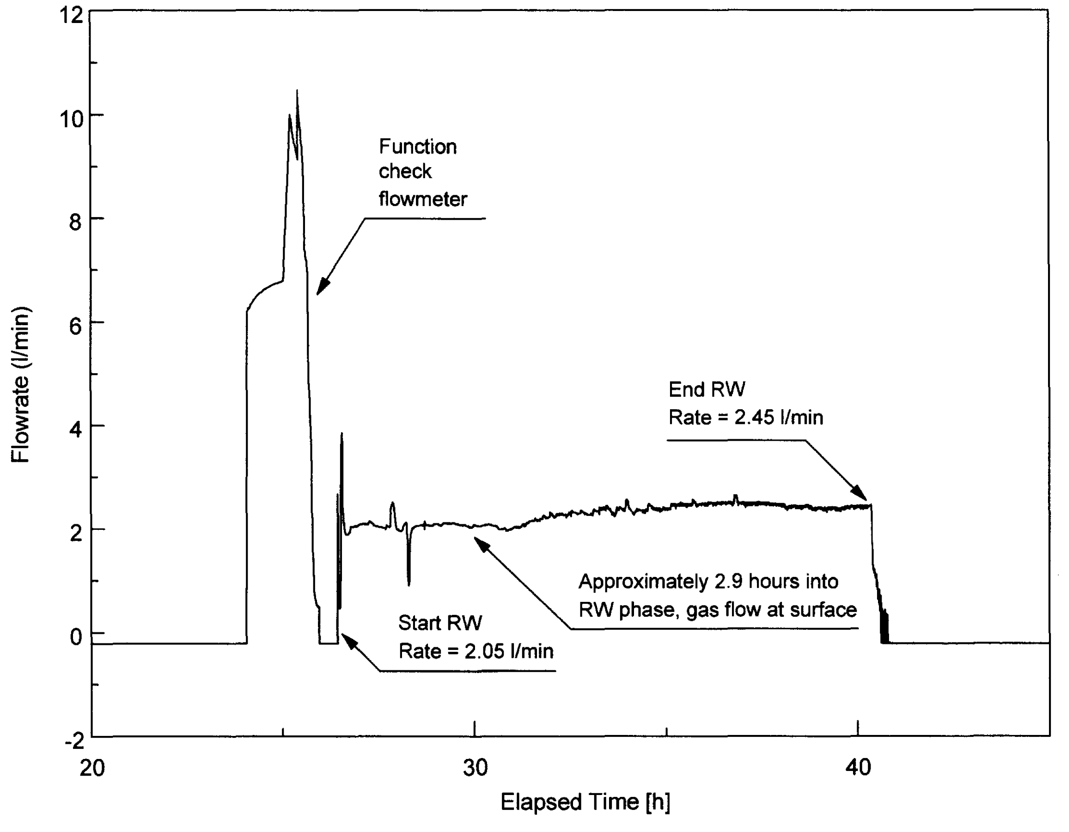


FIG. 5.21: SB4a/s - VM4; Water rate measured during RW phase after flow through separator

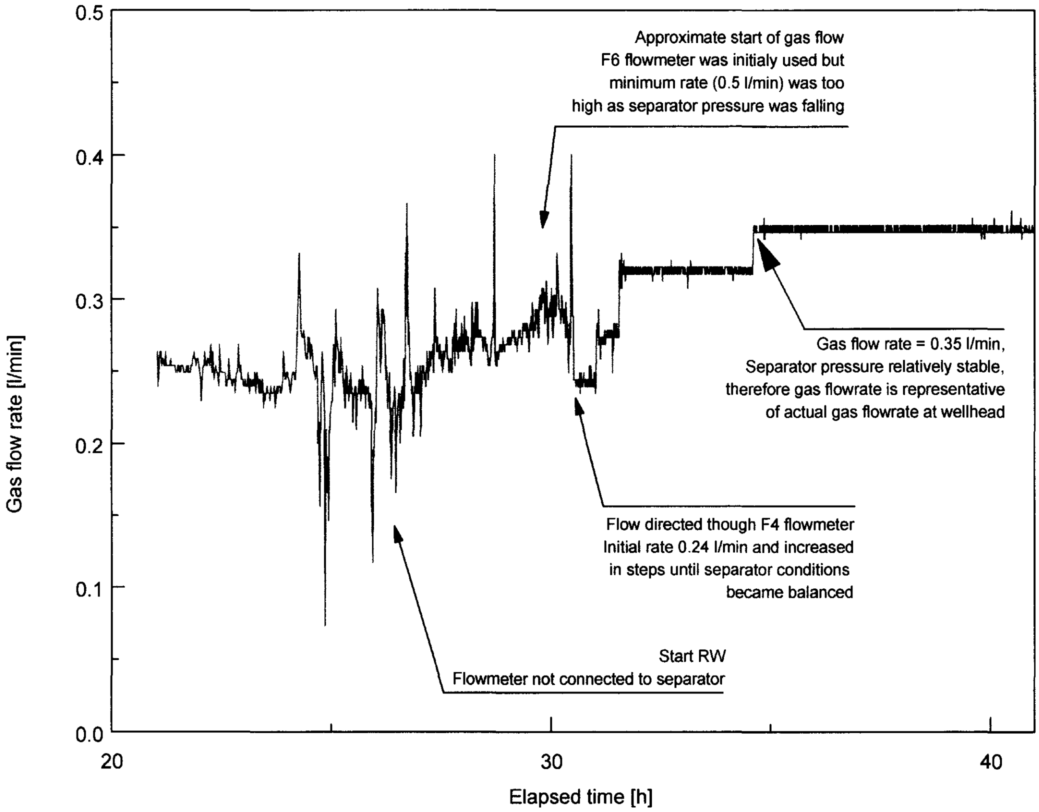


FIG. 5.22: SB4a/s - VM4; Gas rate measured during RW phase after flow through separator

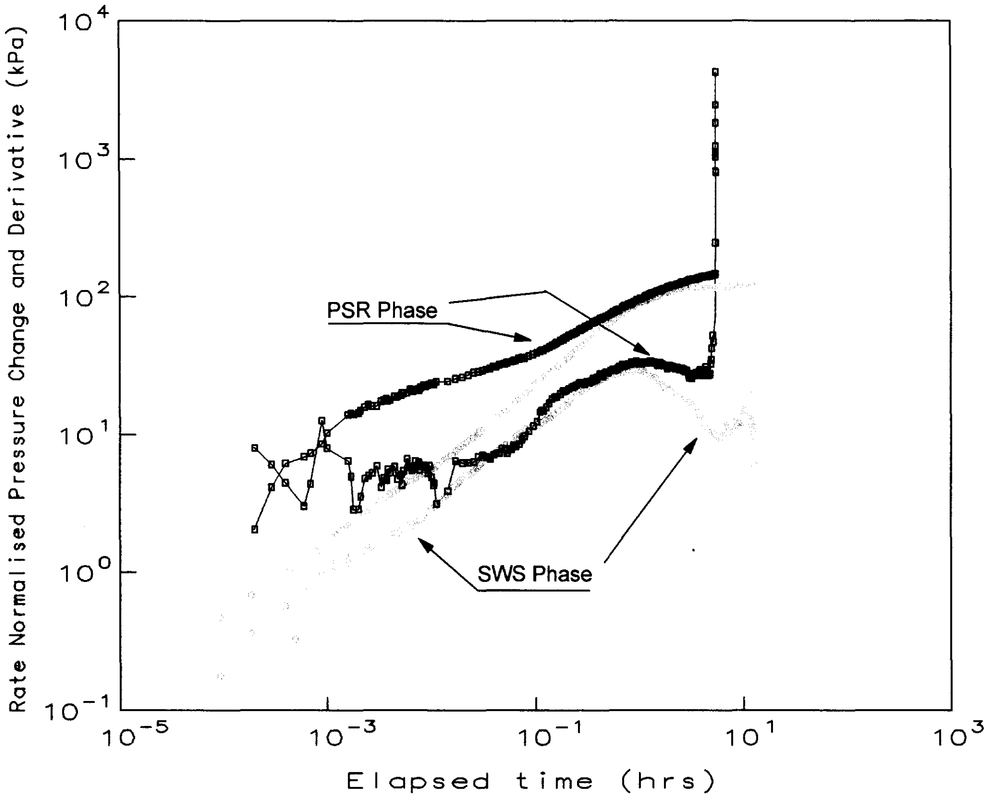


FIG. 5.23: SB4a/s - VM4; Rate normalised multidiagnostic plot of PSR and SWS phases

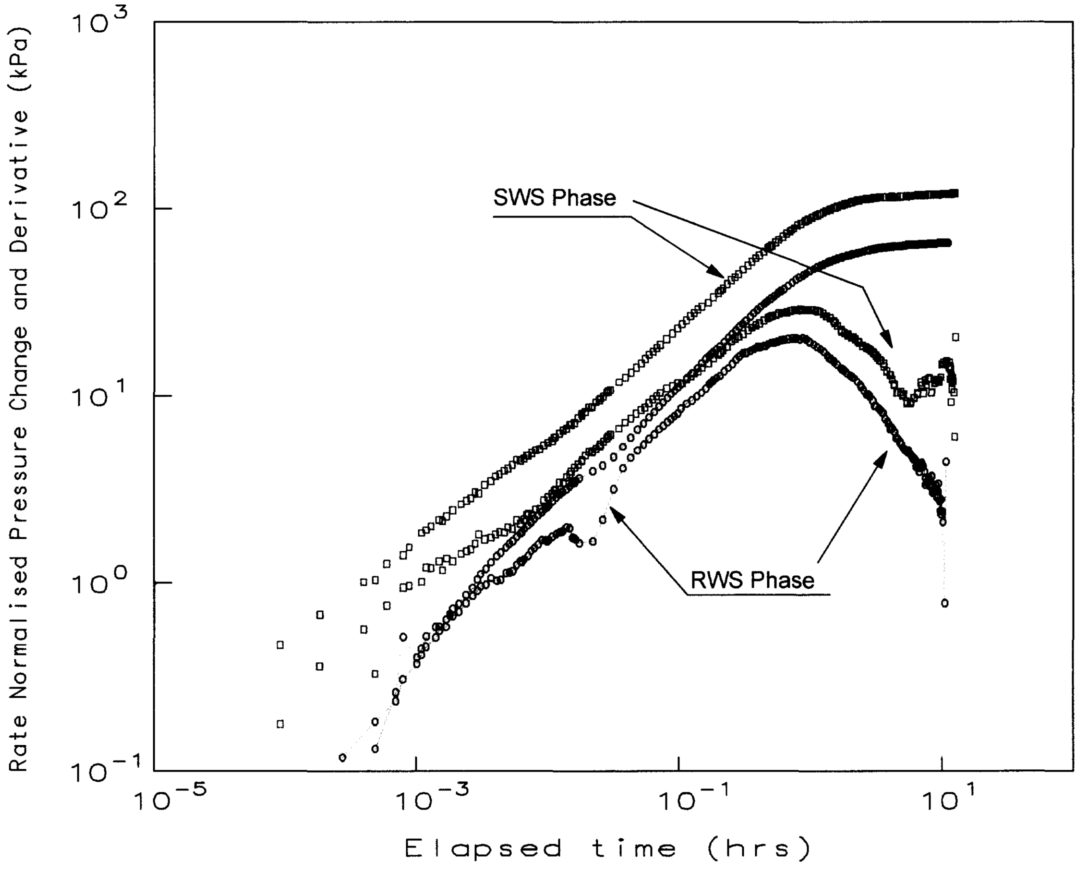


FIG. 5.24: SB4a/s - VM4; Rate normalised multidiagnostic plot of SWS and RWS phases

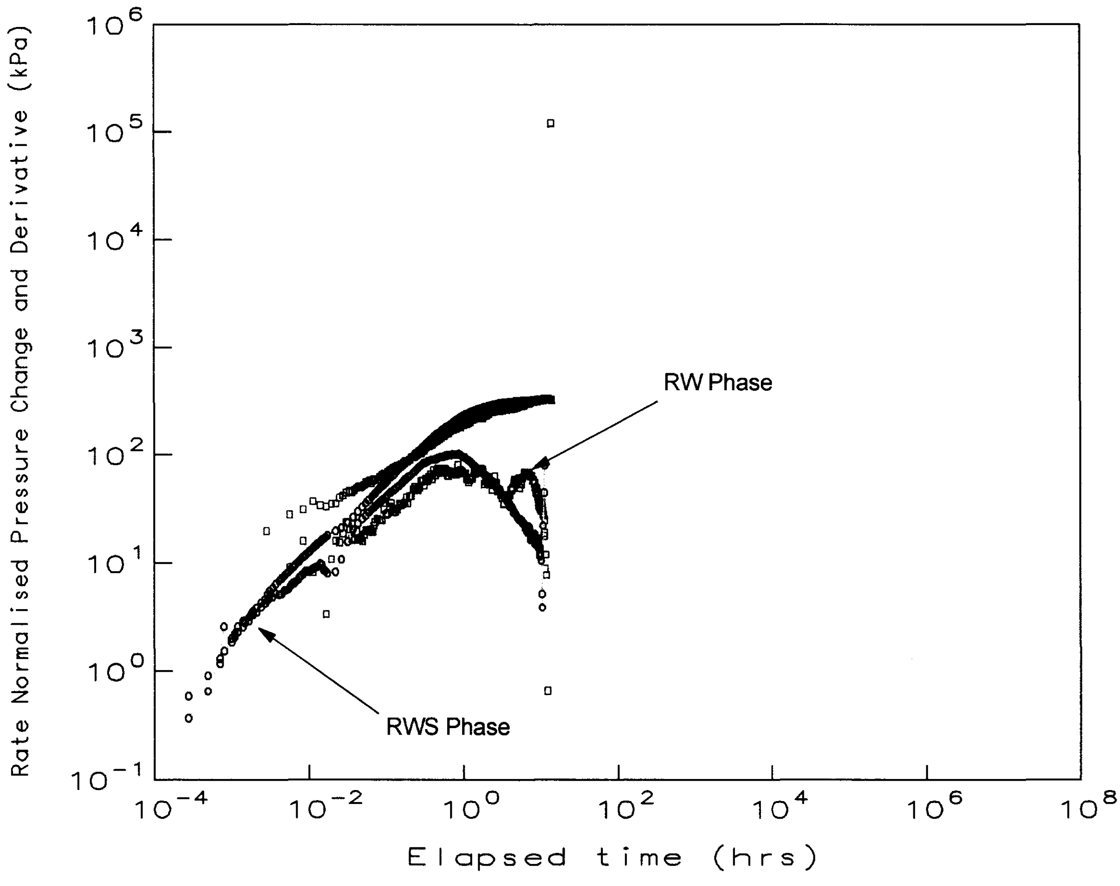


FIG. 5.25: SB4a/s - VM4; Rate normalised multidiagnostic plot of RW and RWS phases

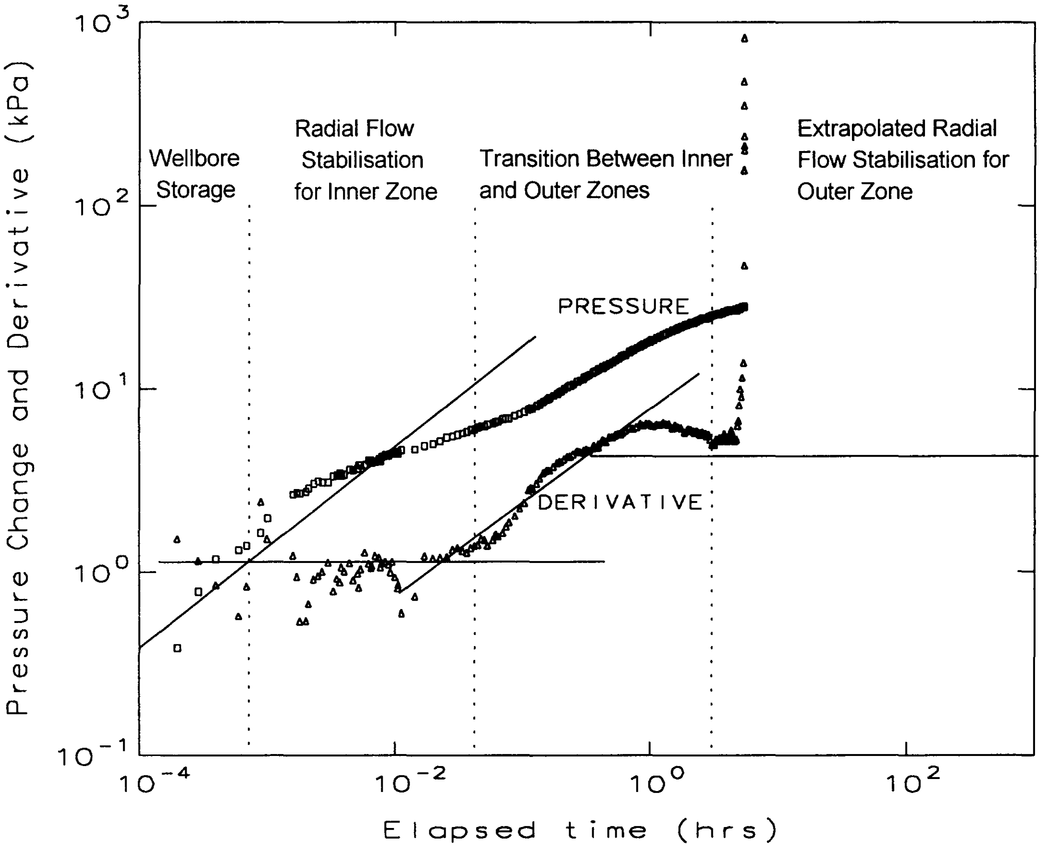
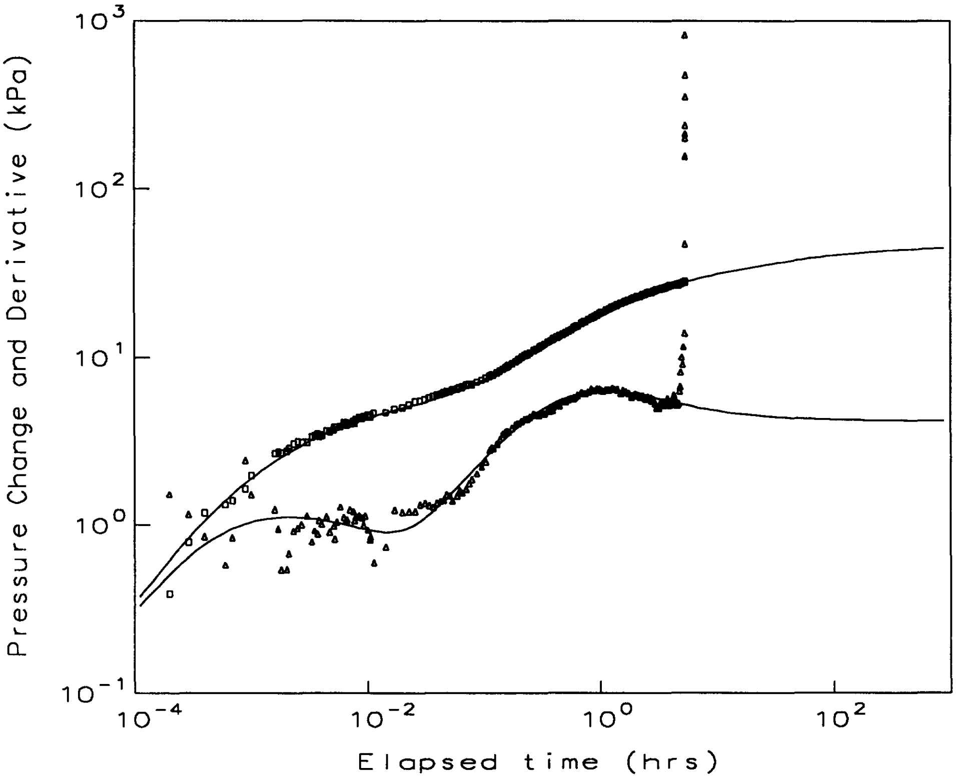


FIG. 5.26: SB4a/s - VM4; PSR phase; Diagnostic plot; composite model with decreasing storativity and mobility with increasing distance from the borehole

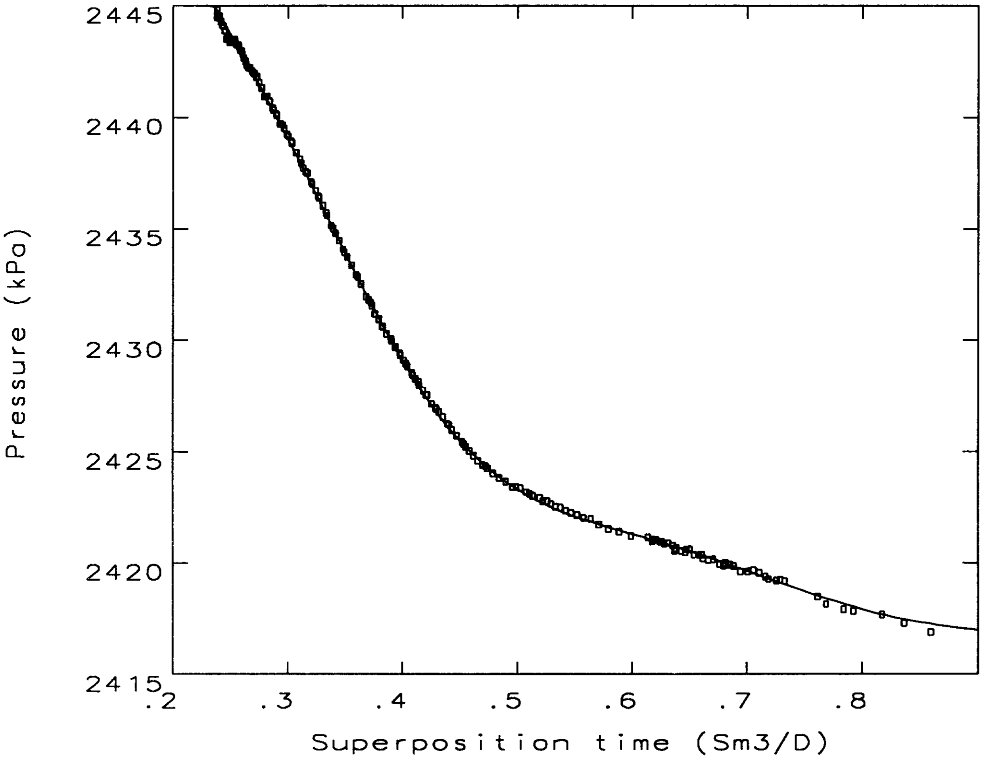


RESULTS		
(pav)i	2462.272	kPa
pwf	2416.510	kPa
kh(1)	195.6	mD.m
k1	2.261	mD
C	1.405E-06	m3/kPa
S(w)	0.00	
S(t)	-2.74	
r1	2.	m
(pch)1/2	11.35	
(kh/u)1/2	4.969	
ri	32.	m
PI	0.003059	m3/D/kPa
FE	1.000	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.27: SB4a/s - VM4; PSR phase; Log-log match

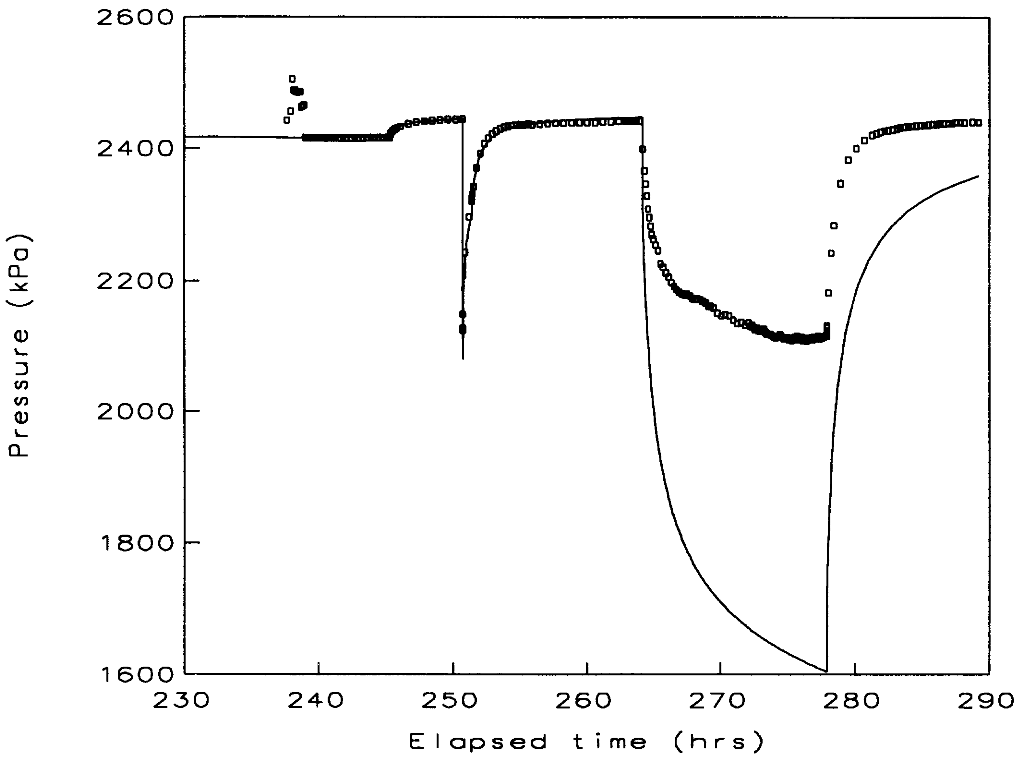


	RESULTS	
(pav)i	2462.272	kPa
pwf	2416.510	kPa
kh(1)	195.6	mD.m
k1	2.261	mD
C	1.405E-06	m3/kPa
S(w)	0.00	
S(t)	-2.74	
r1	2.	m
(pch)1/2	11.35	
(kh/u)1/2	4.969	
ri	32.	m
PI	0.003059	m3/D/kPa
FE	1.000	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

FIG. 5.28: SB4a/s - VM4; PSR phase; Superposition HORNER match

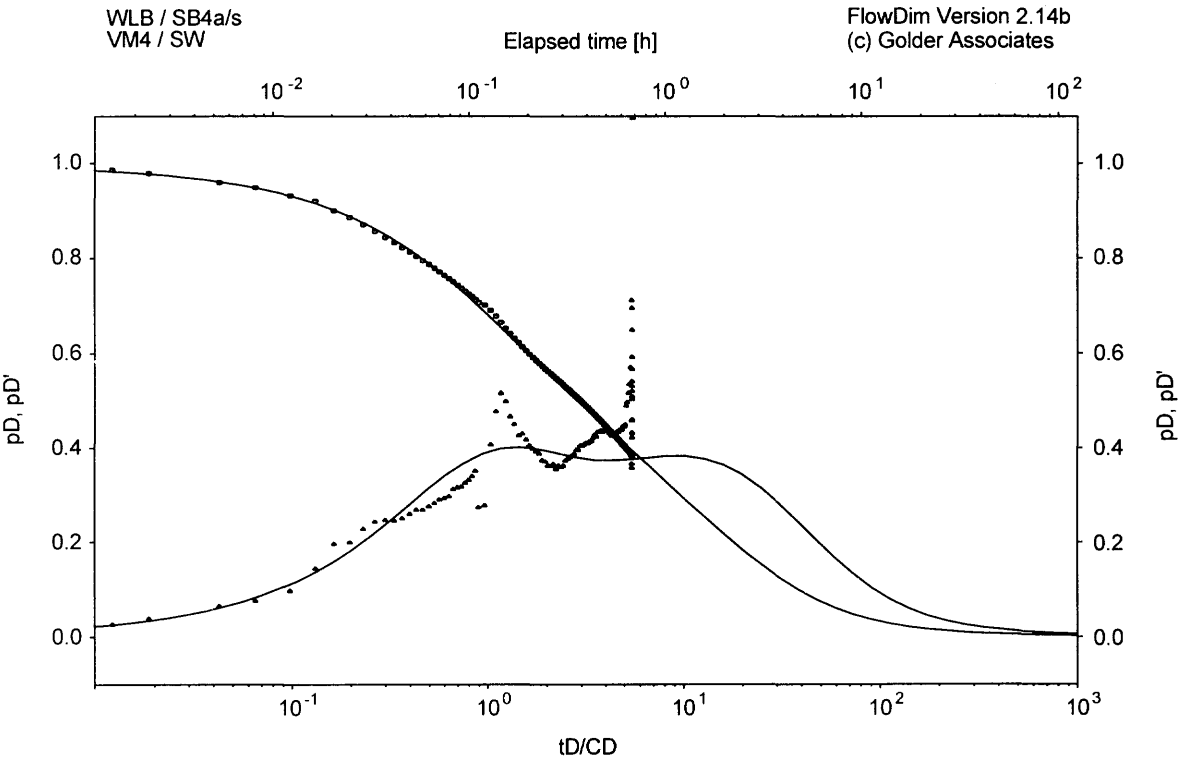


RESULTS		
(pav)i	2462.272	kPa
pwf	2416.510	kPa
kh(1)	195.6	mD.m
k1	2.261	mD
C	1.405E-06	m3/kPa
S(w)	0.00	
S(t)	-2.74	
r1	2.	m
(pch)1/2	11.35	
(kh/u)1/2	4.969	
ri	32.	m
PI	0.003059	m3/D/kPa
FE	1.000	fraction

MODEL

Wellbore Storage and Skin (C and S)
Composite
Infinite Lateral Extent

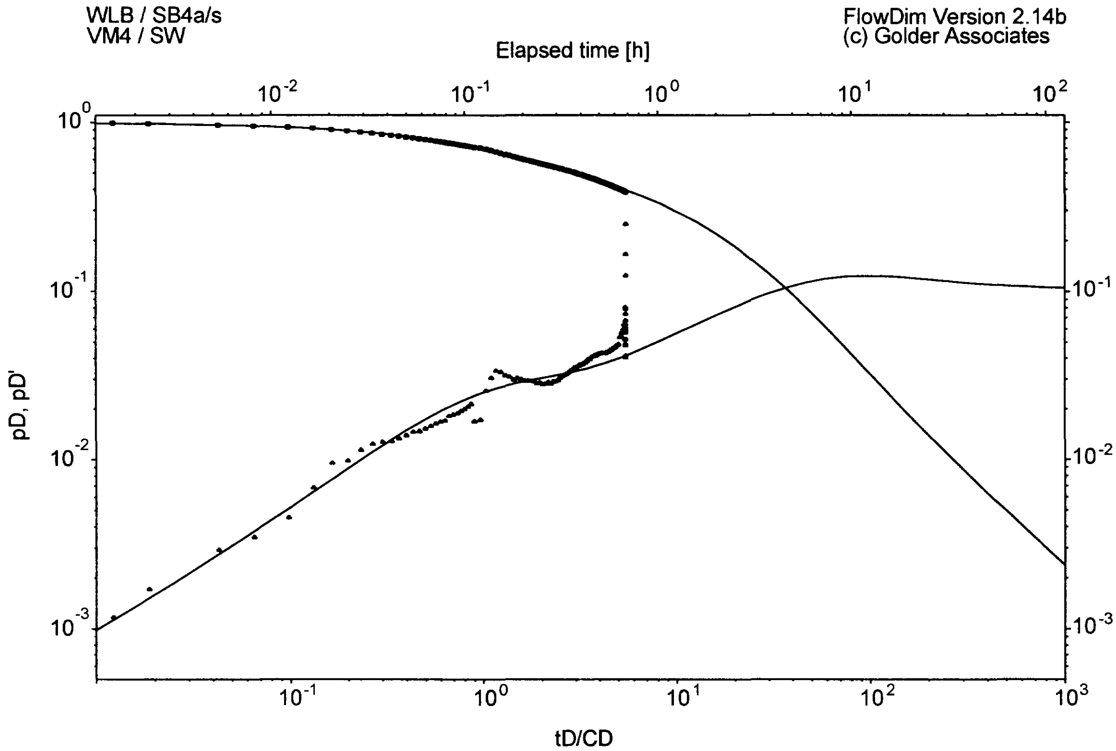
FIG. 5.29: SB4a/s - VM4; PSR phase; Measured and simulated pressure response (PI phase not shown)



FLOW MODEL : Two shell composite
BOUNDARY CONDITIONS: Slug/pulse
WELL TYPE : Source
SUPERPOSITION TYPE : No superposition
PLOT TYPE : Ramey A

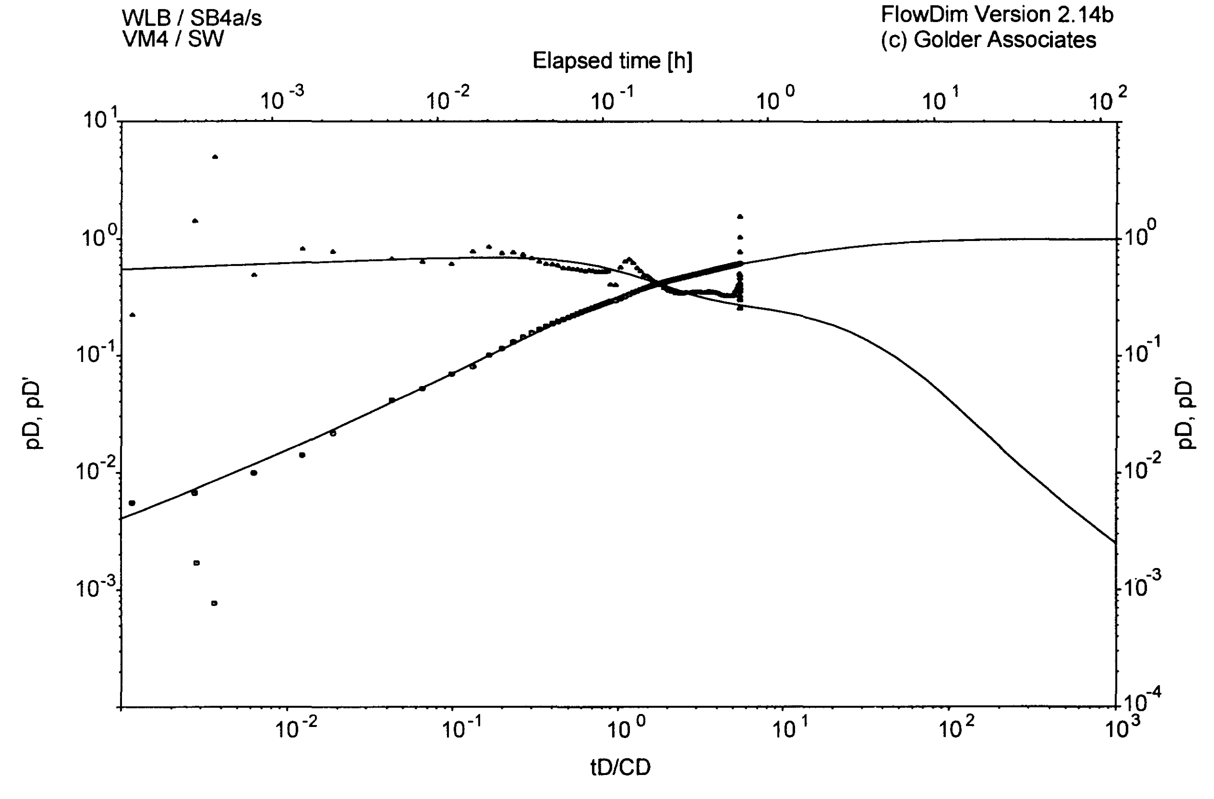
T	9.79E-07	m2/s
S	7.07E-04	-
C	2.82E-07	m3/Pa
n1	2.00E+00	-
n2	2.00E+00	-
rD1	1.20E+01	-
brw	4.50E+00	-

FIG. 5.30: SB4a/s - VM4; SW phase; RAMEY A match



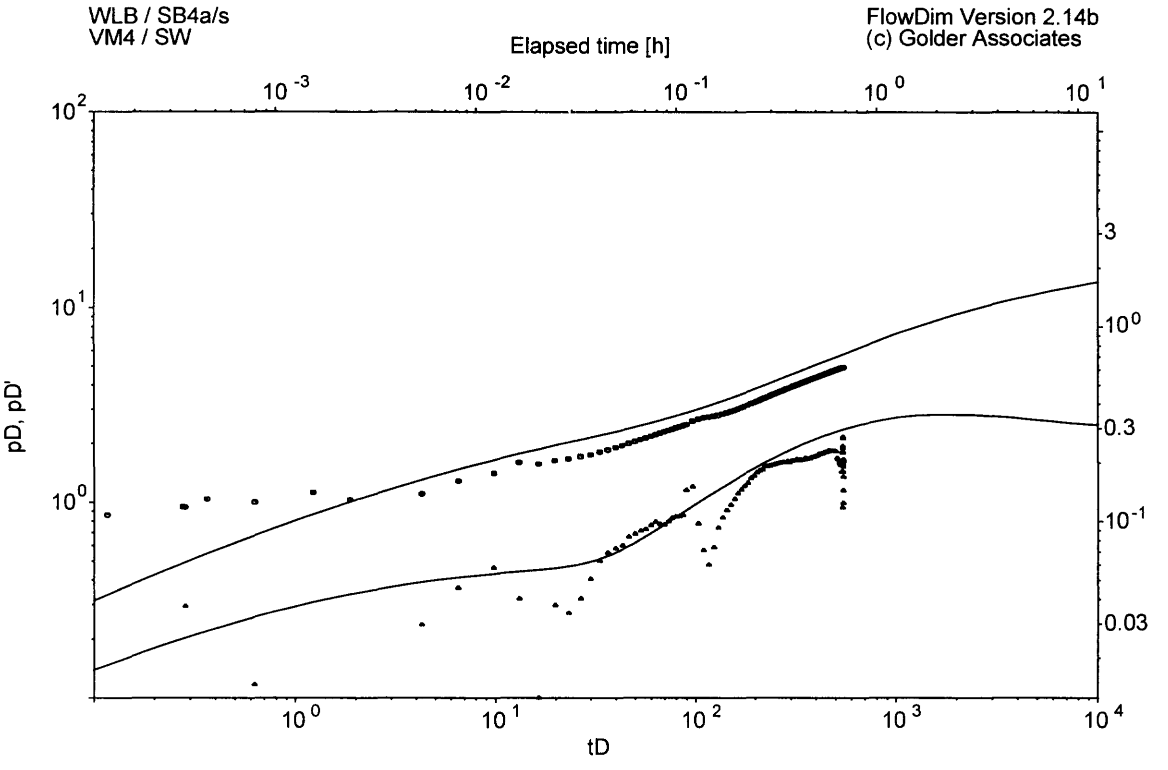
FLOW MODEL	: Two shell composite	T	9.79E-07	m2/s
BOUNDARY CONDITIONS: Slug/pulse		S	7.07E-04	-
WELL TYPE	: Source	C	2.82E-07	m3/Pa
SUPERPOSITION TYPE : No superposition		n1	2.00E+00	-
PLOT TYPE	: Ramey B	n2	2.00E+00	-
		rD1	1.20E+01	-
		brw	4.50E+00	-

FIG. 5.31: SB4a/s - VM4; SW phase; RAMEY B match



FLOW MODEL : Two shell composite	T	9.79E-07	m2/s
BOUNDARY CONDITIONS: Slug/pulse	S	7.07E-04	-
WELL TYPE : Source	C	2.82E-07	m3/Pa
SUPERPOSITION TYPE : No superposition	n1	2.00E+00	-
PLOT TYPE : Ramey C	n2	2.00E+00	-
	rD1	1.20E+01	-
	brw	4.50E+00	-

FIG. 5.32: SB4a/s - VM4; SW phase; RAMEY C match



FLOW MODEL : Two shell composite
BOUNDARY CONDITIONS: Slug/pulse
WELL TYPE : Source
SUPERPOSITION TYPE : No superposition
PLOT TYPE : Peres, Reynolds

T	9.79E-07	m2/s
S	7.07E-04	-
s	0.00E+00	-
n1	2.00E+00	-
n2	2.00E+00	-
rD1	1.20E+01	-
brw	4.50E+00	-

FIG. 5.33: SB4a/s - VM4; SW phase; Deconvoluted log-log match

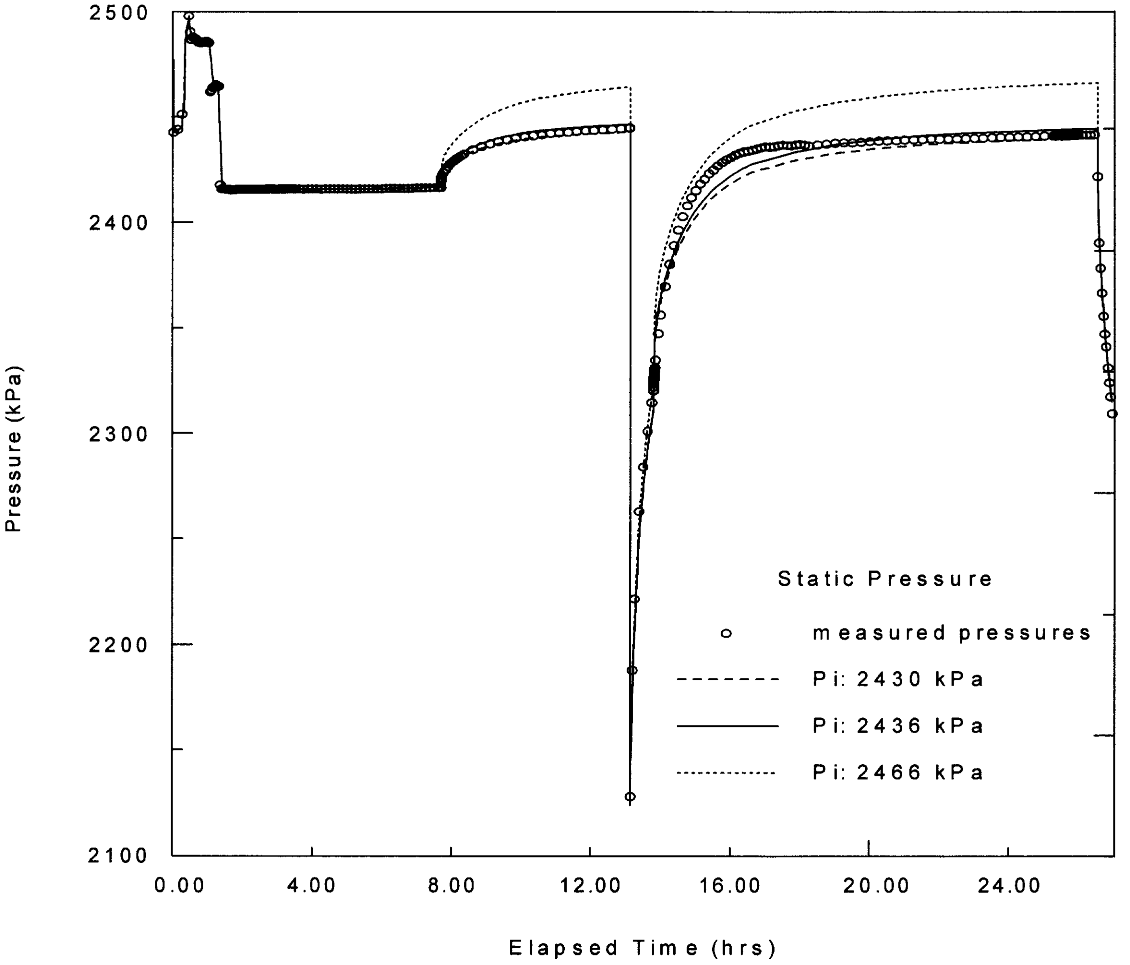


FIG. 5.34: SB4a/s - VM4; PSR to SWS phases; Consistency check with GTFM

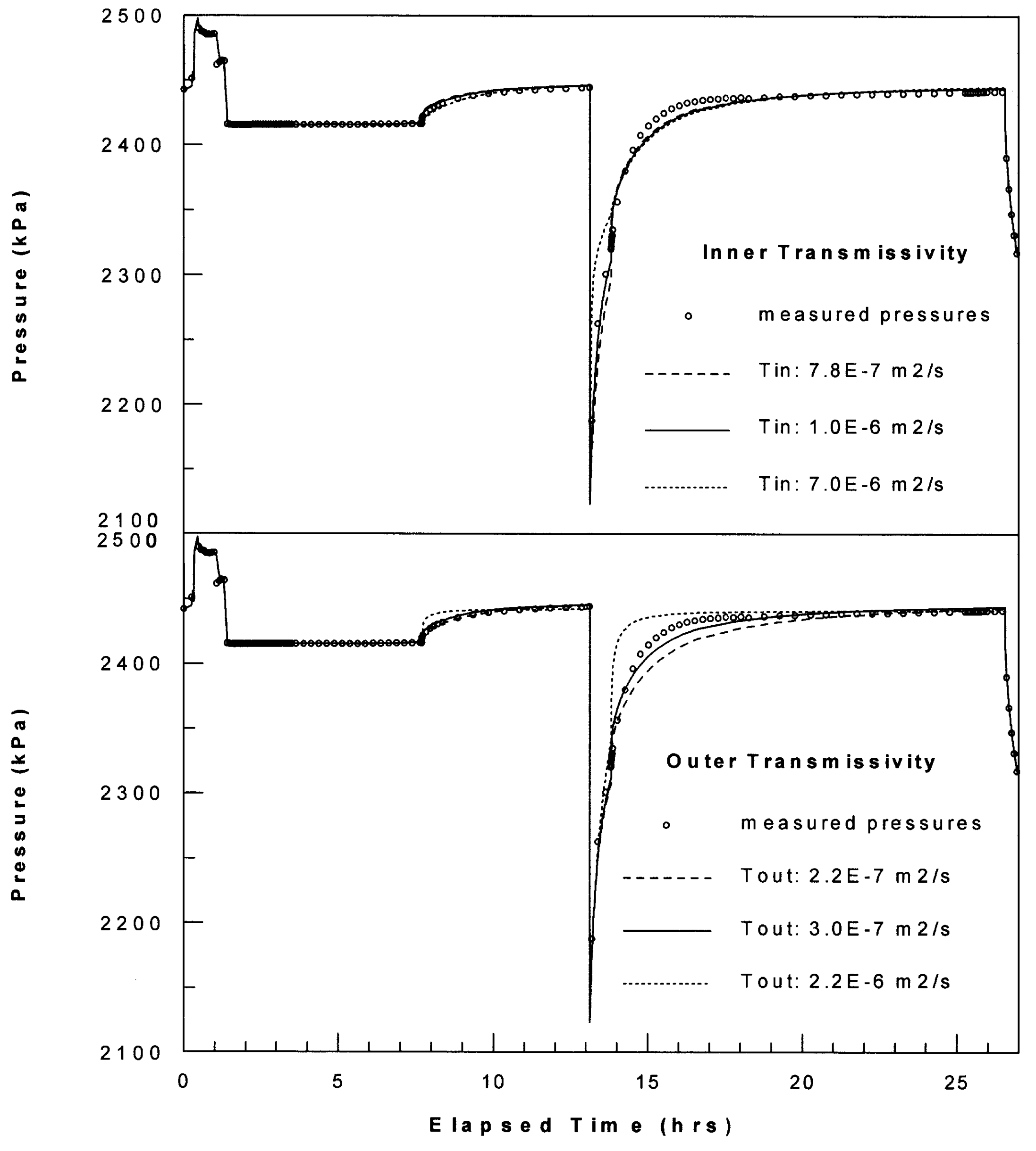


FIG. 5.35: SB4a/s - VM4; PSR to SWS; Consistency check with GTFM

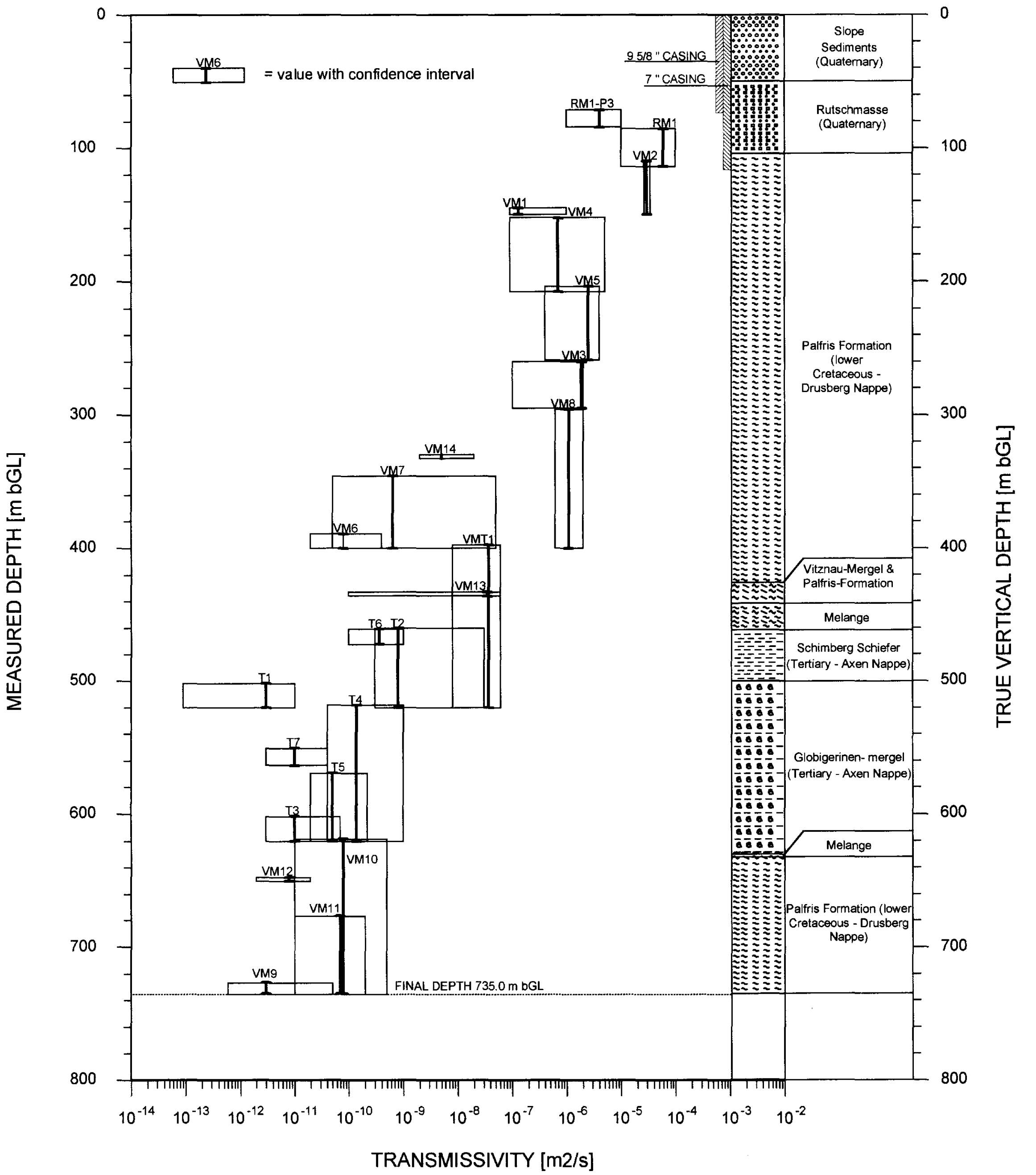


FIG. 6.1: Borehole SB4a/v - test analysis results - transmissivity profile

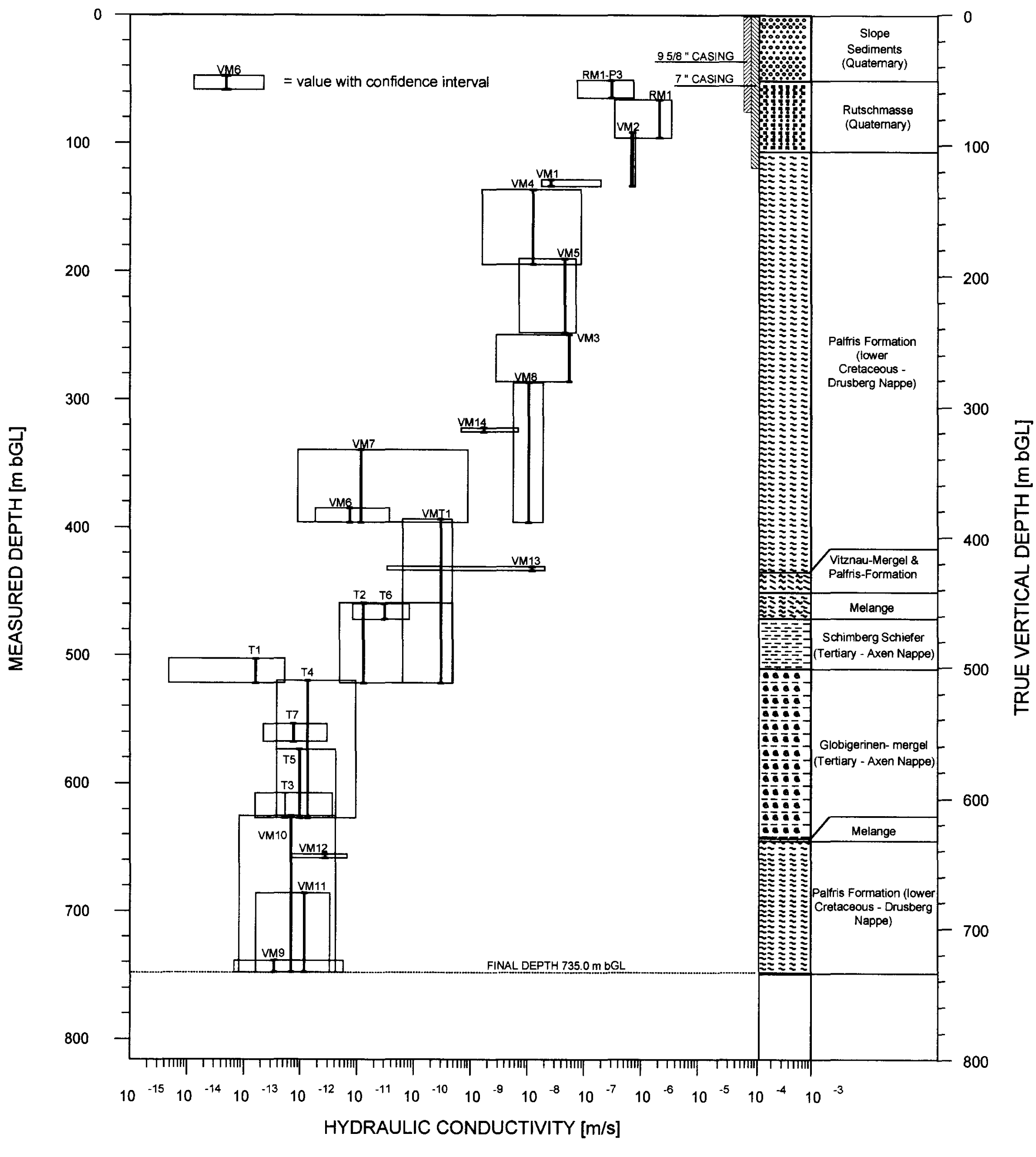


FIG. 6.2: Borehole SB4a/v - test analysis results - hydraulic conductivity profile

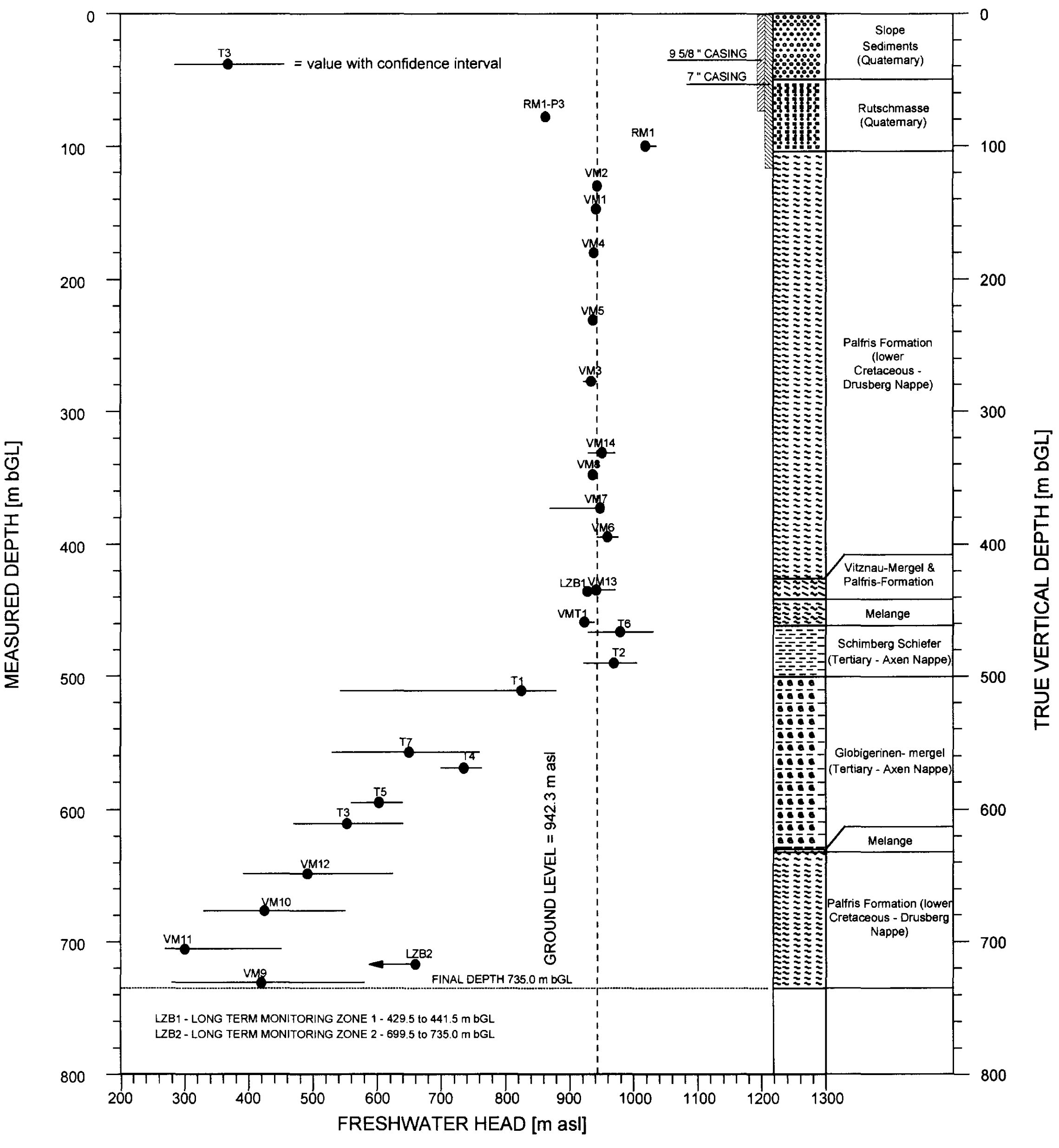


FIG. 6.3: Borehole SB4a/v - test analysis results - equivalent freshwater head profile

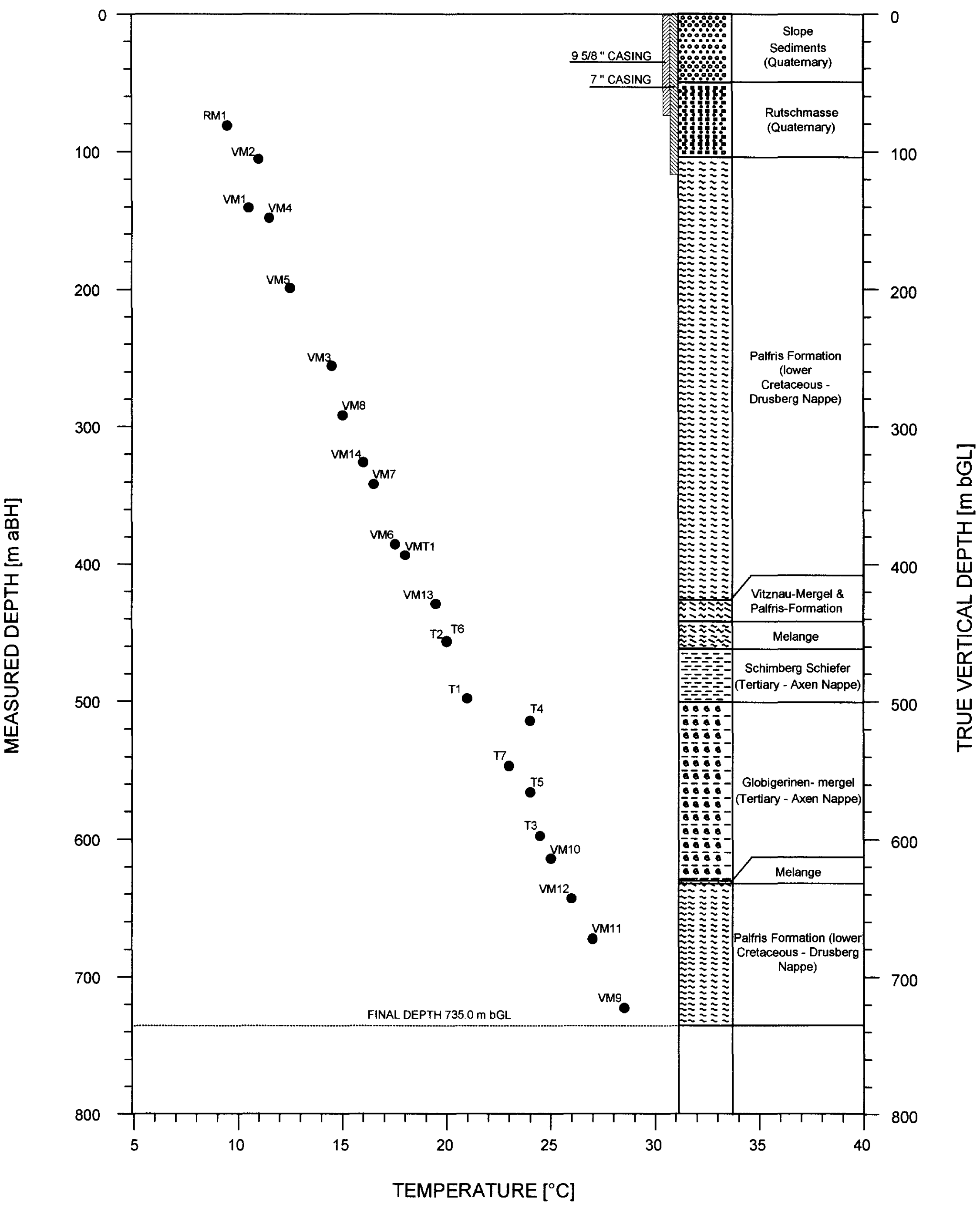


FIG. 6.4: Borehole SB4a/v - test analysis results - temperature profile

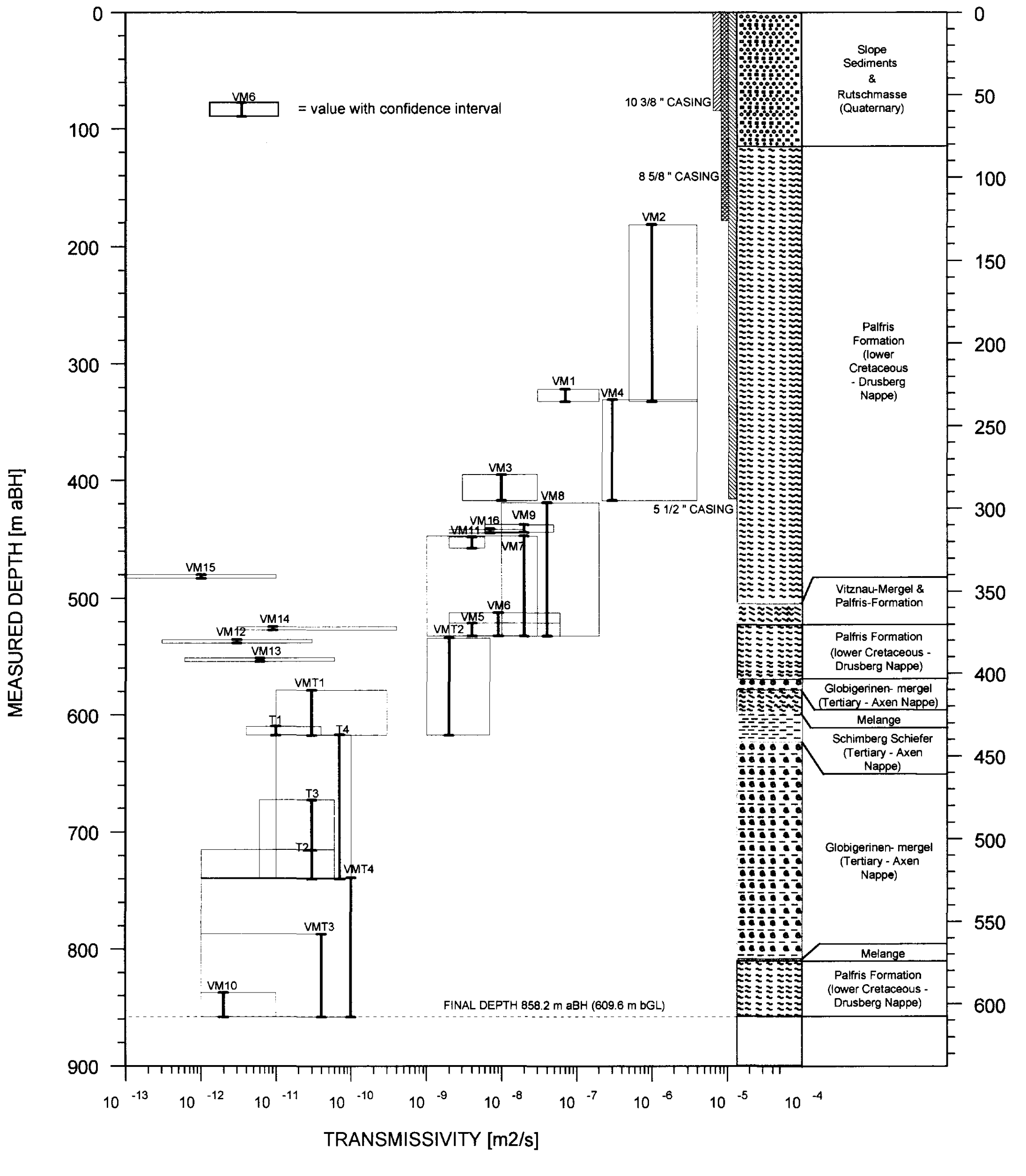


FIG. 7.1: Borehole SB4a/s - test analysis results - transmissivity profile

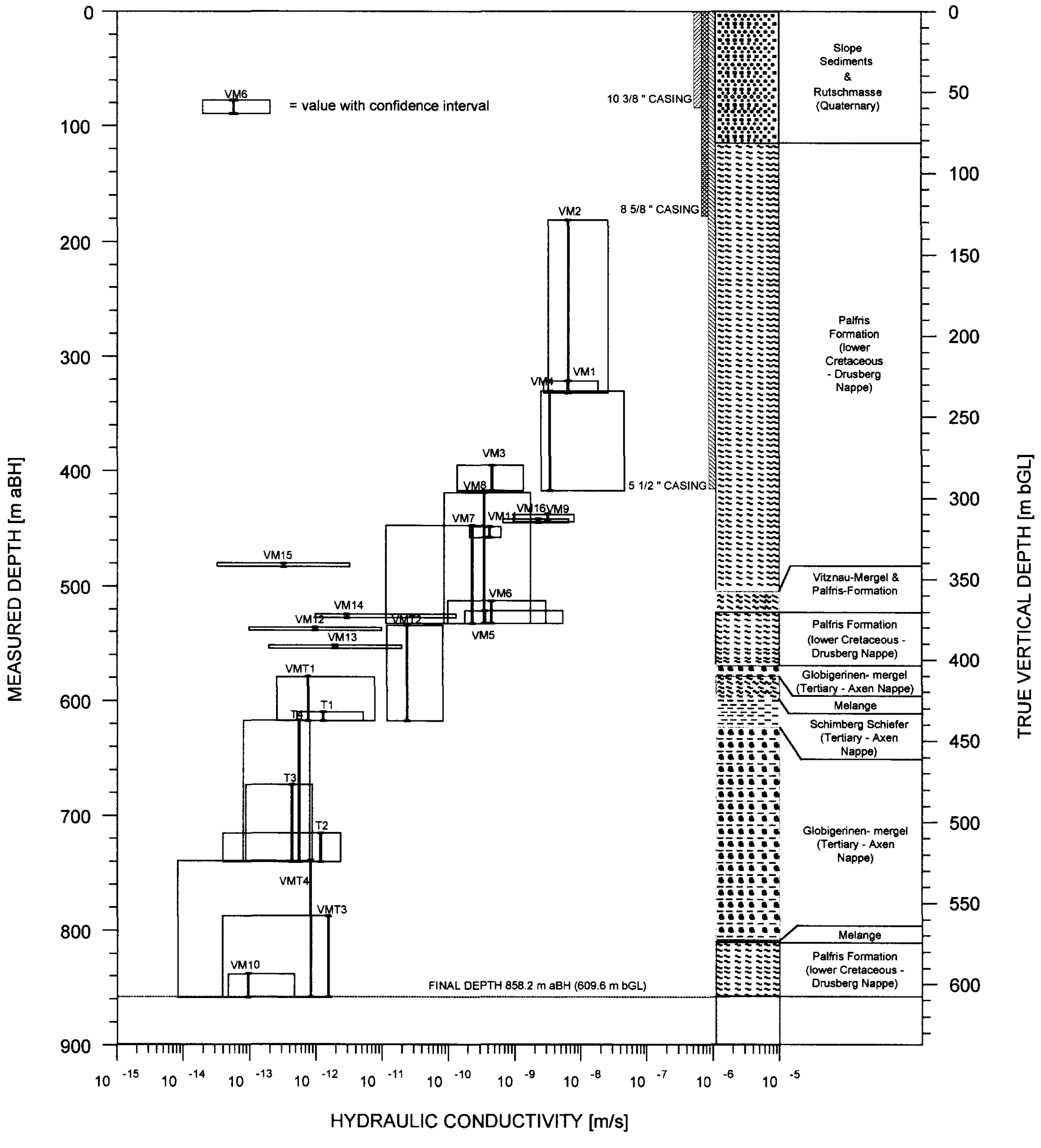


FIG. 7.2: Borehole SB4a/s - test analysis results - hydraulic conductivity profile

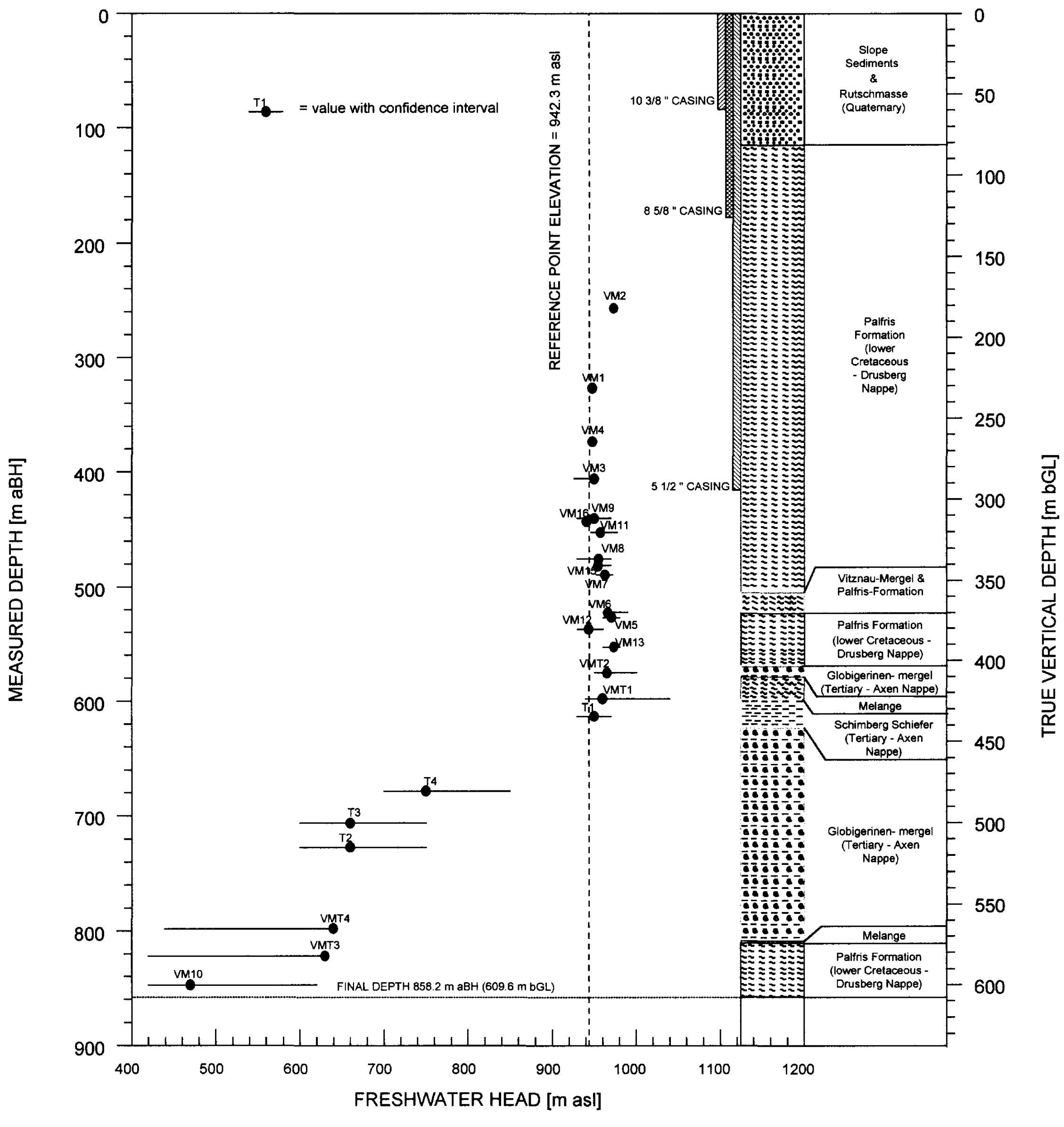


FIG. 7.3: Borehole SB4a/s - test analysis results - equivalent freshwater head profile

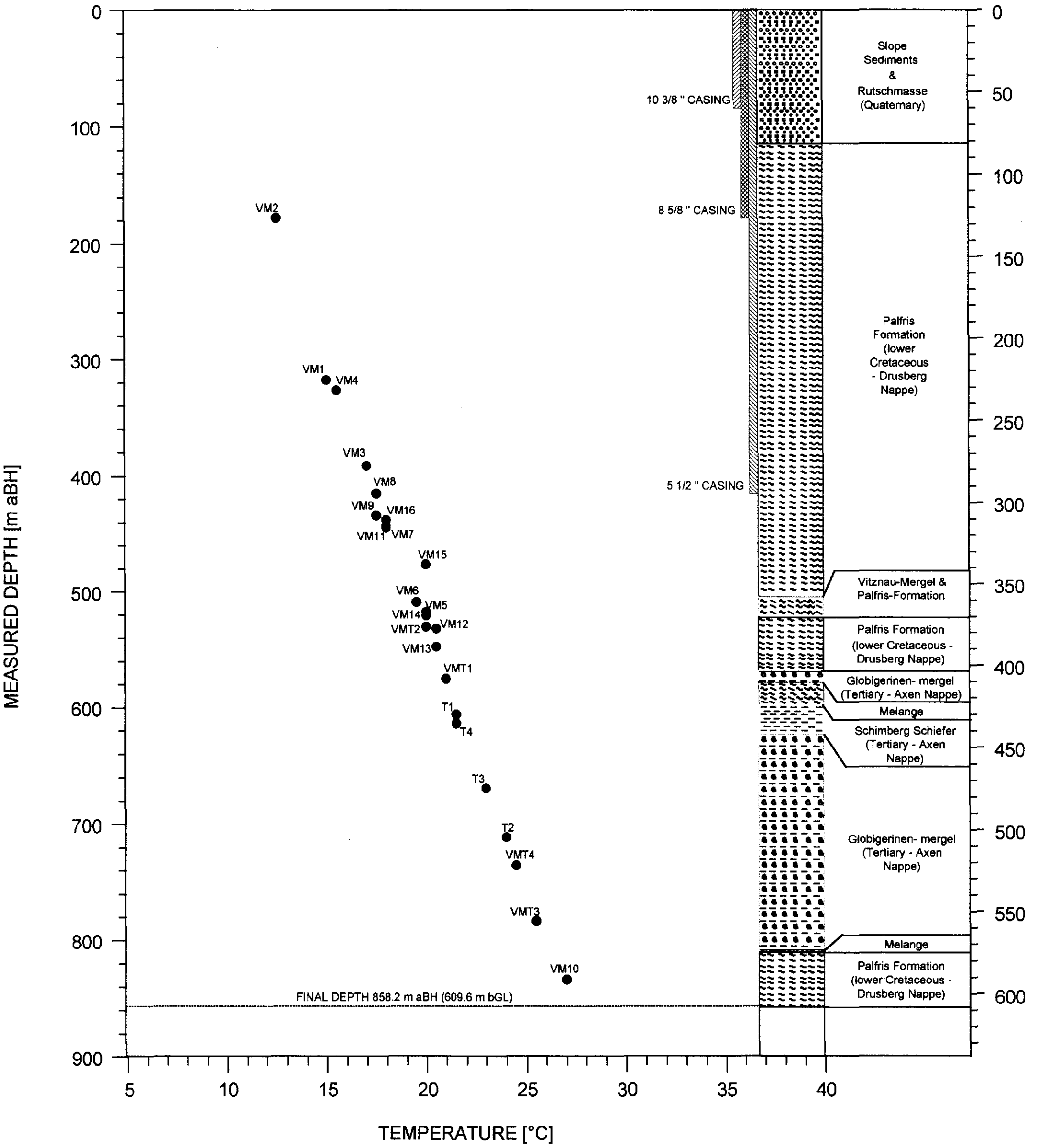


FIG. 7.4: Borehole SB4a/s - test analysis results - temperature profile

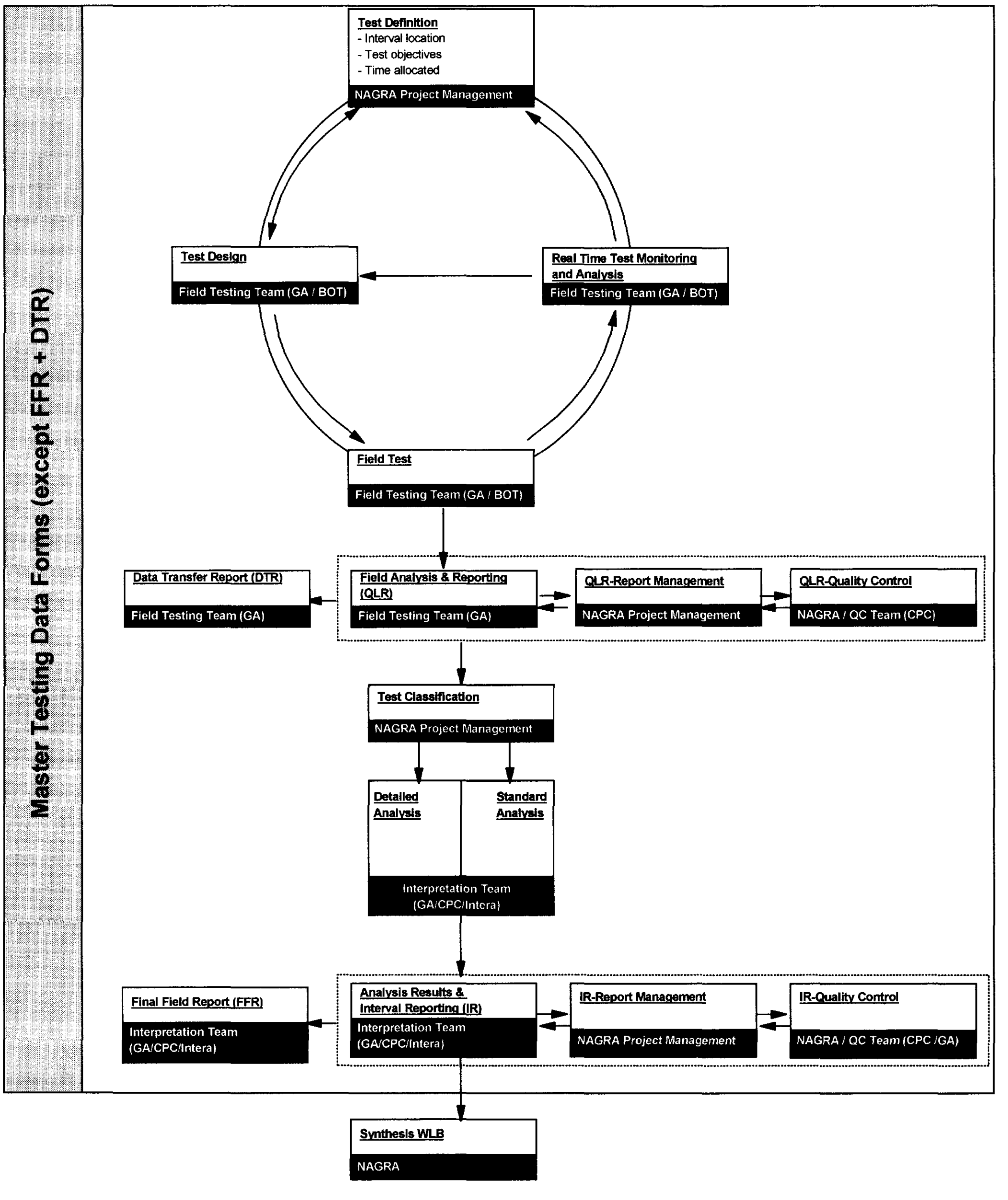


FIG. 8.1: Flow chart of the SB4a test program at Wellenberg

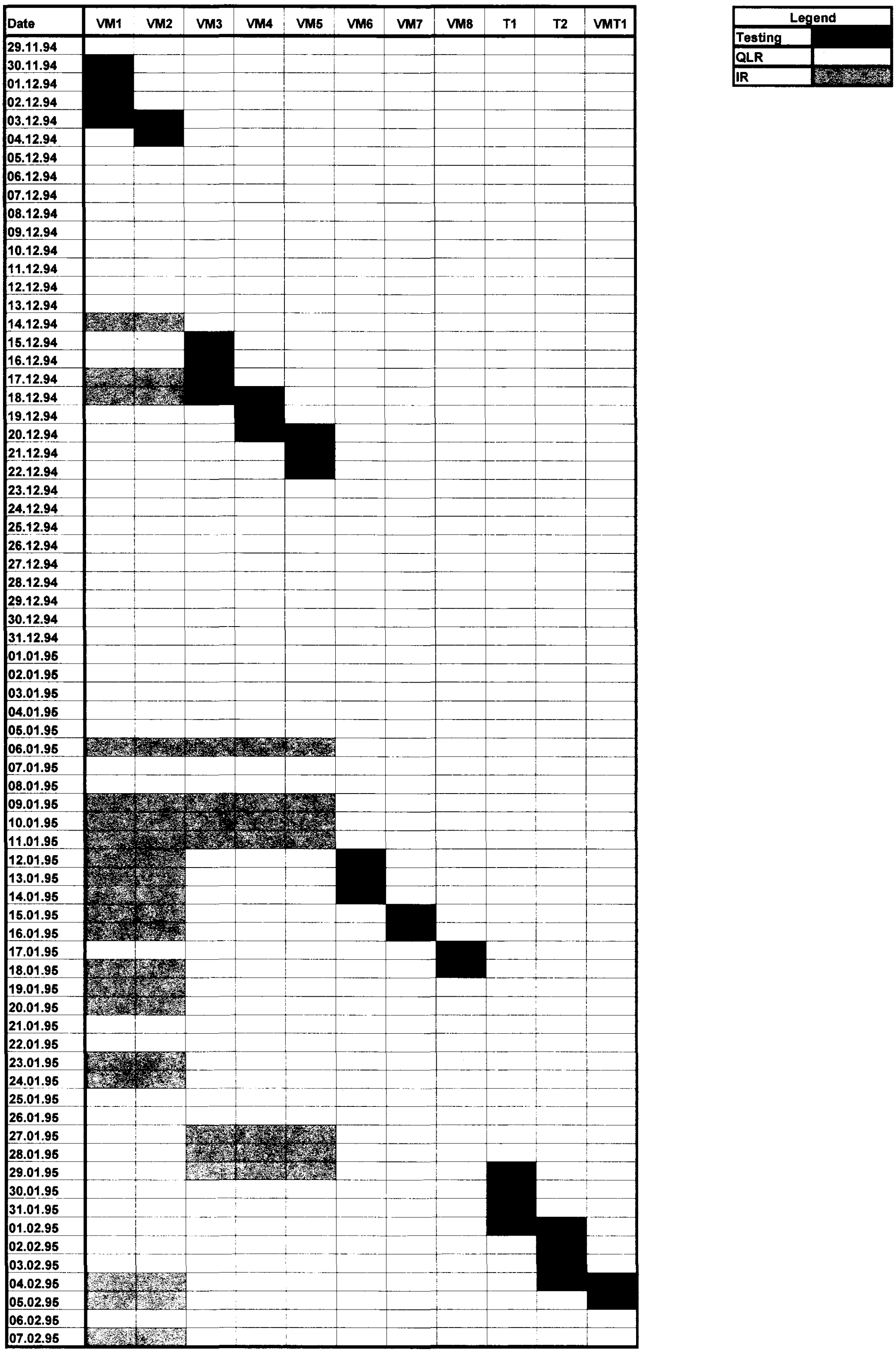


FIG. 8.2: Project activity schedule; example of a time slice of the project

APPENDIX B:
TEST SUMMARIES OF HYDRAUIC TESTING IN SB4A/VERTICAL WITH FIELD ANALYSES RESULTS

Introduction

Appendices B and C summarise the data acquisition and analyses for derivation of hydraulic parameters for tests performed in both parts of the borehole, SB4a/v and SB4a/s. The tests are presented in a chronological order. Each test is shown on two pages. The first page shows the downhole pressures and typically accompanied by two vital figures which document the performed analyses. On the second page, the test sequence is described, relevant borehole and interval information are presented, any equipment problems or adverse effects are commented upon, and the results are shown with their confidence limits. It is important to review these tests knowing the level of effort to which the data sets were analysed: standard or detailed interpretation. This shown on the top of the second page.

Typically, three figures are presented for each test:

- measured pressures;
- log-log diagnostic plot showing both pressure and pressure derivative data for a single phase in the test;
- measured and simulated pressures for the entire test sequence performed with either Interpret/2 or GTFM.

The downhole pressures were measured with a TCWL gauge containing 3 sensors. In a single packer arrangement, P1 and P2 measure test interval pressures while P3 monitors the annulus pressure. The double packer set-up uses P1 to monitor the test conditions below the bottom packer. Page 2 for each test documents the equipment set-up. The measured pressures are annotated to show when sampling was performed or to highlight equipment problems.

The log-log plot was used as the principal tool to diagnose the flow model and therefore it represents the single most important step for interpretation. Since a log-log plot needed to be picked from a single phase for presentation, a set of rules was invoked for consistency and to optimise the selection to best represent the formation response. Typically, the shut-in following a constant rate withdrawal or slug period was used. These periods are not effected by rate variations, normally the longest lasting phase and follow a well defined flow period performed in the latter part of the test. As a result, there is good formation character beyond the effect of wellbore storage and the period is less influenced by uncertainties in borehole history. If gas was measured during the tests, the diagnostic plots for the effected periods are usually dominated by storativity changes near the borehole to completely mask the formation response. In this case, the log-log plots were selected from early phases in the test which show minimal impact from gas effects. For some low transmissivity intervals, a deconvolution log-log plot of pulse phases is presented as the normal log-log plot of recovery phases were dominated by wellbore storage effects.

It should be noted that there are several adverse effects in addition to wellbore storage which can mask the true formation response seen on log-log plots:

- At the start of some tests, the closing of the shut-in tool disturbs the interval. This can be seen as a separation of the pressure and pressure derivative data in early time before joining to form a unit slope. In addition, incorrect selection of start time and start pressure may have a similar effect.

- Secondly, the phenomena of 'roll-overs', changes in pressure gradient due to borehole history, will be seen as a sharp decrease in the derivative data.

- Finally, in low transitivity environments, the slope of the pressure derivative data in late time is strongly correlated to the assumed borehole history used in the analysis.

The plot for the entire simulation was taken from either the analyses with Interpret/2 or GTFM. In Interpret/2, the simulation plot uses the model and parameters derived in a single phase to match the entire test sequence. In contrast, GTFM matches the entire tests sequence in Cartesian coordinates using parameters derived in the traditional analytical approach as an initial guess. In GTFM simulations for the vertical part of the borehole, sensitivity runs were also included for transmissivity and static formation pressure.

The quality of the match between the data and the entire simulation provides an indication for the overall understanding of the test response. Poor matches may be attributed to the following:

- incorrect flow model and parameters;

- changes in the near wellbore conditions during the test, i.e. skin or gas saturation;

- errors in the representation of the borehole history period in the analysis.

In a few cases, no simulation plot is presented as a detailed analysis was not performed. Additional log-log plots are used as a replacement.

Test performed for gas saturation or gas threshold pressure were subject to extensive interpretations with TOUGH2/ITOUGH2. In this case, a plot has be included to document these analyses.

The summary page is made up of three main parts: test description, comments, and tabulated information on the interval and derived parameters. The test description details pertinent information for each period within the test and includes a full account for the measured rate data. It should be noted that the rate data pre-fixed by a negative sign denotes injection into the formation. All rate data represents measurements at the surface. In the comments section, the following information is typically discussed;

- fulfilment of objectives defined at start of test;

- function check of downhole gauges and flowmeters during the test;

- relative impact of pressure history on the test response;

- periods in the test which may be effected by temperature variation;

- character of the formation response as seen on log-log plots.

The tabulated data includes the derived hydraulic parameters and their confidence limits. These numbers should be viewed knowing the level of analyses. A detailed analysis is a much more rigorous then the standard interpretation and attempts to set the confidence limits in a semi-quantitative manner. The quoted radius of investigation was computed with the derived transmissivity, assumed storativity and assumed flow geometry. Therefore it typically has a confidence range on the order of a factor of 10.

Factors effecting the test response are listed at the bottom of the page. Description of equipment problems are expanded upon in the text. All tests are effected by pressure history but the relative impact is described in the comments. Typically, temperature variation may only be a factor in the initial phases with relatively stable conditions subsequent to the PSR period. Gas effects are noted when gas is measured at the surface or when the transducers show a gas phase rising in the test tubing. A 'possible' response to gas effects indicates indirect evidence such as noisy rate data in a production period or measured wellbore storage coefficients inconsistent to the theoretical values. It should be noted that some tests were not optimised for gas segregation. As a result, a 'no' to gas effects should not be regarded as single phase conditions within the interval.

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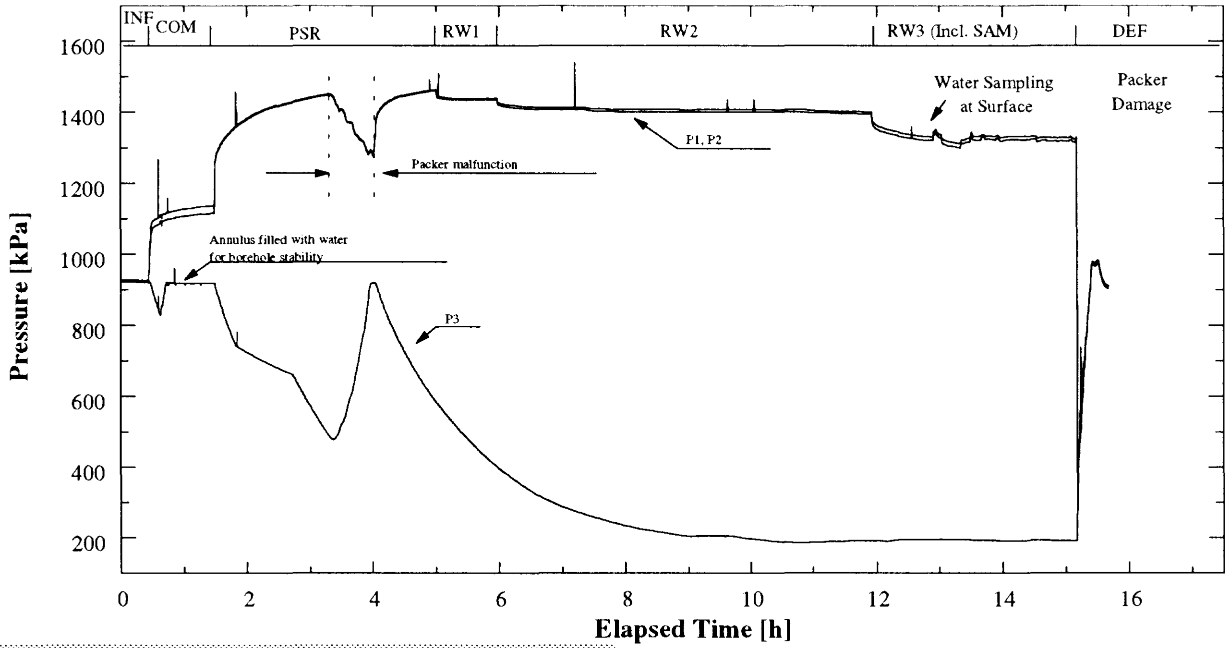
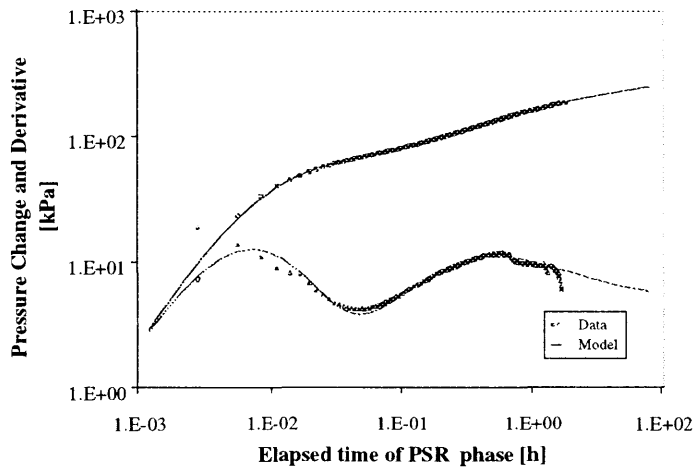
BOREHOLE SB4a/v - INTERVAL RM1 | 85.5 - 114.0 m bGL

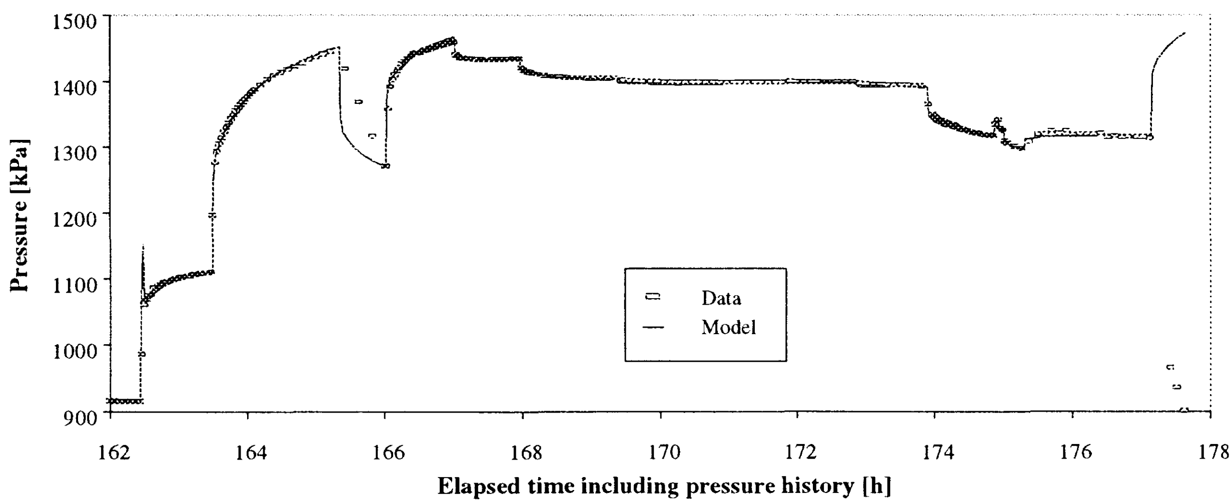


Pressures Measured During RM1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v RM1	85.5 to 114.0 m bGL	Reference: NIB 94-81A Detailed Analysis

Test Sequence Description:

The test started with the inflation of the packer with Nitrogen to 4000 kPa on 7th November 1994 at 08:00.

COM - The shut-in tool remained open for a 1.05 h compliance period and, due to the artesian interval conditions, fluid was flowing at the surface.

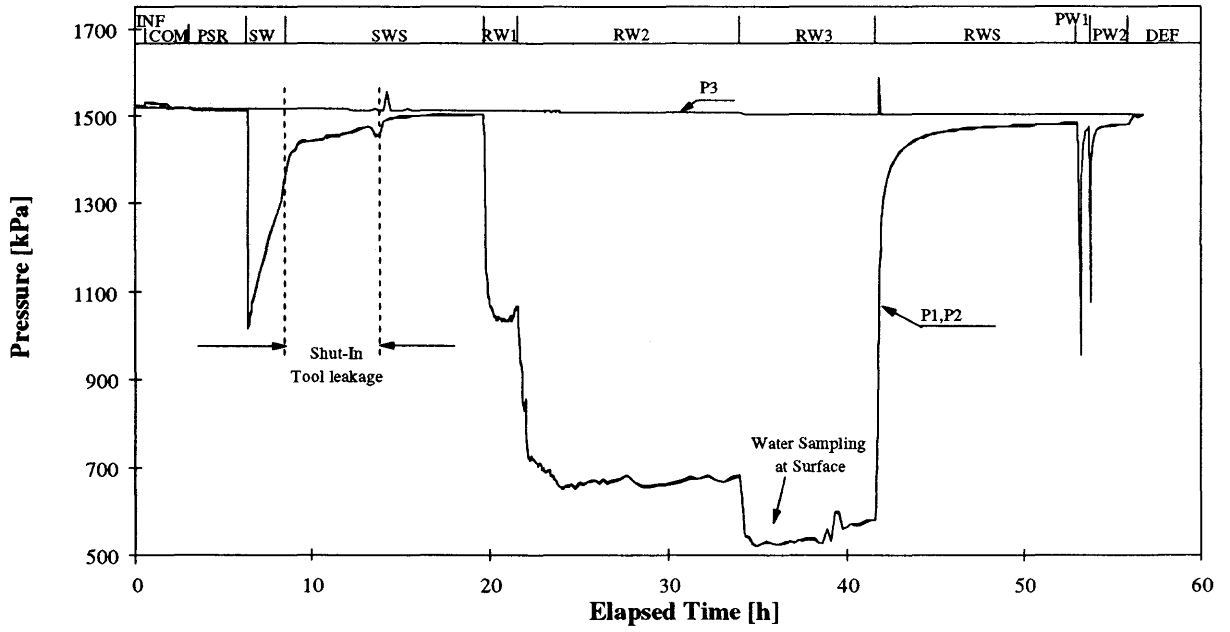
PSR - Following this period, the test interval was shut-in for 3.52 h with a final build-up pressure of 1461 kPa. Approximately 1.80 h into this period, the packer lost pressure due to a leak (gas bubbles in the annulus) and allowed hydraulic communication between the interval and the annulus; the pressure in the interval decreased and fluid was injected into the annulus. The hydraulic communication continued for 0.70 h when the packer seal was re-established. To compensate for the leak, a back pressure of 4000 kPa was maintained in the packer for the remainder of the test by a constant injection of nitrogen.

RW1, 2 & 3 - The PSR was followed by a production stage containing 3 constant rate phases. The rates during RW1 (0.97 h), RW2 (5.97 h) and RW3 (3.25 h) were 17 l/min, 28 l/min and 48 l/min, respectively. Groundwater sampling at the surface was performed during RW3, resulting in noisy pressure data.. The total drawdown at the end of this period was approximately 140 kPa below the final pressure of the PSR stage and was terminated after 2.25 h due to the loss of packer pressure. Therefore, the final constant rate period and shut-in period, outlined in the test design, were not performed. After the test was terminated, the packer showed holes near the top of the tool which suggests that the leak was directed to the annulus.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. However, the test was complicated by packer problems. The production periods were performed in 'steps' to ensure there was sufficient drawdown at the end of the RW phases to allow for water sampling. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at P2 depth increased by 0.8 °C during packer inflation but was relatively stable for remainder of test.

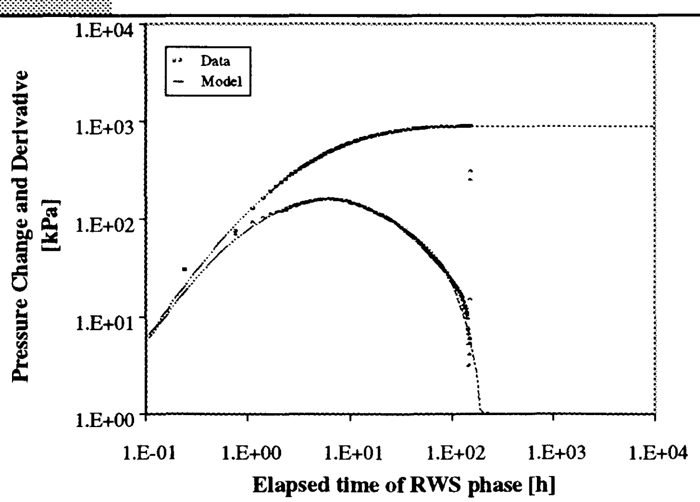
Packer configuration	Single Packer	
Date of test	7th November 1994	
Test interval depth	85.49 to 114.00 m bGL 85.46 to 113.96 m bGL	measured true vertical
Test interval length	28.51 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	85.00 - 104.30 m bGL QUATERNARY-Rutschmasse (land slide); Clay with Valanginien Marl Components 104.30 - 114.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	6.1E-05 m^2/s 1.0E-05 to 1.0E-04 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	1018.8 m asl (PSR) 1018 to 1035 m asl	
Radius of investigation	150 m ± 50 m	
Stabilised temperature at downhole sensor depth	9.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Acting Radial Flow	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL VM1	145.0 - 149.9 m bGL

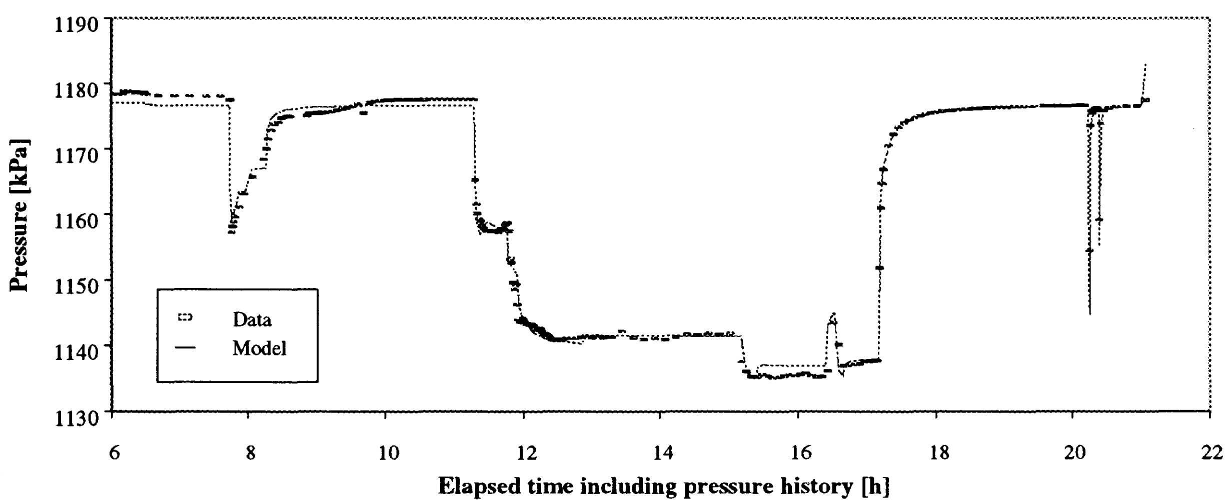


Pressures Measured During VM1

Flow Model:
Inner Boundary: Partially Penetrating Well with Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM1	145.0 to 149.9 m bGL	Reference: NIB 94-81B Detailed Analysis

Test Sequence Description:

COM - After packer inflation to 4000 kPa with Nitrogen, the shut-in tool remained open for 1.13 h to allow temperature conditions to stabilise and to obtain an initial estimate for the borehole history rate. The COM rate was calculated to - 2E-2 l/min and indicates that the formation was over pressurised during the historical period.

PSR - This was confirmed in the subsequent 4.72 h shut-in during which the pressures declined.

SW - Following the PSR period, the interval was subjected to a 500 kPa slug withdrawal which lasted 1.96 h with 58% recovery.

SWS - The subsequent build-up period was 11.32 h in duration. However, the pressure response after 0.57 h of shut-in indicated that there was leakage from the test interval. The shut-in tool was recycled and then sealed with 1379 kPa of back pressure for the remainder of this period.

RW1, 2 & 3 - The shut-in tool was then opened and the test section was produced in a series of stepped constant rate periods. The first drawdown (RW1) was 1.85 h in duration and produced at a rate of 0.8 l/min. The rate was then increased to 1.4 l/min for 12.73 h (RW2) to maximise the 'clean up' rate in the interval. The final production rate was variable due to sampling activities at the surface, however, the flowrate stabilised at 1.5 l/min in the last 2 h of RW3.

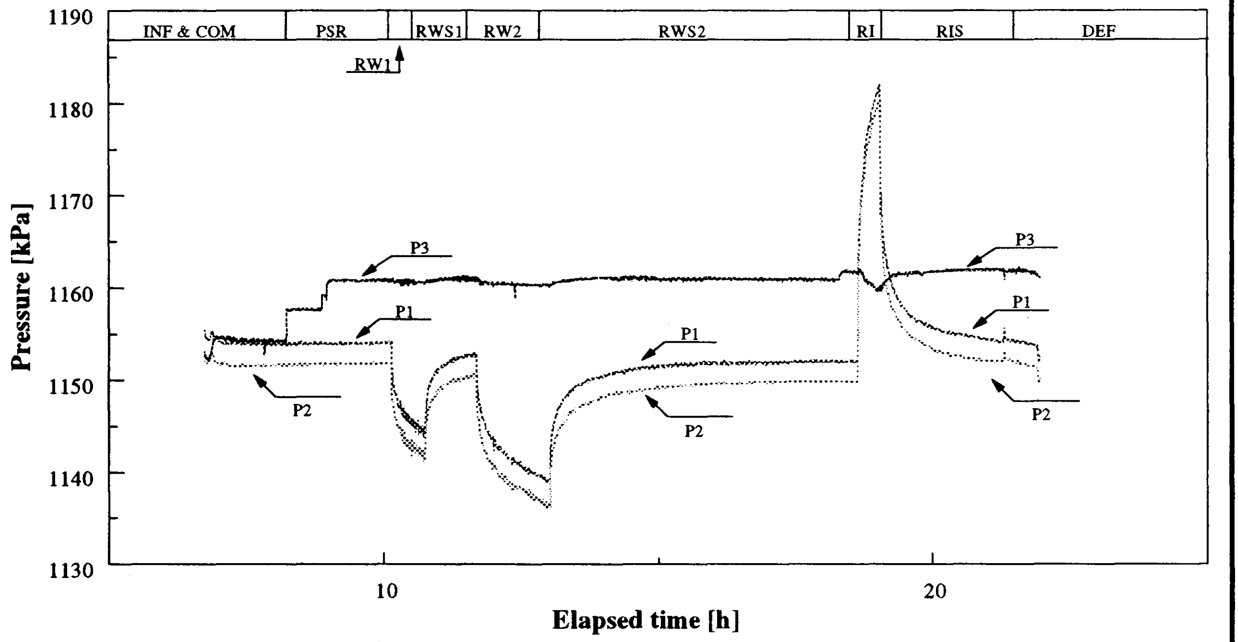
RWS - The shut-in tool was then closed and the pressure allowed to recover for 11.51 h.

PW1& 2 - This period was followed by two pulse withdrawal tests (PW1 and PW2) to obtain physical measurements of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The production periods were performed in 'steps' to ensure there was sufficient drawdown at the end of the RW phases to allow for water sampling. A second pulse phase (PW2) was performed at the end of the test because PW1 was considered unreliable as shut-in tool opening time was too long. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at P2 sensor depth was relatively stable throughout the test.

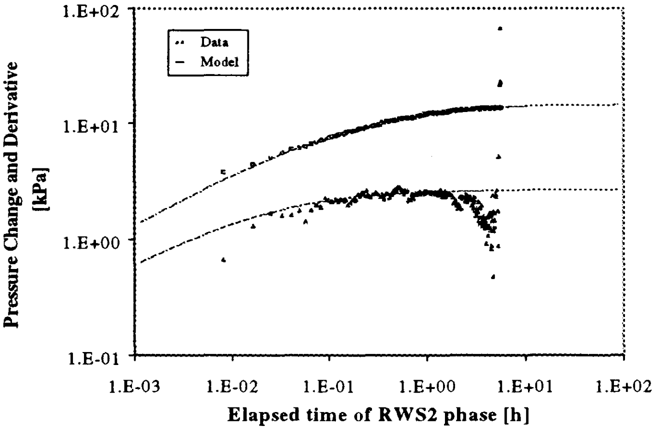
Packer configuration	Single Packer	
Date of test	1st - 3rd December 1994	
Test interval depth	145.00 to 149.90 m bGL 144.97 to 149.87 m bGL	measured true vertical
Test interval length	4.90 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	145.00 - 149.90 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.3E-07 m^2/s 9E-08 - ? (upper limit in excess 1E-06 m^2/s, very sensitive to flow model)	
Best estimate of freshwater head Confidence interval of freshwater head	942.0 m asl 940 - 945 m asl	
Radius of investigation	57 m	
Stabilised temperature at downhole sensor depth	10.5 °C	
Recommended flow model	Partially Penetrating Well Homogeneous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL VM2	110.0 - 149.9 m bGL

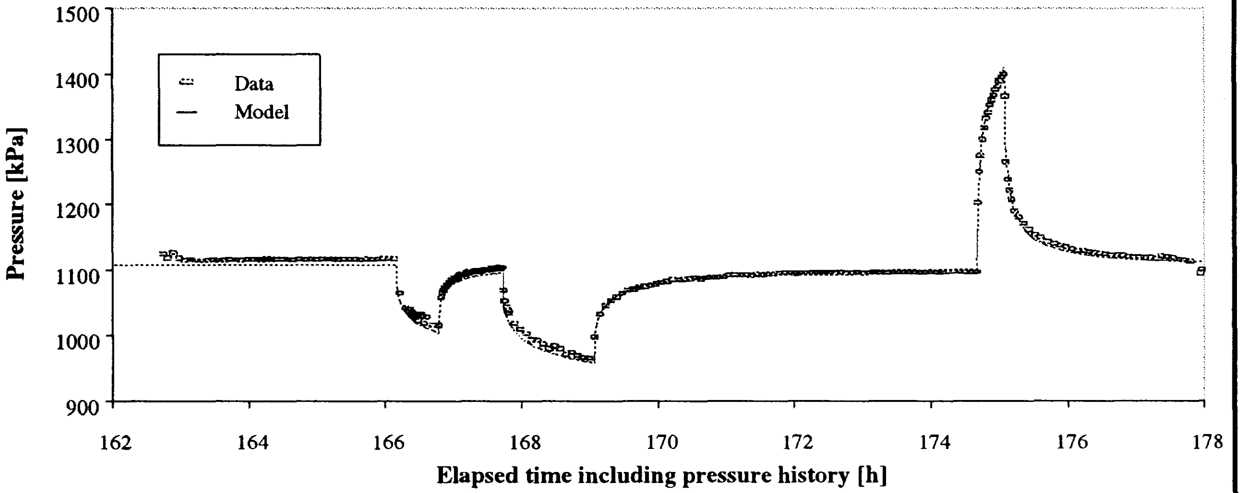


Pressures Measured During VM2

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS2 Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM2	110.0 to 149.9 m bGL	Reference: NIB 94-81B Standard Analysis

Test Sequence Description:

COM - After packer inflation to 4200 kPa with Nitrogen, the shut-in tool remained open for 0.95 h to allow temperature conditions to stabilise and to obtain an initial estimate for the borehole history rate. The low estimate for the historical rate (-4E-3 l/min) indicates that the static interval pressure is nearly at hydrostatic conditions.

PSR - This was confirmed in the subsequent 1.93 h shut-in period with no significant change in pressure.

RW1 - Following the PSR period, the interval was produced at a flowrate of approximately 5 l/min. At the end of this 0.62 h period, the total drawdown was only 11 kPa which was terminated due to poor rate control.

RWS1 - The subsequent build-up period (RWS1) was 0.95 h in duration.

RW2 - It was followed by a second production period. In this period, the rate was increased to 6 l/min, nearly the maximum output of the system, and remained stable until power supply problems caused the pump to stop.

RWS2 - The interval was immediately shut-in due to the seal between the rotor and the stator and shortly thereafter, the shut-in tool was also closed (RWS2). The RWS2 shut-in continued for 5.63 h.

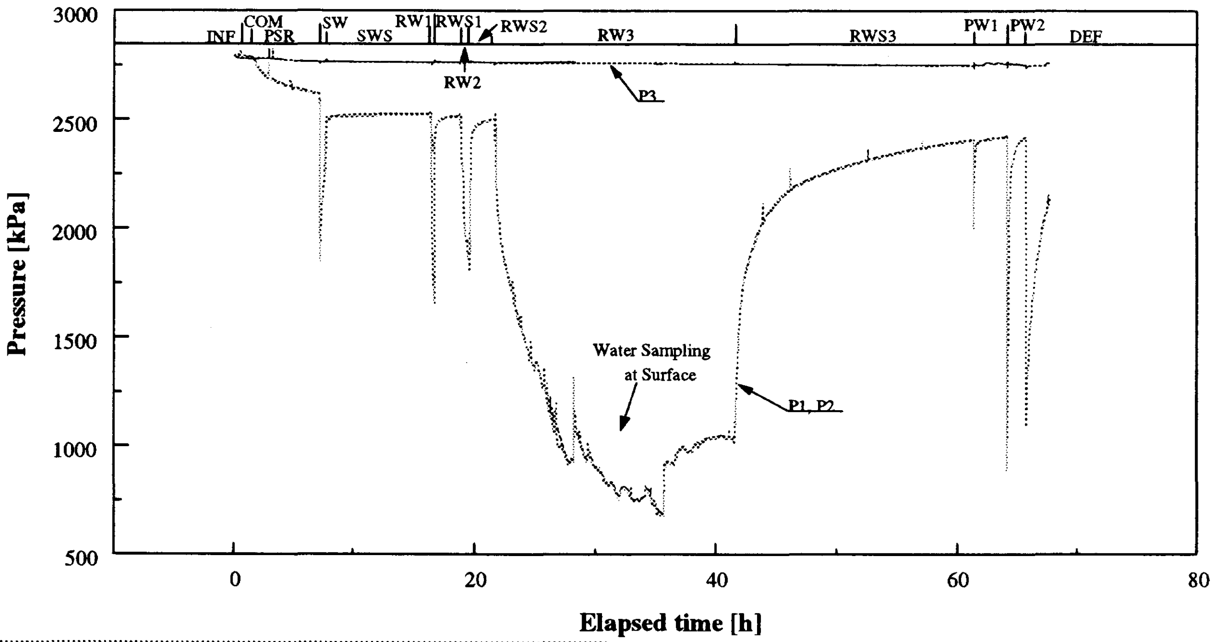
RI - To create a larger formation response and provide a means to confirm the reliability of derived parameters by showing consistency between results from different test types, an injection test was performed with a rate of approximately 17 l/min for a duration of 0.40 h. The total pressure build-up was approximately 30 kPa with the duration limited by equipment constraints.

RIS - A final build-up period ensued and lasted 2.23 h when the packer was deflated.

Comments: All objectives were achieved. During the test, it was decided not to collect water samples. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at P2 depth increased by 0.6 °C during INF, COM and PSR phases and decreased by 0.9 °C during the injection phase and increased by 0.8 °C in the subsequent recovery period; otherwise the readings were relatively stable.

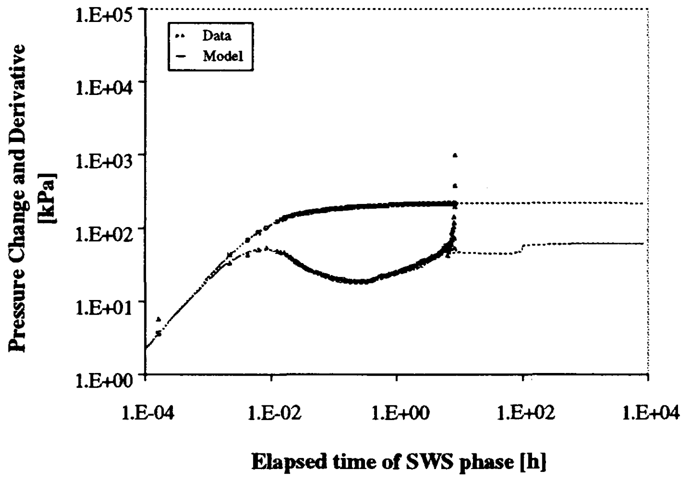
Packer configuration	Single Packer	
Date of test	4th December 1994	
Test interval depth	109.96 to 149.90 m bGL 109.94 to 149.87 m bGL	measured true vertical
Test interval length	39.94 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	114.00 - 149.90 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	2.9E-05 m^2/s 2.7E-05 - 3.3E-05 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	943.9 m asl 943.9 - 944.0 m asl	
Radius of investigation	650 m	
Stabilised temperature at downhole sensor depth	11.0 °C	
Recommended flow model	Wellbore Storage and Skin Homogeneous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL VM3	260.1 - 295.0 m bGL

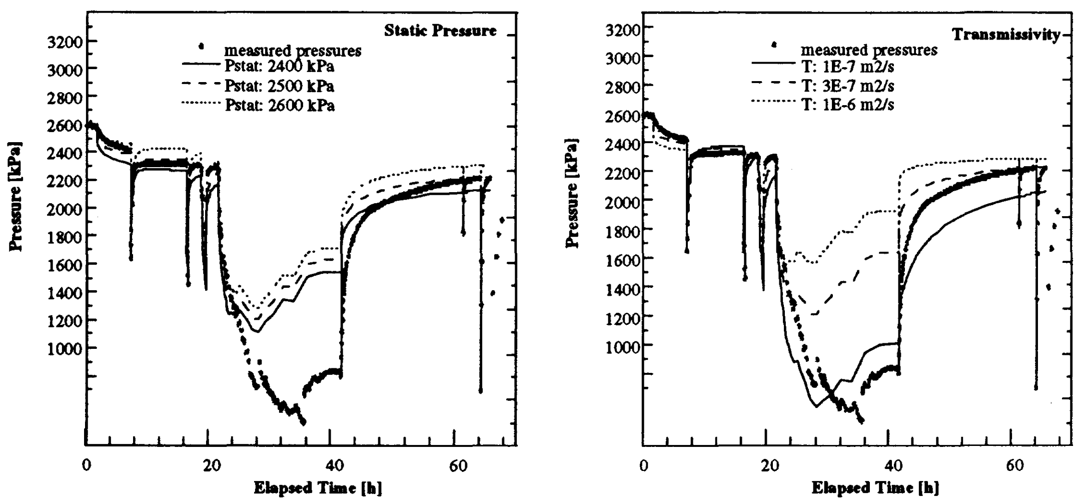


Pressures Measured During VM3

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v VM3	260.1 to 295.0 m bGL	Reference: NIB 94-81C Detailed Analysis

Test Sequence Description:

COM - After inflation of the packer to 5000 kPa with water, the test was started with a 1.06 h COM phase, during which a rate of -9E-3 l/min was measured.

PSR - The subsequent PSR phase (5.55 h), designed to give a first estimate of the static formation pressure, showed an atypical response which could not be related to any tool problems. Checks confirmed the packer seal as well as the seal of the shut in tool. This atypical response was possibly caused by ongoing compliance effects in the interval.

SW - The PSR phase was followed by a brief SW period (0.56 h). This was designed to yield a quick estimate of the formation parameters for use in the design of subsequent test stages.

SWS - The shut in tool was then closed for a SWS phase of 8.70 h.

RW1& 2 - It was planned that a long period of constant rate extraction should follow, in order to stress the formation and induce gas segregation and two phase flow, and to obtain the groundwater sample. Initially, problems with the Moyno pump prevented this. The first two trials RW1 (0.26 h) with water rates between 5.8 and 7.8 l/min, and RW2 (0.79 h) with water rates between 3.2 and 5.8 l/min, were relatively short.

RWS1 & 2 - They were followed by recovery periods (RWS1 and RWS2 respectively).

RW3 - The RW3 period lasted 20.00 h and included sampling. The initial water rate was 4.9 l/min and increased to 6.0 l/min in 1.55 h, when gas flow was first observed. At a pressure of ca.1687 kPa , the sudden erratic flowrate, sharp rises in the interval pressure and smell of H_2S, were all indicators of gas flow. The water component of the flowrate gradually decreased throughout the remainder of the period to a final rate of 2.0 l/min. The gas flowrate decreased gradually from 8.5 l/min at the time of first measurements to approximately 2.3 l/min when the separator was bypassed for sampling at the wellhead, 12.85 h into the period. The entire groundwater sampling period lasted 4.30 h. During sampling the production rates were difficult to control. The pressure recovered from 672 to 909 kPa due to the pump inadvertently shutting off. After sampling at the surface was completed, the separator was re-connected and relatively stable conditions for the remanding 4.3 hours of the period: the water flowrate was 2.0 l/min, and the gas flowrate was 0.2 l/min.

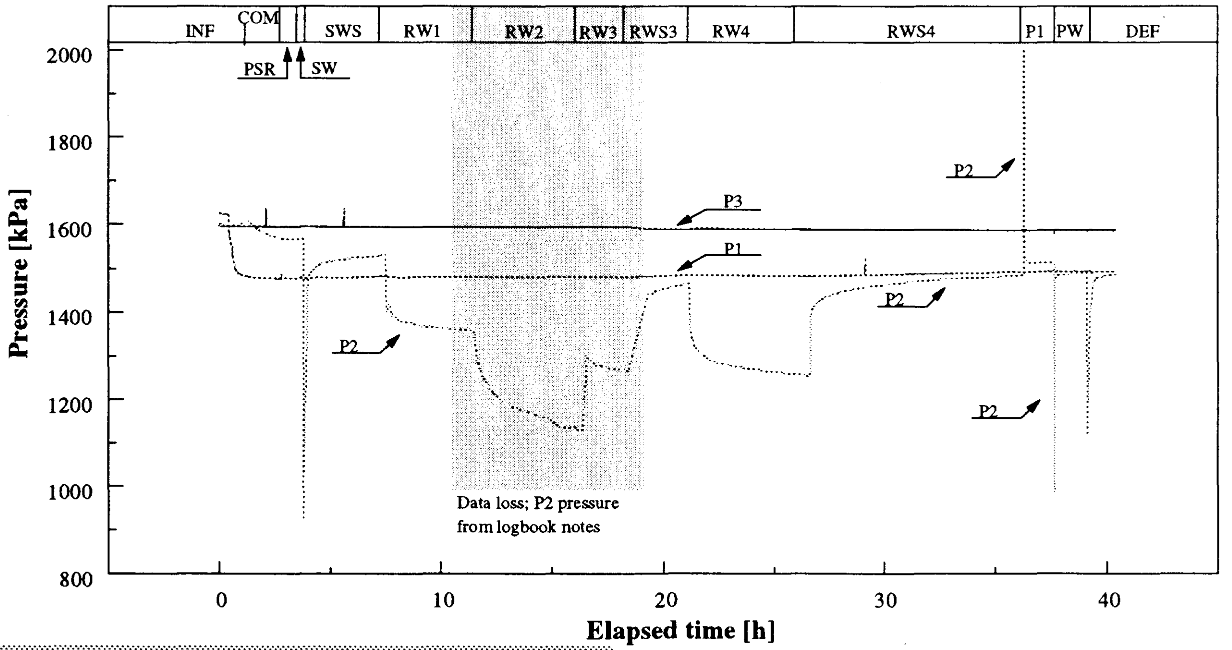
RWS3 - The pressure recovery RWS3 lasted 19.79 h.

PW1&2 - The test was concluded with two pulse withdrawal events (PW1 and PW2) to obtain physical measurements of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The temperature at P2 sensor depth was relatively stable throughout the test.

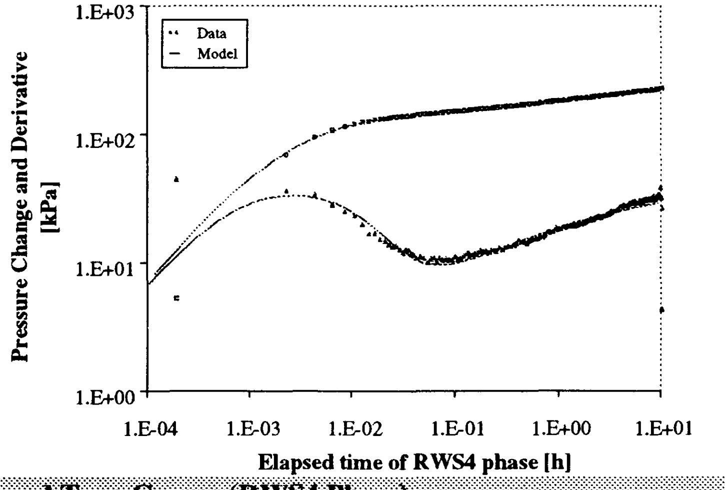
Packer configuration	Single Packer	
Date of test	15th - 18th December 1994	
Test interval depth	260.05 - 295.00 m bGL 260.00 - 294.94m bGL	measured true vertical
Test interval length	34.95 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	260.05 - 295.00 m bGL LOWER CRETACEOUS-Valanginian; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.9E-6 m^2/s 1.0E-7 - 2.0E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	934 m asl 922 - 942 m asl	
Radius of investigation	74 m	
Stabilised temperature at downhole sensor depth	14.5 °C	
Recommended flow model	Wellbore storage and skin Composite Infinite in lateral extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No Yes

BOREHOLE SB4a/v - INTERVAL VM4	152.5 - 207.7 m bGL

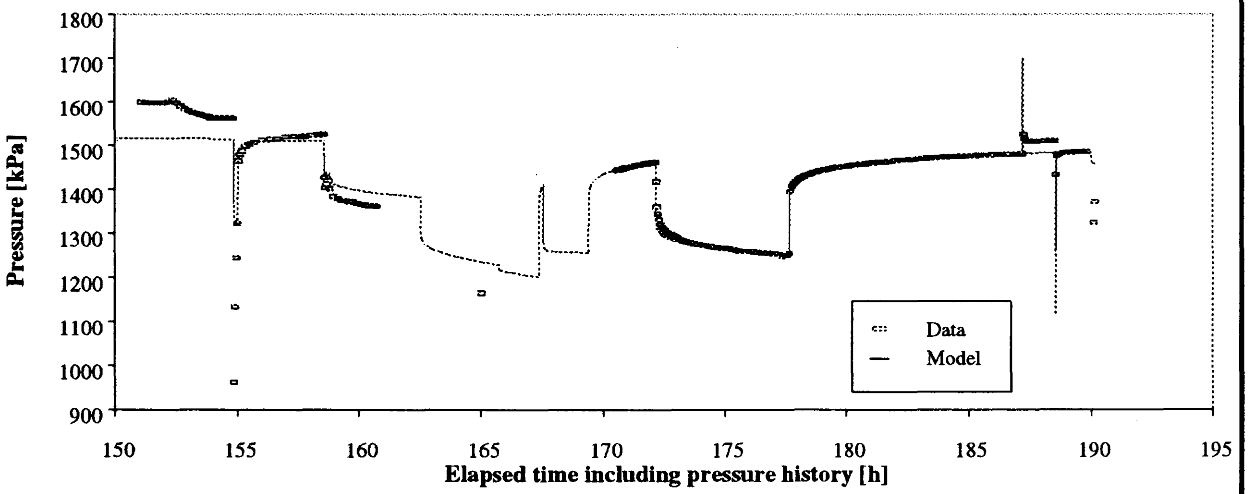


Pressures Measured During VM4

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS4 Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM4	152.5 to 207.7 m bGL	Reference: NIB 94-81C Standard Analysis

Test Sequence Description:

COM - After the inflation of both packers to 5000 kPa with water, the test was started with a 1.53 h COM phase, during which a rate of -8E-2 l/min was measured.

PSR - The subsequent PSR phase (0.96 h) showed little response. The pressure levelled out relatively quickly to 1566 kPa. This untypical response was probably caused by high skin induced during drilling.

SW - The PSR phase was followed by a brief SW period (0.18 h). This was designed to yield a quick estimate of the formation parameters for use in the design of subsequent test stages.

SWS - The shut in tool was then closed for a SWS phase of 3.52 h.

RW1, 2 & 3 - A three step constant rate withdrawal period (RW1, RW2 and RW3) followed, with a total duration of 10.93 h. The rate was increased from an initial 3.6 l/min up to 7.7 l/min in order to maximise the drawdown and induce gas segregation around the wellbore. Problems with the Moyno pump forced a subsequent rate reduction to 6.3 l/min. Gas flow was observed during the RW2 event. The reported gas flow rate of 0.4 l/min should be regarded with caution. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

RWS3 - After the RW periods the interval was shut in and the recovery (RWS3) was measured for 2.77 h. Due to a data loss it was decided to repeat the production period.

RW4 - The RW4 phase lasted 5.51 h at an average total rate of 6.3 l/min. During the RW4 event gas flow was observed. The reported gas flow rate 0.2 l/min should be regarded with caution. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

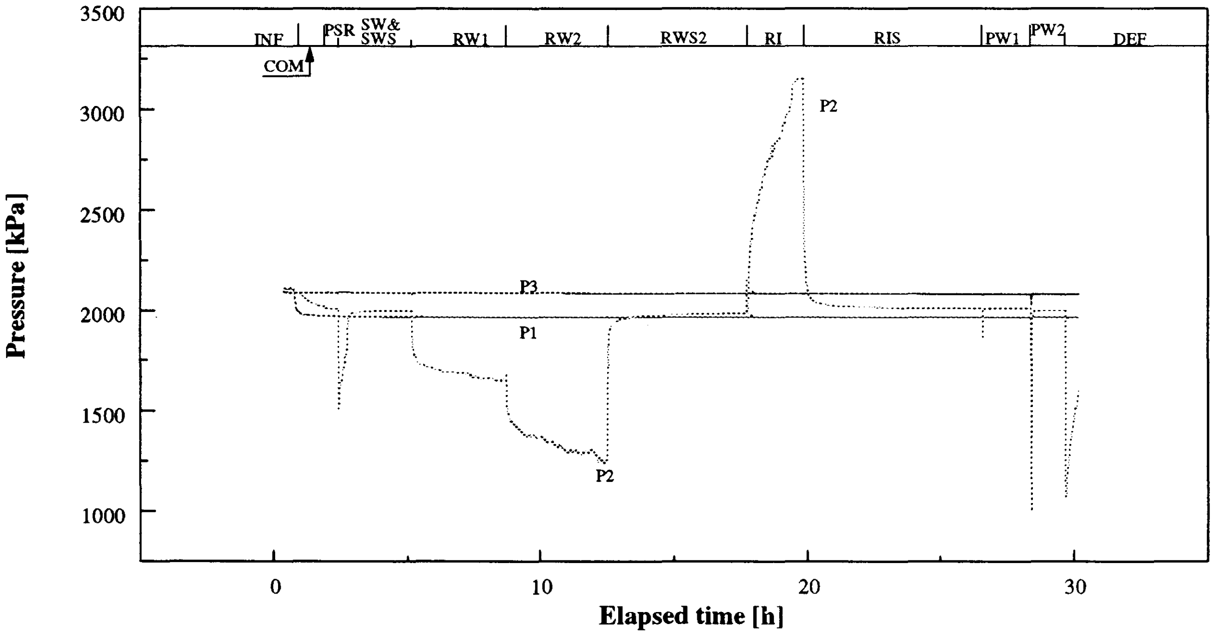
RWS4 - The RW4 period was followed by a 9.61 h recovery phase (RWS4).

PI & PW - The test was concluded with a pulse injection (PI) and a pulse withdrawal (PW) phase. The pulse events were designed to to obtain physical measurements of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. Although both gas and water were measured in the main production period, single phase parameters derived in the analysis of individual phases showed a reasonable match to the entire simulation. The temperature at P2 sensor depth was relatively stable throughout the test.

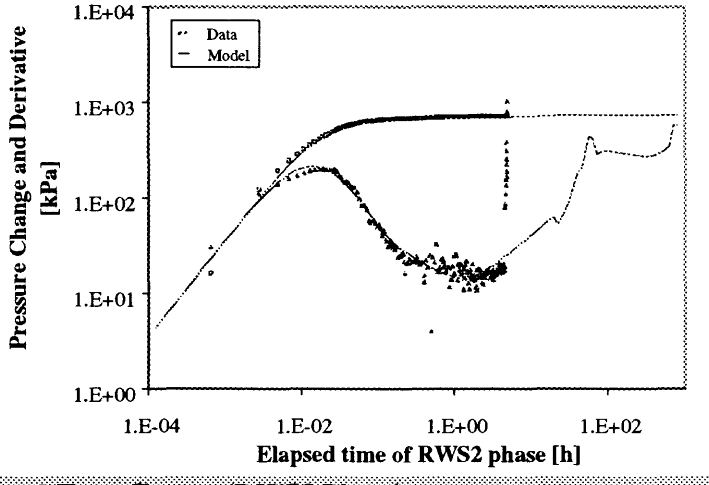
Packer configuration	Double Packers	
Date of test	18th - 20th December 1994	
Test interval depth	152.46 - 207.68 m bGL 152.43 - 207.64 m bGL	measured true vertical
Test interval length	55.22 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	152.46 - 207.68 m bGL LOWER CRETACEOUS-Valanginian; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	7.00E-7 m^2/s 9.00E-8 m^2/s - 5.00E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	938 m asl 935 m asl - 941 m asl	
Radius of investigation	80 m	
Stabilised temperature at downhole sensor depth	11.5 °C	
Recommended flow model	Wellbore storage and skin Composite Infinite in lateral extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No Yes

BOREHOLE SB4a/v - INTERVAL VM5	203.5 - 258.8 m bGL

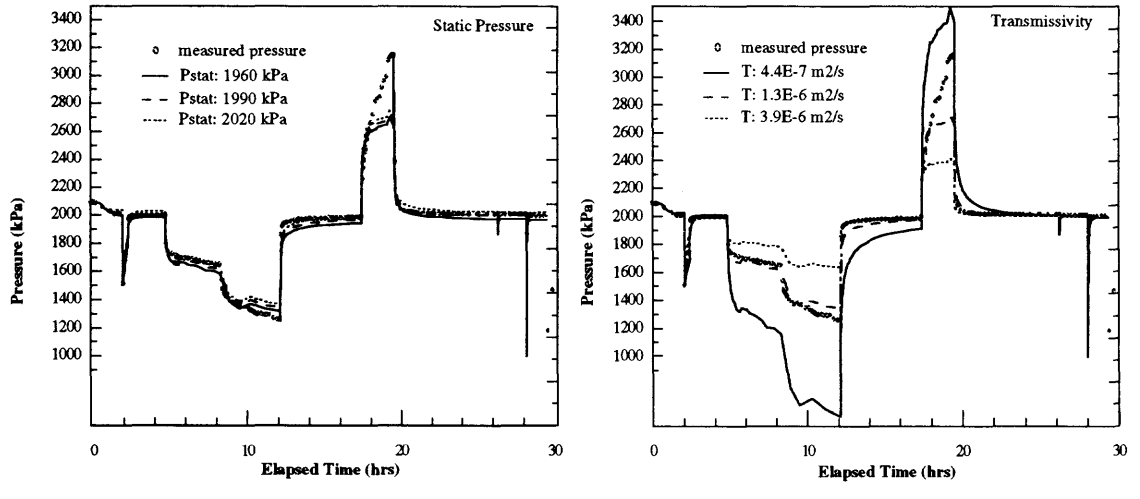


Pressures Measured During VM5

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS2 Phase)



Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v VM5	203.5 to 258.8 m bGL	Reference: NIB 94-81C Standard Analysis

Test Sequence Description:

COM - After the inflation of both packers to 5000 kPa with water, the test was started with a 1.53 h COM phase, during which a rate of -2.5E-1 l/min was measured.

PSR - The subsequent PSR phase (0.96 h) showed little response, suggesting a static formation pressure near 2000 kPa.

SW - The PSR-phase was followed by a brief SW period (0.18 h). This was designed to yield a quick estimate of the formation parameters for use in the design of subsequent test stages.

SWS - The shut in tool was then closed for a SWS phase of 2.41 h.

RW1 & 2 - A two step constant rate withdrawal period (RW1 and RW2) followed, with a total duration of 7.33 h. The rate was increased from an initial 2.5 l/min up to 4.4 l/min in order to maximise the drawdown and induce gas segregation around the wellbore. Gas flow was observed during the RW2 event. The reported gas flow rate of 0.5 l/min should be regarded with caution. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

RWS2 - After the RW periods the interval was shut in and the recovery (RWS2) was measured for 5.26 h..

RI - A constant rate injection phase of 2.09 h followed at an injection rate of -5.1 l/min. The goal of this phase was to ensure 100% water saturation in the vicinity of the wellbore.

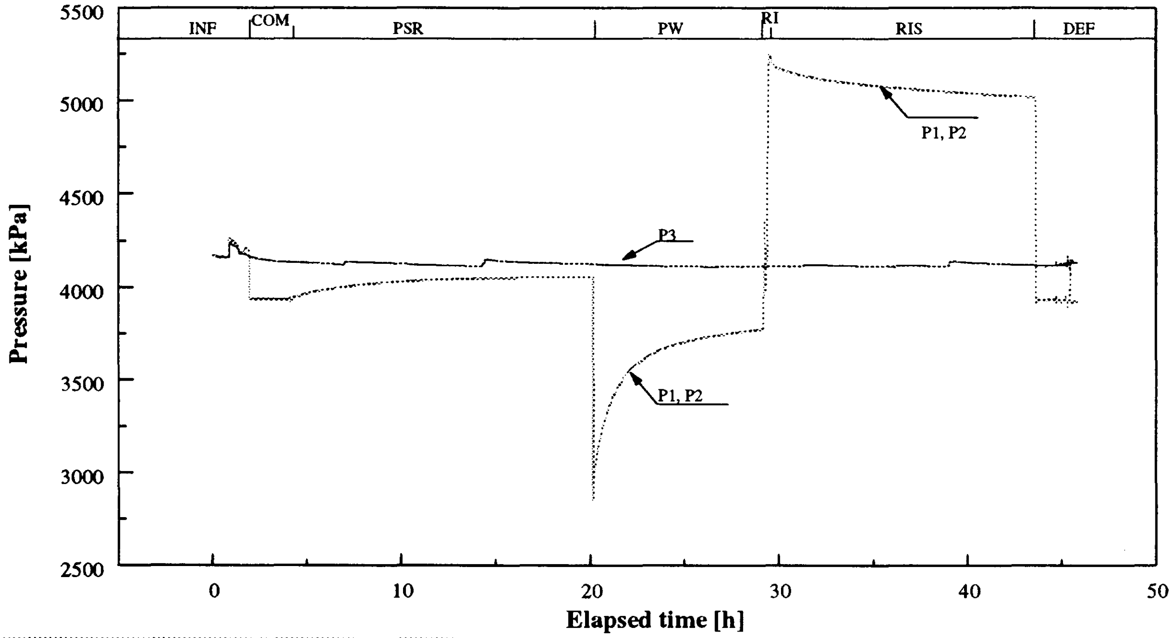
RIS - The recovery phase lasted 6.74 h.

PW1 & 2- The test was concluded with two pulse withdrawal phases (PW1 and PW2). The pulse events were designed to to obtain physical measurements of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. Although both gas and water were measured in the main production period, single phase parameters derived in the analysis of individual phases showed a reasonable match to this part of the test. The injection phase shows a non-ideal response and may be attributed to stress effects on fractures connected to the borehole due to varying pressure conditions or 'plugging' and 'unplugging' of fractures from sediment carried in suspension with the fluid injected into the formation. The temperature at the P2 sensor depth was relatively stable throughout the test except during the injection period with a reduction of 1.14 °C and increase by the same amount in the recovery period.

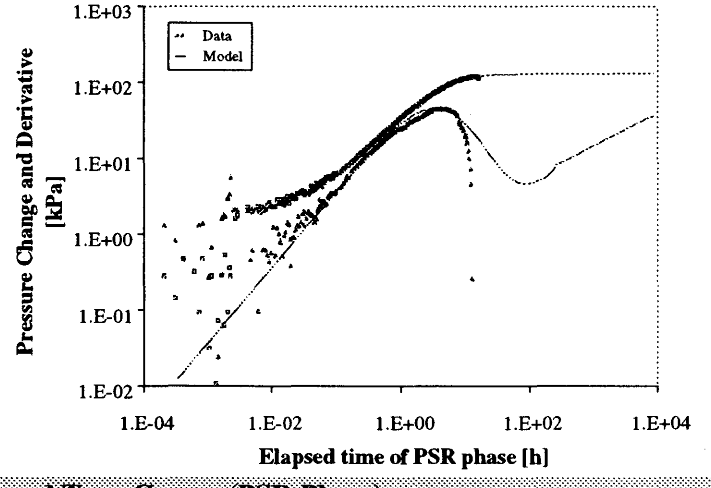
Packer configuration	Double Packer	
Date of test	20th - 22nd December 1994	
Test interval depth	203.53 - 258.75 m bGL 203.49 - 258.70 m bGL	measured true vertical
Test interval length	55.22 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	203.53 - 258.75 m bGL LOWER CRETACEOUS-Valanginian; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	2.53E-6 m^2/s 4E-7 to 4E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	937 m asl 933 - 939 m asl	
Radius of investigation	60 m	
Stabilised temperature at downhole sensor depth	12.5 °C	
Recommended flow model	Wellbore storage and skin Composite Infinite lateral extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No Yes

BOREHOLE SB4a/v - INTERVAL VM6	389.5 - 400.0 m bGL

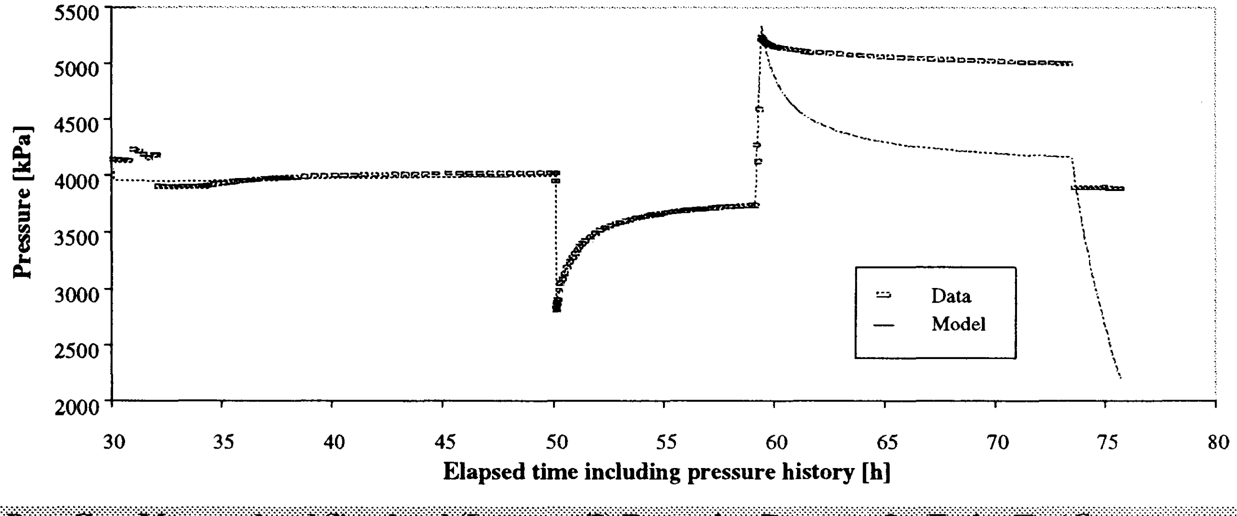


Pressures Measured During VM6

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM6	389.5 to 400.0 m bGL	Reference: NIB 94-81D Standard Analysis

Test Sequence Description:

After lowering the tools to test depth 1.5 m^3 of uranin tracered fresh water was pumped into the tubing. Since the fluid was injected near the bottom of the borehole (screen depth 398 to 400 m bGL), the flushing activites should allow for complete displacement of the mud from the test interval. When flushing was complete, the surface valve was closed to prevent the denser drilling mud from displacing the flushing fluid. The packer was then inflated to 5500 kPa using water.

COM - The shut-in tool remained open for a 2.18 h compliance period to allow temperature to equilibrate and to obtain an initial estimate of the historical rate. The level in the tubing, after being stable, started rising at a very slow rate, the equivalent flowrate is 1E-3 l/min.

PSR - In the subsequent 15.97 h PSR period the pressure recovered 120 kPa to an end pressure of 4048 kPa.

PW - During the PSR period, fluid was swabbed from the tubing to a depth of 107 m bGL. A PW phase was subsequently performed in the test interval. The pressure recovered to approximately 76 % of the total drawdown in 9.10 h.

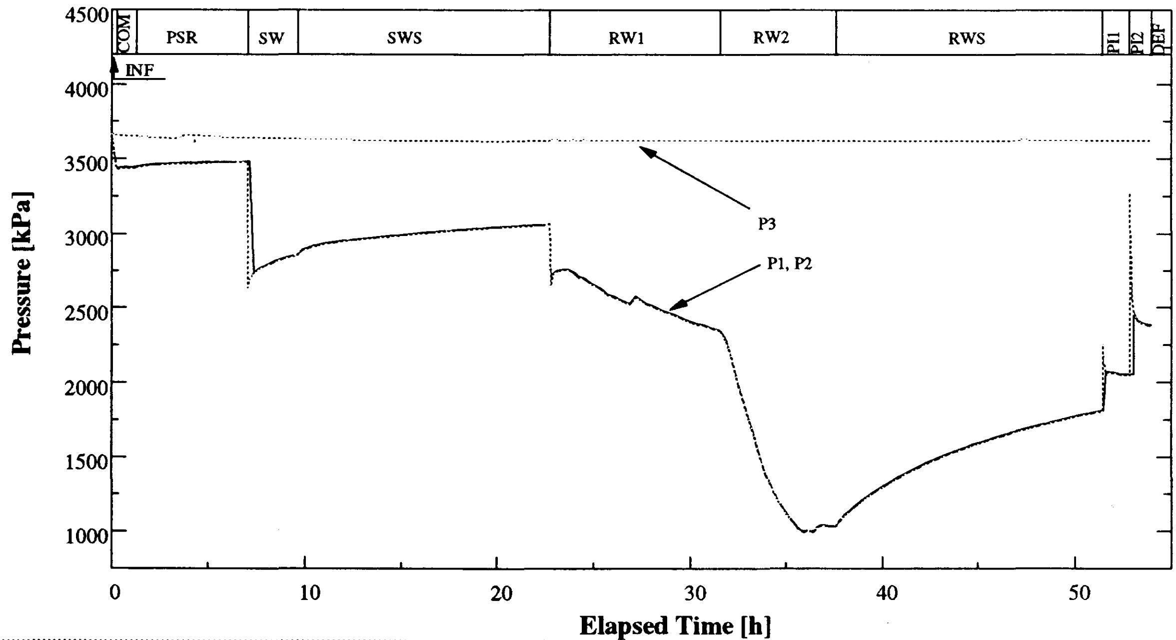
RI - The recovery period following a constant rate event would allow a confirmation of transmissivity derived in the pulse and extrapolation of the pressure to determine the static formation pressure. Due to the low permeability of the interval and hence low required pumping rates, a constant rate withdrawal period was not possible because it would have exceeded the lower limit of the equipment. The injection period was 0.30 h in duration, with an average rate of 0.3 l/min, resulting in a pressure increase to 5229 kPa. The variation in rate during this period was noisy (approximately 0 to 1.5 l/min) due to equipment limitations.

RIS - Recovery was relatively slow in the subsequent shut-in period, with an end pressure of 5012 kPa after 14.10 hours. The slow recovery may be in part due to plugging of the borehole walls during the injection phase.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the moderate interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The closing of the shut-in tool distorted the early time data in the PSR phase. The injection phase shows a non-ideal response and may be attributed to stress effects on fractures connected to the borehole due to varying pressure conditions or 'plugging' and 'unplugging' of fractures from sediment carried in suspension with the fluid injected into the formation. The temperature at the P2 sensor depth increased by 2.7°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

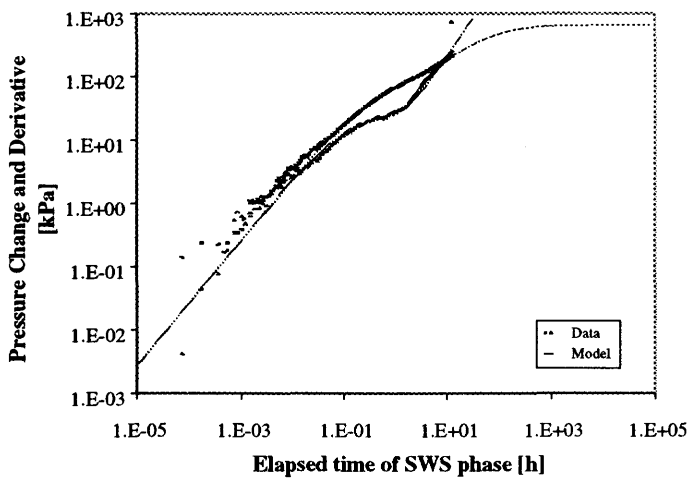
Packer configuration	Single Packer	
Date of test	12th - 14th January 1995	
Test interval depth	389.50 to 400.00 m bGL 389.43 to 399.93 m bGL	measured true vertical
Test interval length	10.50 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	389.50 to 400.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	8.0E-11 m^2/s 2E-11 to 4E-10	
Best estimate of freshwater head Confidence interval of freshwater head	960 m asl 944 to 976 m asl	
Radius of investigation	3 m	
Stabilised temperature at downhole sensor depth	17.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/v - INTERVAL VM7 | 345.9 - 400.0 m bGL

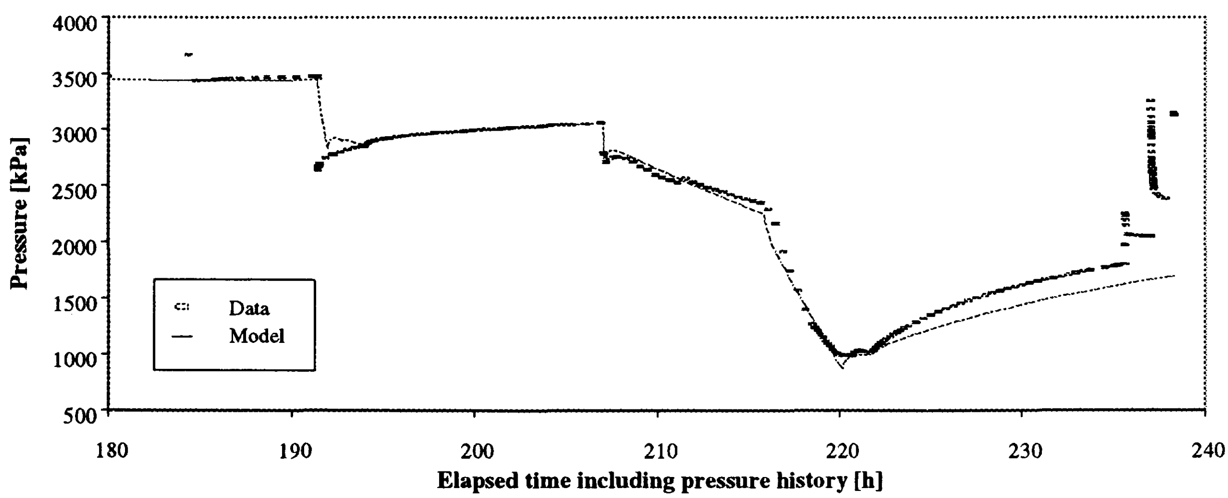


Pressures Measured During VM7

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM7	345.9 to 400.0 m bGL	Reference: NIB 94-81D Standard Analysis

Test Sequence Description: After moving the tools to 27 m below VM7 test depth 2.0 m^3 of uranin tracered fresh water was circulated down the tubing. The screen depth during flushing activities was approximately 381 to 383 m bGL, which should have allowed for displacement of the majority of the drilling mud from the interval. After flushing activites, the tools were pulled up to test depth and the packer was inflated with water to 5000 kPa.

COM - The shut-in tool remained open for 0.93 h during the compliance period, to allow temperature of the interval fluid to equilibrate and to obtain an initial estimate of the historical rate. There was no discernible change in the tubing fluid level at this time.

PSR - A slight pressure build-up (39 kPa) during the subsequent 5.84 h PSR period was recorded. There was an anomalous kink 0.10 h into recovery which may be attributed to temperature effects. The temperature was slowly rising and then showed a sharp increase from 15.5 to 16.0 °C.

SW - During the PSR phase fluid was swabbed to a depth of 91 m below the top of the tubing whilst the shut-in tool was closed, in preparation for the ensuing SW period. In the SW phase, the pressure recovered by approximately 28% of the original drawdown in 2.53 h with an average flow rate of 0.34 l/min.

SWS - The test section was then shut-in for about 13.16 h during which the pressure recovered to 3062 kPa, still some 400 kPa below the final PSR pressure.

RW1 & 2 - A RW period was subsequently conducted. The rates for the production period were determined using the SW and SWS preliminary analysis results; the rate was set to 0.2 l/min for the first 8.8 hours (RW1); the rate was then increased to 1.0 l/min (RW2) and gas flow was soon measured, initially at 14 l/min, but falling to 10 l/min by the end of the period. The liquid flow rate declined to less than 0.1 l/min in the same period and the pressure in the interval fell rapidly to 1033 kPa. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

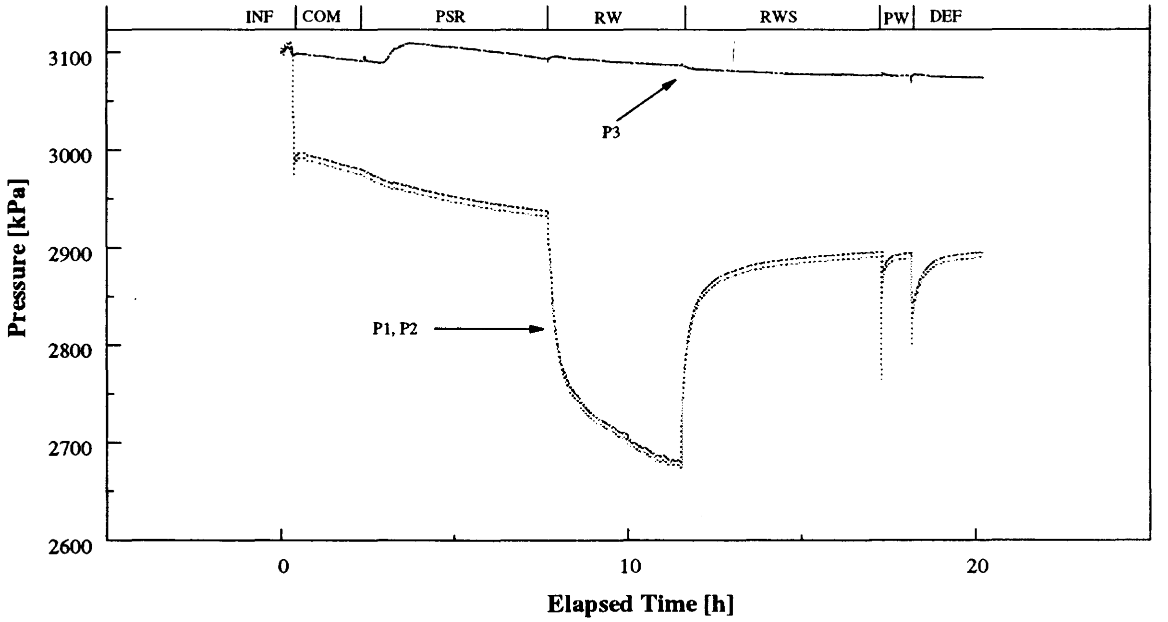
RWS - The subsequent shut-in lasted 13.85 h and was dominated throughout by wellbore storage due to the high gas concentration in the interval after the RW2 phase.

PI & 2 - The test was concluded with two pulse injection phases to obtain physical measurements of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. A power supply problem resulted in the loss of 45 min of data during the RW phase. The borehole history effects on the test response were minimal due to the moderate transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The temperature at the P2 sensor depth increased by 1.6°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

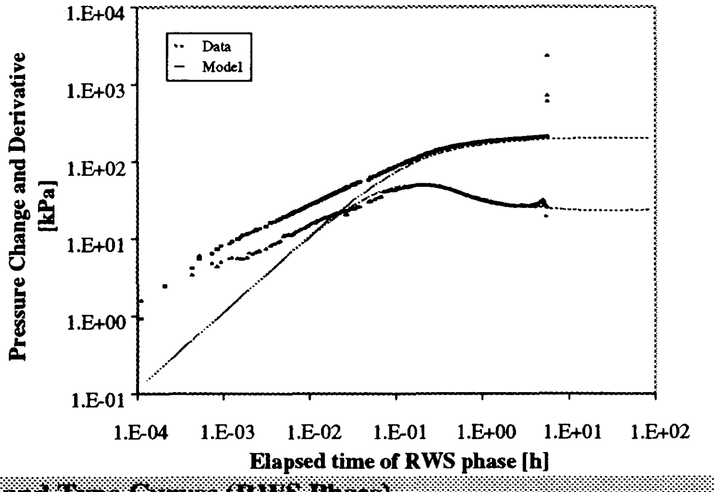
Packer configuration	Single Packer	
Date of test	15th to 17th January 1995	
Test interval depth	345.90 to 400.00 m bGL 345.84 to 399.93 m bGL	measured true vertical
Test interval length	54.10 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	345.90 to 400.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	6.4E-10 m^2/s 5E-11 to 5E-8 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	948 m asl 870 to 950 m asl	
Radius of investigation	3 m	
Stabilised temperature at downhole sensor depth	16.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes Yes Yes

BOREHOLE SB4a/v - INTERVAL VM8	295.8 - 400.0 m bGL

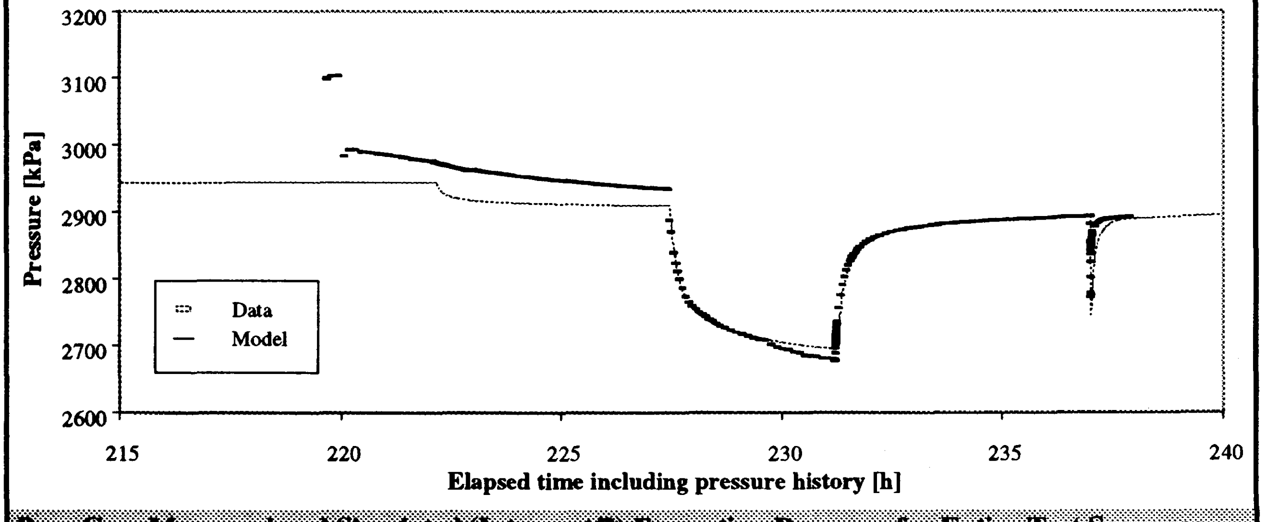


Pressures Measured During VM8

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM8	295.8 to 400.0 m bGL	Reference: NIB 94-81D Standard Analysis

Test Sequence Description:

Prior to the start of the test the tools were lowered to 3 singles below the packer seat and 1.5 m^3 of uranin tracered fresh water was pumped into the tubing. The screen depth for injection of flushing fluid was between 331 and 333 m bGL. The packer was then inflated to 5000 kPa using water.

COM - After packer inflation the shut-in tool remained open for a 1.62 h compliance period to allow temperature of the fluid in the interval to equilibrate to the formation fluid temperature. In this period, the fluid level declined in the tubing at an equivalent rate of -3E-2 l/min.

PSR - A PSR period followed to attain preliminary estimates of the formation properties. There was an anomalous pressure rise in this period which could not be correlated with either activities on the surface or equipment problems.

RW - Subsequently, the shut-in tool was opened for the RW period and fluid was produced from the interval at a rate of 2.2 l/min. At the end of this period the rate became noisy (at a P2 formation pressure of 2677 kPa), which may indicate gas flow. However, no gas was measured at the surface.

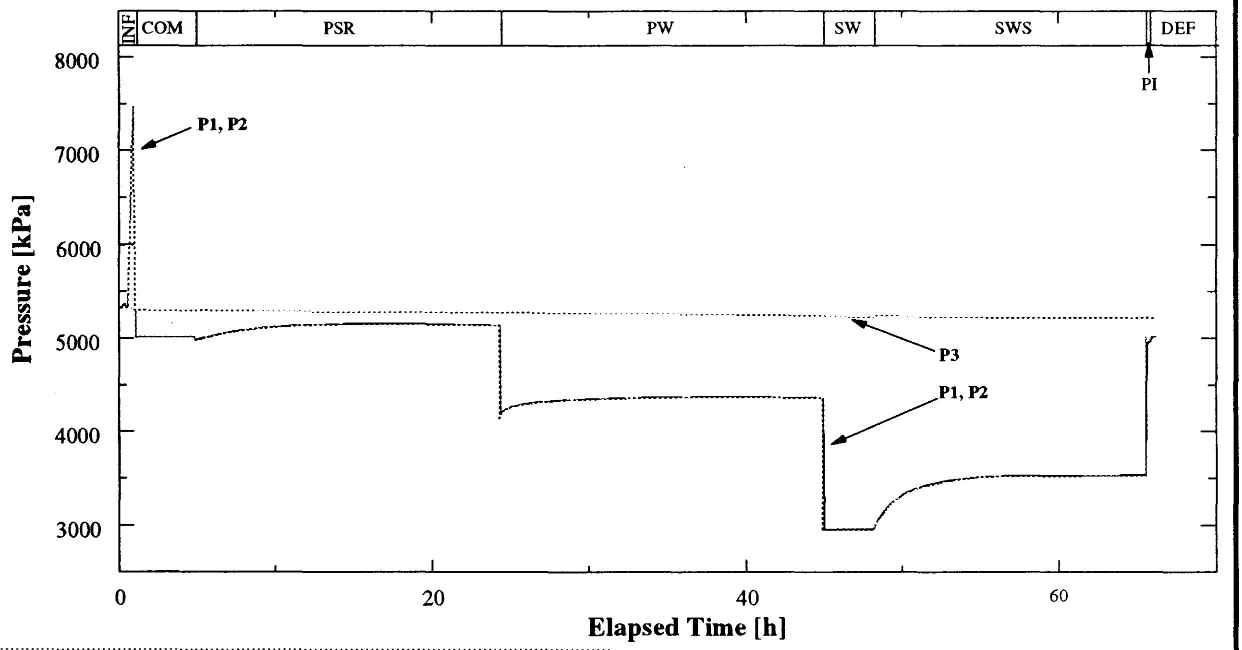
RWS - It was decided to shut-in the interval to minimise potential gas flow, which would complicate the interpretation of the data set for single phase hydraulic parameters. The RWS period continued for 5.77 h.

PW - A pulse withdrawal was performed to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties. The drawdown was relatively shallow (to 2764 kPa) to prevent possible gas effects. After the 0.88 h PW phase the packer was deflated and the test was terminated.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Although the recommended inner boundary condition is wellbore storage and skin, the match to the early time data can be significantly enhanced with a fracture flow model. The borehole history effects on the test response were minimal due to the moderate transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at P2 sensor depth was relatively stable throughout the test.

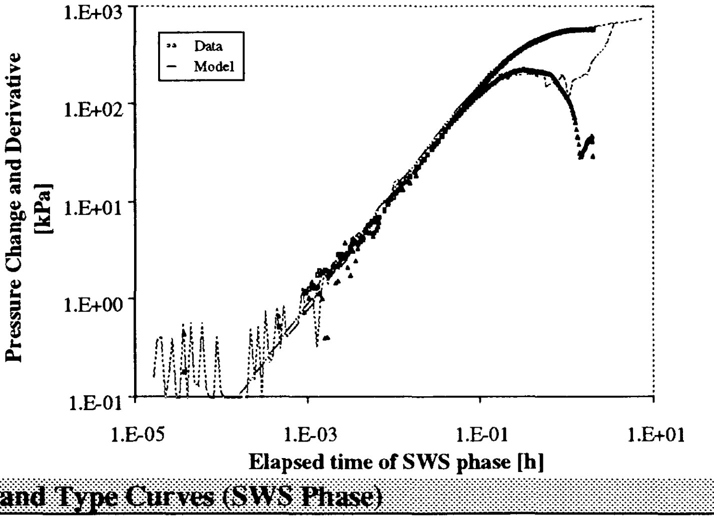
Packer configuration	Single Packer	
Date of test	17th to 18th January 1995	
Test interval depth	295.84 to 400.00 m bGL 295.78 to 399.93 m bGL	measured true vertical
Test interval length	104.16 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	295.84 to 400.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.1E-6 m^2/s 6E-7 to 2E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	936 m asl 930 to 940 m asl	
Radius of investigation	26 m	
Stabilised temperature at downhole sensor depth	15.0 °C	
Recommended flow model	Wellbore Storage and Skin Homogenous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No (see comments for RW Phase)

BOREHOLE SB4a/v - INTERVAL T1 | **501.6 - 520.0 m bGL**

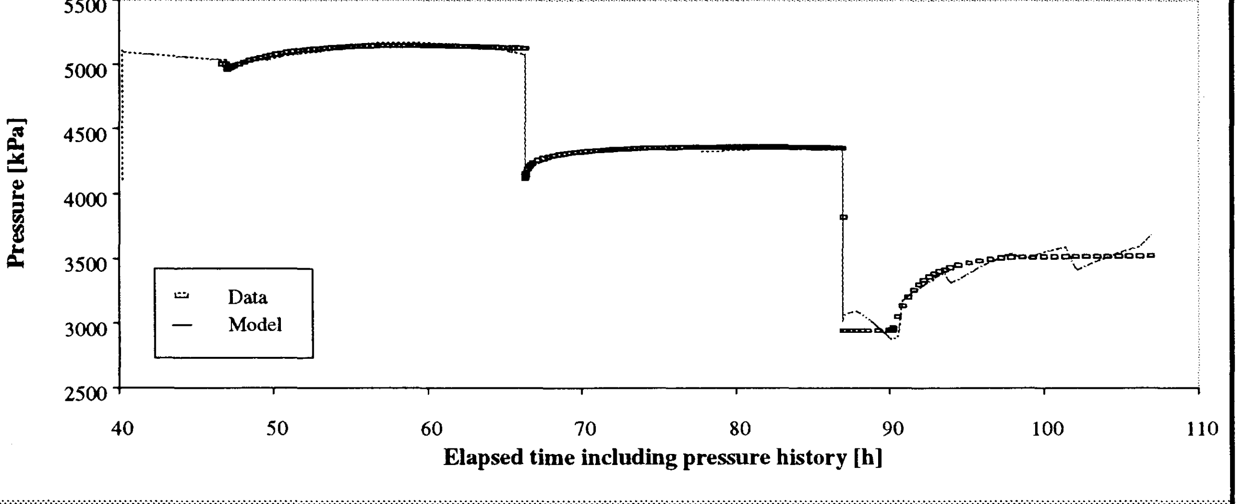


Pressures Measured During T1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v T1	501.6 to 520.0 m bGL	Reference: NIB 94-81E Detailed Analysis

Test Sequence Description:

After lowering the tools to the test depth the system was first flushed with approximately 1.5 m^3 of uranin tracered water and the packer then inflated with 6000 kPa pressure using water.

COM - The shut-in tool remained open for about 3.92 h during the compliance period, to allow temperature effects to dissipate and to obtain an initial estimate of the historical rate. There was no discernible flow at this time.

PSR - A pressure build-up of 171 kPa during the subsequent 19.42 h PSR period was recorded. An anomalous pressure drop of approximately 52 kPa occurred at the start of the PSR; this response was later connected to problems with the shut-in tool. The temperature increased throughout the test; however, most change occurred in the PSR period (+1.5 ^{0}C).

PW - Fluid was swabbed to a depth of 100 m below the top of the tubing and a PTX gauge then positioned 20 m underwater in preparation for the PW period. The PW phase was initiated by opening the tool for 42 s and continued, after closure of the tool, for a further 20.62 h. Fluid was swabbed to approximately 210 m below the top of the tubing during the PW build-up phase.

SW - The shut-in tool was then opened for the 3.22 h SW period; the fluid level rose by 0.44 m in this time which represents an equivalent flowrate of 4.62E-03 l/min.

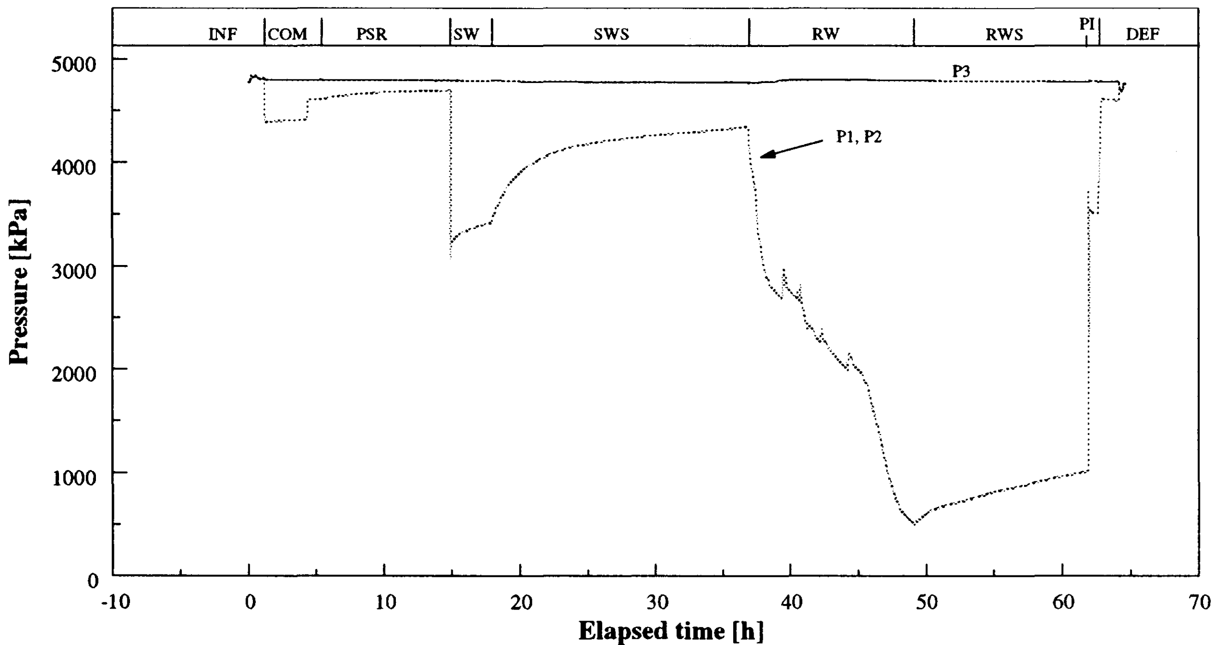
SWS - The test section was then shut-in for 17.37 h during which the pressure recovered to 3530 kPa; although the pressure was rising at the end of this period, it was still some 1601 kPa below the final PSR pressure. An anomaly occured (55.45 to 56.11 h test elapsed time) in the form of a 2 kPa pressure drop, which strongly influenced the subsequent formation response. The cause of this behavoir is uncertain, but may be linked to borehole instability. The sharp fall off in the derivative data on the log log plot is attributed to this anomaly.

PI - The test was concluded with a pulse injection phase to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved except it was not possible to collect a representative water sample within a reasonable time period due to the relatively low transmissivity of the interval. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and anomalous pressure responses. The GTFM/MULTIFIT simulations showed that the PSR phase was substantially effected by temperature effects.

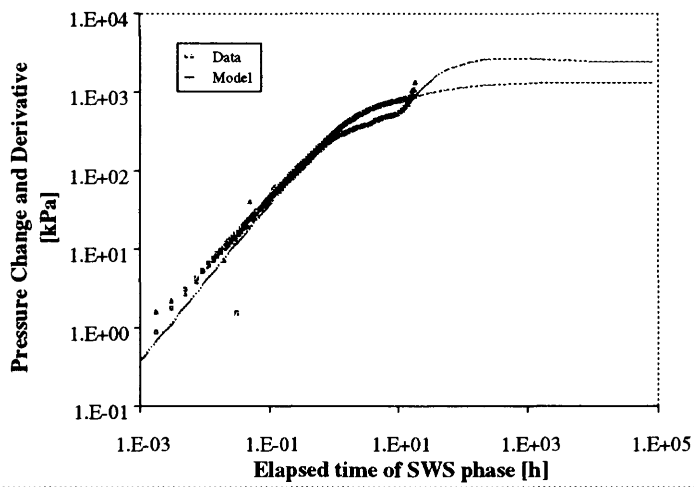
Packer configuration	Single Packer	
Date of test	30th January - 1st February 1995	
Test interval depth	501.57 to 520.00 m bGL 501.35 to 519.77 m bGL	measured true vertical
Test interval length	18.43 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	501.57 - 520.00 m bGL SCHIMBERG SCHISTS and GLOBIGERINA MARLS- sandy marls with mica with layers of sandy clay marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-12 m^2/s 9E-14 to 1E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	826 m asl 543 to 879 m asl	
Radius of investigation	1 m	
Stabilised temperature at downhole sensor depth	21.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/v - INTERVAL T2 | **460.0 - 520.0 m bGL**

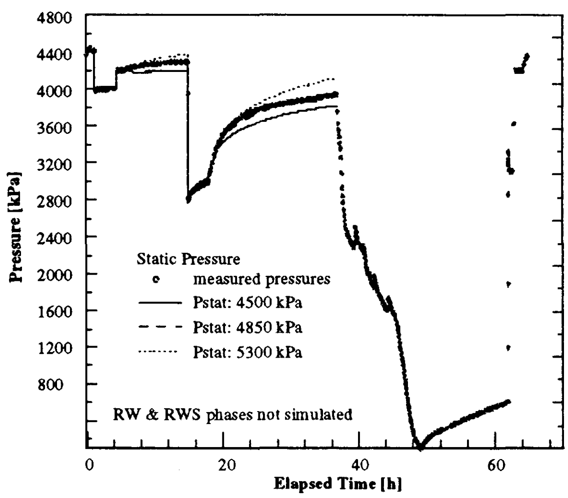


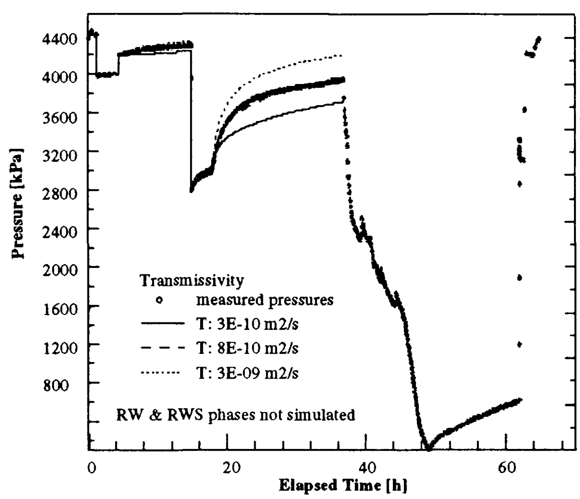
Pressures Measured During T2

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)





Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v T2	460.0 to 520.0 m bGL	Reference: NIB 94-81E Standard Analysis

Test Sequence Description:

After moving the tools up to the T2 test depth, the interval fluid was displaced with uranin tracered freshwater. This was followed by packer inflation to 6000 kPa with water.

COM - The shut-in tool remained open for 3.80 h (COM) to allow for the partial dissipation of temperature effects and to obtain an initial estimate of the historical rate. An equivalent flowrate of 1E-2 l/min was computed from the rise of the fluid level in the tubing during the final 90 min of measurement.

PSR - In the PSR period, the pressure increased 89 kPa over 9.88 h. There was an anomalous kink in the early time data which could not be attributed to an equipment problem.

SW - Fluid was swabbed from the tubing during the PSR to induce a drawdown to 3205 kPa when the shut-in tool was opened for the subsequent SW phase. The SW phase was 3.03 h in duration, with a recovery of 14 % of the total drawdown.

SWS - In the following SWS phase, the pressure recovered from 3421 kPa to 4345 kPa in 18.90 h.

RW - A 12.23 h RW period, with a total drawdown of 3841 kPa, was conducted to confirm the transmissivity derived in the analysis of the SW and SWS phases and to investigate for the presence of gas. The average water flowrate was approximately 0.5 l/min during the initial 10.3 h of the period, but subsequently declined to 0 l/min. Gas flow was first indicated by a noisy flowrate 8.4 h into the phase, but was too low to be measured until a significant increase occurred at the time the water rate reduced to 0 l/min. The first manual measurement of the gas flow was taken 10.5 hours into the period at 29 l/min; this decreased to 12 l/min by the end of the phase. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

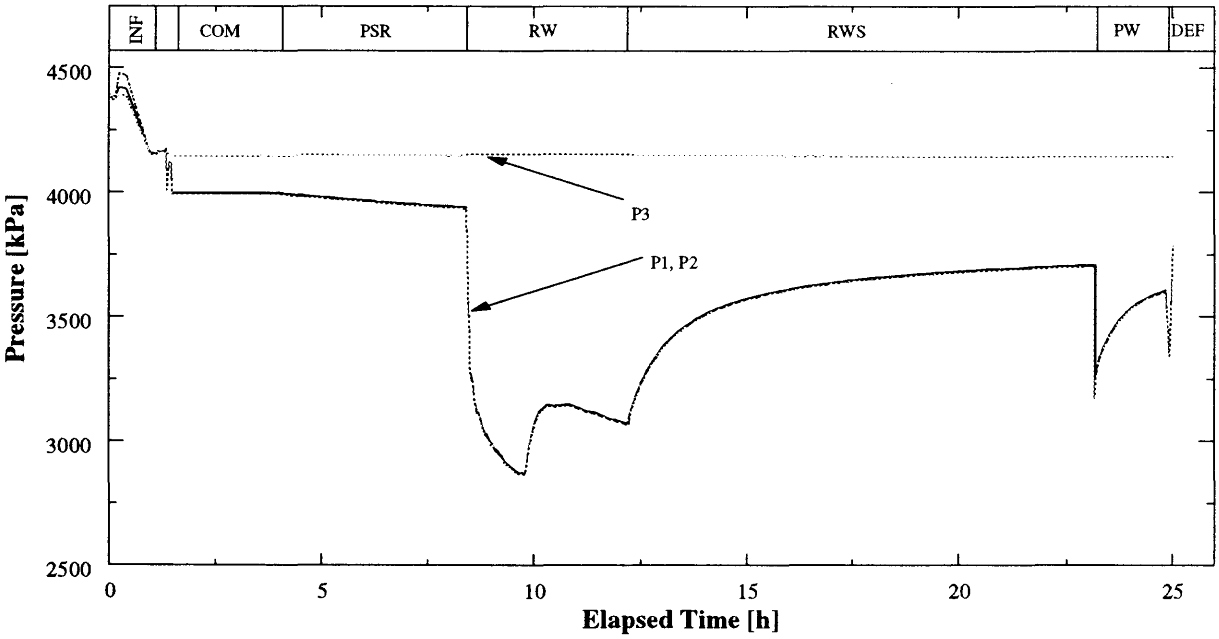
RWS - In the subsequent RWS period, the pressure recovered to 1011 kPa in 12.90 h.

PI - The test was concluded with a PI phase to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the moderate transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The GTFM/MULTIFIT simulations showed that the effect of temperature variations on the test response was insignificant.

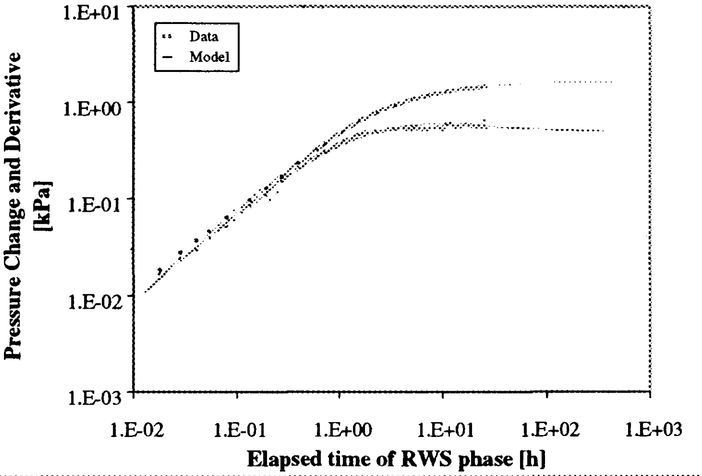
Packer configuration	Single Packer	
Date of test	1st - 4th February 1995	
Test interval depth	460.00 to 520.00 m bGL 459.80 to 519.77 m bGL	measured true vertical
Test interval length	60.00 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	460.00 - 520.00 m bGL SCHIMBERG SCHISTS & GLOBIGERINA MARLS	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	8.0E-10 m^2/s 3E-10 to 3E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	970 m asl 923 to 1005 m asl	
Radius of investigation	90 m	
Stabilised temperature at downhole sensor depth	20 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/v - INTERVAL VMT1	397.7 - 520.0 m bGL

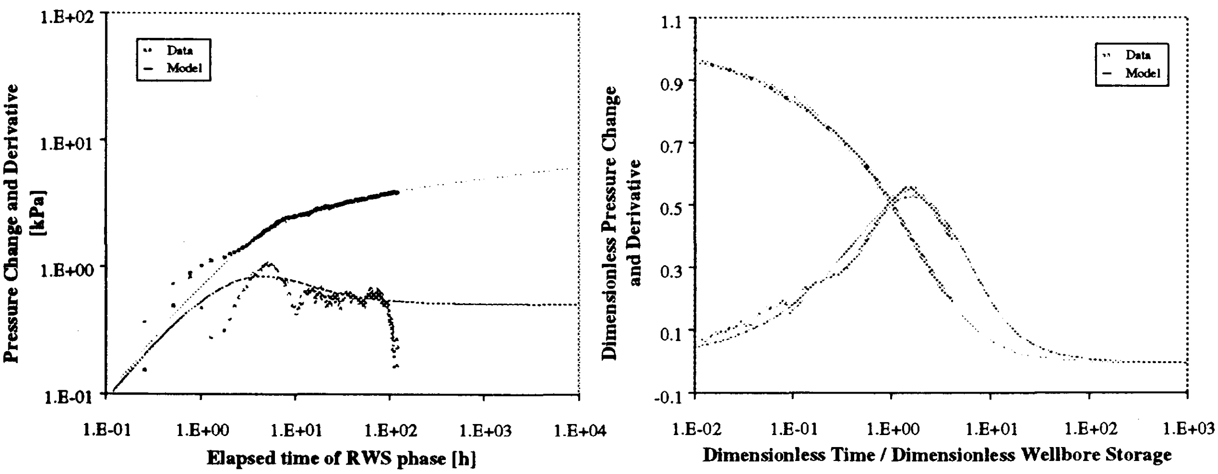


Pressures Measured During VMT1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS Phase)



Log-Log Match for Production Period and Ramey A Match for Pulse Withdrawal Phase

TEST SUMMARY BOREHOLE SB4a/v VMT1	397.7 to 520.0 m bGL	Reference: NIB 94-81E Standard Analysis

Test Sequence Description:

Prior to starting the test the tool was positioned ca. 27 m below the planned packer seat and the interval was flushed with 3 m^3 of tracered freshwater in order to avoid plugging the tool and the formation with drilling mud during the test. Subsequently the tool was moved into position and the packer then inflated to 6000 kPa with water.

COM - The test was started with a 2.58 h COM phase to allow the temperature in the interval to equilibrate and to dissipate part of the unknown wellbore history effects. A rate of -1.7E-3 l/min was measured during the COM phase.

PSR - The subsequent PSR-phase (4.36 h) response was entirely dominated by wellbore storage and ongoing temperature effects (17.4 to 17.9 °C). Due to time limitation and because a significant part of the interval had already been characterised in previous tests (T1 and T2), the decision was made not to run any diagnostic phase, but to proceed with a constant rate withdrawal event.

RW - The initially designed rate of 1.0 l/min proved to be too high and had to be reduced after a few min to 0.6 l/min. The RW phase lasted 3.77 h. No gas was measured at the surface. However gas presence in the interval in the middle of the event was suggested by the atypical interval pressure behaviour, by rising pressures in the surface equipment and by the increased wellbore storage in subsequent phases. The absence of gas at the surface is difficult to explain, though might have been substantiated by prolonging the RW phase.

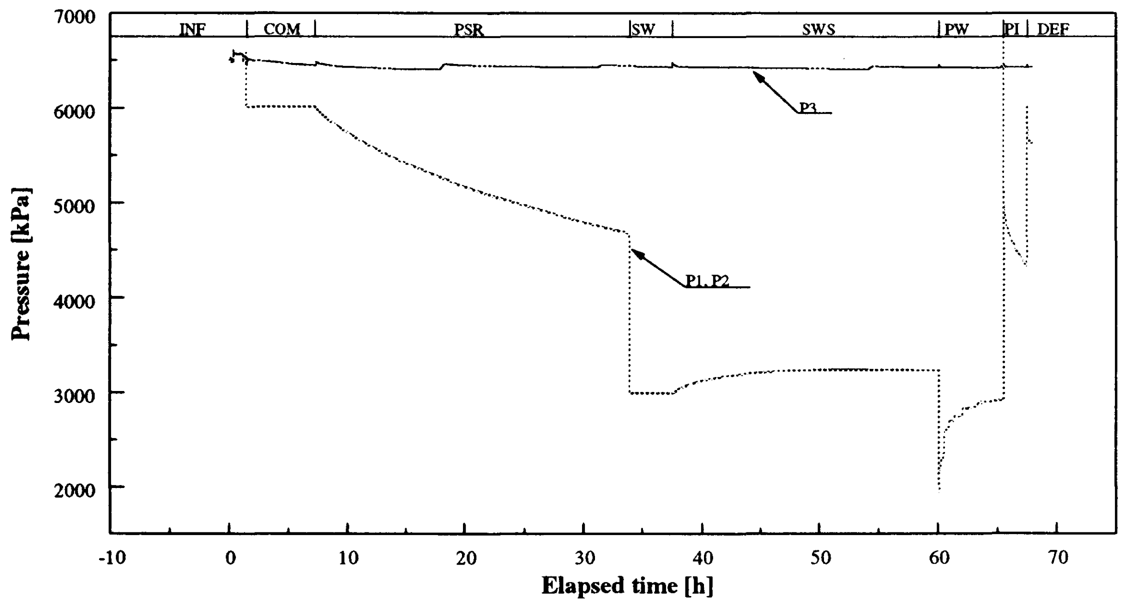
RWS - After the RW period the interval was shut in and the recovery (RWS) was measured for 10.96 h.

PW - The test was concluded with a pulse withdrawal phase (PW) to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the moderate transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at the P2 sensor depth increased by 1.9°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

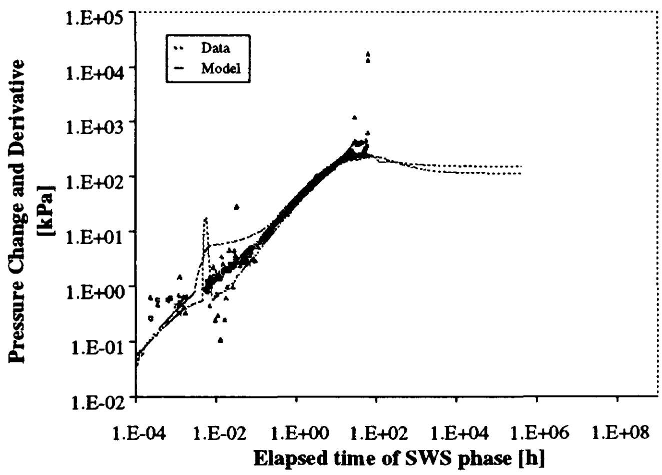
Packer configuration	Single Packer	
Date of test	4th - 5th February 1995	
Test interval depth	397.69 to 520.00 m bGL 397.51 to 519.77 m bGL	measured true vertical
Test interval length	122.31 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	397.69 - 441.53 m bGL - PALFRIS formation & VITZNAU marls - argillaceous marls and light-grey calcareous marls and sandy calcareous marls 441.53 - 461.60 m bGL (ductile shear zone) - PALFRIS formation & VITZNAU marls (as above); SCHIMBERG schists - grey, sandy calcareous marls with mica 461.60 - 520.00 m bGL - SCHIMBERG schists & GLOBIGERINA marls (See T1)	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.7E-08 m^2/s 8E-09 - 6E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	923 m asl 916 - 938 m asl	
Radius of investigation	7 m	
Stabilised temperature at downhole sensor depth	18 °C	
Recommended flow model	Wellbore Storage and Skin Homogeneous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes Possibly (see description of RW)

BOREHOLE SB4a/v - INTERVAL T3	601.5 - 620.0 m bGL

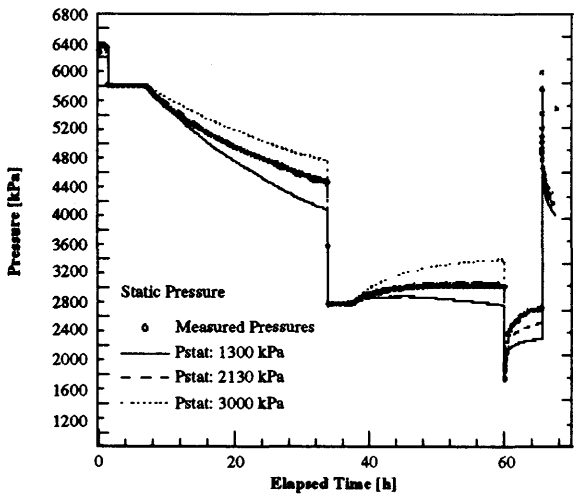


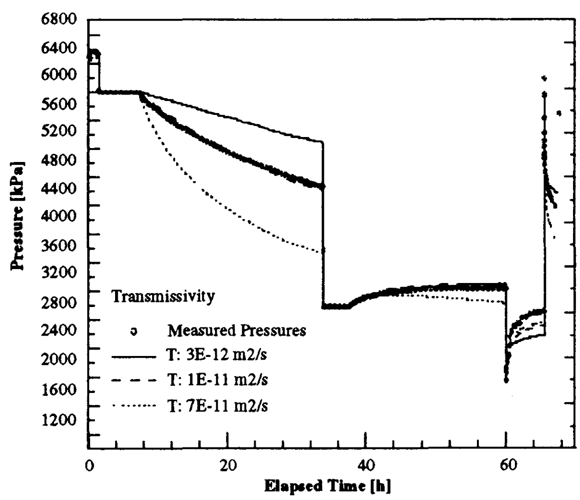
Pressures Measured During T3

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)





Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v T3	601.5 to 620.0 m bGL	Reference: NIB 94-81F Standard Analysis

Test Sequence Description:

The interval was flushed with 2 m^3 of tracered freshwater, prior to packer inflation and the start of the test, in order to avoid plugging the tool and the formation with drilling mud. The packer was inflated to 6000 kPa with water.

COM - The test began with a 5.80 h COM phase to allow the temperature in the interval to equilibrate and to dissipate part of the unknown wellbore history effects. The initial flow rate measured during the COM phase (+1.0E-2 l/min) was inconsistent with the subsequent test response (sub-hydrostatic freshwater head) and may be attributed to thermal effects. It is believed that the flow rate measured during the second half of the COM phase (-1.0E-3 l/min) reflected actual flow conditions in the formation under hydrostatic pressure; this rate was therefore employed as a measure of the historical flow rate.

PSR - The subsequent PSR phase (26.57 h) response was dominated by wellbore storage and near wellbore effects. The PSR response indicated a very low interval transmissivity, though an enhanced mobility is likely in proximity to the wellbore.

SW - An SW period with an initial pressure difference of 1693 kPa was performed after the PSR phase. The SW period showed a recovery of only 6 kPa during 3.65 h, thereby confirming the low formation transmissivity. The main objective of the SW phase was to produce a measurable flow rate prior to the SWS phase.

SWS - The SWS phase (22.60 h) was designed to yield both a reliable transmissivity and an equivalent freshwater head. Pressure response was dominated by wellbore storage, though in late time the build-up produced a "roll over" (change of the pressure gradient) suggesting a static formation pressure below 3200 kPa (measured at transducer depth).

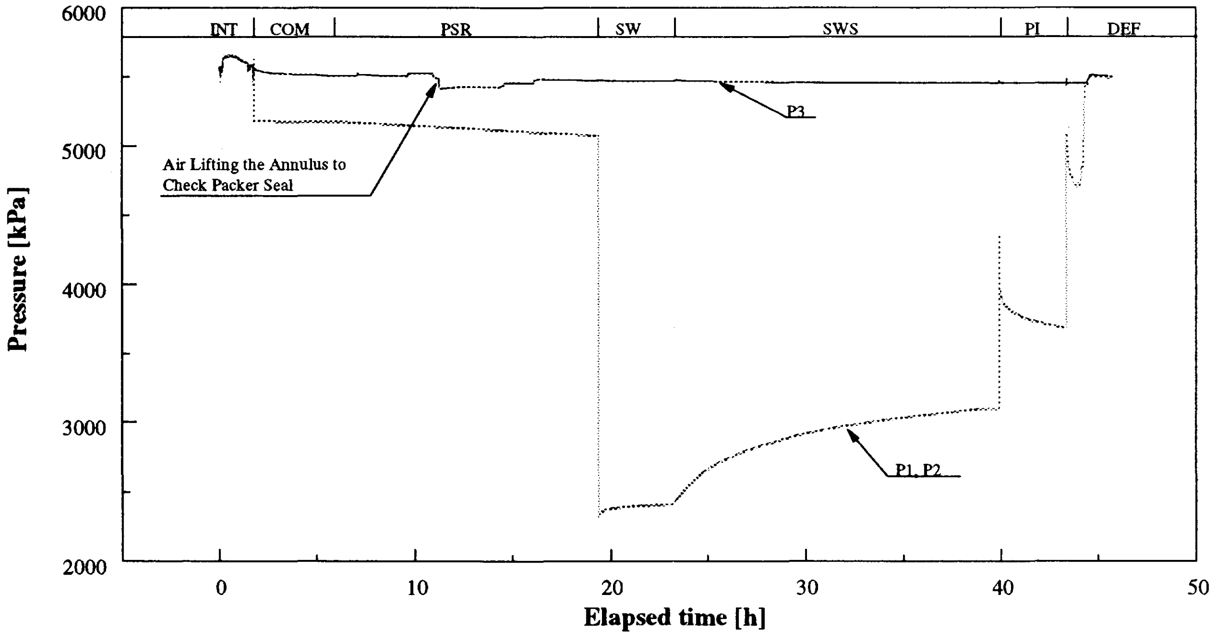
PW - A PW phase (5.41 h) with an additional drawdown of 1283 kPa was conducted in an attempt to constrain the derived head value. The PW phase showed an atypical pressure response with several pressure discontinuities. The cause of this behaviour is difficult to ascertain, though there is a correlation between the pressure jumps observed in the interval and corresponding jumps observed in the annulus. The latter are small (1 - 2 kPa), but indicate connection, perhaps in the form of gas escaping from the interval. This may help to explain why the PW and subsequent PI phase yielded low wellbore storage values (PW: 4.96E-10 m^3/Pa; PI: 4.31E-10 m^3/Pa). The PW phase was not analysed, though the end pressure of the event (2912 kPa) can be assumed as a lower limit for static formation pressure.

PI - The test was concluded with a 1.95 h PI phase to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and 'roll overs' (change in pressure gradient) due to the influences of borehole history. The temperature at the P2 sensor depth increased by 4.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

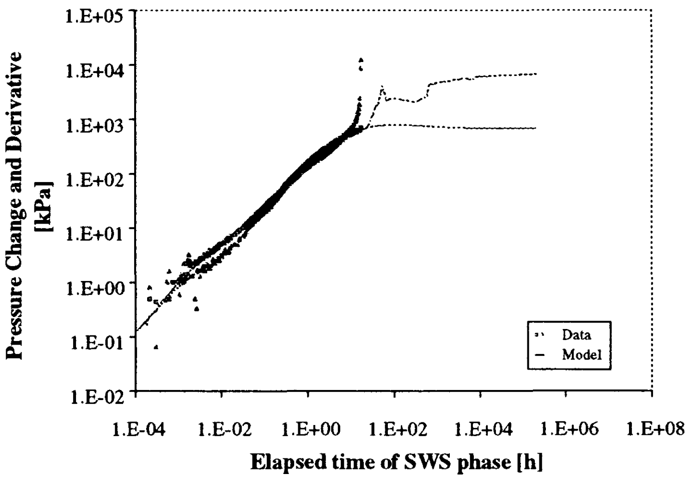
Packer configuration	Single Packer	
Date of test	13th to 15th February 1995	
Test interval depth	601.49 to 620.00 m bGL 601.16 to 619.66 m bGL	measured true vertical
Test interval length	18.51 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	601.49 - 620.00 m bGL TERTIARY- Globigerina Marls; Micaceous sandy marls.	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.00E-11 m^2/s 3E-12 - 7E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	553 m asl 470 - 640 m asl	
Radius of investigation	20 m	
Stabilised temperature at downhole sensor depth	24.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes Possibly (indirect evidence)

BOREHOLE SB4a/v - INTERVAL T4 | **518.1 - 620.0 m bGL**

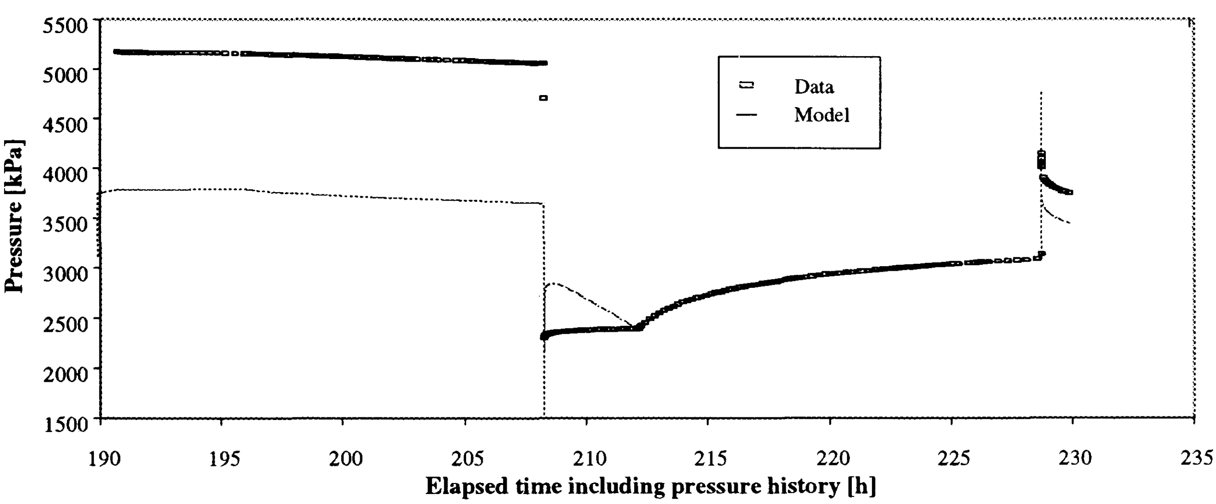


Pressures Measured During T4

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v T4	518.1 to 620.0 m bGL	Reference: NIB 94-81F Standard Analysis

Test Sequence Description:

The interval was flushed with 3 m^3 of tracered freshwater, prior to packer inflation and the start of the test, in order to avoid plugging the tool and the formation with drilling mud. The packer was inflated to 6500 kPa with water.

COM - The test began with a 5.27 h COM phase to allow the temperature in the interval to equilibrate and to dissipate part of the unknown wellbore history effects. The initial flow rate measured during the COM phase (+1.0E-3 l/min) was inconsistent with the subsequent test response (sub-hydrostatic freshwater head) and may be attributed to thermal effects. It is believed that the flow rate measured during the second half of the COM phase (-1.0E-3 l/min) reflected actual flow conditions in the formation under hydrostatic pressure; this rate was therefore employed as a measure of the historical flow rate.

PSR - The subsequent PSR-phase (12.27 h) response indicated a very low interval transmissivity, though an enhanced mobility is likely in proximity to the wellbore.

SW - An SW period with an initial pressure difference of 2757 kPa was performed after the PSR phase. The SW period showed a recovery of only 96 kPa during 3.91 h, thereby confirming the low formation transmissivity. The main objective of the SW phase was to produce a measurable flow rate prior to the SWS phase.

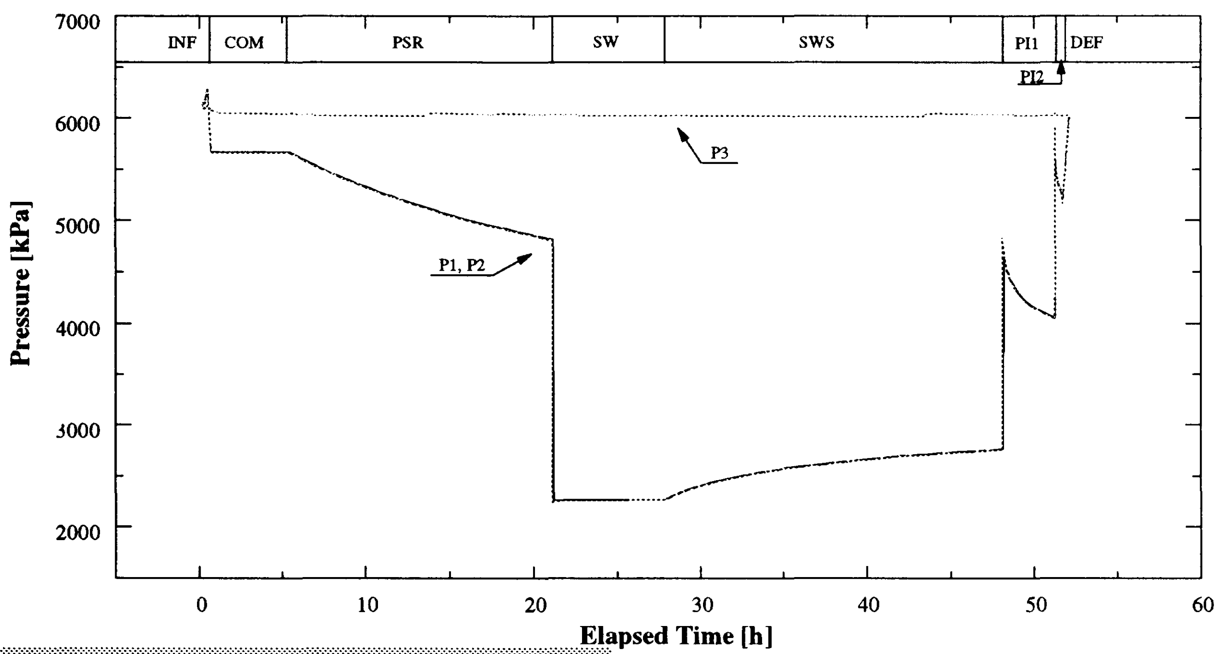
SWS - The SWS phase (16.00 h) was designed to yield both a reliable transmissivity and an equivalent freshwater head. Pressure response was dominated by wellbore storage and near wellbore effects; however, in late time the slope of the derivative increases indicating a reduction in mobility away from the wellbore.

PI - The test was concluded with a 3.47 h PI phase, with an initial pressure difference of 1266 kPa, in an attempt to constrain the derived head value and to measure the wellbore storage coefficient.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects. The temperature at the P2 sensor depth increased by 2.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

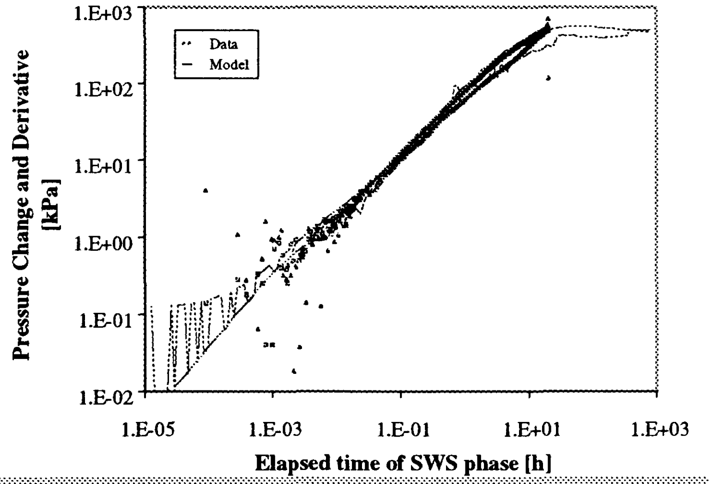
Packer configuration	Single Packer	
Date of test	16th to 17th February 1995	
Test interval depth	518.05 to 620.00 m bGL 517.77 to 619.66 m bGL	measured true vertical
Test interval length	101.95 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	518.05 - 620.00 m bGL TERTIARY-Globigerina Marls / Schimberg-Schiefer; Micaceous, silty, calcareous and sandy marls.	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.40E-10 m^2/s 4E-11 - 1E-09 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	736 m asl 700 - 763 m asl	
Radius of investigation	20 m	
Stabilised temperature at downhole sensor depth	24.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/v - INTERVAL T5	569.3 - 620.0 m bGL

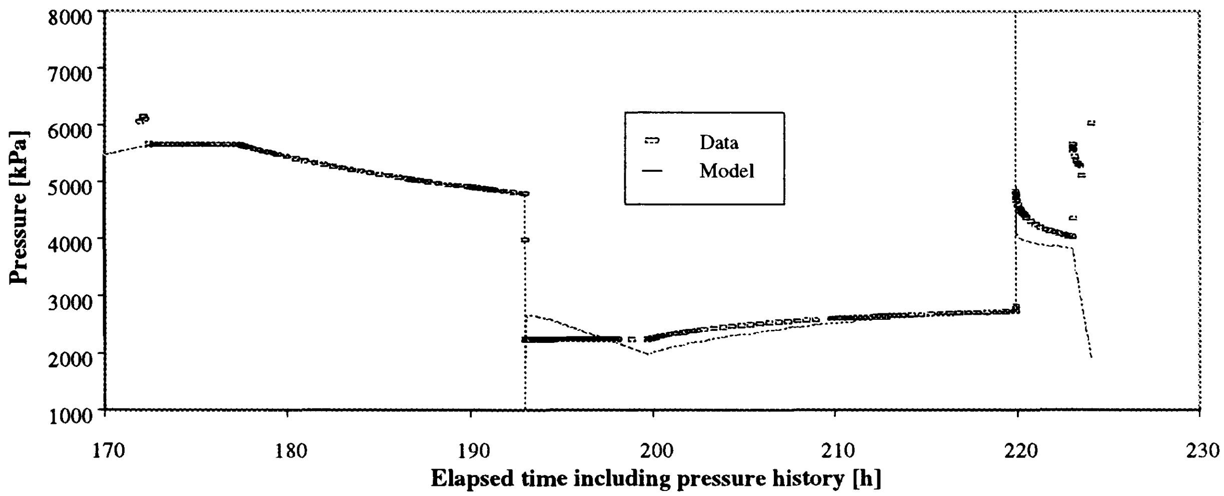


Pressures Measured During T5

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v T5	569.3 to 620.0 m bGL	Reference: NIB 94-81F Standard Analysis

Test Sequence Description:

The interval was flushed with 2 m^3 of tracered freshwater, prior to packer inflation, in order to avoid plugging the tool and to minimise "mudcake" if injection phases are performed. The packer was inflated to 6500 kPa with water.

COM - The test began with a 4.96 h COM phase to allow the temperature in the interval to equilibrate. During the initial 90 min of the COM, the fluid level in the tubing increased and may be attributed to the non-isothermal conditions. The decreasing fluid level (equivalent rate = -1.00E-3 l/min) in the latter part is consistent with the sub-hydrostatic formation pressure.

PSR - In the subsequent 15.66 h PSR period, the recovery rate combined with the large overpressure from borehole history suggested a low interval permeability.

SW - Therefore, in order to induce flow in the subsequent SW, a relatively large drawdown was created by swabbing fluid from the tubing to a depth of ca. 342 m b GL. The SW period showed a recovery of only 14 kPa during 6.77 h, thereby confirming the low formation transmissivity. The main objective of the SW phase was to produce a measurable flow rate prior to the SWS phase, as the low recovery during the phase would not yield reliable formation parameters.

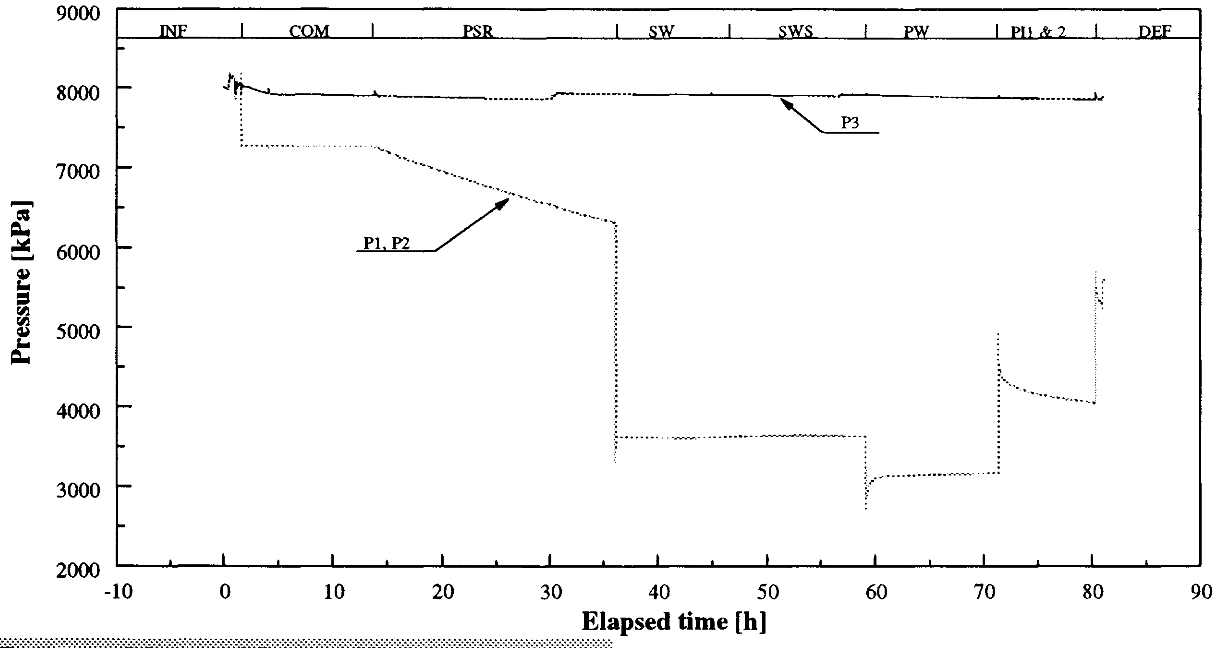
SWS - The SWS phase (20.21 h) was designed to allow derivation of both transmissivity and an equivalent freshwater head.

PI1 & 2 - The test was concluded with two pulse injection phases to confirm the near wellbore transmissivity derived in the previous periods and to measure for the wellbore storage coefficient. In PI1, the wellbore storage constant computed from the change in fluid level (5.9E-11 m^3/Pa) was not reasonable and therefore a second pulse was performed. However, the measured wellbore storage constant from PI2 was also low (6.8E-10 m^3/Pa). The reason for these low values is uncertain but is consistent with measurements in tests T3 and T4.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects. No gas was measured during the test but the low measurements for the wellbore storage coefficient could be explained with gas in the wellbore, i.e. gas escapes the interval when the shut-in tool is briefly opened. The temperature at P2 depth increased by 1.43 °C during the COM and PSR phases but was relatively stable for remainder of test. The temperature at the P2 sensor depth increased by 1.5°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

Packer configuration	Single Packer	
Date of test	18th to 20th February 1995	
Test interval depth	569.28 to 620.00 m bGL 568.97 to 619.66 m bGL	measured true vertical
Test interval length	50.72 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	569.28 - 620.00 m bGL TERTIARY- Globigerina Marls; Micaceous sandy marls.	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	5.00E-11 m^2/s 2E-11 - 2.2E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	603 m asl 560 - 639 m asl	
Radius of investigation	20 m	
Stabilised temperature at downhole sensor depth	24.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes Possibly (no direct evidence)

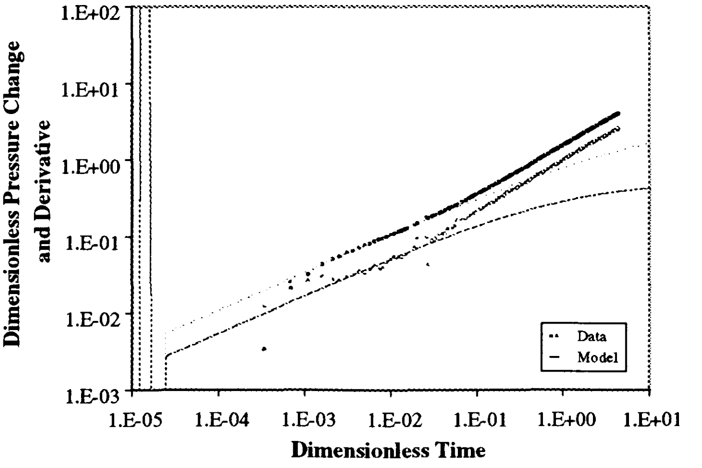
BOREHOLE SB4a/v - INTERVAL VM9	726.5 - 735.0 m bGL



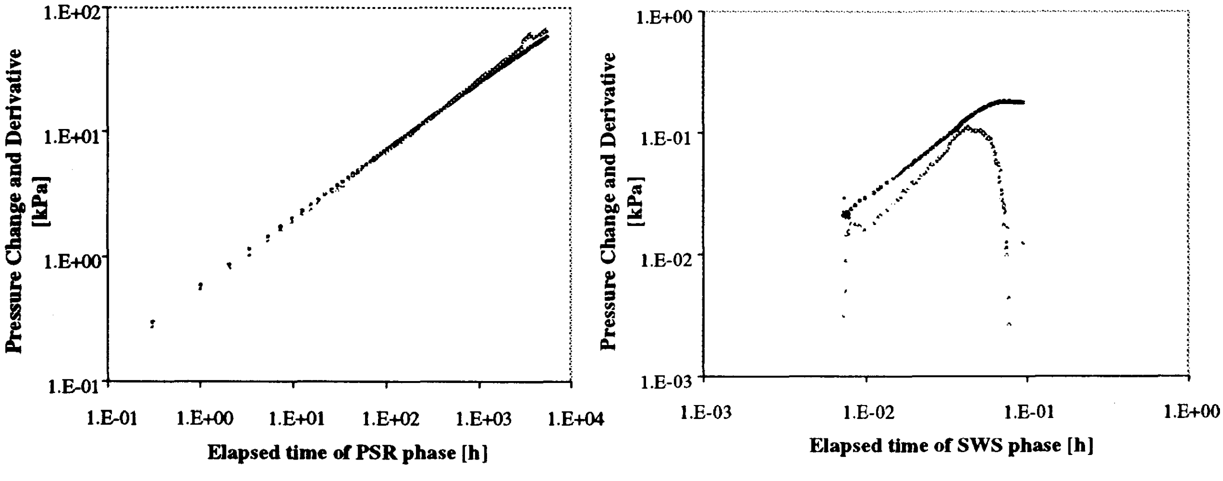
Pressures Measured During VM9

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent

Rem.: Composite Model Recommended for Entire Test Response Based on Additional Analysis



Representative Log-Log Diagnostic Plot and Type Curves (PI1 Phase)



Log-log plots of PSR (dominated by wellbore storage effects) and SWS ('roll over' effect) phases

TEST SUMMARY BOREHOLE SB4a/v VM9	726.5 to 735.0 m bGL	Reference: NIB 94-81G Standard Analysis

Test Sequence Description:

The interval was flushed with 2 m^3 of tracered freshwater (screen depth 731 to 733 m bGL), prior to packer inflation , in order to avoid plugging the tool and the formation with drilling mud. The packer was inflated to 6000 kPa with water.

COM - The test began with a 12.06 h COM phase to allow the temperature in the interval to equilibrate and to dissipate part of the unknown wellbore history effects. The average flow rate measured during the COM phase was -1.5E-4 l/min.

PSR - The subsequent PSR phase response (22.31 h) was dominated by wellbore storage, indicating a very low interval transmissivity.

SW - An SW period (8.75 h) with an initial pressure difference of 2701 kPa was performed after the PSR phase. The SW pressure started declining after a brief initial build up. Since gas flow, a plausible explanation for the anomalous response, was excluded, this behaviour is considered to be an indication for the formation pressure conditions in the vicinity of the borehole, lower than ca. 3600 kPa. The flowrate for this phase is uncertain and complicated by disturbances created by movement of the PTX transducer.

SWS - The subsequent shut-in period lasted 14.21 h and showed very little pressure recovery. At late times a change in the interval pressure gradient occurred ("roll over") confirming the low pressure conditions around the borehole. The final SWS pressure (3627 kPa) is considered to represent an upper limit of the static formation pressure.

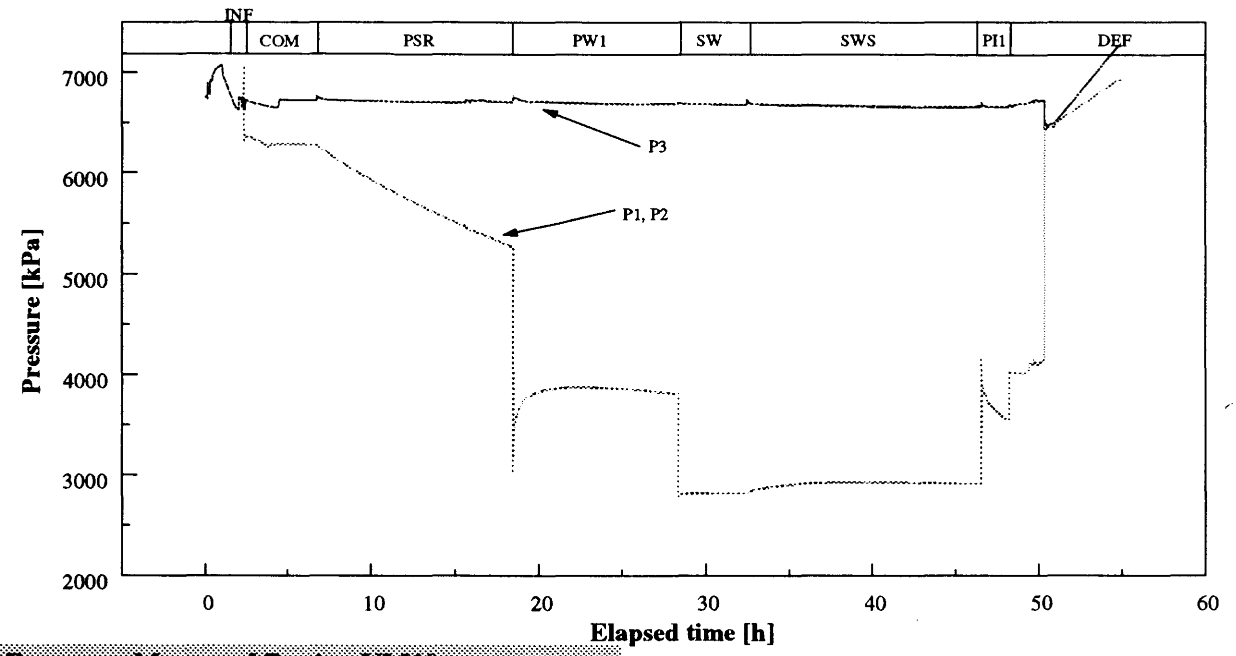
PW - A PW phase lasting 12.29 h was subsequently initiated, using an additional pressure difference of 900 kPa. The PW recovered up to a pressure of 3153 kPa with no suggestion of a "roll over", which qualifies this value as a best estimate for the lower limit of the static formation pressure.

PI1&2 - The test was concluded with two pulse injection phases (PI1 and PI2) lasting 9.00 h and 0.59 h, respectively. The aim of these events was to further confirm the near wellbore formation parameters derived from the previous events and to obtain additional measurements of the wellbore storage coefficient.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and 'roll overs' (change in pressure gradient) in pressure due to the influences of borehole history. The temperature at the P2 sensor depth increased by 5.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

Packer configuration	Single Packer	
Date of test	28th February- 4th March 1995	
Test interval depth	726.50 to 735.00 m bGL 726.37 to 734.86 m bGL	measured true vertical
Test interval length	8.50 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	726.50 to 735.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.00E-12 m^2/s 6E-13 to 5E-11 m^2/s [1)]	
Best estimate of freshwater head Confidence interval of freshwater head	420 m asl 280 to 580 m asl	
Radius of investigation	0.5 m	
Stabilised temperature at downhole sensor depth	28.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

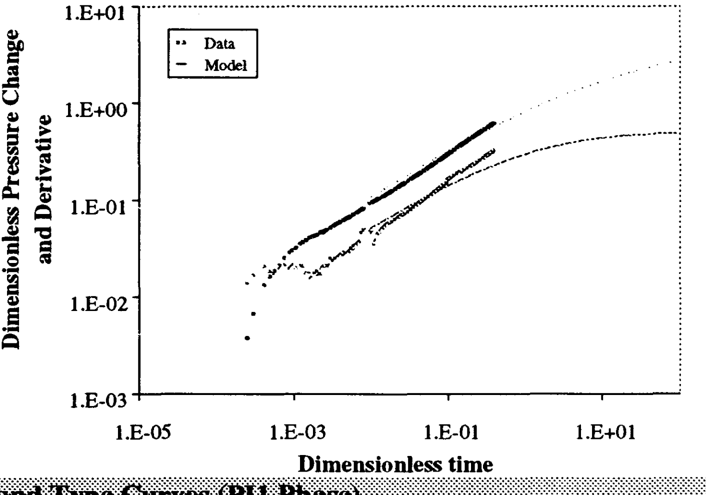
BOREHOLE SB4a/v - INTERVAL VM10	618.3 - 735.0 m bGL



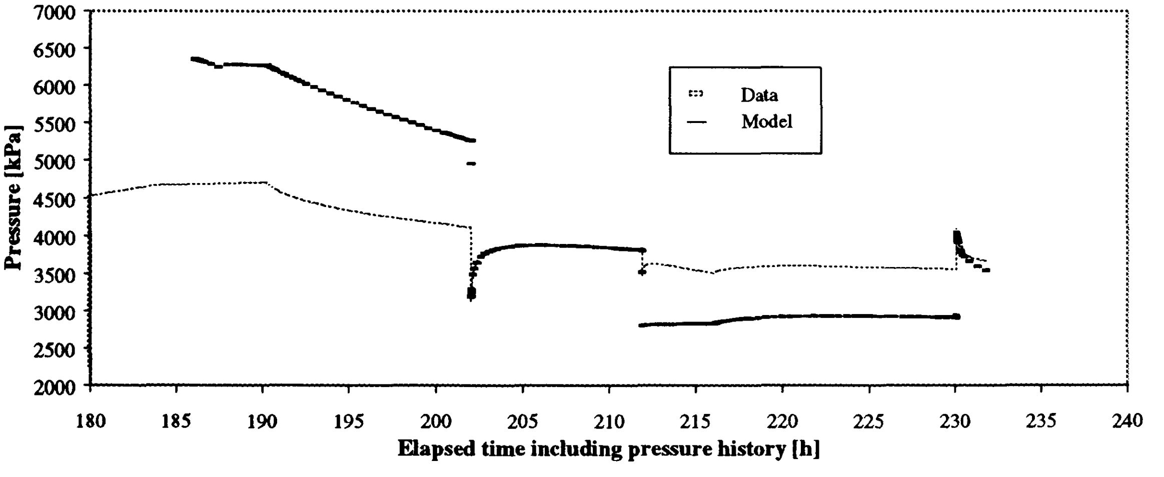
Pressures Measured During VM10

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent

Rem.: Composite Model Recommended for Entire Test Response Based on Additional Analysis



Representative Log-Log Diagnostic Plot and Type Curves (PI1 Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v VM10	618.3 to 735.0 m bGL	Reference: NIB 94-81G Standard Analysis

Test Sequence Description:

The interval was flushed with 3 m^3 of tracered freshwater (screen depth 651 to 653 m bGL), prior to packer inflation, in order to avoid plugging the tool and to minimise "mudcake" if injection phases are performed. However, the density of fluid (1020 kg/m^3) above the gauge computed from the P2 pressure suggests that that flushing was not complete. The incomplete flushing was confirmed by the somewhat anomalous response at the start of the COM with the pressure dropping over 100 kPa while the fluid level remained relatively stable in the tubing. This response may be due to the replacement of the drilling fluid above the gauge with the less dense tracered freshwater. The packer was inflated to 7500 kPa with water.

COM - The test began with a. 4.32 h COM phase to allow the temperature in the interval to equilibrate. The decreasing fluid level (equivalent rate = -3.5E-3 l/min) in the latter part is consistent with the sub-hydrostatic formation pressure.

PSR - In the subsequent 11.74 h PSR period, the recovery rate combined with the large overpressure from borehole history suggested a low interval permeability.

PW1 - Therefore, a relatively large drawdown (2093 kPa) PW1 was conducted to obtain an estimate of the permeability and monitor the recovery data for indications of the static formation pressure. The recovery was approximately 30 % during the 9.91 h duration with a 'roll over' in late time indicating a lower static formation pressure then the pressure measured at the end of the phase.

SW - During the latter part of the PW1 phase, fluid was swabbed from tubing to create a drawdown for the subsequent SW period. The SW phase lasted 4.07 h with an average equivalent flowrate of 1.3E-2 l/min with a total recovery of less than 5 %. Although this phase would not be amenable to a reliable analysis, it can be approximated to a constant rate period providing a well defined boundary condition for the subsequent SWS phase.

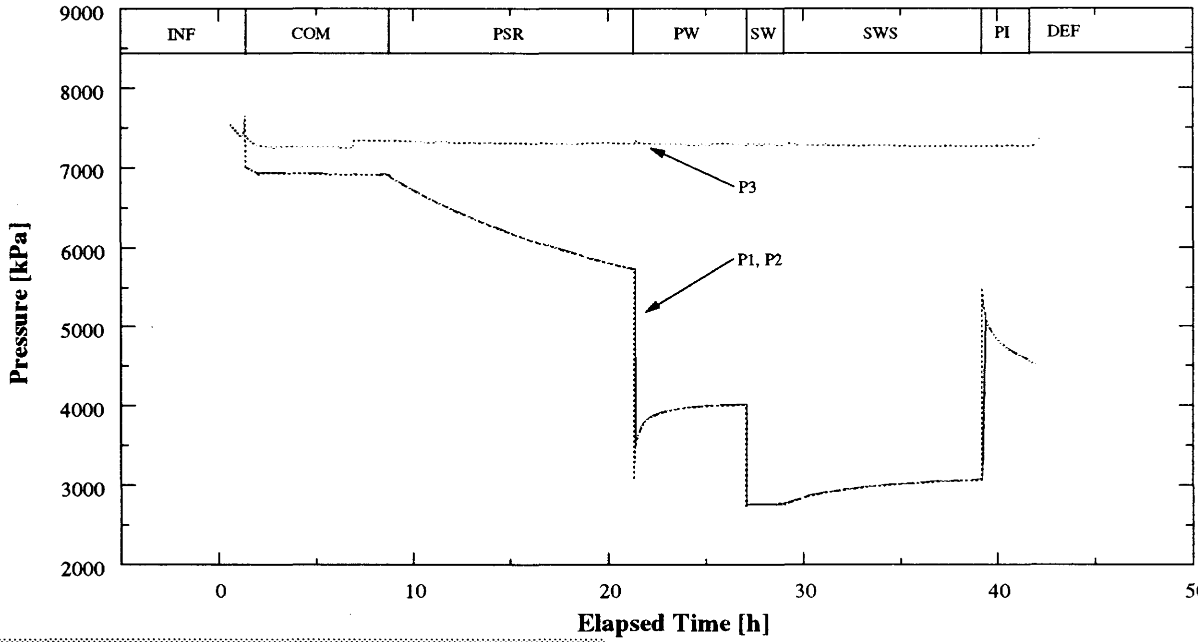
SWS - The total duration of the SWS phase was 14.09 h with a recovery from 2817 kPa to 2903 kPa. Because a 'roll over' occurred in the late time, the end pressure provides a maximum for the static formation pressure.

PI - The test was concluded with 1.69 h PI phase to confirm the wellbore storage constant (C) measured in the PW phase, which has a direct influence on the derived transmissivity. The good agreement between the measured C values from the two phases, 1.69E-9 m^3/Pa for PW1 and 1.56E-9 m^3/Pa for PI, confirms the reliability of these parameters.

Comments: All test objectives were achieved. Unusual oscillations of 1-2 kPa when pressure changes were small (<5 kPa/h) in P3 pressure throughout the test and in P1-P2 pressures during latter part of SWS suggested electronic problem with the downhole gauges. Checks for accuracy of readings showed the measurements to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and 'roll overs' (change in pressure gradient) due to the influences of borehole history. The temperature at the P2 sensor depth increased by 0.4°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

Packer configuration	Single Packer	
Date of test	4th to 6th March 1995	
Test interval depth	618.33 to 735.00 m bGL 618.22 to 734.86 m bGL	measured true vertical
Test interval length	116.67 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	618.33 to 630.40 m bGL TERTIARY - Globigerina Marls 630.40 to 735.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	8.00E-11 m^2/s 1E-11 to 5E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	425 m asl 330 to 550 m asl	
Radius of investigation	ca. 0.5 m	
Stabilised temperature at P2 depth	25.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

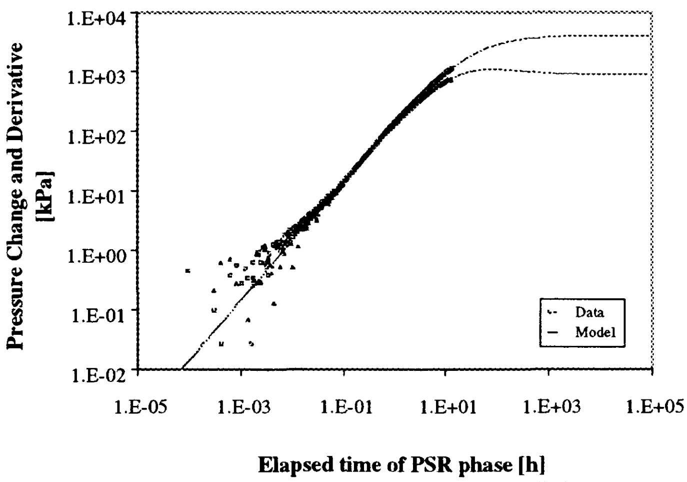
BOREHOLE SB4a/v - INTERVAL VM11	676.2 - 735.0 m bGL



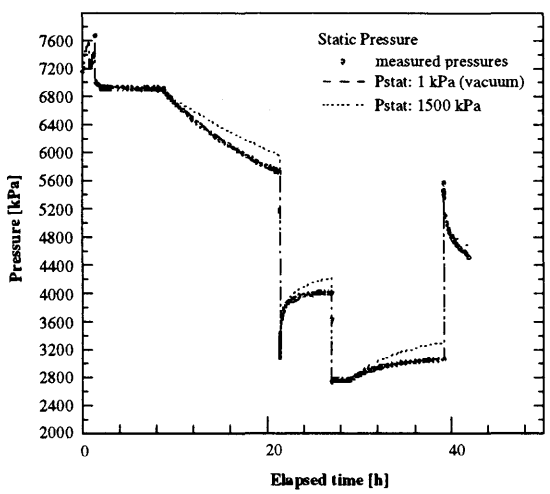
Pressures Measured During VM11

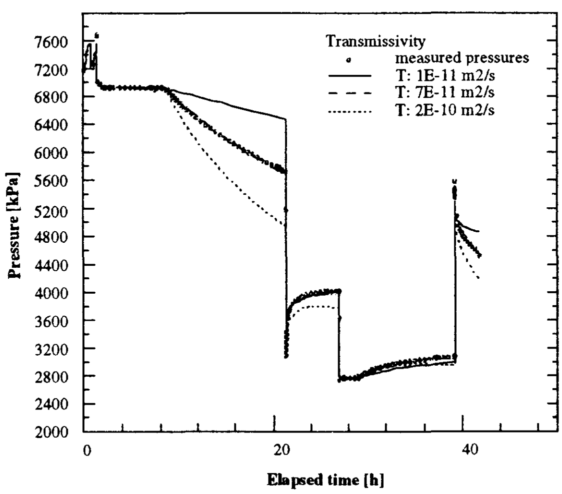
Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent

Rem.: Composite Model Recommended for Entire Test Response Based on Additional Analysis



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)





Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v VM11	676.2 to 735.0 m bGL	Reference: NIB 94-81G Standard Analysis

Test Sequence Description: An attempt was made to flush the interval with 3 m^3 of tracered freshwater prior to packer inflation, but the hose linking the tank to the wellhead ruptured and only half the intended volume was successfully pumped into the borehole. The density of fluid (1046 kg/m^3) above the gauge computed from the P2 pressure confirmed that the flushing was incomplete. The flushing procedure is performed in order to avoid tool plugging and to minimise "mudcake" build-up in the event of an injection phase during the test. The Packer was inflated to 7500 kPa with water.

COM - The test began with a 7.31 h COM phase to allow the temperature in the interval to equilibrate. The decreasing fluid level (equivalent rate = -2.3E-3 l/min) in the latter part is consistent with the sub-hydrostatic formation pressure. A series of anomalous pressure spikes of constant amplitude and period were generated by the gauge towards the end of this phase; the cause for this behaviour was latter atttributed to an electronic problem. This effect was not considered serious enough to warrant terminating the test as the accuracy of the readings were within the expected range. The noise disappeared when the tool was closed for the subsequent PSR phase, suggesting that it only became disruptive when very stable pressures prevailed.

PSR - In the subsequent 12.67 h PSR period, the recovery rate combined with the large overpressure from borehole history suggested a low interval permeability.

PW - A PW was therefore conducted with a relatively large drawdown (2646 kPa) to obtain an estimate of the permeability and to ensure pressures in the test interval approached the anticipated static formation pressure. The recovery was approximately 35% over the 5.68 h duration with pressures still rising by 1.5 kPa/h at the time the tool was opened for the ensuing SW phase. Fluid was swabbed from the tubing towards the end of the PW phase to create a drawdown in the subsequent SW phase.

SW - The SW period lasted 2.02 h with an average flowrate of approximately 5.0E-03 l/min - it was terminated prematurely due to the resurgence of the gauge problem cited earlier. This phase was not subjected to an analysis owing to a very limited recovery; however, it may be approximated to a constant rate episode, thus providing a well boundary condition for the subsequent SWS phase.

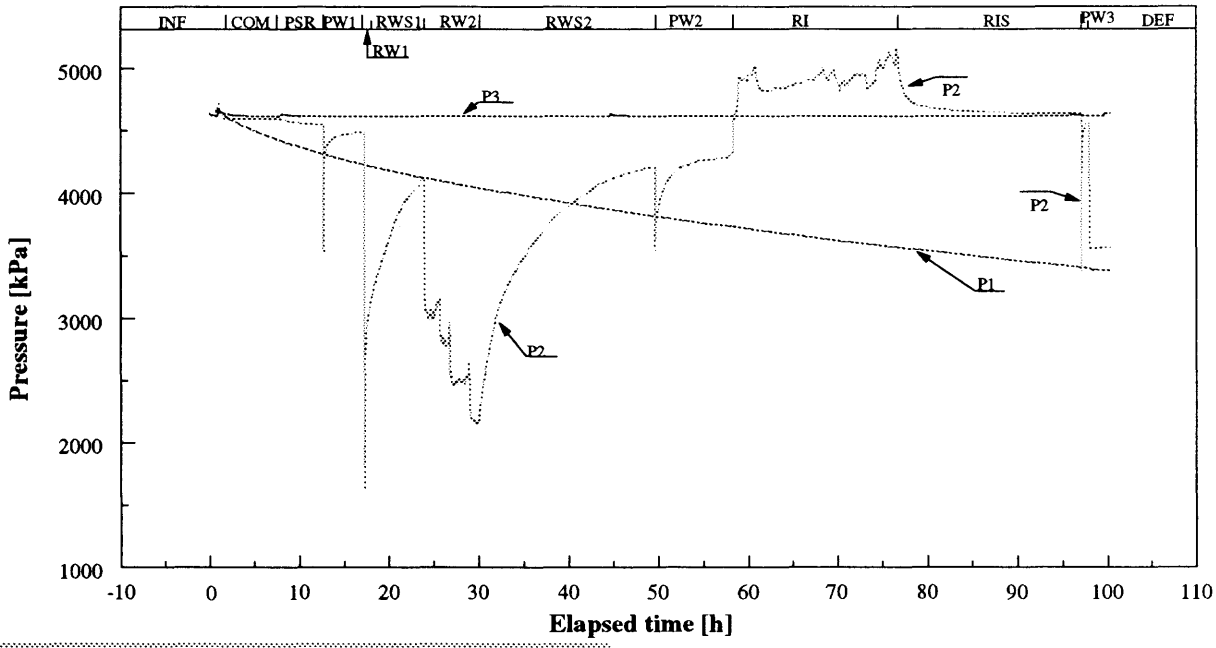
SWS - The total duration of the SWS phase was 10.16 h and recovered from 2757 kPa to 3063 kPa; the pressure was still rising at the end.

PI - The test was concluded with 2.52 h PI phase which was primarily designed to confirm the wellbore storage constant (C) measured in the PW phase. The C value obtained from both phases was found to be consistent (PW: 8.09E-10 m^3/Pa; PI: 7.26E-10 m^3/Pa).

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. However, the gauges showed spikes with constant period and amplitude when the pressure changes became small. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects. The temperature at the P2 sensor depth increased by 2.9°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test. The MULTIFIT/GTFM simulations showed that the effect of temperature variations on the test response was small.

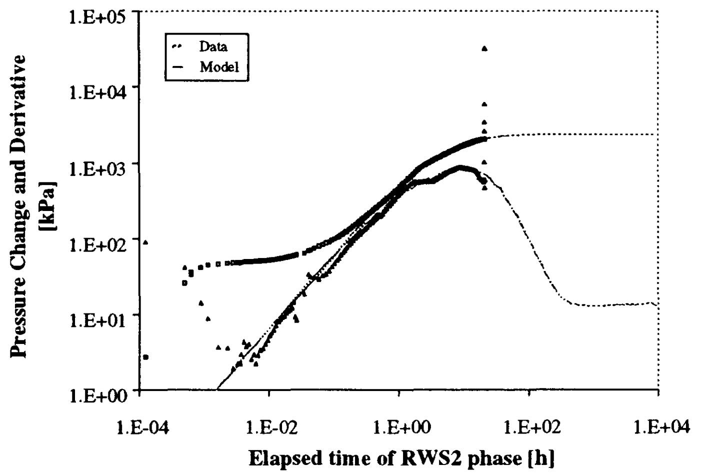
Packer configuration	Single Packer	
Date of test	6th to 8th March 1995	
Test interval depth	676.16 to 735.00 m bGL 676.04 to 734.86 m bGL	measured true vertical
Test interval length	58.84 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	676.16 to 735.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	7.00E-11 m^2/s 1E-11 to 2E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	300 m asl 270 m to 450 m asl	
Radius of investigation	ca. 0.5 m	
Stabilised temperature at P2 depth	27.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL T6	460.7 - 472.3 m bGL

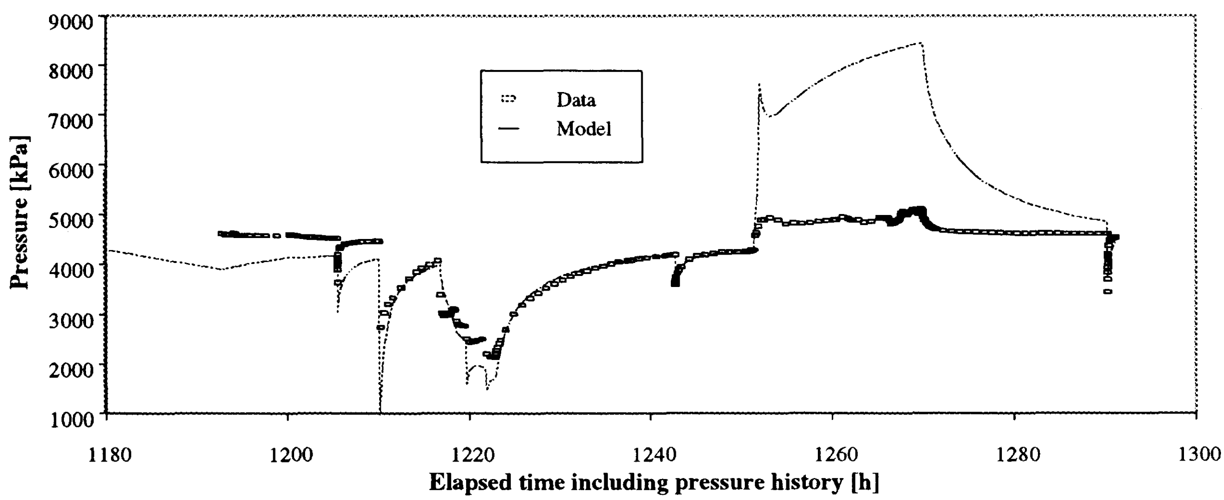


Pressures Measured During T6

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS2 Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/v T6	460.7 to 472.3 m bGL	Reference: NIB 94-81E Detailed Analysis

Test Sequence Description: The interval was flushed with 3 m^3 of tracered freshwater (screen depth 467 to 469 m bGL), prior to packer inflation. The packers were inflated to 8000 kPa with water.

COM - The test began with a 5.82 h COM phase to allow the temperature in the interval to equilibrate. The decreasing fluid level (equivalent rate = -5.4E-4 l/min) in the latter part suggests recovery to a sub-hydrostatic formation pressure.

PSR - During the subsequent 5.20 h PSR period, the pressure decreased to 4542 kPa, a value which may be regarded as an upper limit of the static formation pressure.

PW1 - A pulse withdrawal phase (PW1) was than conducted with an initial pressure difference of ca. 1000 kPa to obtain a first estimate of the permeability and allow for a direct measurement of the wellbore storage coefficient (C) at the beginning of the test. A C-value of 6E-10 m^3/Pa was measured. The recovery was approximately 90 % during the 4.57 h duration of the period.

RW1 - A constant rate withdrawal phase (RW1) was then initiated; however, there were technical difficulties which resulted in a large uncontrolled drawdown and a premature termination of the period (0.10 h).

RWS1 - The following shut-in phase (RWS1 - 6.60 h) showed an atypical response, which was probably caused by stress effects in the formation, induced by the large drawdown during the preceding production period.

RW2 - A second production period (RW2 - 6.04 h) with an average rate of 15 ml/min followed. The pressure response reflects the technical difficulties associated with maintaining a constant rate at very low flows. Periodical attempts at regulating the surface rate using a needle valve caused rate fluctuations up to ca. 100 ml/min. Although the flow control design was set up for two phase conditions, no gas was measured at the surface during abstraction.

RWS2 - The interval was subsequently shut-in (RWS2) for 19.69 h. The early time data of this period is distorted by a squeeze generated whilst closing the shut-in tool. Slope discontinuities in the late time pressure response suggests stress related effects.

PW2 - A second pulse withdrawal phase (PW2 - 4.82 h) was conducted in order to provide a C-value measurement at the end of the production period. A C-value of 4.7E-10 m^3/Pa was derived.

RI - A constant rate injection period lasting 18.45 h followed. The rates at the start of the injection phase changed somewhat as they were adjusted to achieve an optimum value; thereafter, however, the injection rate remained nearly constant at 20 ml/min.

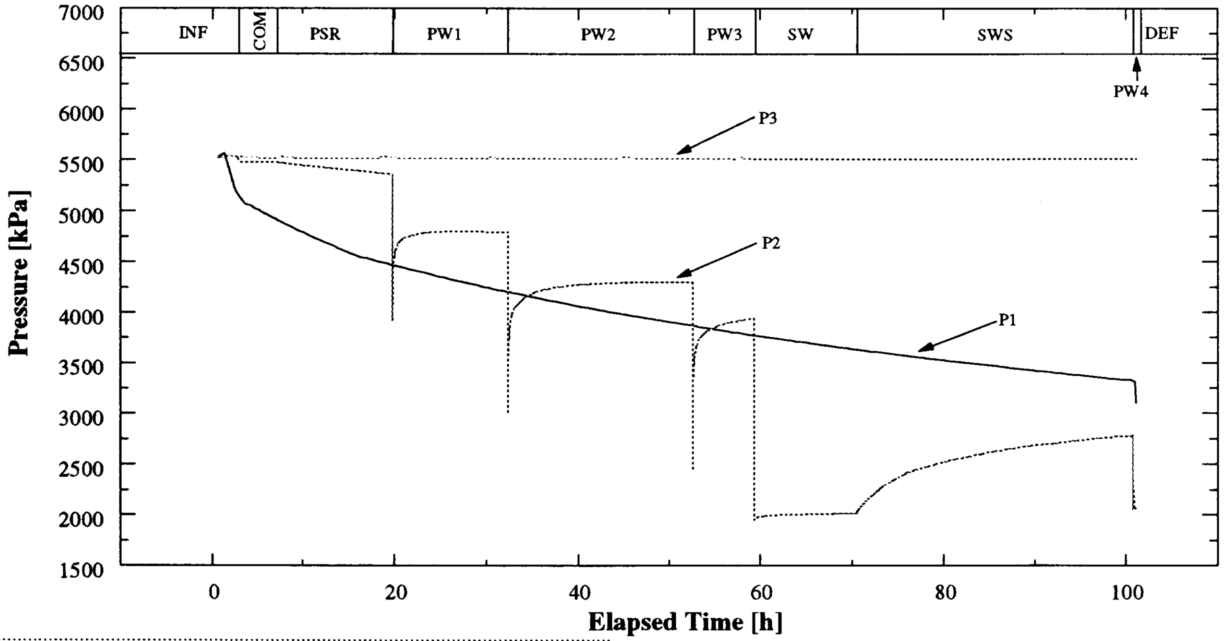
RIS - The subsequent fall-off phase lasted 20.26 h.

PW3 - The test was concluded with a third pulse withdrawal lasting 0.91 h, which yielded a C-value of 4.7E-10 m^3/Pa.

Comments: All test objectives were achieved except it was not possible to collect a representative water sample within a reasonable time period due to the relatively low transmissivity of the interval. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a significant influence on the test response due to the extensive duration. Although both gas and water were measured in the main production period, single phase parameters derived in the analysis of individual phases showed a reasonable match to this part of the test. The injection phase shows a non-ideal response. The temperature at the P2 sensor depth increased by 2.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test. The downhole chamber sample tool was used (Fig. 2.4).

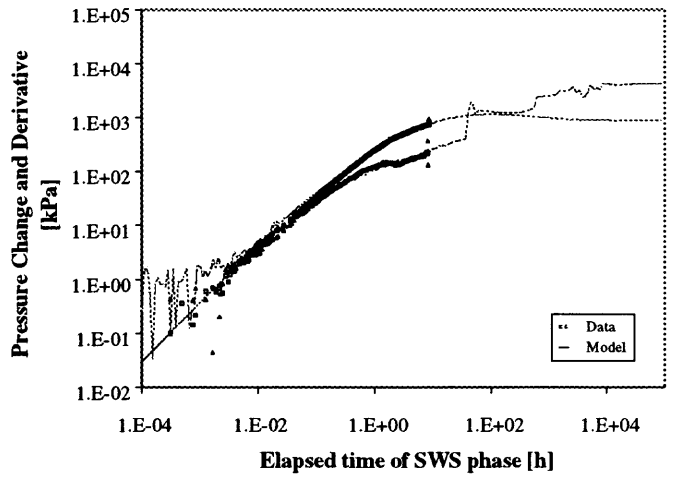
Packer configuration	Double Packers	
Date of test	17th to 21st March 1995	
Test interval depth	460.73 to 472.34 m bGL 460.53 to 472.13 m bGL	measured true vertical
Test interval length	11.61 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	460.73 to 472.34 m bGL TERTIARY - Schimberg schists & globigerina marls; sandy marls with mica with layers of sandy clay marls	
Test objectives defined at start of test	Transmissivity; Flow Model, Equivalent Freshwater Head, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.6E-10 m^2/s 1E-10 to 1E-09 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	979 m asl 929 to 1030 m asl	
Radius of investigation	20 m	
Stabilised temperature at downhole sensor depth	20.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL T7 | 550.5 - 563.6 m bGL

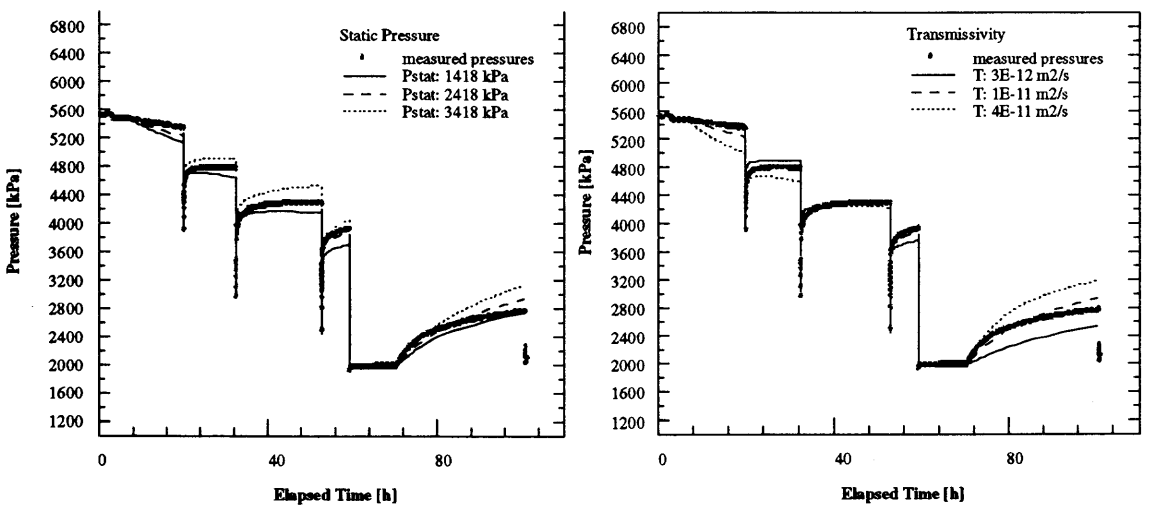


Pressures Measured During T7

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v T7	550.5 to 563.6 m bGL	Reference: NIB 94-81F Detailed Analysis

Test Sequence Description:

The interval was flushed with 2 m^3 of tracered water prior to packer inflation for the first seat. Hydraulic communication was observed around the top packer shortly after the start of the test. The original packer seat (551.9 to 563.5 m bGL) was thus aborted and the elements deflated. The upper packer was successfully unseated (23.03.95 at 09:30) soon after termination of the test, but the lower packer would not deflate. It was finally unseated and the tools brought to the surface on the evening of the 24.03.95. The packer inflate line was found to have been squashed by material from the formation; hence, a short wiper trip followed to remove debris from the borehole. The description below describes the second and successful attempt at testing the T7 interval using an amended packer seat. The packers were inflated to 8000 kPa with water.

COM - The test began with a 4.03 h COM phase to allow the temperature in the interval to equilibrate. The decreasing fluid level (equivalent rate = -3.06E-03 l/min) in the latter part of the COM phase suggests recovery to a sub-hydrostatic formation pressure.

PSR - During the subsequent 12.87 h PSR period, the pressure decreased to 5360 kPa, a value which may be regarded as an upper limit of the static formation pressure.

PW1, 2 & 3 - A pulse withdrawal phase (PW1) was then performed with an initial pressure difference of ca. 1440 kPa; this was to derive a first estimate of the permeability and to obtain a direct measurement of the wellbore storage capacity (C = 3.25E-09 m^3/Pa) at the beginning of the test. The pressure began to decline ('roll-over') at the end of this period. A second pulse withdrawal phase (PW2 - 20.33 h) was conducted to draw the interval pressure down (ca. 1860 kPa) towards the anticipated static formation pressure, and to corroborate the permeability and wellbore storage capacity measurements produced in the first pulse. The derived C-value of 3.24E-09 m^3/Pa was in good agreement. The pressure began to 'roll-over' for a second time towards the end of this period, so a third pulse (PW3) was performed (ca. 1890 kPa drawdown). This lasted 6.65 h, during which time the pressures were continuously increasing. The derived C-value of 1.96E-09 m^3/Pa was slightly lower than those produced from the first two pulses.

SW - A slug withdrawal period (SW) lasting 11.19 h then ensued; the flow rate during this time was 2.38E-02 l/min, computed from the pressure change.

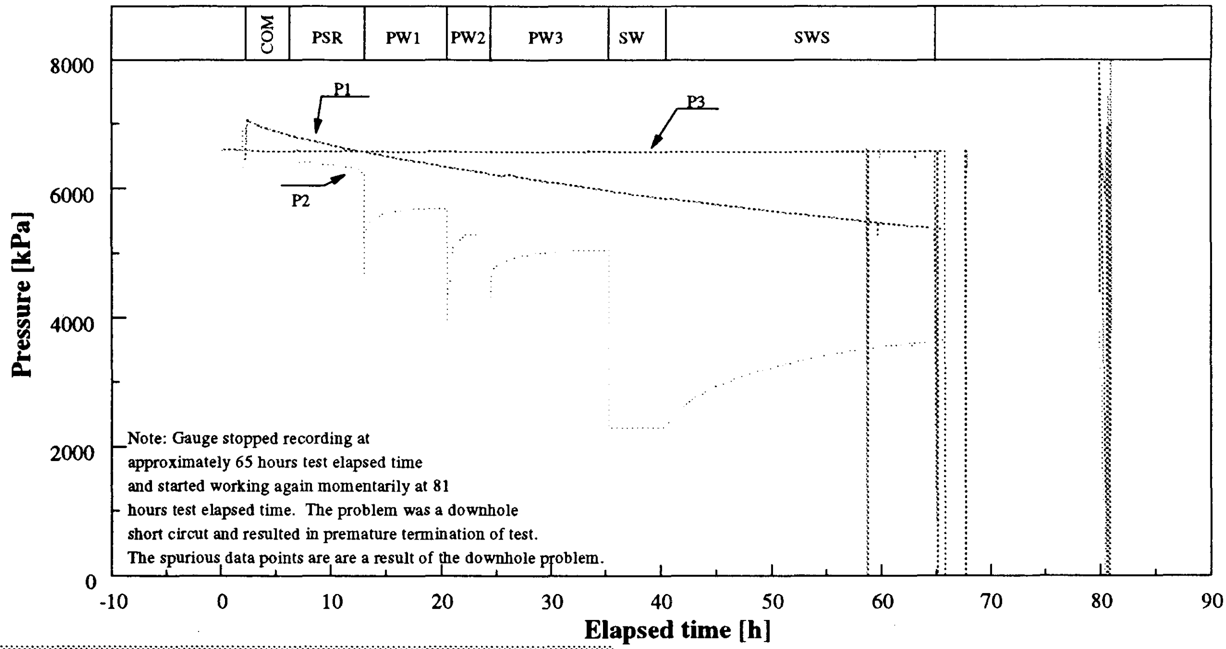
SWS - The subsequent build-up (SWS) lasted 30.23 h with a pressure recovery of 764 kPa (to 2283 kPa) and no indication of a 'roll-over'.

PW4 - The test was concluded with a brief (0.14 h) pulse withdrawal; this yielded a wellbore storage capacity of 1.29E-09 m^3/Pa..

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity, static formation pressure below the hydrostatic conditions of the borehole and extensive duration. The log-log diagnostic plots are dominated by wellbore storage effects and transitional data. The temperature at the P2 sensor depth increased by 2.4°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test. The MULTIFIT/GTFM simulations showed that the effect of temperature variation on the test response was very small. The downhole chamber sample tool was used (Fig. 2.4).

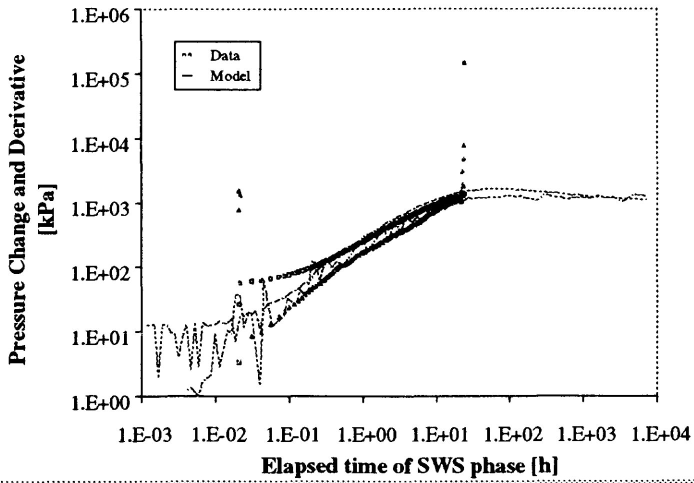
Packer configuration	Double Packers	
Date of test	26th to 30th March 1995	
Test interval depth	550.45 to 563.56 m bGL 550.15 to 563.25 m bGL	measured true vertical
Test interval length	13.11 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	550.45 - 563.56 m bGL TERTIARY-Globigerina Marls / Schimberg-Schiefer; Silty and calcareous sandstone interbedded with thin layers of sandy marl - some micaceous material present.	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.00E-11 m^2/s 3E-12 - 4E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	650 m asl 530 - 760 m asl	
Radius of investigation	6 m	
Stabilised temperature at P2 depth	23.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

BOREHOLE SB4a/v - INTERVAL VM12	647.1 - 650.0 m bGL

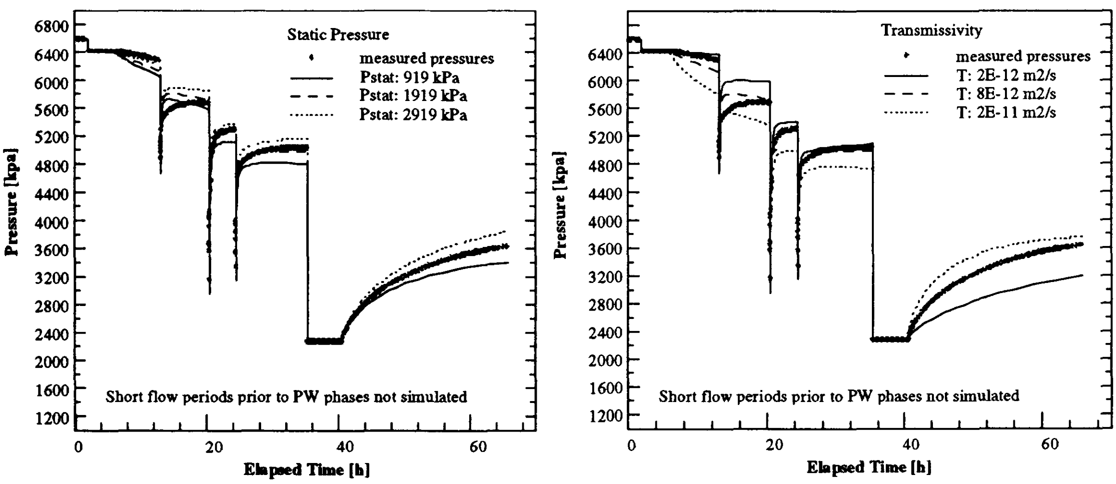


Pressures Measured During VM12

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v VM12	647.1 to 650.0 m bGL	Reference: NIB 94-81G Standard Analysis

Test Sequence Description:

The mud in the test interval was displaced by circulating 2 m^3 of tracered freshwater down the tubing in order to avoid plugging the tool and to minimise "mudcake" if injection phases are performed.

COM - After inflating the packers to 8000 kPa, the test began with a 3.08 h COM phase to allow the temperature in the interval to equilibrate. The decreasing pressure (equivalent rate = -7.3E-3 l/min) is consistent with the sub-hydrostatic formation pressure.

PSR - In the subsequent 6.92 h PSR period, the fall off in pressure was characterised by anomalous kinks.

PW1, 2 & 3 - The first pulse withdrawal (PW1 - 7.42 h) was performed with a drawdown of ca. 148 m. In late time, the pressure 'rolled over' (change in pressure gradient) with an end pressure of 5685 kPa, thereby providing an upper bound for the static formation conditions. The second pulse (PW2 - 3.98 h) lowered the pressure to 3238 kPa with a total drawdown of ca. 250 m. Again, the pressure recovery showed uncharacteristic kinks which could be correlated to disturbances in the lower guard zone. At this time, it was decided to perform a third pulse withdrawal (PW3) to see if the anomalous responses re-occurred. The third pulse withdrawal (10.82 h) showed a normal recovery and therefore the test continued. During the latter stages of PW3, fluid was swabbed from the tubing to a depth of ca. 420 m bGL, below the expected freshwater head, in preparation for the SW phase.

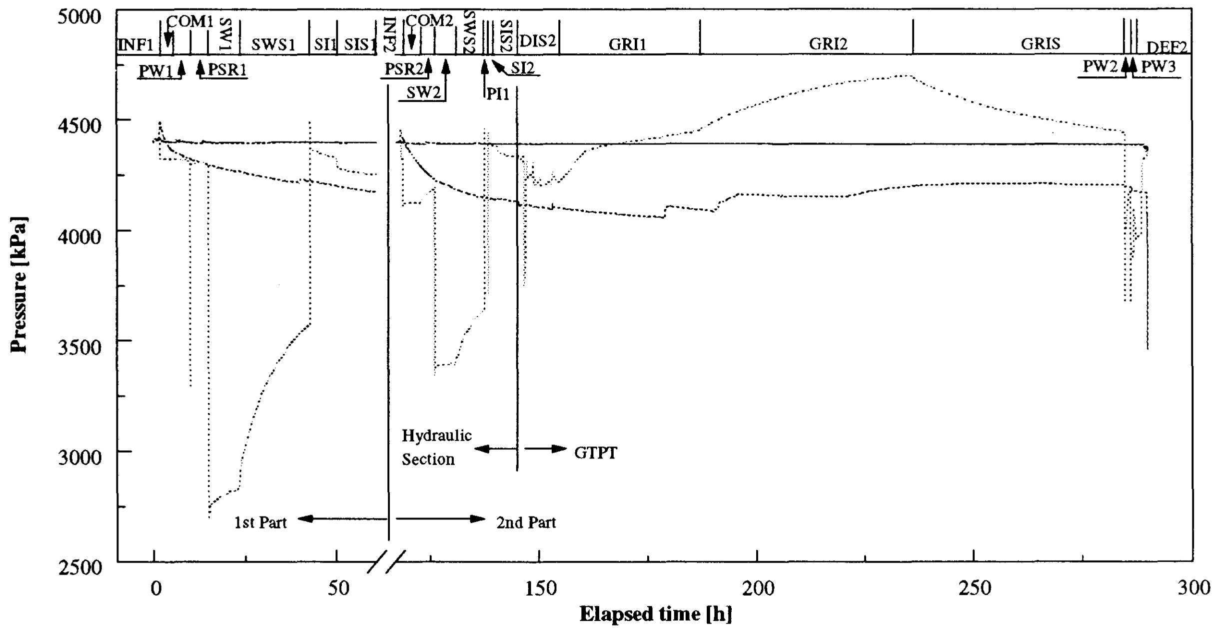
SW - The SW phase was 5.36 h in duration with less then 5% recovery. Two anomalies can be seen in the recovery data. The first disturbance suggests that there was intermittent hydraulic communication with the lower guard zone and may have partially corrupted the data in the PSR and PW2 phases. It was decided to terminate the test at this time and the PTX transducer was removed from the well resulting in the second kink. However, it was later resolved to continue the test as the connection appeared to be through a diffuse fracture network and not along the packer, i.e. not a direct connection.

SWS - The subsequent SWS phase lasted 25.20 h before the gauges malfunctioned. During this time, the pressure recovered from 2286 to 3647 kPa. The test continued for an additional 19 h in attempt to repair the gauge problem before deflation of the packers. The gauges were briefly revitalised at 81 hours test elapsed time but the readings are considered suspect and therefore eliminated from the analyses.

Comments: All test objectives were achieved except for the determination of the gas threshold pressure which was abandoned due to the low interval transmissivity. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. However, a downhole short circuit resulted in the premature termination of the test. Intermittent hydraulic connection through a diffuse fracture network between the test interval and lower guard zone may have attributed to uncharacteristic responses in the PSR, PW1 and SW phases. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity, static formation pressure below the hydrostatic conditions of the borehole and extensive duration. The log-log diagnostic plots are dominated by wellbore storage effects and transitional data. The temperature at the P2 sensor depth increased by 4.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test. The MULTIFIT/GTFM simulations showed that the effect of temperature variation on the test response was very small.

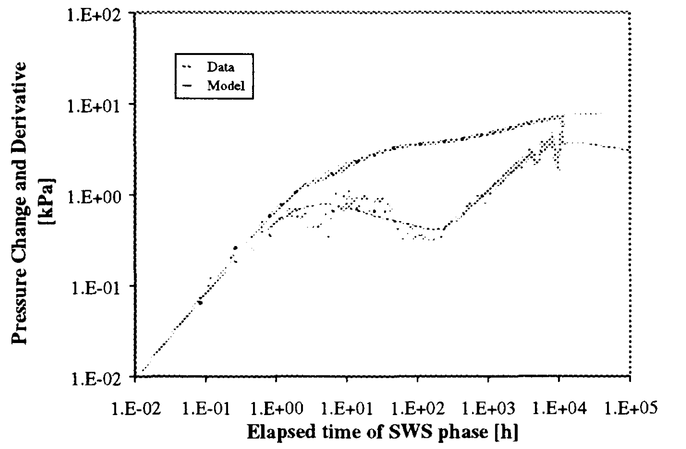
Packer configuration	Double Packers	
Date of test	2nd to 5th April 1995	
Test interval depth	647.13 to 650.00 m bGL 647.02 to 649.88 m bGL	measured true vertical
Test interval length	2.87 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	647.13 to 650.00 m bGL LOWER CRETACEOUS-Valanginien; Palfris Formation; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	8.00E-12 m^2/s 2E-12 to 2E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	492 m asl 392 to 624 m asl	
Radius of investigation	ca 0.5 m	
Stabilised temperature at P2 depth	26.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/v - INTERVAL VM13 | **433.0 - 435.9 m bGL**

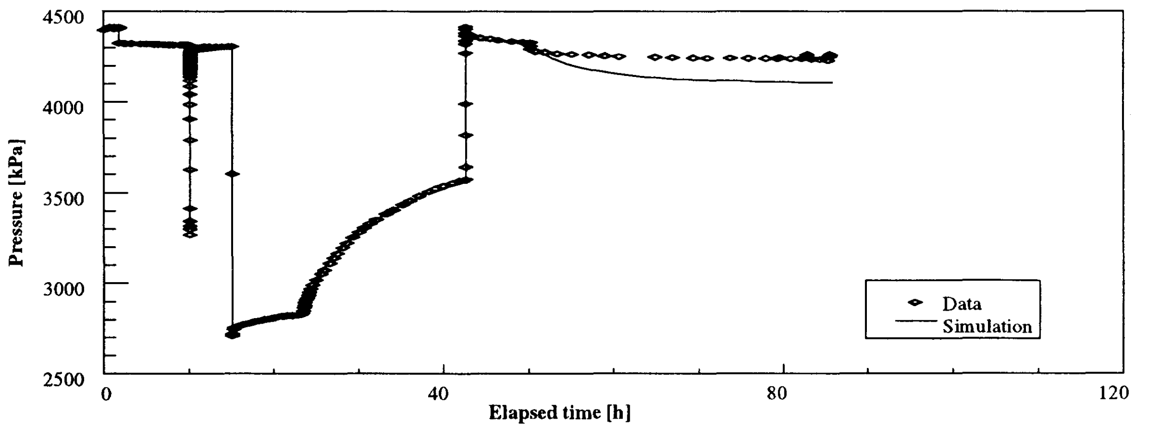


Pressures Measured During VM13

<u>Flow Model</u>:
Inner Boundary: Wellbore Storage and Skin
Formation: Two Shell Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SIS1 Phase)



Base Case Measured and Simulated (GTFM) Formation Response

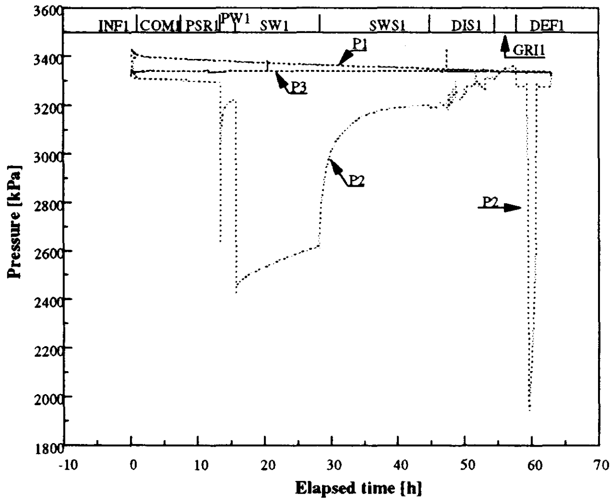
TEST SUMMARY BOREHOLE SB4a/v VM13	433.0 to 435.9 m bGL	Ref: NIB 94-81H Rev.1 Detailed Analysis

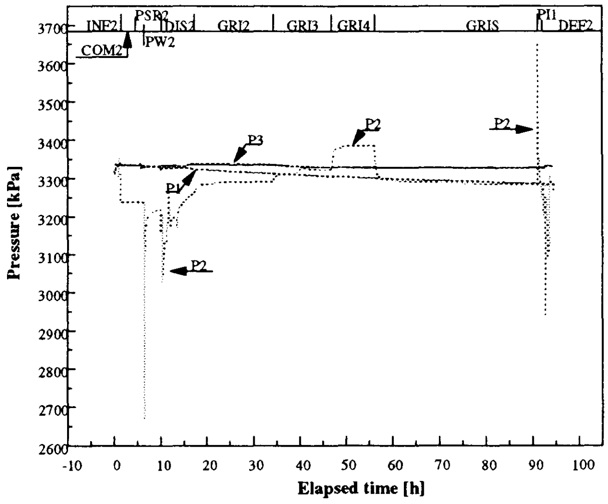
Test Sequence Description: After lowering the tools to test depth, the drilling mud in the interval was displaced with freshwater.
COM1 - The packers were then inflated to 7000 kPa using water and followed by a 3.48 h COM period.
PSR1 - There was little pressure change during this 4.31 h phase indicating the static formation pressure is near hydrostatic conditions.
PW1 - Fluid was swabbed from the tubing to a depth of ca. 100 m bGL and the shut-in tool was opened for 13 seconds for PW1. The entire duration of PW1 was 4.92 h with nearly 100 % recovery. During PW1, fluid was swabbed to ca. 165 m bGL for the SW1 phase.
SW1 - The SW1 phase was 8.17 h in duration with a recovery of 7.4 %.
SWS1 - The shut-in tool was then closed for the SWS1 phase. The log-log plot of this phase showed little diagnostic character for flow model identification and therefore it was decided to perform a SI-SIS sequence.
SI1 - Because the freshwater head was expected to be near hydrostatic conditions, an 8.94 m tubing section was added to the string and filled with fluid for the SI1 phase. The SI1 phase lasted 7.54 h and provided a well defined rate for the subsequent SIS phase.
SIS1 - A log-log plot of the SIS1 period showed good diagnostic character for flow model identification and therefore was continued for 34.64 h. At this stage, both hydraulic parameters and flow model were relatively well constrained.
DIS1 - During displacement of fluid (DIS1) from the interval with gas, bubbles were observed in the annulus, and latter was attributed to a leak in the gas injection line. Therefore, the tools were pulled to the surface and line repaired. After the injection line was repaired, the tools were lowered to the original test depth and a series of abbreviated periods was performed to confirm previous test results.
COM2 - First another 3.97 h COM period (COM2) was carried out.
PSR2 -It was followed by a second PSR phase, which was 3.38 h in duration.
SW2 - During the latter stages of PSR2, fluid was swabbed to a depth of 95 m for the subsequent SW2 phase. It was decided to reduce the drawdown in comparison to SW1 which may have been effected by degassing effects. The SW2 phase was 4.61 h in duration.
SWS2 - It was succeeded by a 6.93 h SWS2 period.
PI - At this stage, the hydraulic parameters were confirmed from previous periods and it was decided to perform a PI1 period to expedite the recovery of the interval pressure to static formation conditions. However, the pressure recovered almost instantaneously to the starting pressure. Therefore, an SI2-SIS2 sequence was carried out.
SI2-SIS2 - At the end of the 4.76 h SIS2 period, the interval pressure was near the expected static conditions, and with the flow model identified and hydraulic parameters relatively well defined, the prerequisites for the threshold pressure test were now satisfied.
DIS2 - Displace the fluid in the interval with gas using a new specialised tool design, 9.27 h in duration.
GRI1 & 2 - Once the fluid was displaced with gas, the hydraulic shut-in tool was closed and gas injection (GRI1) was started at a rate of approximately 0.54 nl/min and continued for 32.20 h. At approximately 1300 kPa overpressure, the pressure change deviated from the unit slope, characteristic of wellbore storage. The rate was subsequently increased to 1.48 nl/min.
GRIS - At the completion of the 9.26 h GRI2 phase, the interval was shut-in at the surface (GRIS) for 48.72 h.
PW2 &3 - The test was then concluded with two pulse withdrawal events.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a significant influence on the test response due to the extensive duration.

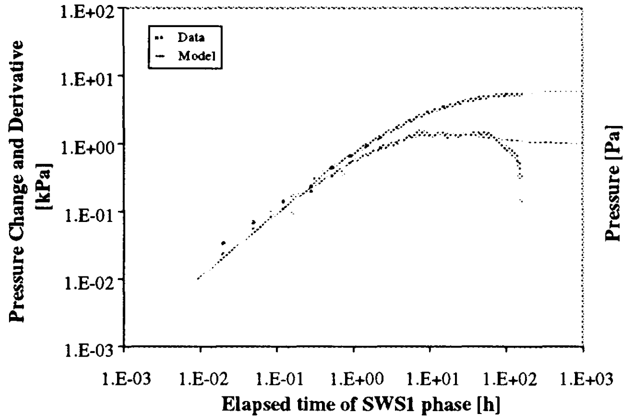
Packer configuration	Double Packer	
Date of test	07th to 19th April 1995	
Test interval depth	433.00 to 435.87 m bGL measured 432.92 to 435.79 m bGL true vertical	
Test interval length	2.87 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	433.00 - 435.87 m bGL LOWER CRETACEOUS-Valanginian; Palfris Formation; Clay and Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Best estimate of transmissivity Confidence interval of transmissivity	3.5E-08 m^2/s 1E-10 - 6E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	942 m asl 930 - 971 m asl	
Radius of investigation	28 to 80 m	
Stabilised temperature at P2 depth	19.5 °C	
Recommended flow model	Wellbore Storage, Radial Composite, Infinite Lateral Extent	
Measured Air-Entry Pressure Two-Phase Flow Parameter Model Brooks-CoreyParameter Air-Entry Pressure Residual Liquid Saturation	1.3E+5 Pa Grant l = 2 (0.5 to 4.0) P_e = 1.0E+5 Pa (5.0E+4 to 6.0E+5 Pa) S_{lr} = 0.25 (0.05 to 0.5)	
Factors affecting test analysis	Equipment, History, Temperature, Gas	Yes

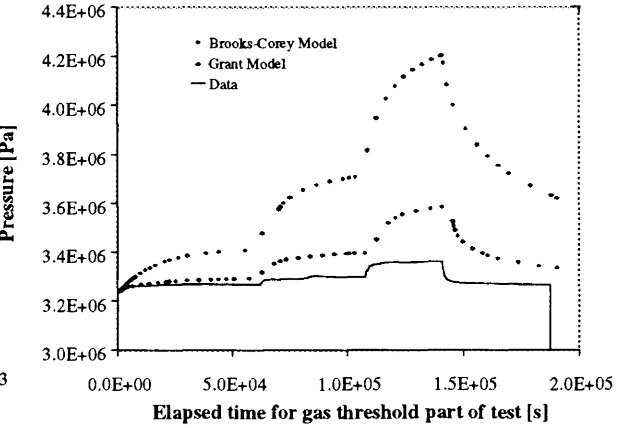
BOREHOLE SB4a/v - INTERVAL VM14 | 329.7 - 332.6 m bGL



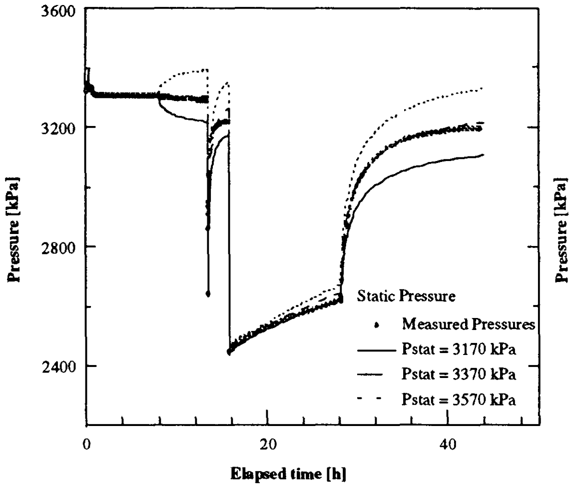


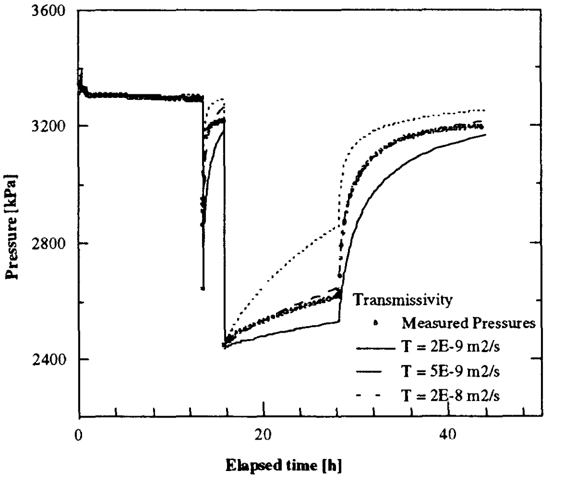
Pressures Measured During First and Second Parts of Test VM14





Log-Log Diagnostic Plot (SWS1 Phase) | **Analysis for Two Phase Flow Parameters**





Simulated (GTFM) Formation Response With Sensitivity Runs

TEST SUMMARY BOREHOLE SB4a/v VM14	329.7 to 332.6 m bGL	Ref: NIB 94-81H Rev.1 Standard Analysis

Test Sequence Description: After lowering the tools to test depth, the drilling mud in the interval was displaced with freshwater.
COM1 - The packers were then inflated to 7500 kPa using water and followed by a 6.82 h COM period.
PSR1 - There was very little pressure change during this 5.46 h phase.
PW1 - Fluid was swabbed from the tubing to a depth of ca. 69 m bGL and the shut-in tool was opened for 10 s for PW1. The entire duration of PW1 was 2.32 h with nearly 100 % recovery.
SW1 - In the latter part of PW1, fluid was swabbed to ca. 89 m bGL for the subsequent SW1 phase. The SW1 phase was 12.43 h in duration with a recovery of ca. 20 %.
SWS1 - The shut-in tool was then closed for the SWS1 phase, which lasted 16.22 h. At this stage, both hydraulic parameters and flow model were relatively well constrained and it was decided to prepare for gas injection.
DIS1 - During displacement of fluid in the interval with gas (DIS1) the 1/4" choke line in the pressure chamber clogged, so it was decided to continue displacement over the test string .
GRI1 - The gas injection (GRI1) was subsequently started at an injection rate of 0.85 l/min. Because of the abnormal pressure response, it was decided to stop injection (after 1.33 h) and reset the test by deflating the packers in order to allow the gas to escape the interval.
INF2 - Before the second packer inflation (INF2) the interval was flushed again with 1.5 m^3 of tracered water, in order to facilitate the gas transport out of the interval. After the packers were set, a series of abbreviated periods were performed to confirm previous test results.
COM2 - Another 3.96 h COM phase was carried out (COM2).
PSR2 - This was followed by a second PSR phase (PSR2) which was 1.10 h in duration.
PW2 - During the latter stages of PSR2, fluid was swabbed to a depth of ca. 63.m bGLfor the subsequent PW2 phase. At the end of the 3.6 h PW2 period, the interval pressure was near the expected static conditions, and with the flow model identified and hydraulic parameters relatively well defined, the prerequisites for the threshold pressure test were now satisfied.
DIS2 -The fluid in the interval was displaced with gas, 7.23 h.
GRI2, 3 & 4 - Once the fluid was displaced with gas, the hydraulic shut-in tool was closed and gas injection (GRI2) was started at a rate of approximately 0.54 l/min continuing for 17.02 h. At approximately 7.9 kPa overpressure, the pressure change deviated from the unit slope, characteristic of wellbore storage. The rate was subsequently increased in two steps to 2.34 l/min (GRI3 - 12.72 h) and 8.26 l/min (GRI4 - 9.20 h), respectively.
GRIS - At the completion of gas injection, the interval was shut-in at the surface (GRIS) for 34.88 h. Due to the low threshold pressure derived, it is not possible to decide if the GRIS phase tended to recover to threshold pressure or to static formation pressure conditions.
PI - The test was concluded with a pulse injection phase (PI1 - 0.77 h).

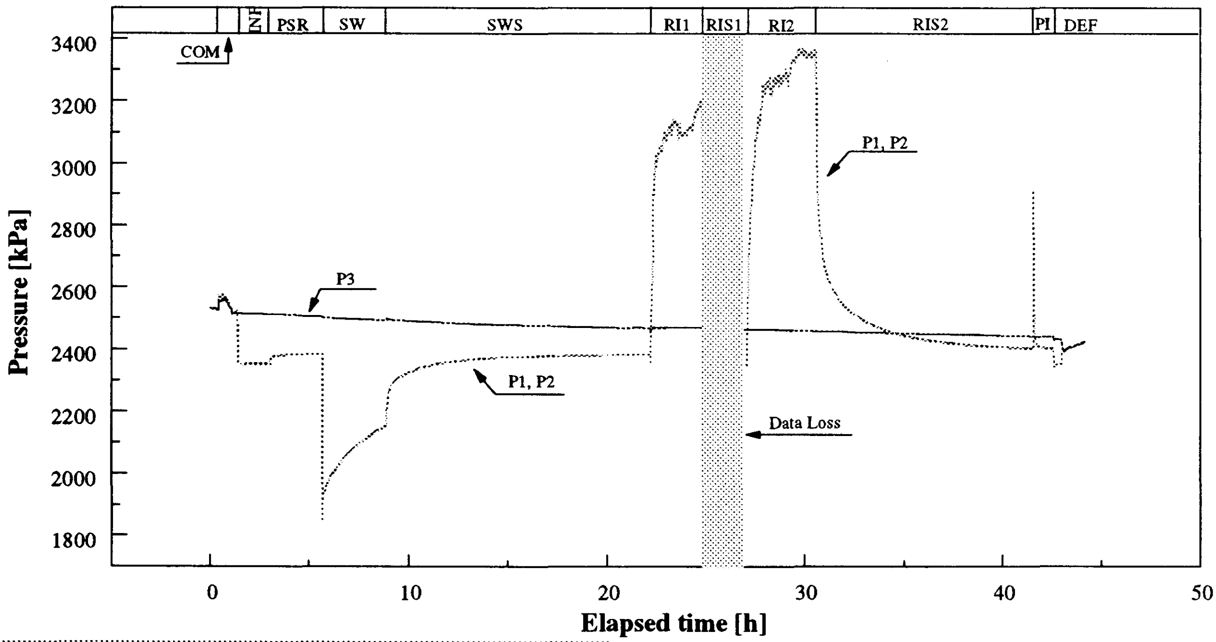
Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a significant influence on the test response due to the extensive duration.

Packer configuration	Double Packer	
Date of test	19th to 25th April 1995	
Test interval depth	329.70 to 332.57 m bGL measured 329.64 to 332.51 m bGL true vertical	
Test interval length	2.87 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	329.70 - 332.57 m bGL LOWER CRETACEOUS-Valanginian; Palfris Formation; Clay and Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Best estimate of transmissivity Confidence interval of transmissivity	5.0E-09 m^2/s 2E-09 - 2E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	951 m asl 930 - 971 m asl	
Radius of investigation	17 m	
Stabilised temperature at P2 depth	16.0 °C	
Recommended flow model	Wellbore Storage and Skin Homogeneous [6)] Infinite Lateral Extent	
Measured Air-Entry Pressure Two-Phase Flow Parameter Model Brooks-CoreyParameter Air-Entry Pressure Residual Liquid Saturation	2.20E+4 Pa Grant l = 2 P_e = 1.2E+4 Pa S_{lr} = 0.25	
Factors affecting test analysis	Equipment, History, Temperature, Gas	Yes

APPENDIX C:
TEST SUMMARIES OF HYDRAUIC TESTING IN SB4A/SLANTED WITH FIELD ANALYSES RESULTS

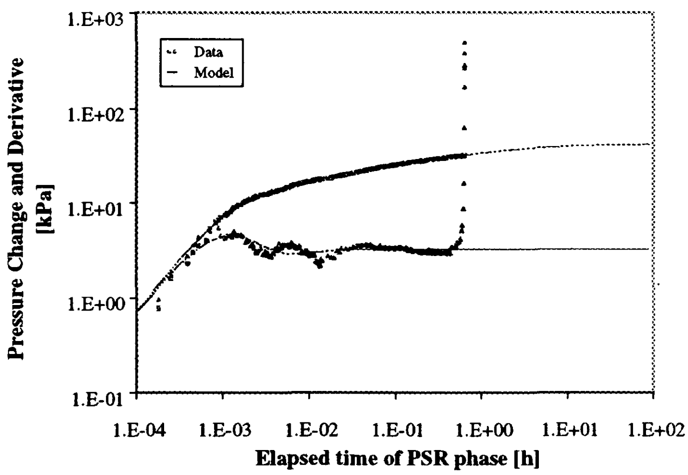
(INTRODUCTION SEE APPENDIX B)

BOREHOLE SB4a/s - INTERVAL VM1	321.5 - 332.2 m aBH/ 231.5 - 239.4 m bGL

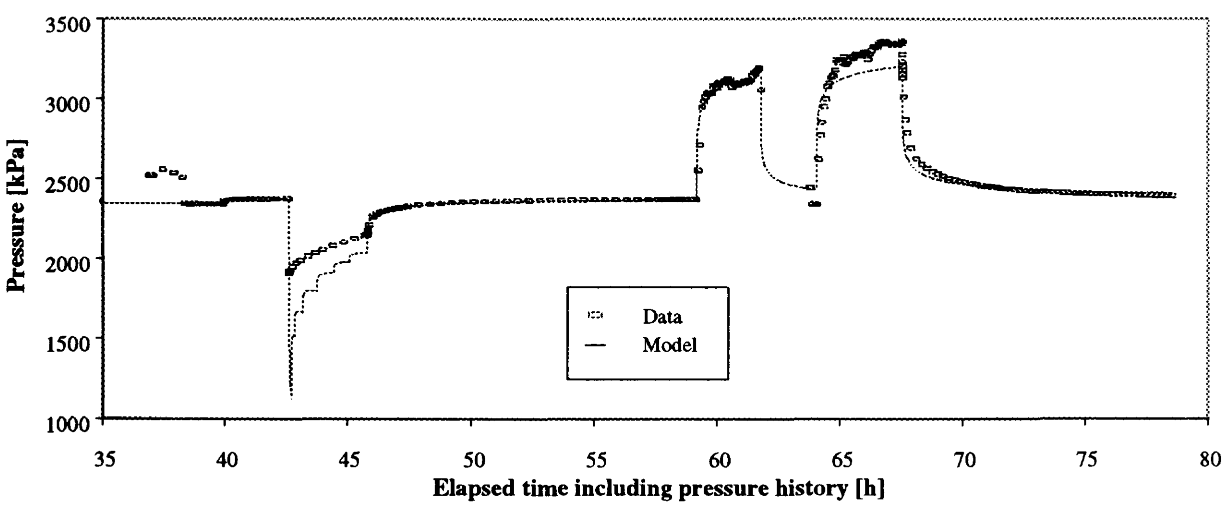


Pressures Measured During VM1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM1	321.5 to 332.2 m aBH 231.5 to 239.4 m bGL	Reference: NIB 95-15A Standard Analysis

Test Sequence Description:

After moving the tools to VM1 test depth 1.5 m^3 of uranin tracered fresh water was circulated down the tubing. The screen depth during flushing activities was approximately 328 to 330 m aBH, which should have allowed for displacement of the majority of the drilling mud from the interval. After flushing activities, the packer was then inflated to 5500 kPa with water.

COM - The shut-in tool remained open for 1.63 h during the compliance period, to allow temperature of the interval fluid to equilibrate and to obtain an initial estimate of the historical rate. Fluid was flowing from the tubing at an average rate of 7.3E-2 l/min suggesting a formation pressure above the hydrostatic conditions in the borehole.

PSR - In the subsequent 2.65 h PSR phase, the pressure increased 32 kPa to an end pressure of 2384 kPa.

SW - During the PSR phase, fluid was swabbed from the tubing to an approximate depth of 40 m aBH in preparation for the ensuing SW phase. The SW phase lasted 3.18 h with a total recovery of 51 %.

SWS - The hydraulic shut-in tool was closed for the SWS period which lasted 13.36 h. In preparation for the planned pumping period, sucker rods were lowered into the tubing but were blocked by restrictions caused by cement in the tubing from previous operations. Therefore, the test design was modified and it was decided to carry out an injection period.

RI1 - The first injection (RI1) period lasted 2.56 h and was prematurely terminated when the flow rate inadvertently dropped to 0 l/min.

RIS1 - The shut-in tool remained open and therefore this phase constitutes a surface shut-in (RIS1). Shortly after the start of the RIS1 period, the data acquisition system stopped recording and did not re-start for approximately 2 h. Because of the problems with rate regulation, it was decided to perform a second injection period.

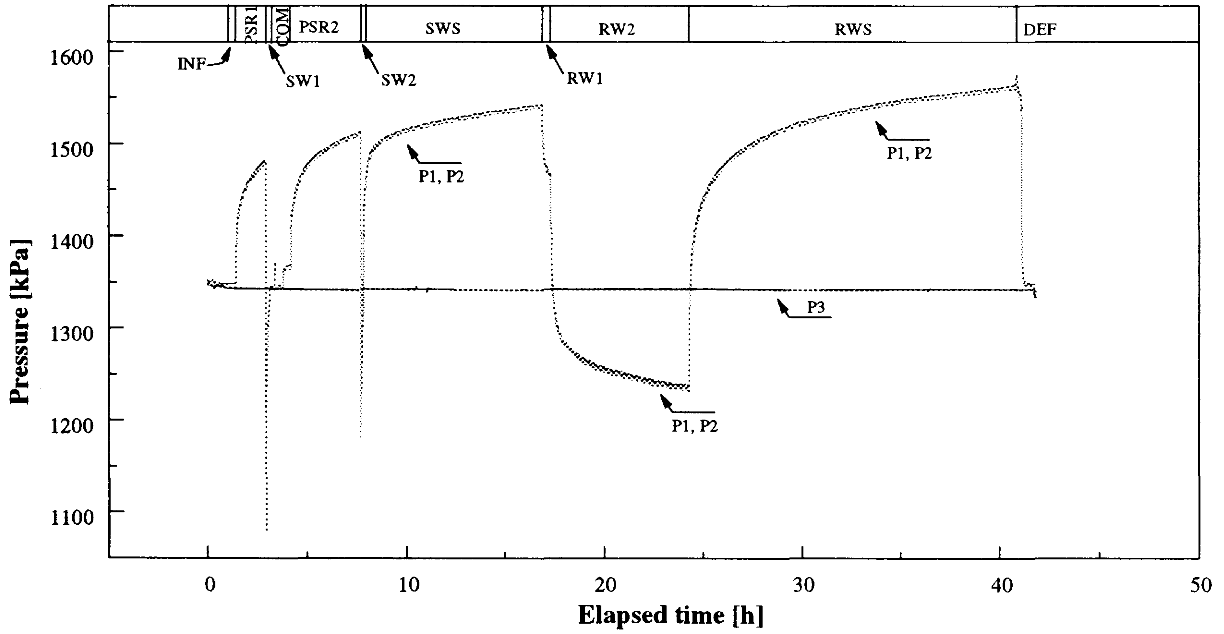
RI2 & RIS2 - The second injection phase (RI2) was 3.46 h in duration and followed by a 11.01 h shut-in (RIS2).

PI - The test was concluded with a 1.01 h pulse injection period.

Comments: All test objectives were achieved. However, it was decided during the test not to collect a water sample. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The injection phase shows a non-ideal response and may be attributed to stress effects on fractures connected to the borehole due to varying pressure conditions or 'plugging' and 'unplugging' of fractures from sediment carried in suspension with the fluid injected into the formation. The temperature at the P2 sensor depth increased by 0.7°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

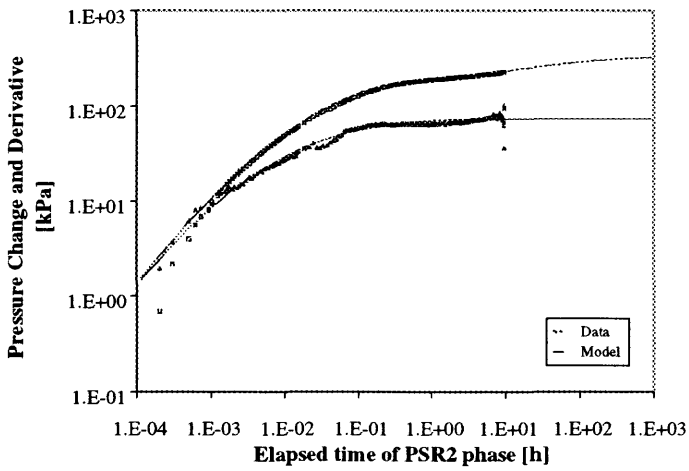
Packer configuration	Single Packer	
Date of test	14th to 16th June 1995	
Test interval depth	321.50 to 332.20 m aBH 231.52 to 239.39 m bGL	measured true vertical
Test interval length (measured along the borehole)	10.70 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	231.52 - 239.39 m bGL (true vertical) LOWER CRETACEOUS-Valanginian; Palfris Formation; silty clay marls and limestone marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	7.0E-8 m^2/s 3.0E-8 to 2.0E-7 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	947 m asl 946 to 948 m asl	
Radius of investigation	20 m	
Stabilised temperature at downhole sensor depth	15.0 °C	
Recommended flow model	Wellbore Storage and Skin Homogenous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/s - INTERVAL VM2	181.6 - 332.2 m aBH/ 128.9 - 239.4 m bGL

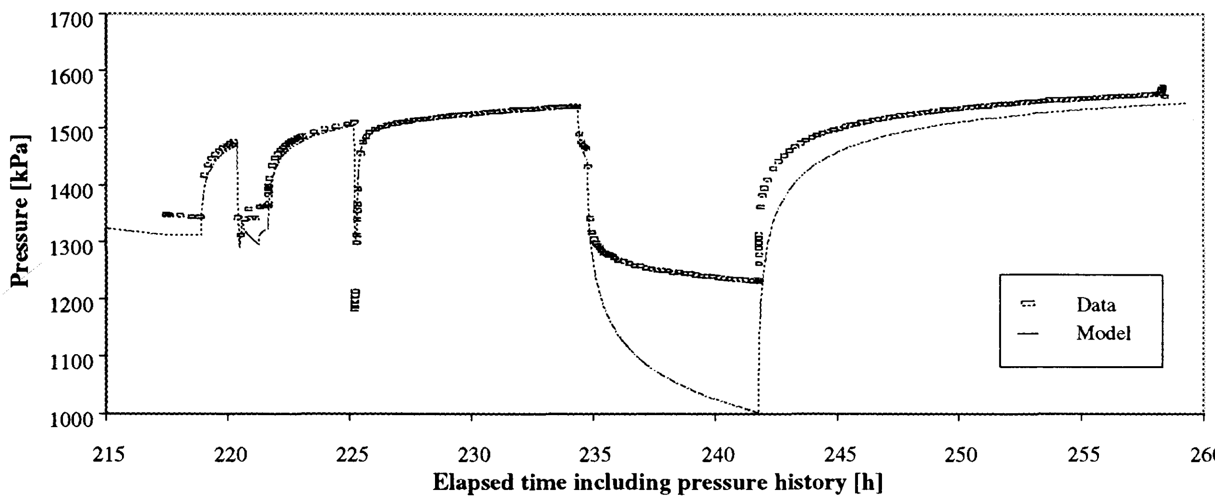


Pressures Measured During VM2

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR2 Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM2	181.6 to 332.2 m aBH 128.9 to 239.4 m bGL	Reference: NIB 95-15A Standard Analysis

Test Sequence Description:

After moving the tools to VM2 test depth 1.5 m^3 of uranin tracered fresh water was circulated down the tubing. The packer was then inflated to 5500 kPa with water.

PSR1 - The test interval pressure began to rise (PSR1) above hydrostatic once the packer was set. Since the shut-in tool was open, a downhole blockage was causing this anomalous response. This period continued for 1.49 h.

SW1 - In attempt to unblock the restriction in the tubing, fluid was swabbed to a depth of ca 40 m aBH (SW1). This attempt was successful as fluid began to fill the tubing and continued for 0.19 h when flow reached the surface to start the COM phase.

COM - An initial flowrate of 2.5 l/min was measured at the wellhead and later 1.9 l/min was measured in the flow control board; the drop in rate is due to the head loss when the flow was re-directed. The COM phase was ended after 1.05 h.

PSR2 - The rise in pressure in the PSR2 phase (3.52 h) confirms a static formation pressure above the hydrostatic conditions of the borehole. Fluid was swabbed to a depth of ca. 40 m aBH for the ensuing SW2 phase. Problems with lowering the swab bar to greater depths, possible due to restrictions in tubing from cement, prevented a larger drawdown.

SW2 - SW2 lasted 0.11 h and was terminated relatively quickly as the recovery was approaching the surface.

SWS - The pressure increased from 1313 kPa to 1539 kPa during the 9.08 h SWS period.

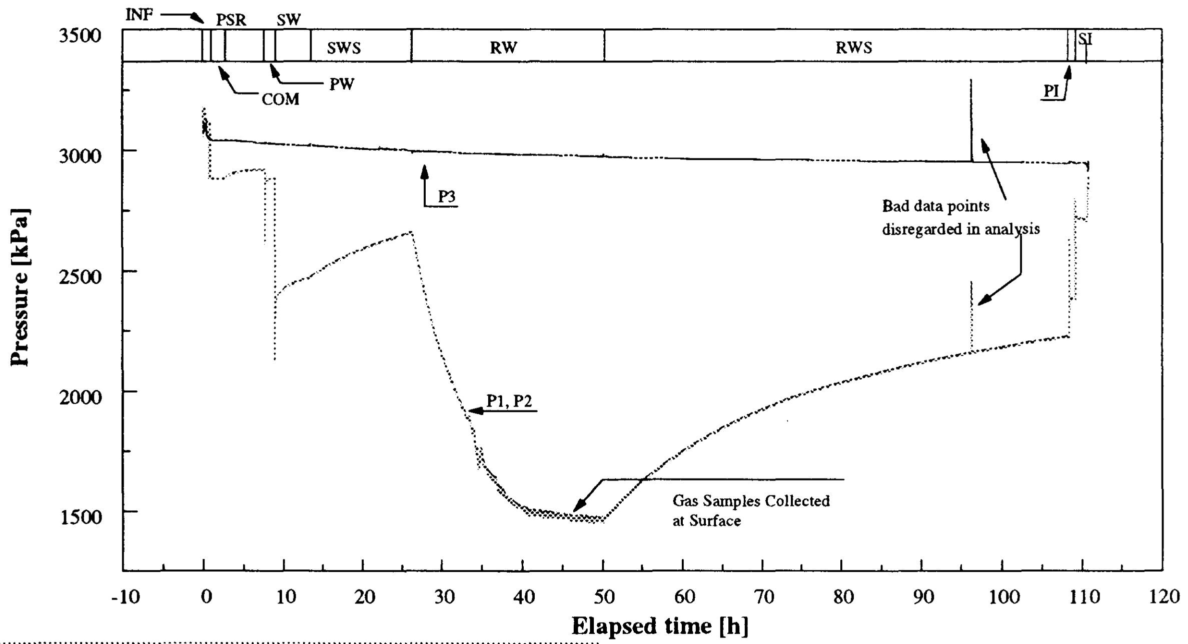
RW1 & 2 - After lowering the sucker rods to depth, the shut-in tool was open for the RW1 phase and pumping began at an initial rate of 1.6 l/min. Due to the relatively small response, the pumping rate was increased after 0.40 h to 5.0 l/min (RW2). Gas flow was recorded during this phase and the smell of hydrogen sulfide was easily recognised. The time for the onset of gas flow at the surface is uncertain but a stable gas flow of 0.5 l/min was measured 1.50 h into the RW2 period. However, since the pressure in the separator was declining slowly, the actual gas flowrate from the borehole is less then measured. At the time of testing it was not certain if the measured gas rate at the surface represents two phase flow, degassing in the formation or degassing in the borehole. The pumping phase was terminated after 7.41 h with a total drawdown of approximately 300 kPa.

RWS - The subsequent RWS lasted 16.48 h with a final pressure of 1563 kPa. Additional slug and pulse phases were planned, but due to stuck sucker rods, used during pumping, the test was terminated.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The temperature measured at P2 sensor depth was relatively stable throughout the test.

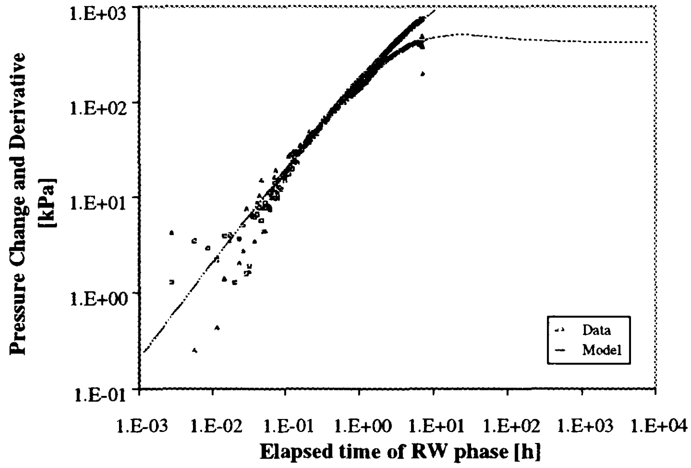
Packer configuration	Single Packer	
Date of test	16th to 18th June 1995	
Test interval depth	181.61 to 332.20 m aBH 128.90 to 239.39 m bGL	measured true vertical
Test interval length (measured along the borehole)	150.59 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	128.90 to 239.39 m bGL (true vertical) LOWER CRETACEOUS-Valanginian; Palfris Formation; silty clay marls and limestone marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.0E-6 m^2/s 5.0E-7 to 4.0E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	973 m asl 968 to 978 m asl	
Radius of investigation	42 m	
Stabilised temperature at downhole sensor depth	12.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No Yes

BOREHOLE SB4a/s - INTERVAL VM3	395.1 - 417.0 m aBH/ 285.7 - 301.9 m bGL

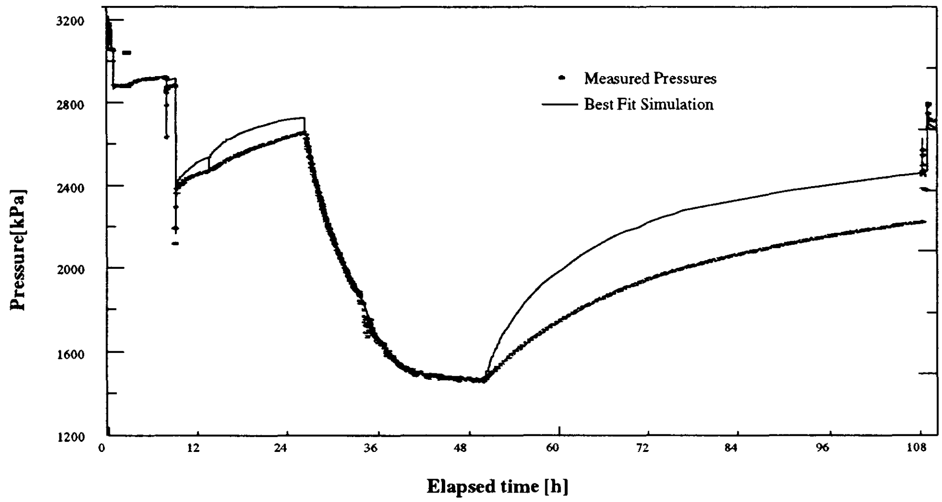


Pressures Measured During VM3

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RW Phase Prior to Gas Flow)



Simulated (GTFM) Formation Response

TEST SUMMARY BOREHOLE SB4a/s VM3	395.1 to 417.0 m aBH 285.7 to 301.9 m bGL	Reference: NIB 95-15A Standard Analysis

Test Sequence Description: After moving the tools to VM3 test depth 2 m^3 of uranin tracered fresh water was circulated down the tubing. With the screen located near the bottom of the borehole, the drilling mud in the interval should have been nearly entirely displaced by the flushing fluid. The packer was then inflated to 5500 kPa with water.

COM - The shut-in tool remained open for 2.10 h to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. The fluid level increased at an equivalent rate of 7.44E-4 l/min but may have been influenced by changing temperatures.

PSR - During the subsequent 4.94 h PSR phase, the pressure increased from 2879 to 2918 kPa, indicating a formation pressure above the hydrostatic conditions in the borehole. In the latter part of the period, fluid was swabbed to 34 m aBH in preparation for the PW.

PW - The shut-in tool was opened for 15 s and then closed; the pressure recovered from 2611 to 2880 kPa during the 1.17 h PW phase. A wellbore storage coefficient of 6.4E-9 m^3/Pa was computed from the change in fluid level while the shut-in tool was open.

SW - A SW phase was then performed with an initial drawdown of approximately 711 kPa. After 4.49 h, the pressure recovered approximately 42%.

SWS - The shut-in tool was closed for the SWS phase. This lasted 17.45 h with an end pressure of 2657 kPa, well below the final pressure of earlier test events. The extended duration of the period was needed in part to install sucker rods into the tubing and set-up the flow control board for the subsequent RW phase.

RW - During the first 7 h of the RW phase, the total flow rate was quite stable at approximately 0.52 l/min with a total drawdown of approximately 780 kPa. At an interval pressure of ca. 1880 kPa, several slugs of gas were measured in the flowcontrol board and then followed by slowly changing, but relatively stable, gas and water rates; the gas rate declined from 10 l/min to 5 l/min while the water rate increased from 0.05 to 0.15 l/min during the latter 17 h of the period. The pumping period was relatively long to acquire relatively stable gas and water rates, which could be compared to solution gas water ratio at downhole conditions. Gas samples were collected at the surface during this period.

RWS - The subsequent RWS phase lasted 58.30 h with an end pressure of 2223 kPa.

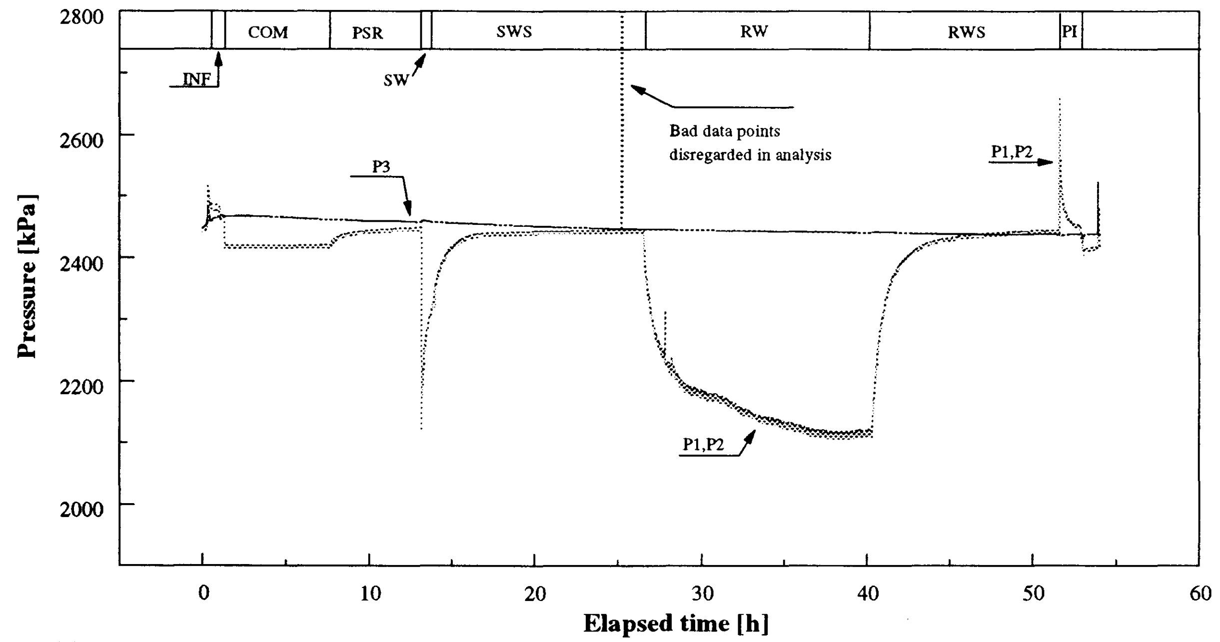
PI - The test was continued with a PI test. There was a considerable change in fluid level when the shut-in tool was briefly opened for the PI phase, an indication of a high gas content in the interval at the end of the RWS period.

SI - The test was concluded with a SI phase.

Comments: All objectives were achieved. During the test, it was decided not to collect water samples due to the small water production in the main pumping period. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The temperature at the P2 sensor depth increased by 1.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

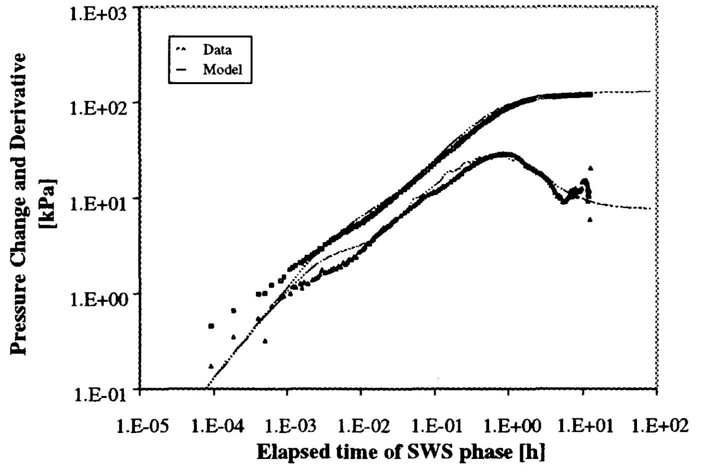
Packer configuration	Single Packer	
Date of test	26th June to 1st July 1995	
Test interval depth	395.10 to 417.00 m aBH 285.69 to 301.85 m bGL	measured true vertical
Test interval length (measured along the borehole)	21.90 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	285.69 to 301.85 m bGL (true vertical) LOWER CRETACEOUS-Valanginian; Palfris Formation; marly clays interbedded with limestone layers containing calcite veins	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Characterisation of Gas Flow, Water and Gas Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.0E-8 m^2/s 3.0E-9 to 3.0E-8 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	950 m asl 926 to 955 m asl	
Radius of investigation	8 m	
Stabilised temperature at downhole sensor depth	17 °C	
Recommended flow model	Wellbore Storage and Skin Homogenous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/s - INTERVAL VM4	**330.5 - 417.0 m aBH/ 238.2 - 301.9 m bGL**

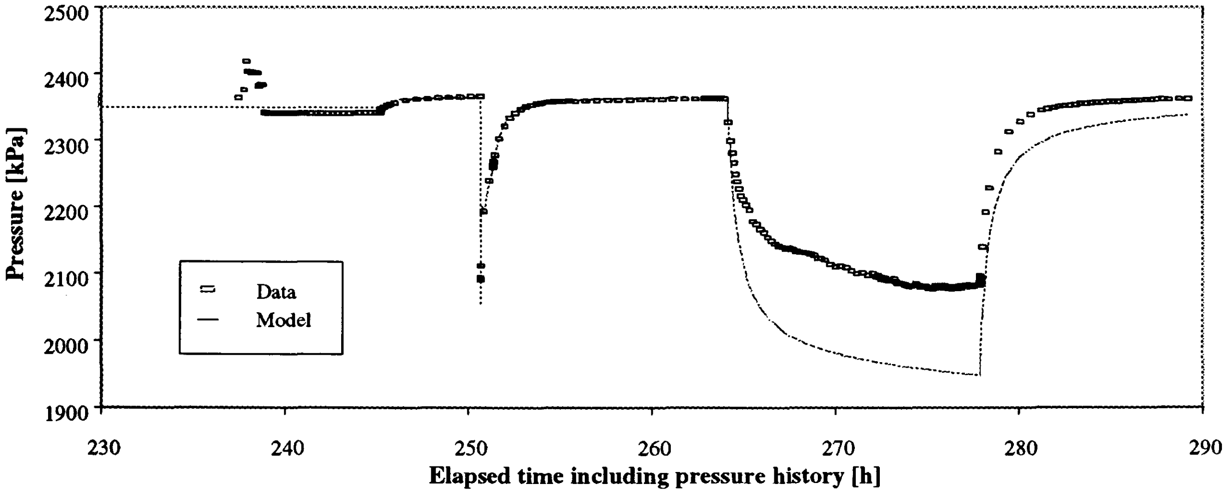


Pressures Measured During VM4

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM4	330.5 to 417.0 m aBH 238.2 to 301.9 m bGL	Reference: NIB 95-15A Detailed Analysis

Test Sequence Description:

After moving the tools to VM4 test depth 2.5 m^3 of uranin tracered fresh water was circulated down the tubing. The packer was then inflated to 5500 kPa with water.

COM - The shut-in tool remained open for a 6.36 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at an average rate of 1.0E-1 l/min, suggesting a static formation pressure above the hydrostatic conditions in the borehole.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 5.43 h PSR phase. In the PSR period, the pressure increased 28 kPa with an final pressure of 2444 kPa. In preparation for the subsequent SW phase, fluid was swabbed from the tubing.

SW - Upon opening the shut-in tool, the pressure fell 323 kPa. The SW phase was terminated after 0.69 h at a recovery of approximately 62 % of the initial drawdown.

SWS - In the following 12.72 h SWS period, the pressure nearly recovered to the same end pressure of the PSR phase.

RW - After the sucker rods were installed into the tubing and the flowmeters were function checked, the shut-in tool was opened with an initial production rate of 2.25 l/min. Approximately 2.9 h after the start of pumping, gas flow was detected at the surface. The initial measured gas flowrate, 0.24 l/min, was less the the actual gas rate at the wellhead as the separator pressure continued to increase. Therefore, the gas outlet rate was slowly increased to 0.35 l/min which stabilised the separator pressure. The water slowly increased throughout the production phase with a final rate of approximately 2.67 l/min. During the entire 13.78 h RW period, the pressure decreased 306 kPa.

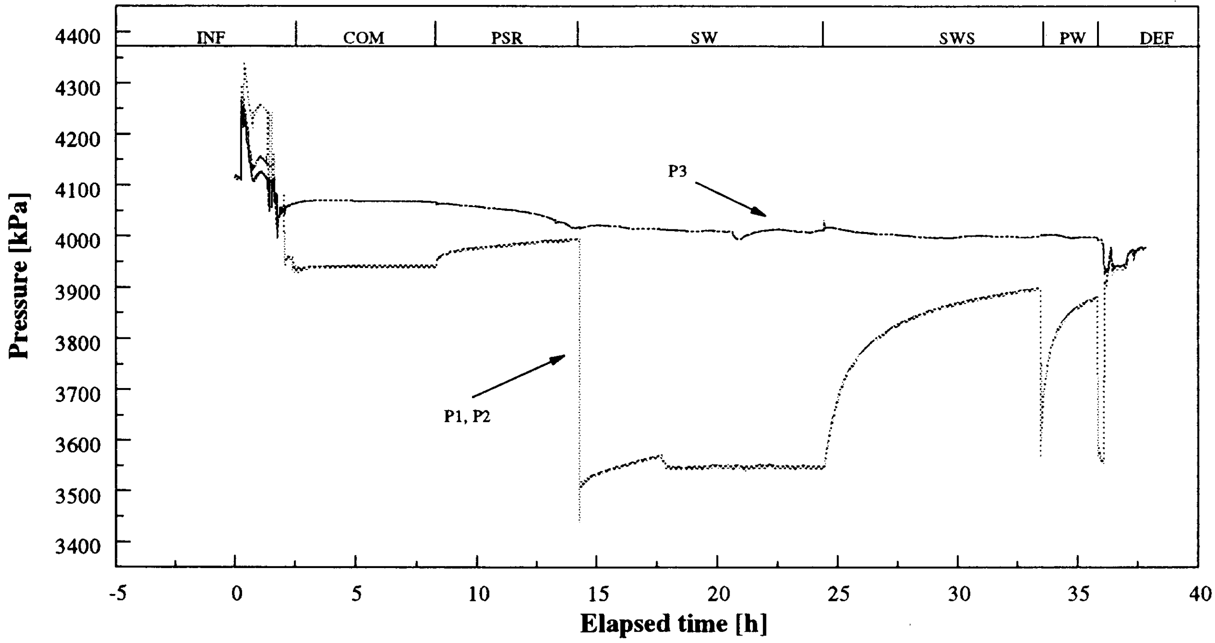
RWS - The subsequent RWS period lasted 11.28 h with a final pressure very close the end pressure of previous shut-in phases.

PI - The test was concluded with a 1.18 hour pulse injection period (PI). It is likely that free gas in the interval at end of RWS escaped when the shut-in tool was briefly opened for PI; this is evident from the large change in fluid level inside the tubing after the shut-in tool was briefly opened which can not be solely attributed to the compressibility of the interval.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The temperature at the P2 sensor depth increased by 1.6°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

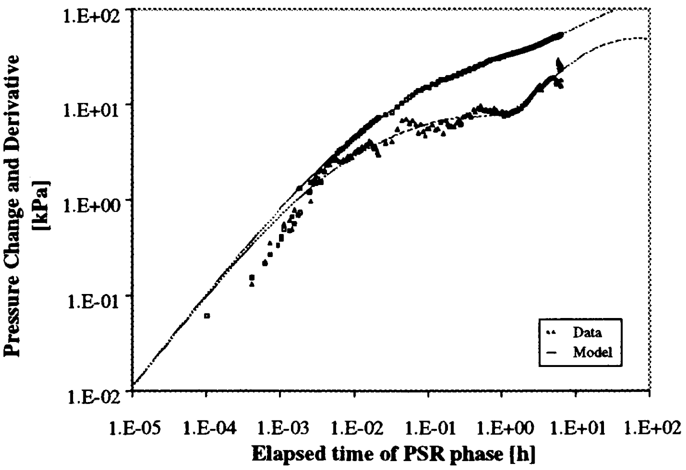
Packer configuration	Single Packer	
Date of test	1st to 3rd July 1995	
Test interval depth	330.52 to 417.00 m aBH 238.15 to 301.85 m bGL	measured true vertical
Test interval length (measured along the borehole)	86.48 m	
Borehole diameter	6 1/4" (= 0.159 m; nominal)	
Geology	238.15 to 301.85 m bGL (true vertical) LOWER CRETACEOUS-Valanginian; Palfris Formation; marly clays interbedded with limestone layers containing calcite veins	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-7 m^2/s 2.2E-7 to 4.0E-6 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	947 m asl 944 to 948 m asl	
Radius of investigation	98 m	
Stabilised temperature at downhole sensor depth	15.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/s - INTERVAL VM5	521.5 - 532.6 m aBH/ 378.0 - 358.9 m bGL

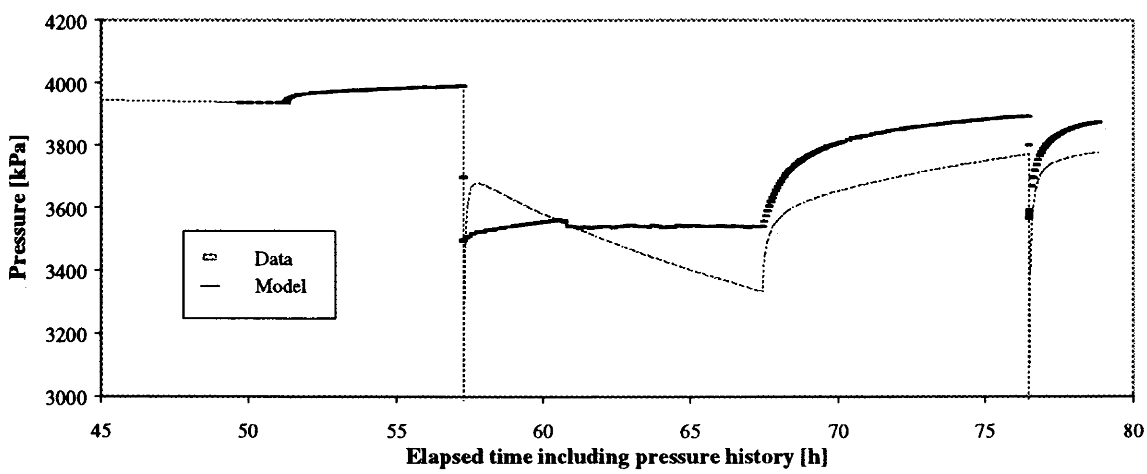


Pressures Measured During VM5

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM5	521.5 to 532.6 m aBH 378.0 to 385.9 m bGL	Reference: NIB 95-15B Standard Analysis

Test Sequence Description:

After moving the tools to test depth 2 m^3 of uranin tracered fresh water was circulated down the tubing. The packer was then inflated to 5500 kPa with water.

COM - The shut-in tool remained open for a 5.89 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at an average rate of 7E-3 l/min, suggesting a static formation pressure above the hydrostatic.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 5.99 h PSR phase. In the PSR period, the pressure increased 53 kPa with a final pressure of 3992 kPa. In preparation for the subsequent SW phase, fluid was swabbed from the tubing to approximately 70 m aBH.

SW - Upon opening the shut-in tool, the pressure fell 492 kPa. The pressure response showed a normal recovery in the initial 3.40 h with an increase of 68 kPa. Subsequently, the pressure fell 24 kPa and then was stable for the remainder 6.70 h of the phase. This response was also seen by the PTX transducer and may be attributed to gas flow. This period may also have been affected by a diffuse hydraulic connection to the annulus as the P3 pressure stabilised at the start of the period after showing a decreasing trend during the PSR.

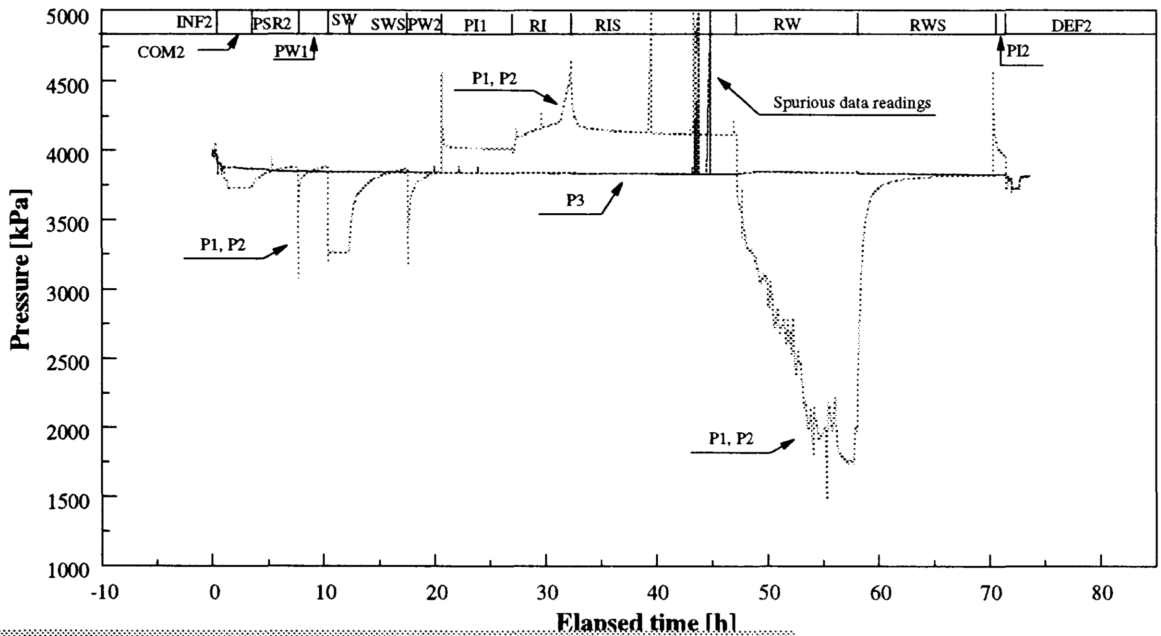
SWS - In the following SWS period, the pressure recovered to 3895 kPa in 9.03 h, 10 kPa lower then the final pressure recorded during the PSR phase.

PW - The test was concluded with a 2.37 h pulse withdrawal phase, the recovery was 95 % of the total 319 kPa drawdown.

Comments: All test objectives were achieved. However, it was not possible to collect a representative water sample due to the expected small water production based on the results from the slug period. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the moderate interval transmissivity. The reliability of single phase parameters derived from the latter part of the slug phase and subsequent periods maybe significantly impacted by gas effects. The annulus pressure showed various trends which could not be attributed to a specific equipment problem during the test. The temperature at the P2 sensor depth increased by 1.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

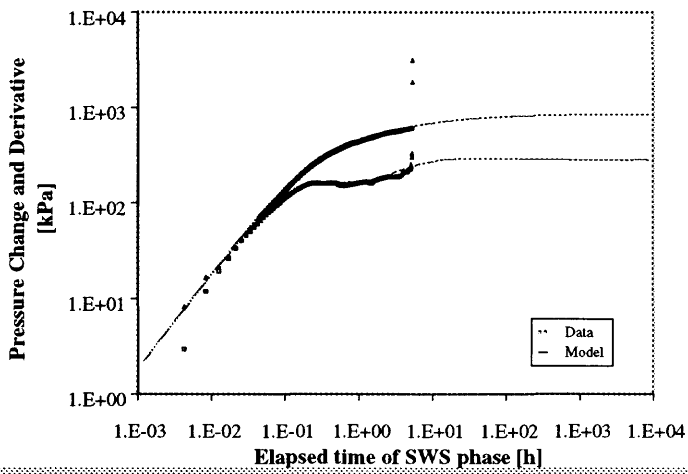
Packer configuration	Single Packer	
Date of test	29th to 31th July 1995	
Test interval depth	521.50 to 532.60 m aBH 378.00 to 385.93 m bGL	measured true vertical
Test interval length (measured along the borehole)	11.10 m	
Borehole diameter	4 3/4" (= 0.124 m; nominal)	
Geology	521.50 - 532.60 m aBH VALANGINIAN - Marly clays and limestone marls with calcite veins (Palfris Formation)	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Characterisation of Gas Flow, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	4.0E-09 m^2/s 2E-09 - 6E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	970 m asl 960 - 980 m asl	
Radius of investigation	7 m	
Stabilised temperature at downhole sensor depth	20 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Possibly (no direct evidence)

BOREHOLE SB4a/s - INTERVAL VM6	512.6 - 532.6 m aBH/ 371.6 - 385.9 m bGL

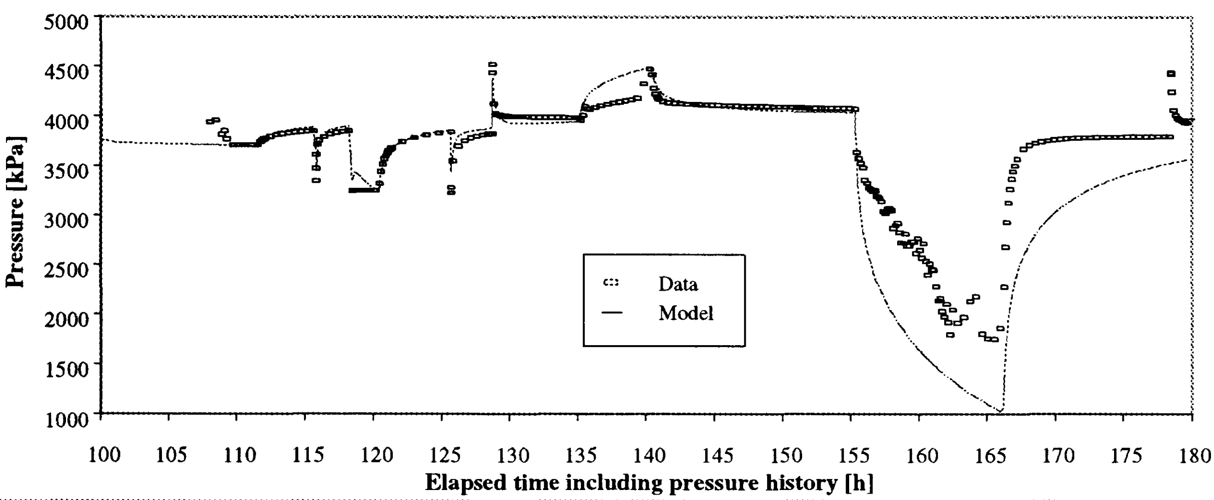


Pressures Measured During VM6 (First Packer Seat Not Shown)

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

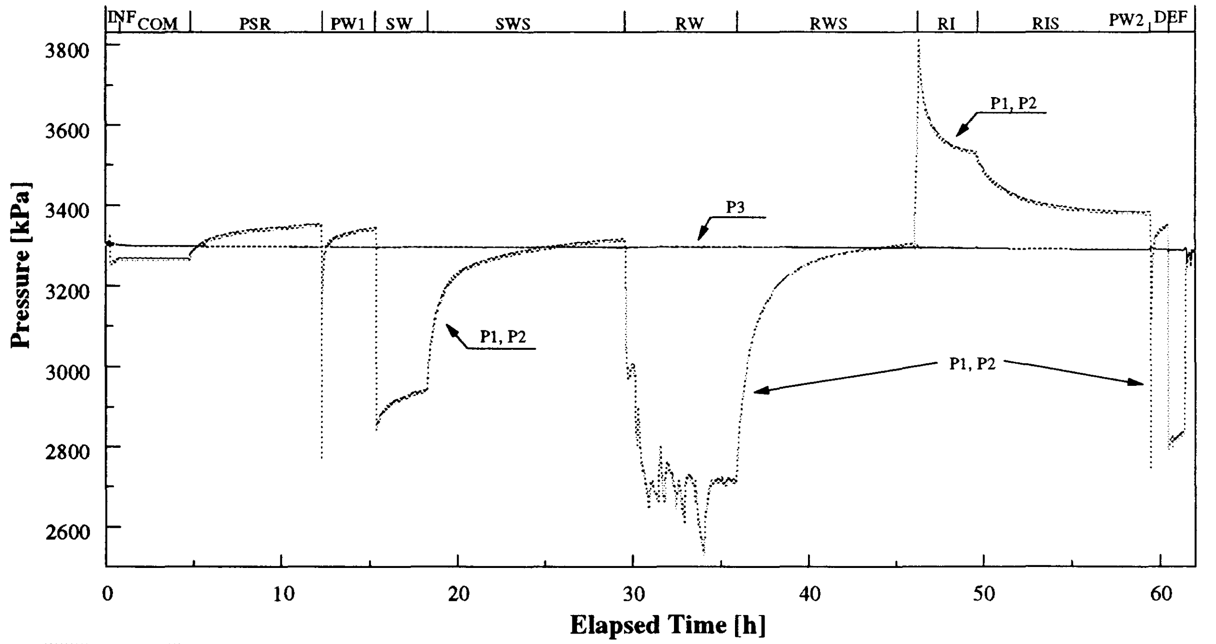
TEST SUMMARY BOREHOLE SB4a/s VM6	512.6 to 532.6 m aBH 371.6 to 385.9 m bGL	Reference: NIB 95-15B Standard Analysis

Test Sequence Description: After moving the tools to test depth 2 m^3 of uranin tracered fresh water was circulated down the tubing. The packer was then inflated with water to 5500 kPa.
COM1 - The shut-in tool remained open for a 3.82 h compliance period. Fluid was flowing from the tubing at an average rate of 3E-2 l/min at the end of the phase, suggesting a static formation pressure above hydrostatic.
PSR1 - Once the temperature stabilised, the shut-in tool was closed for the PSR1 phase. Approximately 2.5 h into the period, a leak in the equipment above shut-in tool was suggested by the rising fluid level in the tubing.. The packer was deflated, the tools were brought to the surface and a leak was discovered in the stator. After replacement of the stator the tools were lowered to 9 m below the packer depth and the interval was flushed again with 2 m^3 of uranin tracered fresh water.
COM2 - After moving the tools to test depth and packer inflation the shut-in tool remained open for 2.19 h.
PSR2 - Once the temperature stabilised, the shut-in tool was closed for a 4.13 h PSR2 phase. In the latter part of PSR2, fluid was swabbed down to ca. 75 m aBH below the top of the tubing in preparation for PW1.
PW1 - The shut-in tool was opened briefly and the pressure fell approximately 675 kPa. In the next 2.64 h of PW1 the recovery was nearly 100 %.
SW - The shut-in tool was then opened for a 1.94 h SW period. The P2 readings indicated very little inflow but the PTX transducer response suggested gas flow, i.e. increrasing pressure from gas rising in the tubing and then falling off after gas escapes from the fluid.
SWS - The shut-in tool was then closed for a 5.27 h in which the pressure recovered to within 15 kPa of the end pressure of PSR2.
PW2 - A second pulse withdrawal (PW2) was then conducted, with a recovery of 97 % over 3.03 h. The PTX showed gas escaping the interval during PW2.
PI1 - A pulse injection period (PI1) was then performed by overpressurising the tubing with 900 kPa and then briefly opening the shut-in tool. The pressure recovered 77 % of the imposed 721 kPa overpressure in 6.38 h. The main purpose of the pulse injection was to completely release any gas accumulated in the test interval.
RI - After the pulse injection period the shut-in tool was opened and an injection phase was started at a rate of 0.06 l/min. The pressure response was unusual. After a small decrease in pressure, due to the pressure in the tubing being just below the interval pressure, the interval pressure increased sharply before 'flattening out' and showing a steady increase for most of the remainder of the period. In late time the pressure started to increase sharply, and the phase was shotly thereafter terminated to avoid 'fracing' the formation.
RIS - The subsequent RIS period lasted 14.85 h, during which sucker rods were lowered into the tubing in preparation for the RW.
RW - The RW period lasted 10.88 h with a total drawdown of over 2100 kPa. The average water flowrate was 0.14 l/min, but it was very erratic. Gas flow was detected after approximately 3.20 h and had an average rate of 18 l/min for the remainder of the period. As gas was reaching the surface in 'slugs' it was difficult to stabilise the separator conditions.
RWS & PI - The test was concluded with a 12.73 h RWS period and a 1.14 h PI2 phase.

Comments: All test objectives were achieved except it was not possible to collect water samples due to the small water production during the main pumping period. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively moderate interval transmissivity. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The injection phase shows a non-ideal response.

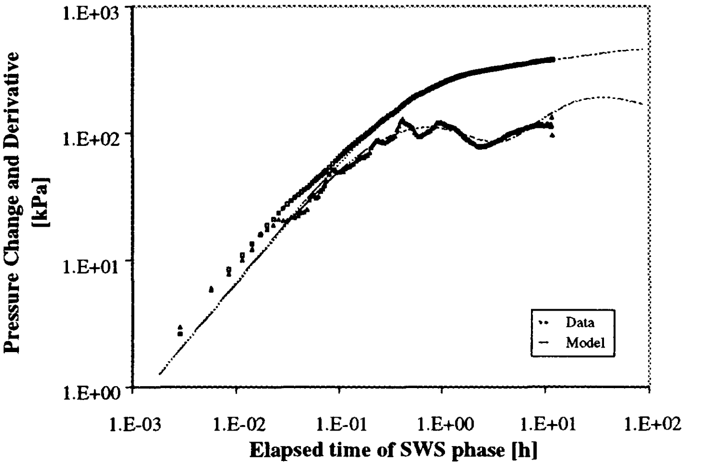
Packer configuration	Single Packer	
Date of test	31th of July to 4th of August 1995	
Test interval depth	512.62 to 532.60 m aBH 371.64 to 385.93 m bGL	measured true vertical
Test interval length (measured along the borehole)	19.98 m	
Borehole diameter	4 3/4" (= 0.124 m; nominal)	
Geology	512.62 - 532.60 m aBH VALANGINIAN - Marly clays and limestone marls with calcite veins (Palfris Formation)	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Characterisation of Gas Flow and Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	9.0E-09 m^2/s 2E-09 - 6E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	966 m asl 960 - 990 m asl	
Radius of investigation	6 m	
Stabilised temperature at downhole sensor depth	19.5 °C	
Recommended flow model	Wellbore Storage and Skin, Composite, Infinite Lateral Extent	
Factors affecting test analysis	Equipment, Temperature History, Gas	No Yes

BOREHOLE SB4a/s - INTERVAL VM7	447.0 - 532.6 m aBH/ 324.0 - 385.9 m bGL

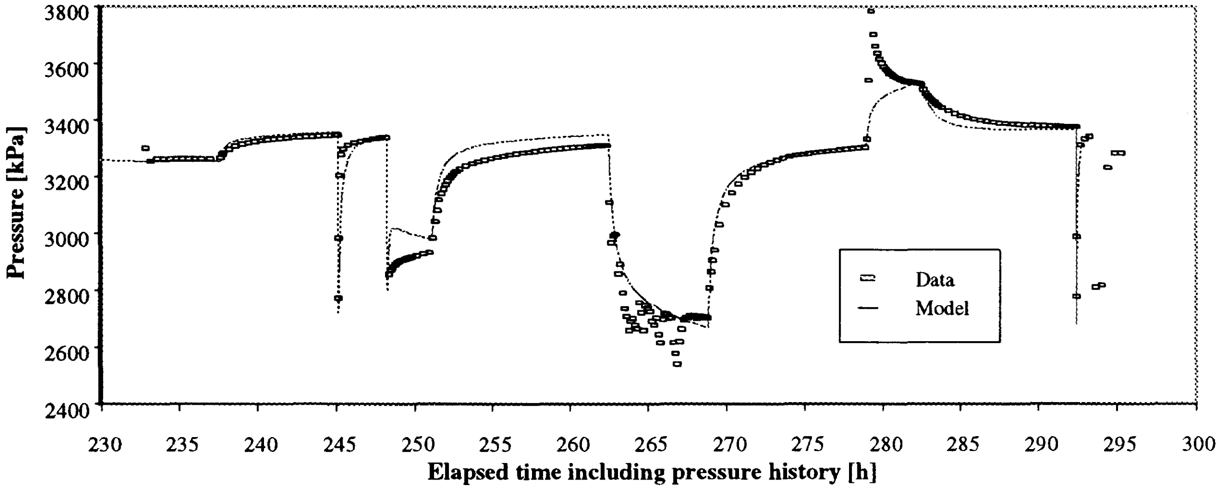


Pressures Measured During VM7

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM7	447.0 to 532.6 m aBH 324.0 to 385.9 m bGL	Reference: NIB 95-15B Standard Analysis

Test Sequence Description: After moving the tools to test depth 3 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen = 471 m aBH). The packer was then moved to testing depth and inflated to 6000 kPa with water.

COM - The shut-in tool remained open for a 4.53 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at an average rate of 4.4E-2 l/min, suggesting a static formation pressure above the hydrostatic.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 7.48 h PSR phase. In the PSR period, the pressure increased 86 kPa with a final pressure of 3348 kPa. In preparation for the subsequent PW1 phase, fluid was swabbed from the tubing to ca. 70 m aBH.

PW1 - Upon opening the shut-in tool, the pressure fell 578 kPa. The PW1 lasted 3.10 h and showed a normal recovery to a final pressure of 3338 kPa. A wellbore storage coefficient (C) of 7.3E-9 m^3/Pa was measured.

SW - The following SW period was initiated with a pressure difference of 504 kPa and recovered ca. 20% during the 2.88 h duration of the period. Gas flow was detected by the PTX measurements during the SW phase.

SWS - In the subsequent SWS phase the pressure recovered to 3311 kPa in 11.34 h, 31 kPa lower then the final pressure recorded during the PSR phase.

RW - The test was continued with a 6.30 h RW phase. An average water rate of 0.3 l/min and an average gas rate of 14 l/min were produced. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

RWS - The subsequent RWS phase lasted 10.09 h and recovered to a final pressure of 3303 kPa.

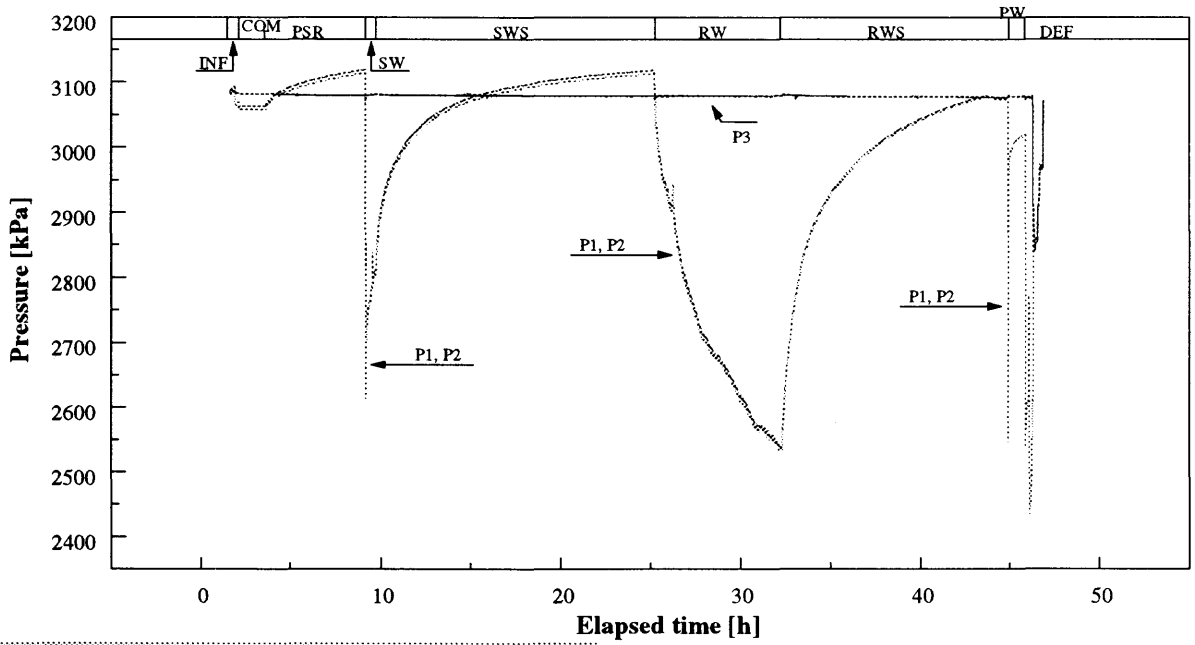
RI - The following constant rate injection phase was conducted at a rate of -0.1 l/min and lasted 3.62 h. The anomalous pressure response during the RI phase was probably caused by phase redistribution phenomena. Although the surface system and the test string were entirely degassed prior to start of phase, a large amount of gas escaped the tubing when releasing the pressure in the surface equipment at the end of the phase .

PW2 - The test was concluded with a 1.01 h pulse withdrawal phase (PW2), the recovery was 95 % of the total 632 kPa drawdown. A C-value of 1.1E-8 m^3/Pa was measured. However, this value should be reviewed with caution, because gas escaped the interval during the brief PW flow period.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent shut-in period is significantly impacted by gas flow. The injection phase shows a non-ideal response . The temperature at the P2 sensor depth increased by 2.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

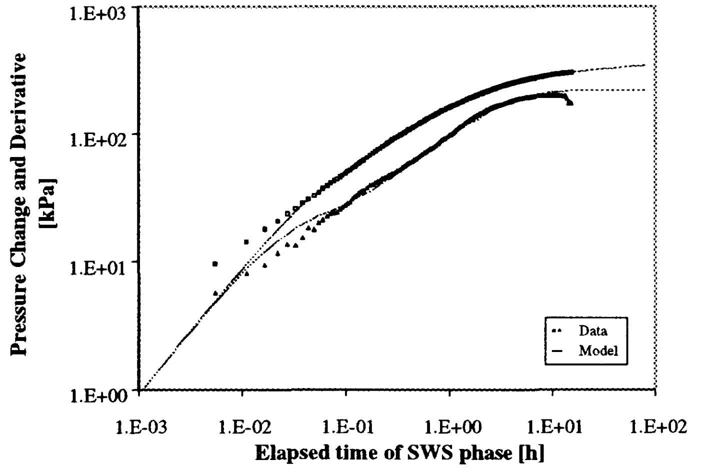
Packer configuration	Single Packer	
Date of test	4th to 7th August 1995	
Test interval depth	447.00 to 532.60 m aBH 324.00 to 385.93 m bGL	measured true vertical
Test interval length (measured along the borehole)	85.60 m	
Borehole diameter	4 3/4" (= 0.124 m; nominal)	
Geology	447.00 - 532.60 m aBH VALANGINIAN - Marly clays and limestone marls with calcite veins (Palfris Formation)	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	2.0E-08 m^2/s 1E-09 - 3E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	962 m asl 952 - 972 m asl	
Radius of investigation	8 m	
Stabilised temperature at downhole sensor depth	18.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/s - INTERVAL VM8 | **418.9 - 532.6 m aBH/ 303.3 - 385.9 m bGL**

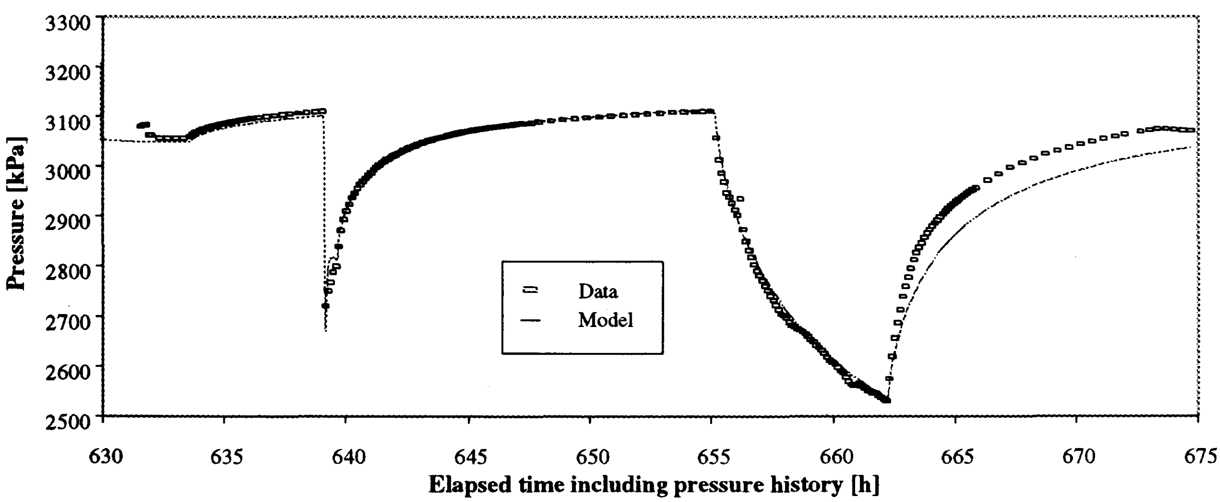


Pressures Measured During VM8

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM8	418.9 to 532.6 m aBH 303.3 to 385.9 m bGL	Reference: NIB 95-15B Standard Analysis

Test Sequence Description:

After moving the tools to VM7 test depth 3 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen = 448 m aBH). The shut-in tool was then closed, the packer was moved to the VM8 testing depth and inflated to 6000 kPa with water.

COM - The shut-in tool remained open for a 1.48 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at an average rate of 7E-2 l/min, suggesting a static formation pressure above the hydrostatic.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 5.53 h PSR phase. In the PSR period, the pressure increased 56 kPa with a final pressure of 3114 kPa. In preparation for the subsequent SW phase, fluid was swabbed from the tubing to ca. 67 m aBH.

SW - Upon opening the shut-in tool, the pressure fell 500 kPa. The SW lasted 0.56 h and recovered 39 % of the total pressure difference at the start. The PTX measurements showed gas escaping from the interval during the SW period.

SWS - In the subsequent SWS phase the pressure recovered to 3113 kPa in 15.51 h. In the latter part of the SWS period sucker rods were lowered into the tubing and flowmeters were function checked in preparation for the RW phase.

RW - The RW phase lasted 7.08 h with a total drawdown of 580 kPa. The average total flow was approximately 0.58 l/min but was erratic due to gas flow. The gas flow was first measured at the surface 0.7 h into the period, with an average rate of 20 l/min for the remainder of the period. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

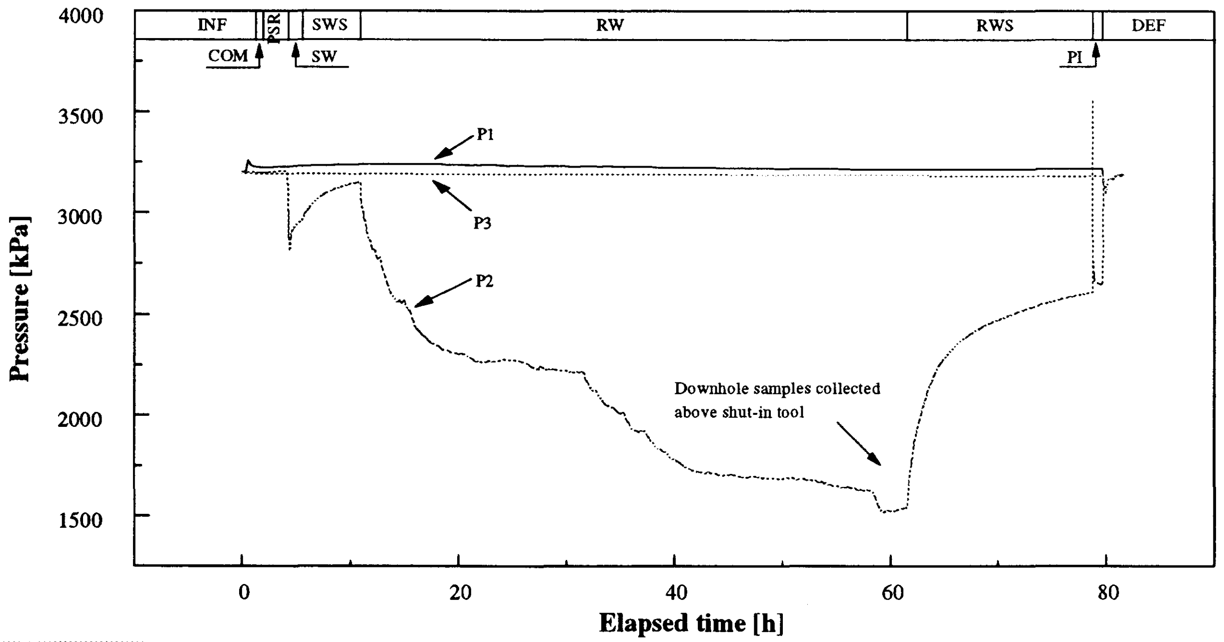
RWS - In the subsequent RWS phase, the pressure recovered from 2533 to 3073 kPa in 12.57 h. The recovery was normal until the final hour of the period when the pressure started to fall. No equipment problems could be attributed to this reaction. The cause of this response is uncertain, but may be related to free gas in the interval.

PW - The test was concluded with a 0.92 h PW phase. The PTX measurements showed gas escaping the interval while the shut-in tool was briefly opened.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. Gas flow was also observed during the SW phase. The temperature at the P2 sensor depth increased by 1.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

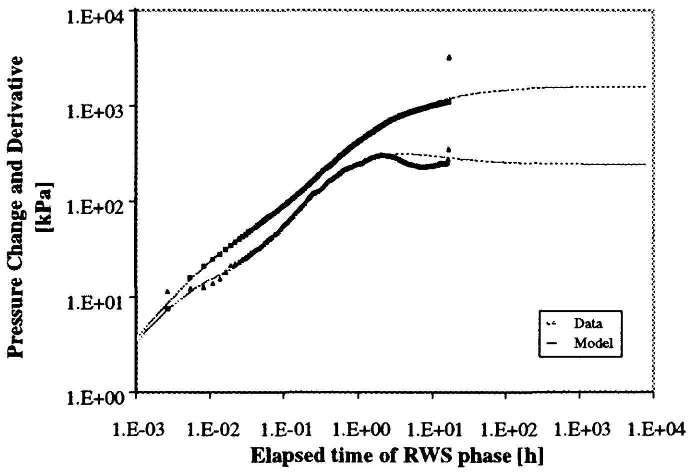
Packer configuration	Single Packer	
Date of test	7th to 9th August 1995	
Test interval depth	418.90 to 532.60 m aBH 303.28 to 385.93 m bGL	measured true vertical
Test interval length (measured along the borehole)	113.70 m	
Borehole diameter	4 3/4" (= 0.124 m; nominal)	
Geology	418.90 - 532.60 m aBH VALANGINIAN - Marly clays and limestone marls with calcite veins (Palfris Formation)	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	4.0E-08 m^2/s 1E-08 - 2E-07 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	955 m asl 930 - 970 m asl	
Radius of investigation	30 m	
Stabilised temperature at downhole sensor depth	17.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/s - INTERVAL VM9	437.5 - 443.7 m aBH/ 317.0 - 321.6 m bGL

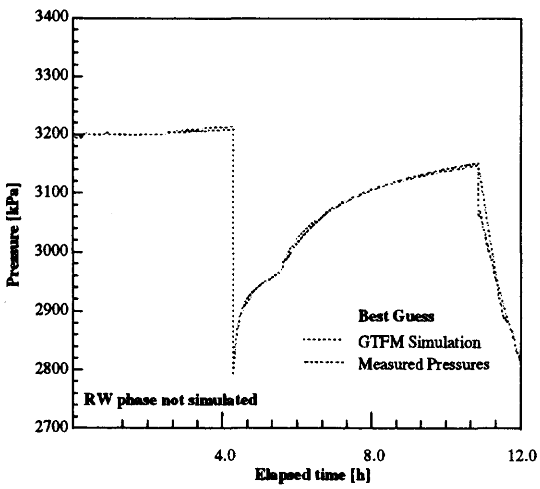


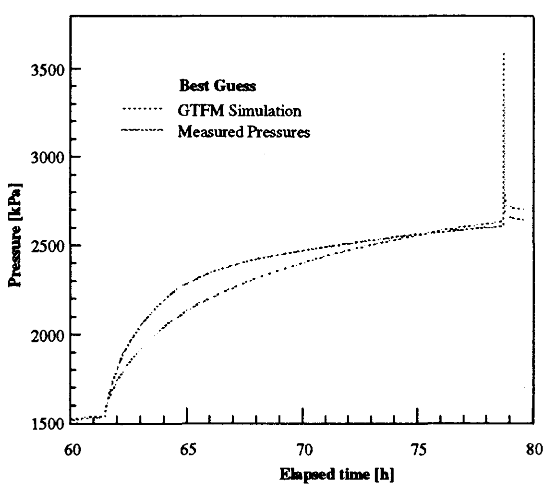
Pressures Measured During VM9

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS Phase)





Simulated (GTFM) Formation Response

TEST SUMMARY BOREHOLE SB4a/s VM9	437.5 to 443.7 m aBH 317.0 to 321.6 m bGL	Reference: NIB 95-15B Detailed Analysis

Test Sequence Description:

After moving the tools to test depth the packers were inflated to 6000 kPa with water. Contrary to normal practice, no flushing occurred because the density of fluid in the borehole was close to freshwater.

COM - The shut-in tool remained open for a 1.96 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was rising inside the tubing at an average rate of 4.6E-3 l/min.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 1.67 h PSR phase. There was a very small pressure increase of 8 kPa suggesting a static formation pressure just above ground level. In preparation for the subsequent SW phase, fluid was swabbed from the tubing to ca. 66 m aBH.

SW - Upon opening the shut-in tool, the pressure fell 418 kPa. The SW lasted 1.30 h and recovered 42 % of the total pressure difference at the start. The PTX measurements showed no indication of gas escaping from the interval during the period.

SWS - In the subsequent SWS phase the pressure recovered to 3148 kPa in 5.27 h, some 57 kPa below the final pressure of the PSR phase. In the latter part of the SWS period sucker rods were lowered into the tubing and flowmeters were function checked in preparation for the RW phase.

RW - The RW phase lasted 50.91 h with a total drawdown of 1604 kPa. The tracer content was monitored in the latter part of the phase to assess the amount of contamination from drilling activities. The average total flow was approximately 0.43 l/min but was erratic due to gas flow. The gas flow was first measured at the surface 1.8 h into the period, with an average rate of 13 l/min for the remainder of the period. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

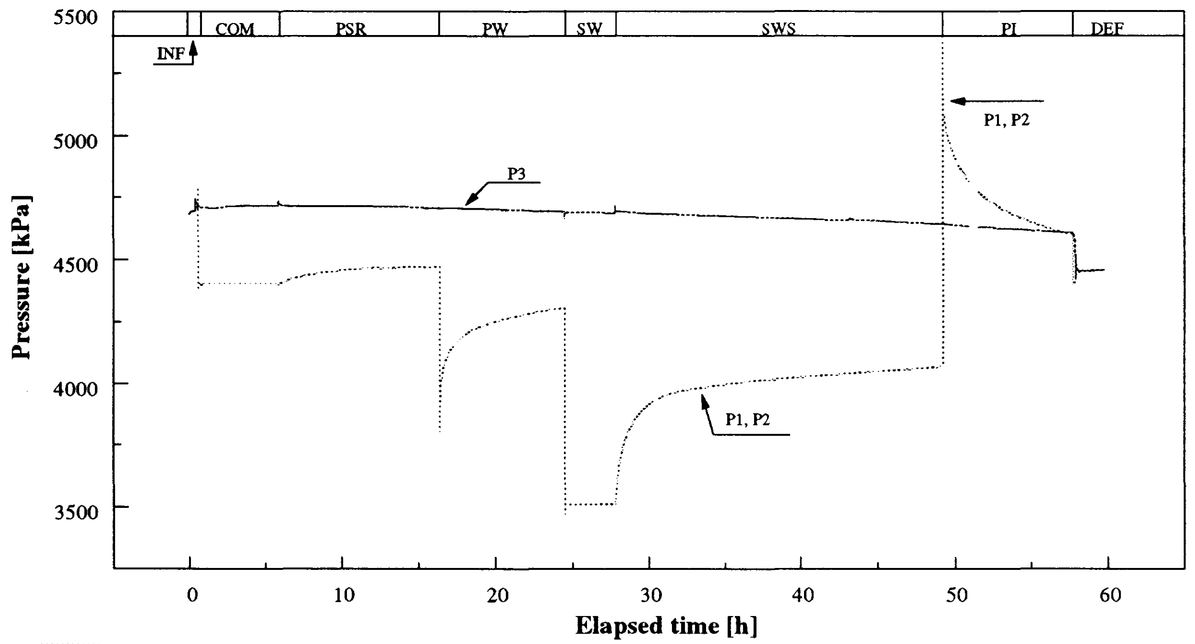
RWS - In the subsequent RWS phase, the pressure recovered from 1544 to 2607 kPa in 17.26 h, well below the end pressure of the previous shut-in periods. Downhole samples were collected above the shut-in tool in the early part of the period.

PI - The test was concluded with a 0.87 h PI phase to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively high interval transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The P1 pressure showed a sinusoidal response which was not correlated to the start of specific test events. The MULTIFIT/GTFM simulations showed that temperature changes do not influence the simulated pressures, as expected with such transmissivity range.

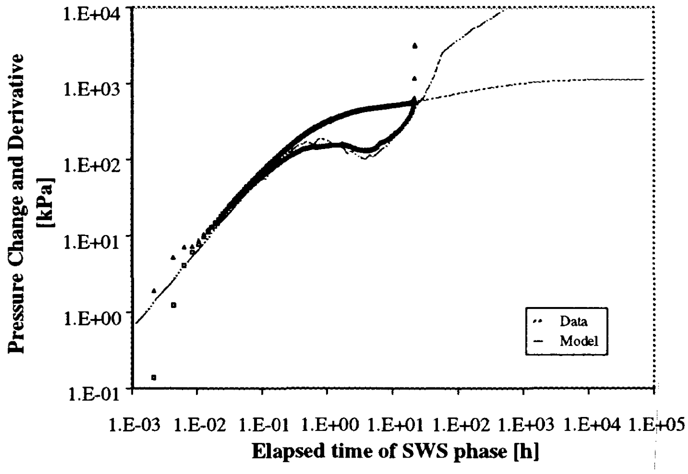
Packer configuration	Double Packers	
Date of test	11th to 14th August 1995	
Test interval depth	437.50 to 443.69 m a BH 317.01 to 321.56 m bGL	measured true vertical
Test interval length (measured along the borehole)	6.19 m	
Borehole diameter	4 3/4" (= 0.124 m; nominal)	
Geology	437.50 - 443.69 m aBH VALANGINIAN - Marly clays and limestone marls with calcite veins (Palfris Formation)	
Test objectives defined at start of test	Water Samples, Transmissivity, Equivalent Freshwater Head and Characterisation of Gas Flow	
Downhole fluid sampling	Yes (samples collected above shut-in tool during RWS)	
Best estimate of transmissivity Confidence interval of transmissivity	2.0E-08 m^2/s 6E-09 - 5E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	950 m asl 930 - 970 m asl	
Radius of investigation	70 m	
Stabilised temperature at downhole sensor depth	17.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No Yes

BOREHOLE SB4a/s - INTERVAL T1	609.7 - 617.3 m aBH/ 440.0 - 445.3 m bGL

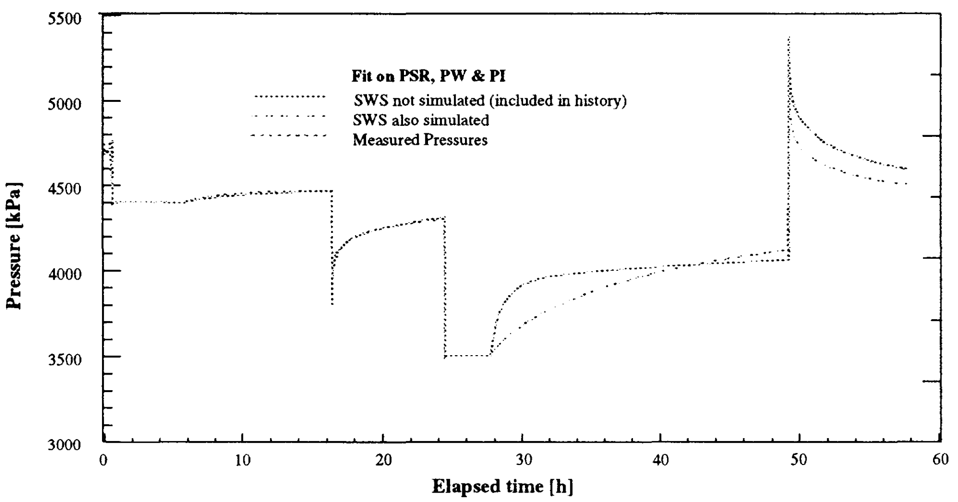


Pressures Measured During T1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Simulated (GTFM) Formation Response

TEST SUMMARY BOREHOLE SB4a/s T1	609.7 to 617.3 m aBH 440.0 to 445.3 m bGL	Reference: NIB 95-15D Standard Analysis

Test Sequence Description:

After moving the tools to 'flushing depth' (615 to 617 m aBH), 2 m^3 of uranin tracered freshwater was circulated down the tubing to displace mud from the test interval. At completion of flushing, the shut-in tool was closed and the tools were moved to T1 test depth.

COM - After the packer was inflated to 6500 kPa with water, the shut-in tool remained open for a 5.26 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining inside the tubing in the latter part of the phase at an average rate of -6.5E-4 l/min.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 10.52 h PSR phase. The pressure increased 69 kPa during this phase which is not consistent with the declining fluid level during the COM period. Additional anomalies during the PSR period were sharp decreases in pressures in late time and continual decline of fluid level inside tubing above the shut-in tool. There are two plausible scenarios for these responses. First, the rising pressures during the PSR period may be attributed to rising temperatures during the period. Even though the P2 temperature was relatively stable at the end of the COM period, the actual interval temperature may not have stabilised which has a big impact on the pressure due to the small interval and low permeability. Therefore, although the interval formation pressure is below ground level, the pressure increased during the PSR period due to increasing temperatures. The pressure rise after the COM phase with declining fluid may also be explained if gas was produced from the interval. The production of gas from the interval would result in declining fluid level in the tubing and also account for the continual decrease in fluid level after the shut-in tool was closed for the subsequent PSR period. In the latter part of the PSR phase, fluid was swabbed from tubing to a depth of ca. 128 m aBH in preparation for the SW period.

SW - The SW period lasted 3.29 h with less then 1 % recovery of the 797 kPa pressure difference at the start, indicating a low transmissivity for the interval.

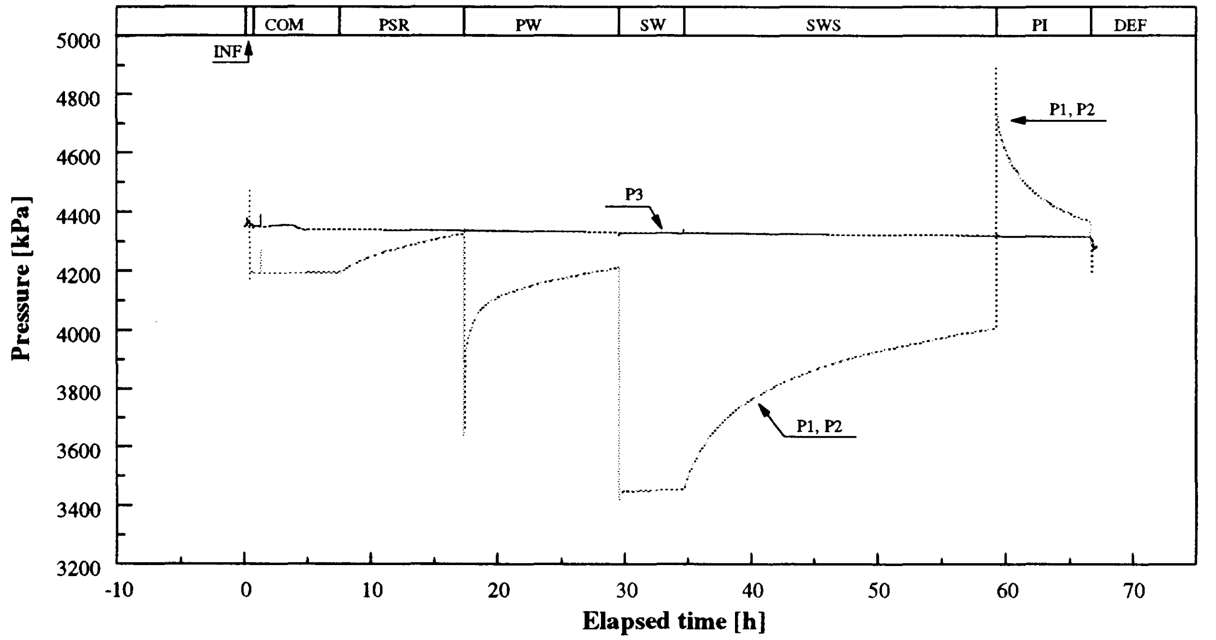
SWS - The subsequent SWS period lasted 21.47 h with a final pressure of 4069 kPa. Due to the low interval transmissivity, the pumping period planned prior to start of test was removed from the program.

PI - The test was concluded with a 8.50 h PI phase to obtain a physical measurement of the wellbore storage and evaluate the near wellbore hydraulic properties.

Comments: All test objectives were achieved except it was not possible to collect a representative water sample within a reasonable time period due to the relatively low transmissivity of the interval. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The MULTIFIT/GTFM analysis showed that the pressure data is only expected to be influenced by temperature variations during the PSR phase.

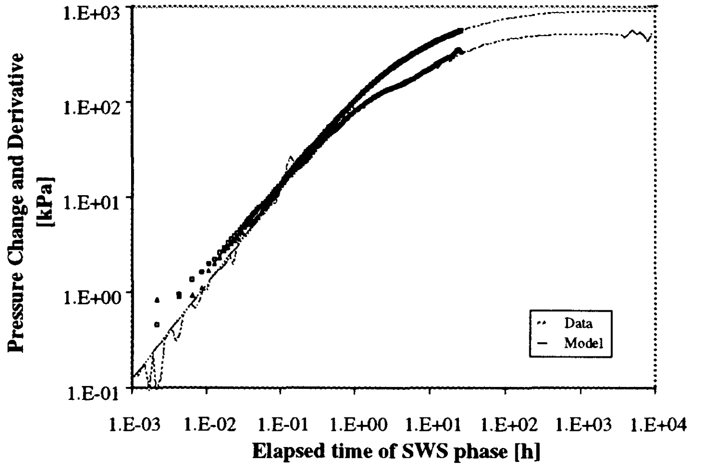
Packer configuration	Single Packer	
Date of test	21st - 24th August 1995	
Test interval depth	609.72 to 617.30 m aBH 440.04 to 445.27 m bGL	measured true vertical
Test interval length (measured along the borehole)	7.58 m	
Borehole diameter	0.124 m; nominal	
Geology	609.72 to 617.30 m aBH TERTIARY; Sandy Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.0E-11 m^2/s 4.0E-12 to 4.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	950 m asl 930 to 970 m asl	
Radius of investigation	4 m	
Stabilised temperature at downhole sensor depth	21.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/s - INTERVAL VMT1	579.0 - 617.3 m aBH/ 418.7 - 445.3 m bGL

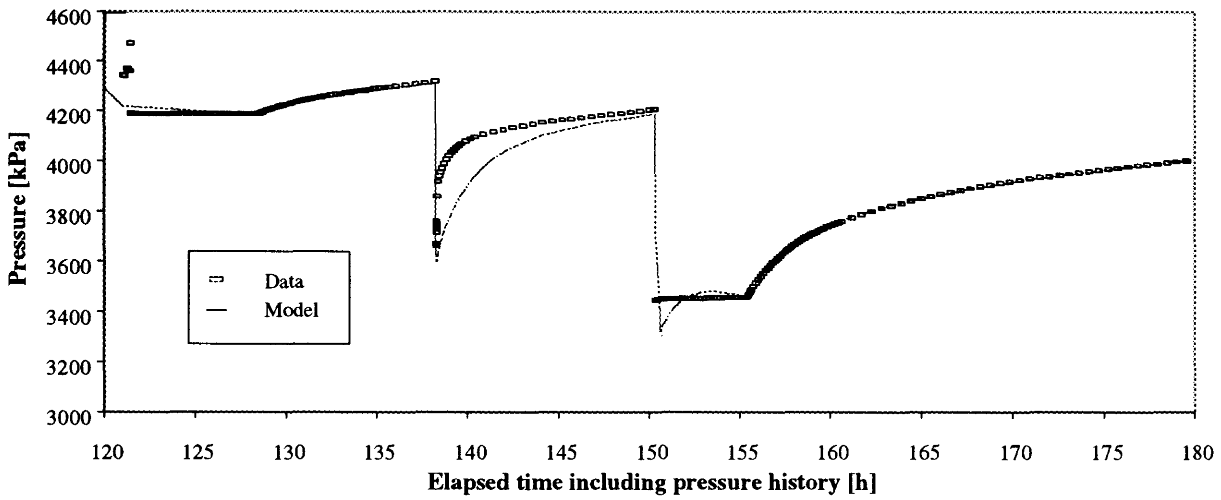


Pressures Measured During VMT1

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VMT1	579.0 to 617.3 m aBH 418.7 to 445.3 m bGL	Reference: NIB 95-15D Standard Analysis

Test Sequence Description:

After moving the tools to flushing depth 3 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 611 m aBH). The packer was then moved to testing depth and inflated to 6500 kPa with water.

COM - The shut-in tool remained open for a 7.15 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was rising in the tubing at an average rate of 4.6E-4 l/min, suggesting a static formation pressure above the hydrostatic.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 9.77 h PSR phase. In the PSR period, the pressure increased 133 kPa with a final pressure of 4325 kPa. In preparation for the subsequent PW phase, fluid was swabbed from the tubing to ca. 77 m aBH.

PW - The subsequent pulse phase lasted 12.14 h with a total recovery of 83 % of the total 664 kPa pressure difference at the start. The brief opening of shut-in for the pulse was longer then normal (2.7 min) due to equipment problems. In the latter part of the period, fluid was again swabbed from the tubing to ca. 110 m aBH in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 770 kPa. The SW lasted 5.12 h and showed no anomalies to suggest gas flow. The SW period recovered less then 2 %.

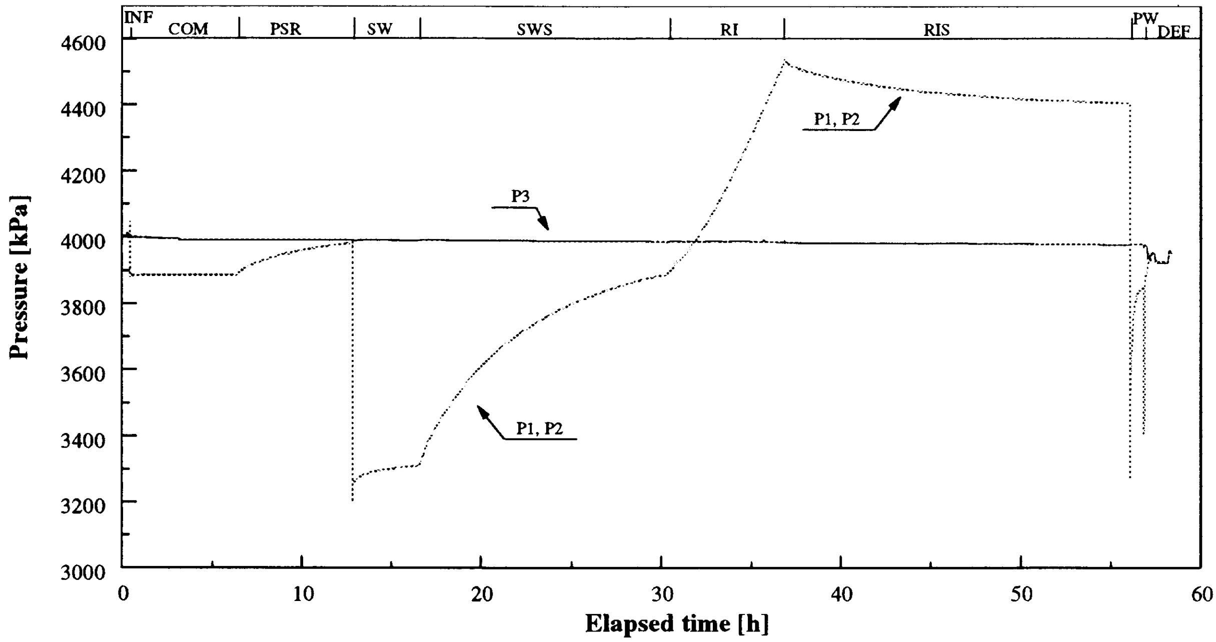
SWS - In the subsequent SWS phase the pressure recovered to 4005 kPa in 24.64 h, some 320 kPa lower then the final pressure recorded during the PSR phase.

PI - The test was concluded with a 7.38 h pulse injection phase. A wellbore storage coefficient (C) of 1.46E-9 m^3/Pa was measured which compares well to the C value measured during the earlier PW event, 1.20E-9 m^3/Pa.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the relatively moderate transmissivity and static formation pressure proximal to the hydrostatic conditions in the borehole. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The temperature at the P2 sensor depth increased by 1.8 °C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

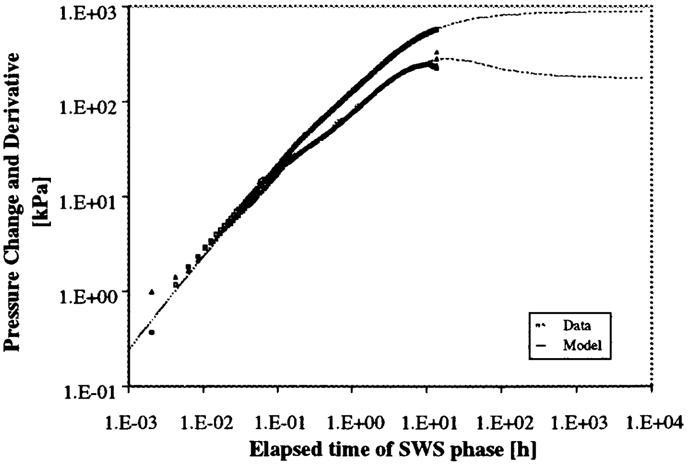
Packer configuration	Single Packer	
Date of test	24th to 27th August 1995	
Test interval depth	578.99 to 617.30 m aBH 418.69 to 445.27 m bGL	measured true vertical
Test interval length (measured along the borehole)	38.31 m	
Borehole diameter	0.124 m; nominal	
Geology	578.99 to 591.11 m aBH VALANGINIAN; Clayey and calcareous Marls 591.11 to 617.30 m aBH TERTIARY; Sandy Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-11 m^2/s 1.0E-11 to 3.0E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	960 m asl 940 to 1040 m asl	
Radius of investigation	2 m	
Stabilised temperature at downhole sensor depth	21.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

BOREHOLE SB4a/s - INTERVAL VMT2	534.3 - 617.3 m aBH/ 387.1 - 445.3 m bGL

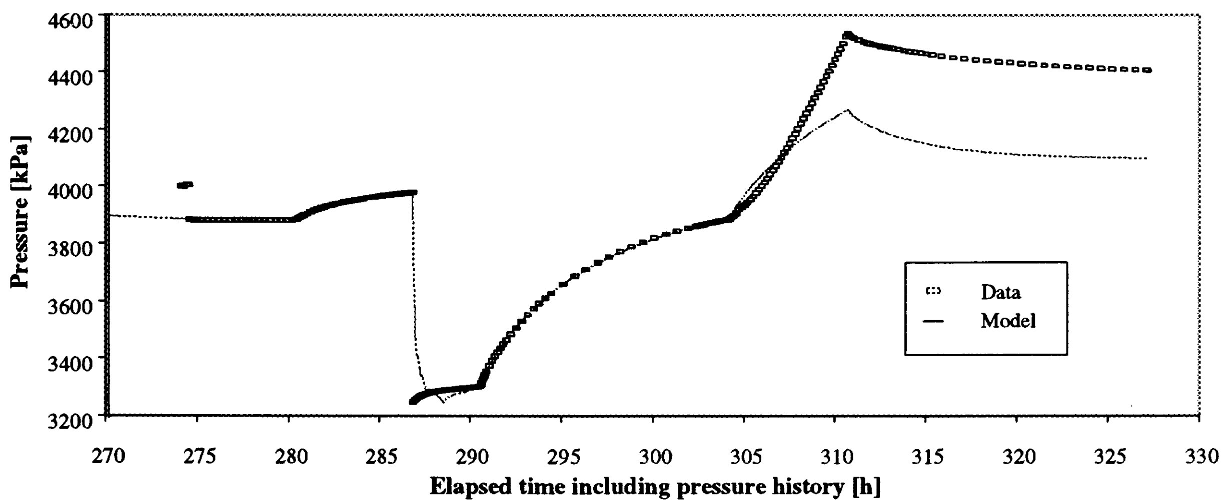


Pressures Measured During VMT2

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VMT2	534.3 to 617.3 m aBH 387.1 to 445.3 m bGL	Reference: NIB 95-15D Standard Analysis

Test Sequence Description:

After moving the tools to flushing depth 3 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 571 m aBH). The packer was then moved to testing depth and inflated to 6500 kPa with water.

COM - The shut-in tool remained open for a 5.83 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at an average rate of 2E-3 l/min, suggesting a static formation pressure above the hydrostatic.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 6.50 h PSR phase. In the PSR period, the pressure increased 95 kPa with a final pressure of 3980 kPa. In preparation for the subsequent SW phase, fluid was swabbed from the tubing to ca. 93 m aBH.

SW - Upon opening the shut-in tool, the pressure fell 729 kPa. The SW lasted 3.77 h and showed a normal recovery to a final pressure of 3309 kPa. The SW period recovered less then 10% of the initial pressure difference.

SWS - In the subsequent SWS phase the pressure recovered to 3887 kPa in 13.70 h, 93 kPa lower then the final pressure recorded during the PSR phase. At this time point in the test it was realised that the formation transmissivity was considerably lower than expected and the plan of conducting a constant rate withdrawal phase was discarded due to hardware limitations. It was decided to conduct a constant rate injection phase with final shut-in instead.

RI - The RI phase lasted 6.56 h and the injection rate was kept constant at -2e-2 l/min using an HPLC Schimadzu pump. The pressure response during the RI phase was atypical.

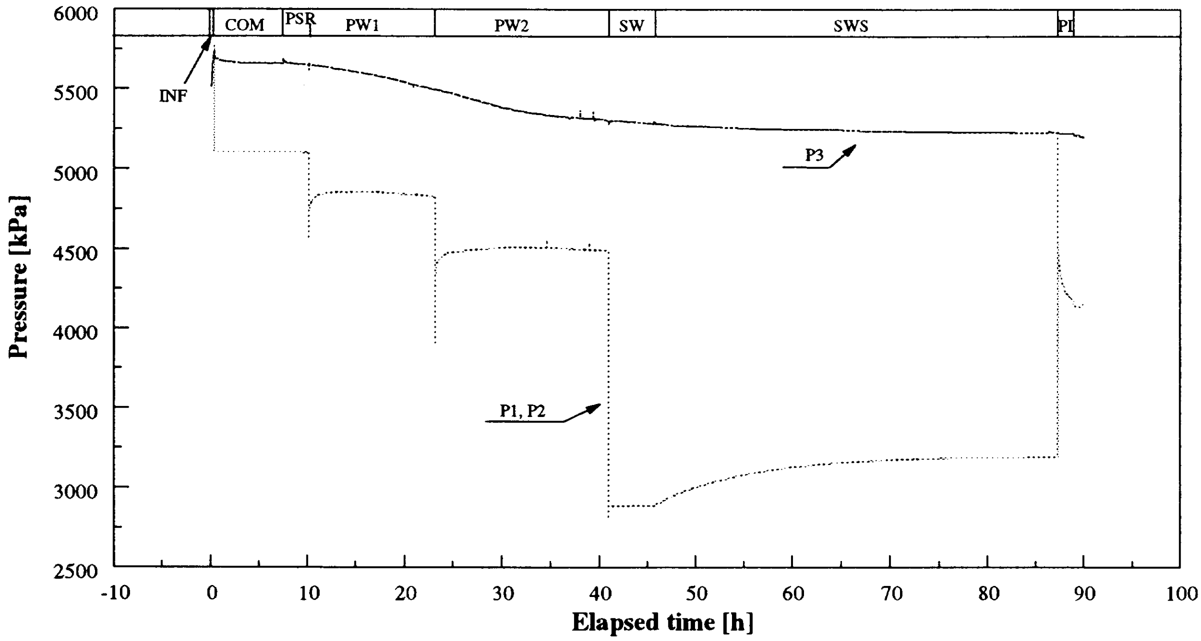
RIS - The subsequent RIS phase lasted 19.22 h and showed very little recovery (135 kPa) to a final pressure of 4404 kPa.

PW - The test was concluded with a 0.76 h pulse withdrawal phase. A wellbore storage value of 3.8E-9 m^3/Pa was measured.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were minimal due to the moderate transmissivity. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The injection phase shows a non-ideal response and may be attributed to stress effects on fractures connected to the borehole due to varying pressure conditions or 'plugging' and 'unplugging' of fractures from sediment carried in suspension with the fluid injected into the formation. The temperature at the P2 sensor depth increased by 1.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

Packer configuration	Single Packer	
Date of test	27th to 29th September 1995	
Test interval depth	534.26 to 617.30 m aBH 387.11 to 445.27 m bGL	measured true vertical
Test interval length (measured along the borehole)	83.04 m	
Borehole diameter	0.124 m; nominal	
Geology	534.26 to 591.11 m aBH VALANGINIAN; Clayey and calcareous Marls 591.11 to 617.30 m aBH TERTIARY; Sandy Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Characterisation of Gas Flow	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	2.0E-9 m^2/s 1.0E-9 to 7.0E-9 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	965 m asl 950 m to 1000 m asl	
Radius of investigation	7 m	
Stabilised temperature at downhole sensor depth	20 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

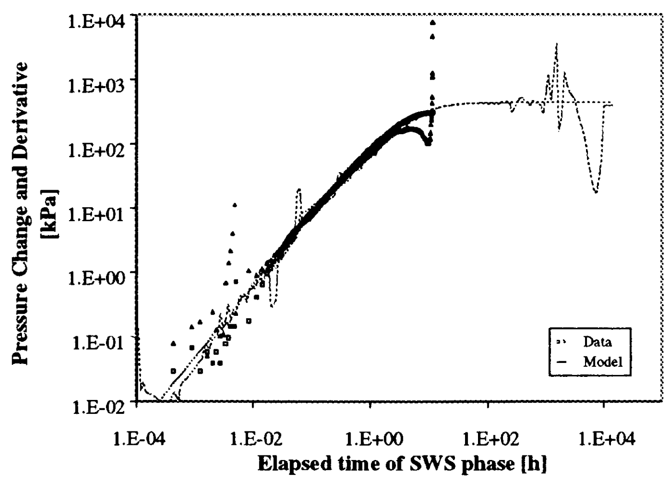
BOREHOLE SB4a/s - INTERVAL T2	715.0 - 740.0 m aBH/ 511.9 - 528.9 m bGL



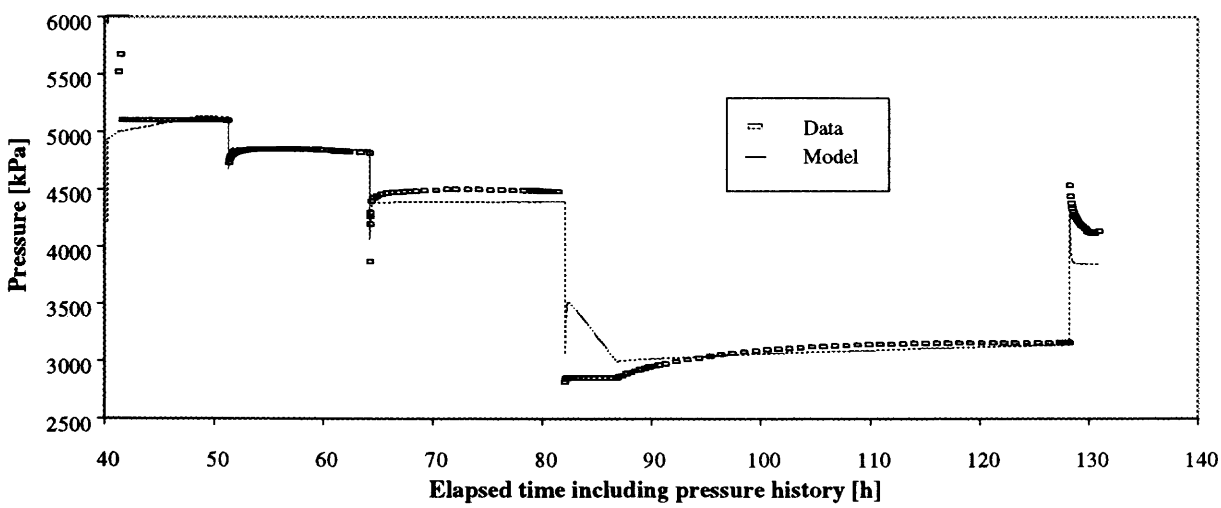
Pressures Measured During T2

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent

Rem.: Composite Model Recommended for Entire Test Response Based on Additional Analysis



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s T2	715.0 to 740.0 m aBH 511.9 to 528.9 m bGL	Reference: NIB 95-15C Standard Analysis

Test Sequence Description:

After moving the tools to flushing depth 2.5 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 734 m aBH). The packer was then moved to testing depth and inflated to 7500 kPa with water.

COM - The shut-in tool remained open for a 7.15 compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. However, there was no measurable change in the fluid level.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 2.59 h PSR phase. In the PSR period, the pressure initially increased about 0.5 kPa before swabbing activities resulted in a sharp 2 kPa pressure drop off. Fluid was swabbed from the tubing to ca. 77 m aBH in preparation for the PW phase.

PW1 & 2 - At the end of the period, the pressure showed a declining trend. The subsequent PW1 period lasted 13.04 h. Because the pressure 'rolled over' (change in pressure gradient), it was decided to perform a second pulse with a larger drawdown. In preparation for PW2, fluid was swabbed from the tubing to ca. 170 m aBH. The second pulse phase was 17.83 h and also showed a 'rolled over'. The end pressure of this period was 4488 kPa, equivalent freshwater head of 880 m asl, which is an upper bound for the static formation pressure due to the 'roll over'. At the end of the period, fluid was once again swabbed to ca. 350 m aBH, below the expected formation pressure, in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 1608 kPa. The SW period lasted 4.74 h and showed less then 1 % recovery indicating a low interval transmissivity.

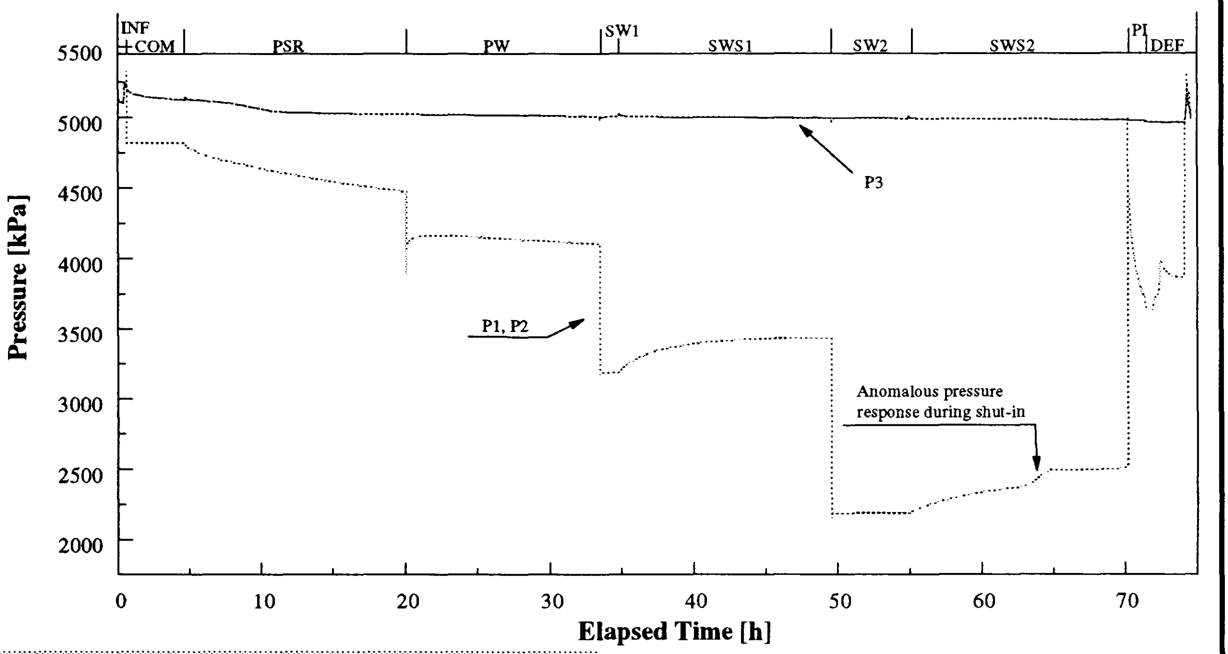
SWS - In the subsequent SWS phase the pressure recovered to 3188 kPa in 41.56 h. The pressure recovery rate was very small in late time and the period was extended to see if the pressure would 'roll over'. However, the pressure continued to rise at less then 1 kPa per hour.

PI - In the late stages of the SWS period, the tubing was filled with tracered water and test was concluded with a 1.60 h pulse injection phase. The measured wellbore storage coefficients in the 3 pulse phases were very consistent and range between 9.9E-10 m^3/Pa and 1.53E-9 m^3/Pa.

Comments: All test objectives were achieved except it was not possible to collect a representative water sample within a reasonable time period due to the relatively low transmissivity of the interval. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and 'roll overs' in pressure due to the influences of borehole history. The temperature at the P2 sensor depth increased by 2.3°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

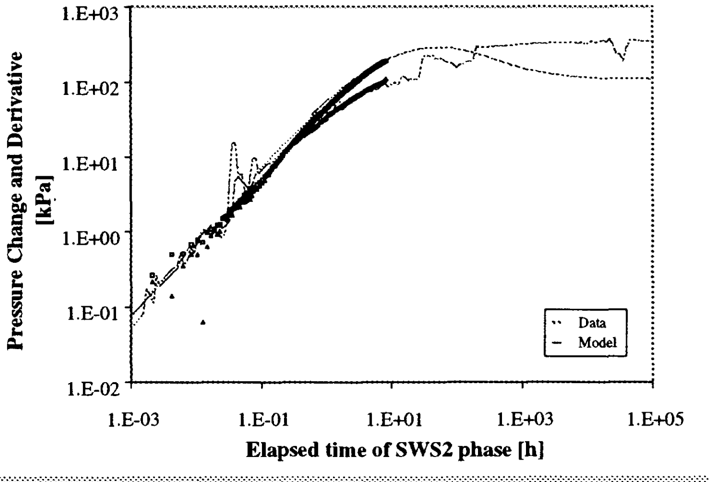
Packer configuration	Single Packer	
Date of test	10th - 13th September 1995	
Test interval depth	715.00 to 740.00 m aBH 511.92 to 528.86 m bGL	measured true vertical
Test interval length (measured along the borehole)	25.00 m	
Borehole diameter	0.124 m; nominal	
Geology	715.00 to 740.00 m aBH TERTIARY; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Water Samples	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-11 m^2/s 1.0E-12 to 6.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	660 m asl 600 to 750 m asl	
Radius of investigation	2 m	
Stabilised temperature at downhole sensor depth	24.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

BOREHOLE SB4a/s - INTERVAL T3	672.7 - 740.0 m aBH/ 483.2 - 528.9 m bGL

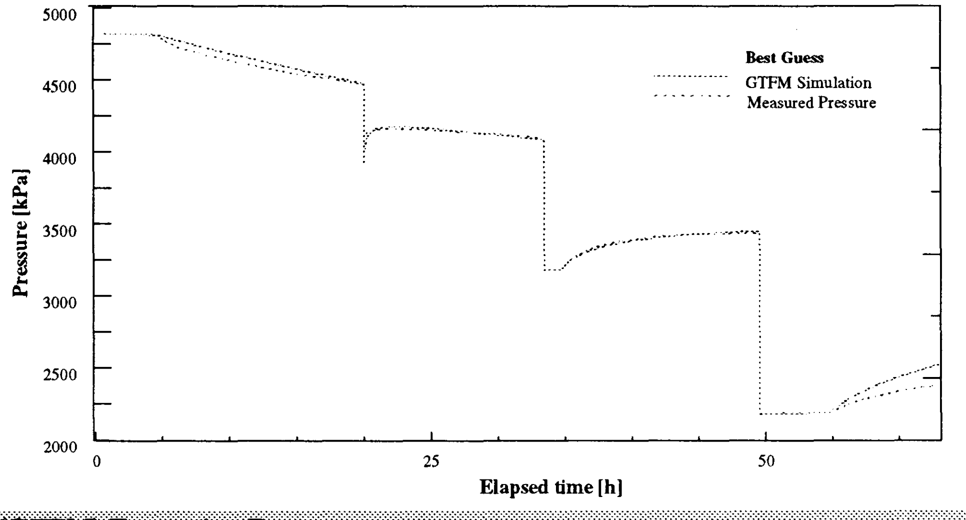


Pressures Measured During T3

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS2 Phase prior to anomaly)



Simulated (GTFM) Formation Response

TEST SUMMARY BOREHOLE SB4a/s T3	672.7 to 740.0 m aBH 483.2 to 528.9 m bGL	Reference: NIB 95-15C Standard Analysis

Test Sequence Description: After deflating the packer for test T2, 1 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 716 m aBH). The packer was then moved to T3 testing depth and inflated to 7500 kPa with water.

COM - The shut-in tool remained open for a 4.04 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. The fluid level was declining at an equivalent rate of - 2.30E-3 l/min.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 15.30 h PSR phase. The pressure drooped 344 kPa indicating a static formation pressure below the hydrostatic conditions of the borehole. In the later stages of the PSR period, fluid was swabbed from the tubing to ca. 132 m aBH in preparation for the PW phase.

PW - The subsequent PW period lasted 13.44 h. Since the pressure showed a declining trend in late time, the final pressure is an upper bound for the static formation pressure (4099 kPa; freshwater Head 870 m asl). At the end of the period, fluid was once again swabbed to ca. 225 m aBH in preparation for the SW phase.

SW1 - Upon opening the shut-in tool, the pressure fell 916 kPa. The SW1 period lasted 1.36 h and showed a total recovery of 1.2 kPa indicating a low interval transmissivity.

SWS1 - In the subsequent SWS1 phase the pressure recovered to 3435 kPa in 14.75 h. The pressure recovery was very small in late time and it was possible that, given sufficient time, the recovery would show a 'roll over' indicating a static formation pressure below the measured pressure. Therefore, it was decided to perform a second SW-SWS sequence with a larger pressure difference at the start to ensure the drawdown would be below the expected static formation pressure. It was also planned for a relatively long SWS period to 'see' far into the formation without complications from a 'roll over' (change in pressure gradient).

SW2 - Upon opening the shut-in tool, the pressure fell 1250 kPa. The SW2 period lasted 5.32 h and showed a total recovery of 4 kPa.

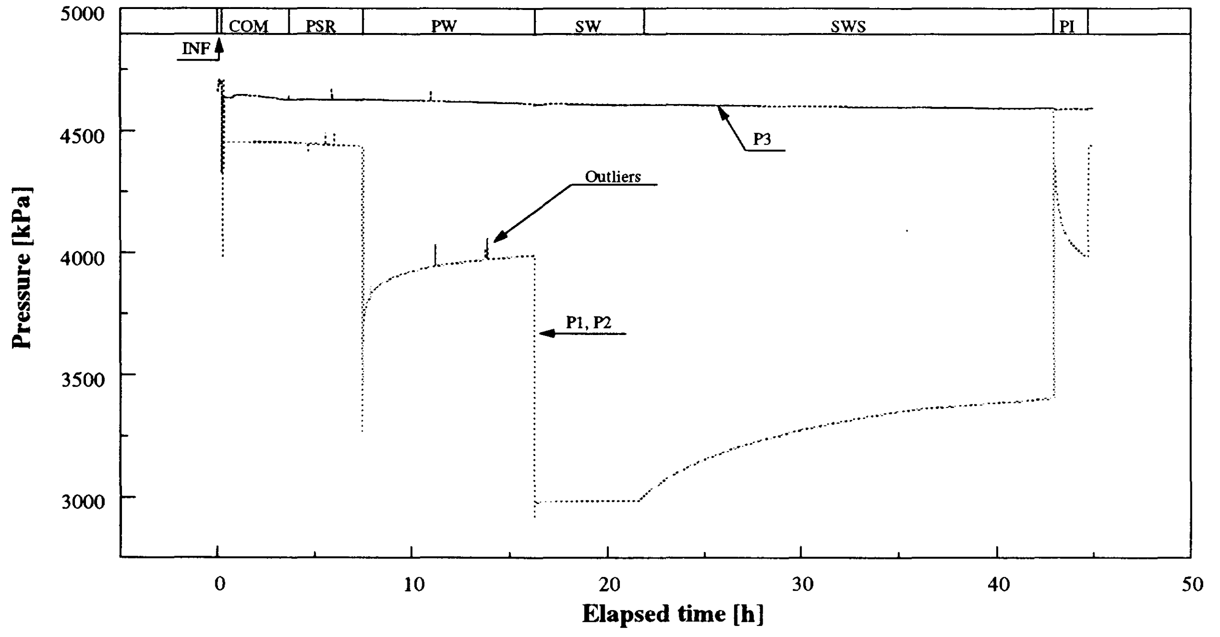
SWS2 - In the subsequent SWS2 phase the pressure recovered to 2376 kPa before showing an anomalous rise in pressure and then flattening off but slowly increasing. The equipment check showed no problems and the response may be attributed to an intermittent connection to the annulus through a diffuse fracture network, although there is no direct evidence.

PI - In the late stages of the SWS2 period, the tubing was filled with tracered water and test was concluded with a 1.21 h pulse injection phase. The measured wellbore storage coefficient (C) from this phase was 1.08E-9 m^3/kPa and compares with the C-value of 1.50 E-9 m^3/kPa measured in the earlier PW phase and the theoretical value of 1.69E-9 m^3/kPa.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and 'roll overs' (change in pressure gradient) in pressure due to the influences of borehole history. The MULTIFIT/GTFM simulations showed that the effect of temperature variation on the test response was insignificant.

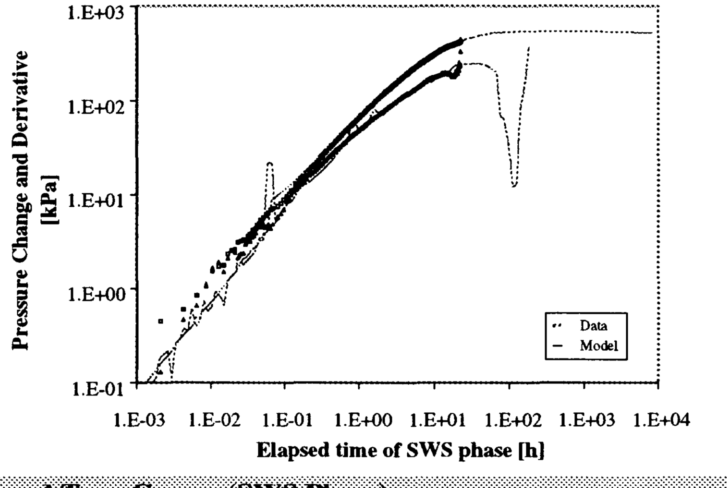
Packer configuration	Single Packer	
Date of test	13th to 16th September 1995	
Test interval depth	672.70 to 740.00 m aBH 483.18 to 528.86 m bGL	measured true vertical
Test interval length (measured along the borehole)	67.30 m	
Borehole diameter	0.124 m; nominal	
Geology	672.70 to 740.00 m aBH TERTIARY; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-11 m^2/s 6.0E-12 to 6.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	660 m asl 600 to 750 m asl	
Radius of investigation	1 m	
Stabilised temperature at downhole sensor depth	23 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

BOREHOLE SB4a/s - INTERVAL T4	617.1 - 740.0 m aBH/ 445.1 - 528.9 m bGL

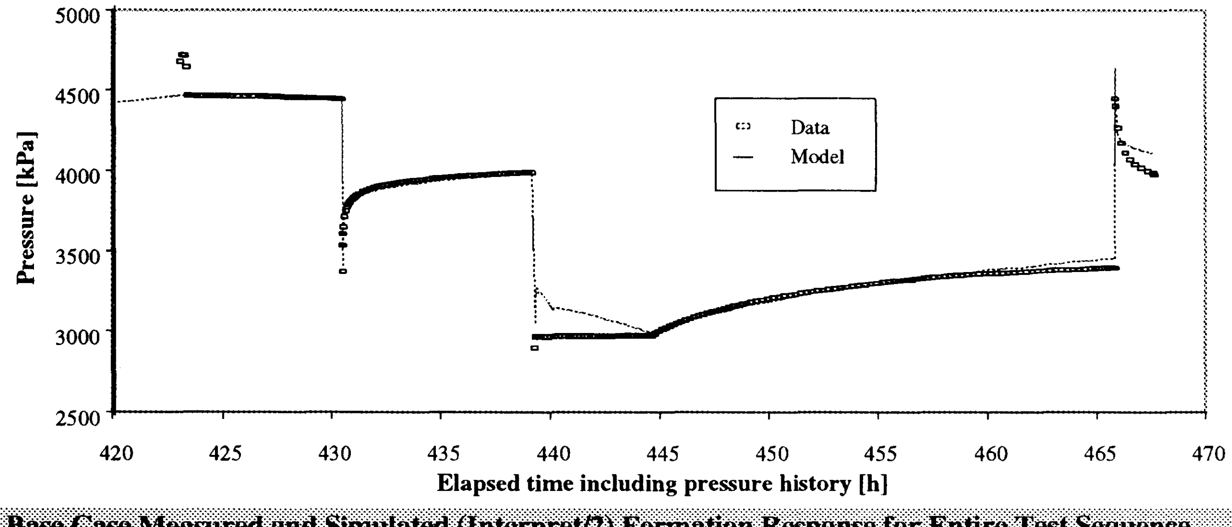


Pressures Measured During T4

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s T4	617.1 to 740.0 m aBH 445.1 to 528.9 m bGL	Reference: NIB 95-15C Standard Analysis

Test Sequence Description:

After deflating the packer for test T3, 2.5 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 748 m aBH). The packer was then moved to T4 testing depth and inflated to 7500 kPa with water.

COM - The shut-in tool remained open for a 3.35 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. However, there was no measurable change in the fluid level.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 3.79 h PSR phase. In the PSR period, the pressure decreased a total of 17 kPa indicating a static formation pressure below the hydrostatic conditions of the borehole. Fluid was swabbed from the tubing to ca. 155 m aBH in preparation for the PW phase.

PW - The subsequent PW period lasted 8.79 h. At the end of the period, fluid was once again swabbed to ca. 225 m aBH, below the expected formation pressure, in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 1017 kPa. The SW period lasted 5.38 h and showed a total recovery of 15 kPa indicating a low interval transmissivity.

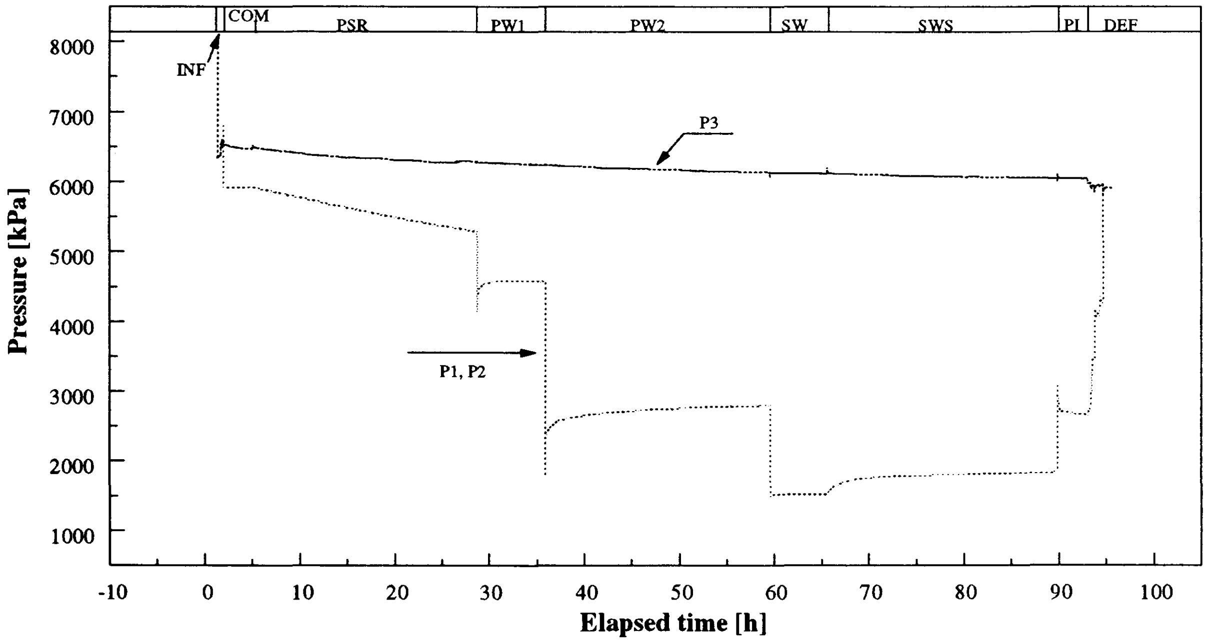
SWS - In the subsequent SWS phase the pressure recovered to 3403 kPa in 21.27 h.

PI - In the late stages of the SWS period, the tubing was filled with tracered water and test was concluded with a 1.76 h pulse injection phase. The measured wellbore storage coefficient (C) from this phase was 1.73E-9 m^3/kPa and compares well with the C-value of 1.56 E-9 m^3/kPa measured in the earlier PW phase and the theoretical value of 2.97E-9 m^3/kPa.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects. The MULTIFIT/GTFM simulations showed that temperature variations has a small effect on pressure response during PSR and PW phases and negligible impact for the remainder of the test.

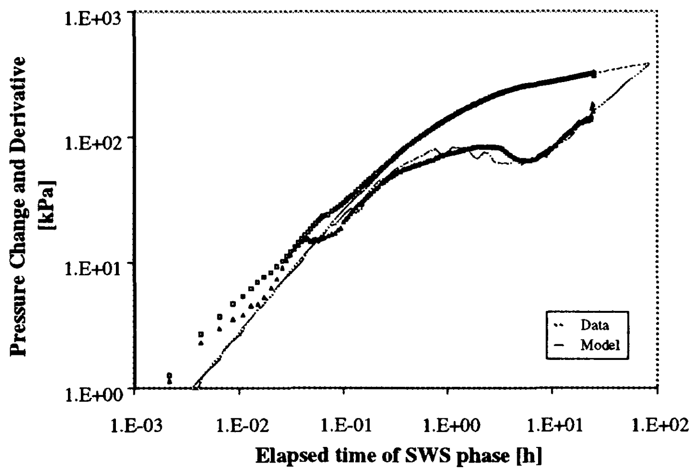
Packer configuration	Single Packer	
Date of test	17th to 19th September 1995	
Test interval depth	617.11 to 740.00 m aBH 445.14 to 528.86 m bGL	measured true vertical
Test interval length (measured along the borehole)	122.89 m	
Borehole diameter	0.124 m; nominal	
Geology	617.11 to 740.00 m aBH TERTIARY; Clay & Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	7.0E-11 m^2/s 1.0E-11 to 1.0E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	750 m asl 700 m to 850 m asl	
Radius of investigation	1 m	
Stabilised temperature at downhole sensor depth	21.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes No No

BOREHOLE SB4a/s - INTERVAL VM10	837.4 - 858.2 m aBH/ 595.4 - 609.6 m bGL

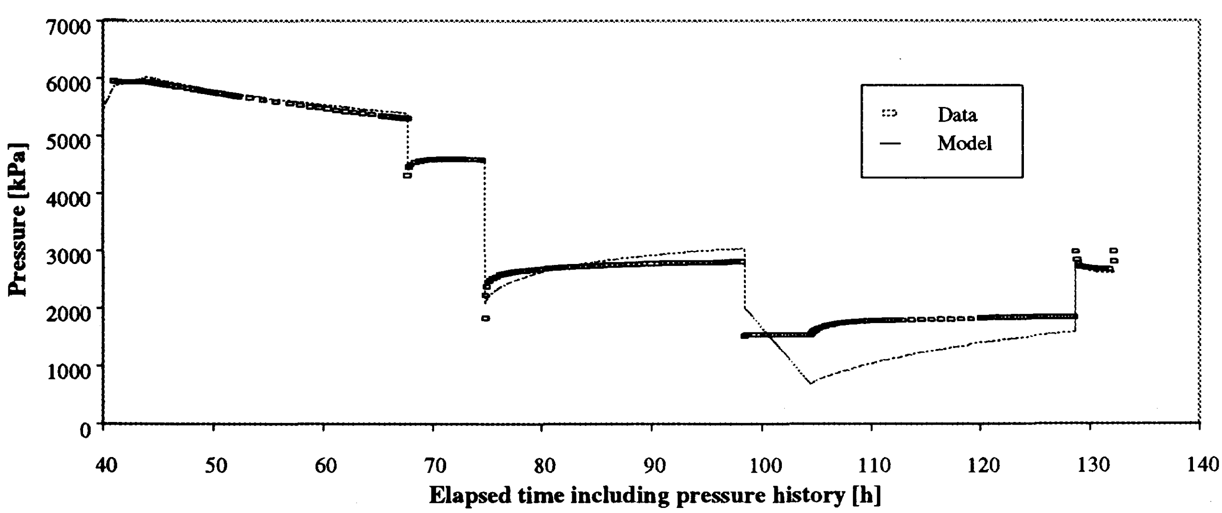


Pressures Measured During VM10

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM10	837.4 to 858.2 m aBH 595.4 to 609.6 m bGL	Reference: NIB 95-15E Standard Analysis

Test Sequence Description:

After moving the tools to flushing depth 2 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 851 m aBH). The packer was then moved to testing depth and inflated to 8000 kPa with water.

COM - The shut-in tool remained open for a 3.06 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining in the tubing at an equivalent rate of -4.16E-4 l/min, confirming a static formation pressure below the hydrostatic conditions in the borehole.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 23.71 h PSR phase. In the PSR period, the pressure decreased 641 kPa with a final pressure of 5284 kPa. In preparation for the subsequent PW1 phase, fluid was swabbed from the tubing to ca. 245 m aBH.

PW1 - The PW1 period lasted 7.17 h and showed a 'roll over' (change in pressure gradient) indicating that the static formation pressure was below the measured pressure (4568 kPa; equivalent freshwater Head 801 m asl). In the latter part of PW1, fluid was swabbed from the tubing to ca. 550 m asl in preparation for PW2.

PW2 - The PW2 period was 23.63 h in duration and showed no 'roll over'. However, a 'roll over' could not be excluded if the period was not terminated due to the low transmissivity of the outer zone but it was concluded that the measured pressure was in the vicinity of the static formation pressure. It was then decided to proceed to the SW-SWS sequence. Fluid was once again swabbed from the tubing to ca. 625 m aBH.

SW - Upon opening the shut-in tool, the pressure fell 1290 kPa. The SW period lasted 6.05 h and showed a recovery of 10 kPa. In the initial 5 min the pressure recovered 7 kPa and then showed a much smaller rate of recovery.

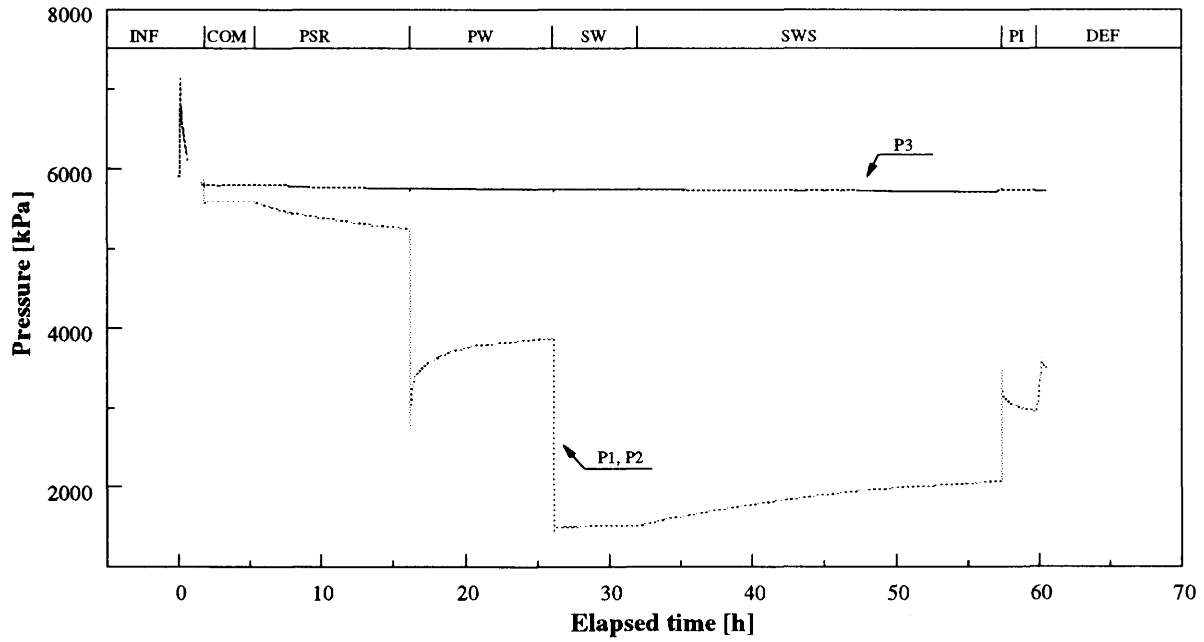
SWS - In the subsequent SWS phase the pressure recovered to 1837 kPa in 24.31 h.

PI - The test was concluded with a 3.12 h PI period. The measured wellbore storage values (C) in the test, 1.27 E-9 m^3/Pa (PW1) and 3.17E-9 m^3/Pa (PI), show good agreement and roughly an half an order of magnitude larger then the theoretical value. There was no measurements for C value in the PW2 period due limitations of the equipment.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The temperature at the P2 sensor depth increased by 2.0°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

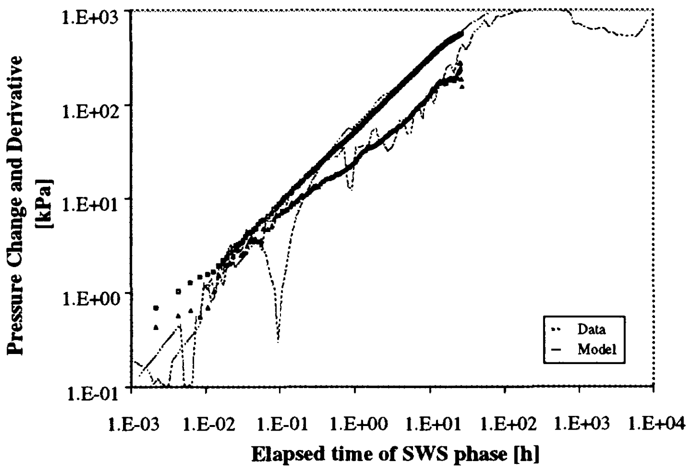
Packer configuration	Single Packer	
Date of test	28th September - 2nd October 1995	
Test interval depth	837.41 to 858.20 m aBH 595.36 to 609.56 m bGL	measured true vertical
Test interval length (measured along the borehole)	20.79 m	
Borehole diameter	0.124 m; nominal	
Geology	837.41 to 858.20 m aBH LOWER CRETACEOUS - Valanginian; Palfris Formation; Clay and Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	2.0E-12 m^2/s 1.0E-12 to 1.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	470 m asl 420 to 620 m asl	
Radius of investigation	< 2 m	
Stabilised temperature at downhole sensor depth	27.0 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/s - INTERVAL VMT3	787.0 - 858.2 m aBH/ 560.9 - 609.6 m bGL

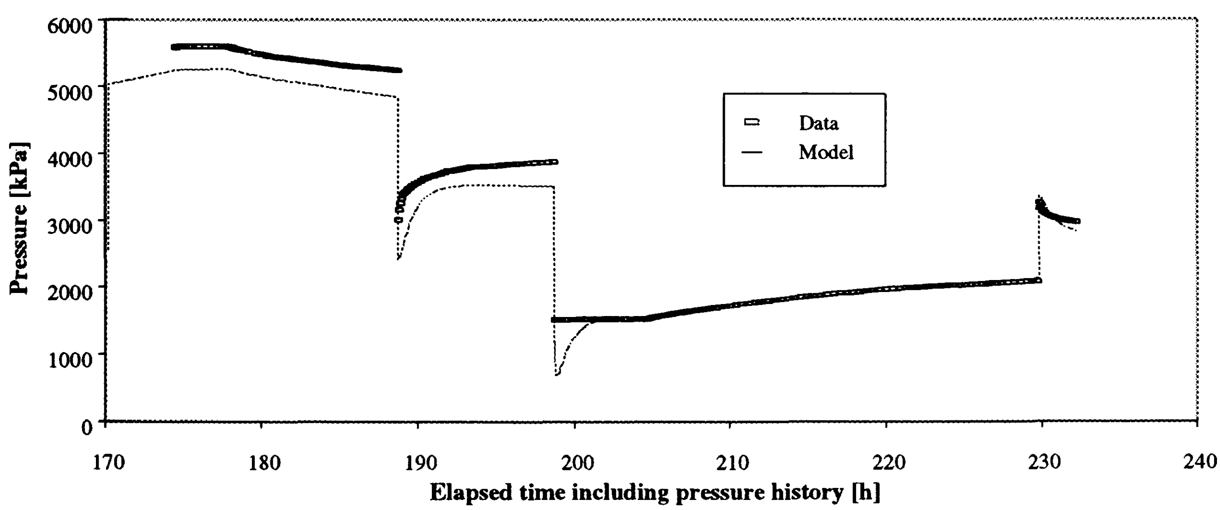


Pressures Measured During VMT3

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VMT3	787.0 to 858.2 m aBH 560.9 to 609.6 m bGL	Reference: NIB 95-15E Standard Analysis

Test Sequence Description:

After deflating the packer for test VM10, 1.5 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 838 m aBH). The packer was then moved to VMT3 testing depth and inflated to 8000 kPa water.

COM - The shut-in tool remained open for a 3.39 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. A flow rate of -1.4E-3 l/min during the COM phase was calculated from the fluid level change in the 2 3/8" test tubing.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 10.86 h PSR phase. In the PSR period, the pressure decreased a total of 345 kPa indicating a static formation pressure below the hydrostatic conditions of the borehole. Fluid was swabbed from the tubing to ca. 400 m aBH in preparation for the PW phase.

PW - The subsequent PW period lasted 9.95 h. At the end of the period, fluid was once again swabbed to ca. 625 m aBH, in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 2381 kPa. The SW period lasted 5.98 h and showed a total recovery of 17 kPa indicating a low interval transmissivity.

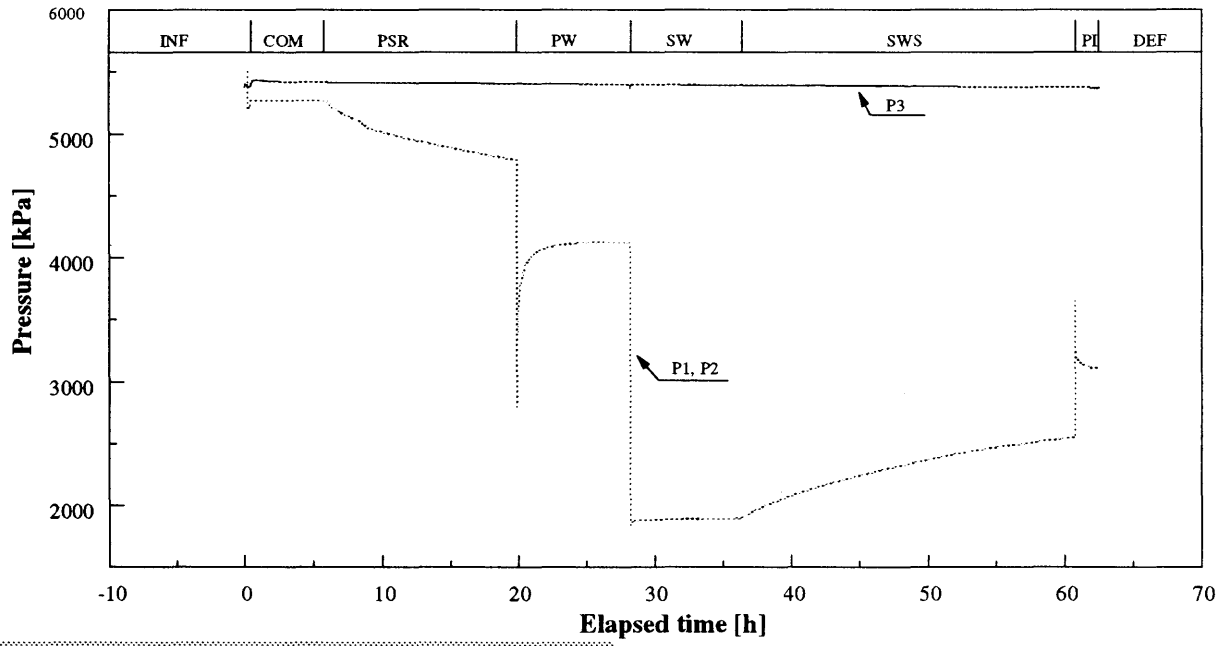
SWS - In the subsequent SWS phase the pressure recovered to 2072 kPa in 25.23 h.

PI - In the late stages of the SWS period, the tubing was filled with tracered water up to ca. 380 m below top of tubing and the test was concluded with a 2.42 h pulse injection phase. The measured C-value (wellbore storage coefficient) from this phase was 1.59E-9 m^3/kPa and compares well with the C-value of 1.13 E-9 m^3/kPa measured in the earlier PW phase and the theoretical value of 1.72E-9 m^3/kPa.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects and transitional data. The temperature at the P2 sensor depth increased by 1.8°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

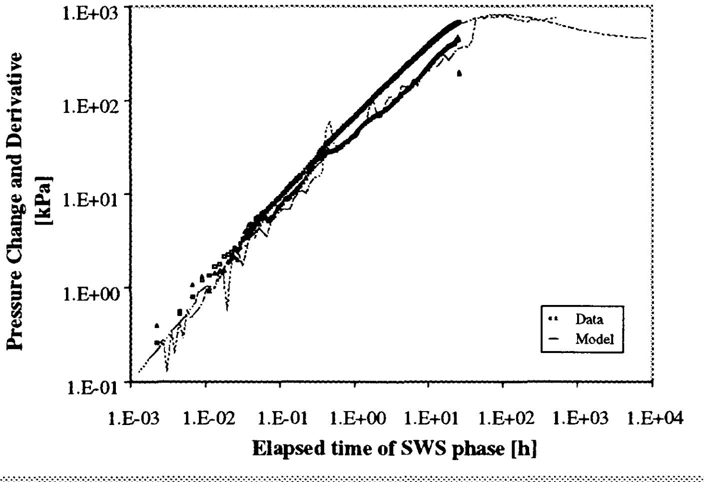
Packer configuration	Single Packer	
Date of test	2nd to 4th October 1995	
Test interval depth	787.00 to 858.20 m aBH 560.92 to 609.56 m bGL	measured true vertical
Test interval length (measured along the borehole)	71.20 m	
Borehole diameter	0.124 m; nominal	
Geology	787.00 to 820.00 m aBH TERTIARY - Globigerina Marl; Sandy and Silty Micaseous Marly Limestone 820.00 to 858.20 m aBH LOWER CRETACEOUS - Valanginian; Palfris Formation; Clay and Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	4.0E-11 m^2/s 1.0E-12 to 4.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	630 m asl 420 to 630 m asl	
Radius of investigation	< 2 m	
Stabilised temperature at downhole sensor depth	25.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/s - INTERVAL VMT4	739.0 - 858.2 m aBH/ 528.2 - 609.6 m bGL

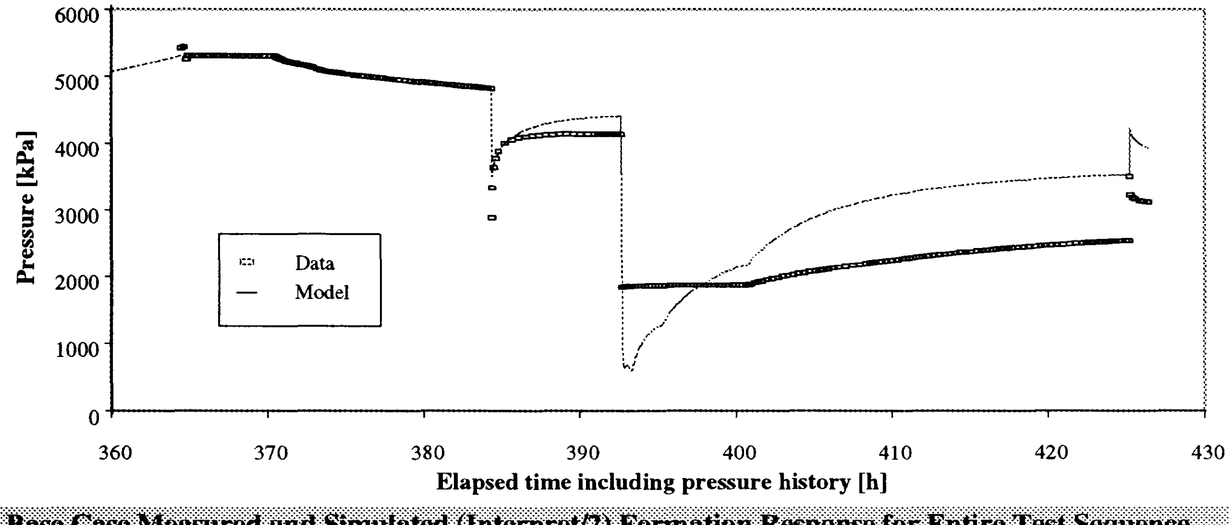


Pressures Measured During VMT4

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VMT4	739.0 to 858.2 m aBH 528.2 to 609.6 m bGL	Reference: NIB 95-15E Standard Analysis

Test Sequence Description:

After deflating the packer for test VMT3, a total of 3 m^3 of uranin tracered fresh water was circulated down the tubing (top of screen ca. = 788 m aBH). The packer was then moved to testing depth and inflated to 7500 kPa with water.

COM - The shut-in tool remained open for a 5.57 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining in the tubing at an equivalent rate of -1.54E-3 l/min, confirming a static formation pressure below the hydrostatic conditions in the borehole.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 13.92 h PSR phase. In the PSR period, the pressure decreased 474 kPa with a final pressure of 4789 kPa. In preparation for the subsequent PW phase, fluid was swabbed from the tubing to ca. 350 m aBH.

PW - The PW period lasted 8.34 h and showed a 'roll over' (change in pressure gradient) but then started to increase again at the end of the phase. There is no plausible explanation for this response. In the latter part of the PW period, fluid was swabbed from the tubing to ca. 500 m aBH in preparation for the SW phase.

SW - The SW period lasted 8.07 h and showed a recovery of 40 kPa with the majority of inflow occurring in the initial 30 min.

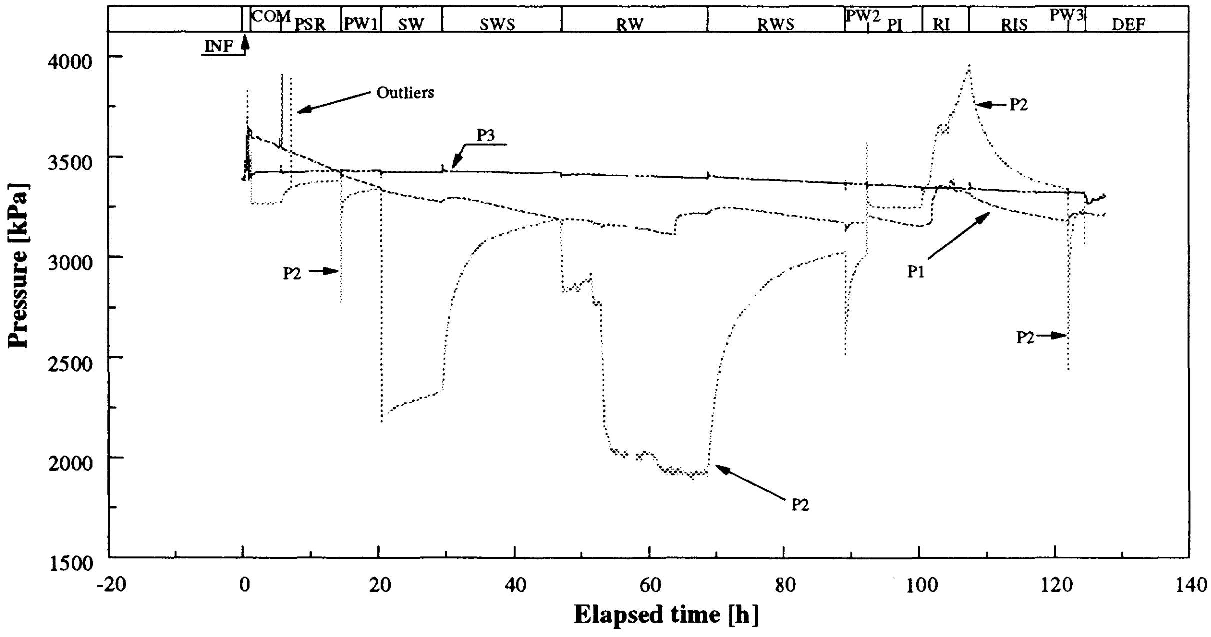
SWS - In the subsequent 24.42 h SWS phase, the pressure recovered to 2550 kPa.

PI - The test was concluded with a 1.19 h PI period. The measured C values (wellbore storage coefficient) in the test, 1.62 E-9 m^3/Pa (PW) and 2.08E-9 m^3/Pa (PI), show good consistency and compare well with the theoretical value.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a relatively significant influence on the test response due to the low interval transmissivity and static formation pressure below the hydrostatic conditions of the borehole. The log-log diagnostic plots are dominated by wellbore storage effects. and transitional data. There was no definitive evidence for packer bypass during the test. However, there were anomalous pressure disturbances in the PSR which could also be correlated to pressure disturbances in the P3 data. The temperature at the P2 sensor depth increased by 2.1°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

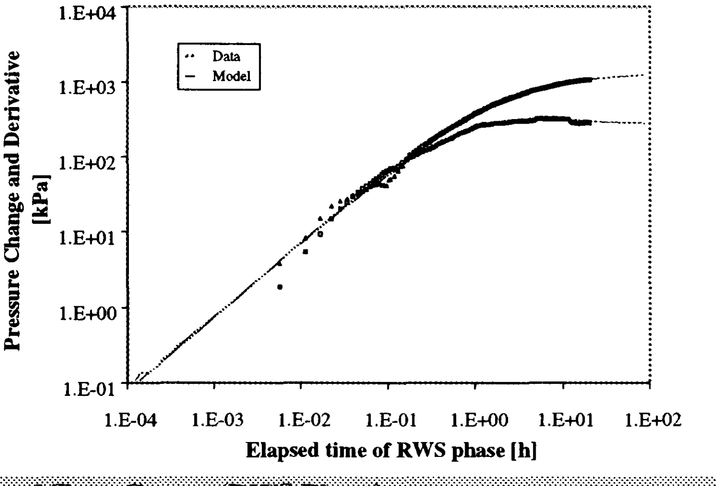
Packer configuration	Single Packer	
Date of test	4th to 7th October 1995	
Test interval depth	739.02 to 858.20 m aBH 528.19 to 609.56 m bGL	measured true vertical
Test interval length (measured along the borehole)	119.18 m	
Borehole diameter	0.124 m; nominal	
Geology	<u>739.02 to 820.00 m aBH</u> TERTIARY - Globigerina Marl; Sandy and Silty Micaseous Marly Limestone <u>820.00 to 858.20 m aBH</u> LOWER CRETACEOUS - Valanginian; Palfris Formation; Clay and Limestone Marls	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.0E-10 m^2/s 1.0E-12 to 1.0E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	640 m asl 440 m to 640 m asl	
Radius of investigation	< 2 m	
Stabilised temperature at downhole sensor depth	24.5 °C	
Recommended flow model	Wellbore Storage and Skin Composite Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	No Yes Yes No

BOREHOLE SB4a/s - INTERVAL VM11	448.0 - 457.5 m aBH/ 324.7 - 331.7 m bGL

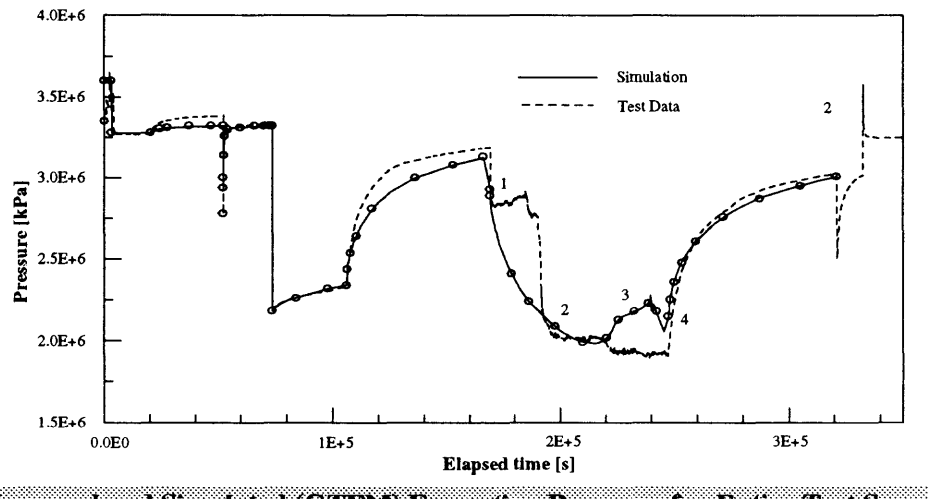


Pressures Measured During VM11

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (RWS Phase)



Base Case Measured and Simulated (GTFM) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM11	448.0 to 457.5 m aBH 324.7 to 331.7 m bGL	Reference: NIB 95-15F Detailed Analysis

Test Sequence Description: After lowering tools to test depth, the lower packer was inflated to 8000 kPa with water and then 2 m^3 of uranin tracered freshwater was circulated down the tubing. At completion of flushing, the upper packer was inflated to 8000 kPa.

COM - The shut-in tool remained open for a 4.46 h compliance period. Fluid was flowing from the tubing at a rate of 7.5E-03 l/min at the end of the period.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 8.91 h PSR phase. In the PSR period, the pressure increased a total of 112 kPa suggesting a static formation pressure above the hydrostatic conditions of the borehole. Fluid was swabbed to ca. 75 m aBH below the top of the tubing in preparation for the PW1 phase.

PW1 - The subsequent PW1 period lasted 5.86 h with a total recovery of 97 %. At the end of the period, fluid was once again swabbed to ca. 163 m aBH in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 1159 kPa. The SW period lasted 9.05 h and showed a total recovery of 14%. There was no suggestion for gas flow during this period.

SWS - In the subsequent SWS phase the pressure recovered to 3188 kPa in 17.57 h. In the late stages of the SWS period, sucker rods were lowered into the tubing and flowmeters were function checked in preparation for the RW phase.

RW - The RW phase lasted 21.72 h with a total drawdown of 1269 kPa. The rate was increased approximately 4.5 h into the period resulting in a distinct pressure decrease. At 6.5 hours into the period, slugs with both gas and water were measured at the surface and therefore it is difficult to make accurate statements on the gas-water ratio. In the latter 15 h of the period, the average water rate was 0.1 l/min and the average gas rate was approximately 0.4 l/min. Accuracy of the measured gas rates were dependent on stability of separator conditions, i.e. pressure, temperature and water level, which were often difficult to maintain.

RWS - At completion of the pumping period, the shut-in tool was closed and pressure recovered to 3027 kPa in 20.44 h. In preparation for the PW2 phase, fluid was swabbed to ca. 117 m aBH from the top of the tubing.

PW2 - The PW2 period lasted 3.11 h with a total recovery above 100 % due to history effects.

PI - The tubing was then filled to the surface for the PI period which lasted 8.20 h.

RI - The RI-RIS sequence was then carried out with an initial injection rate of 50 ml/min. At ca. 2 h into the period, the rate was decreased to 25 ml/min due to the response in P1 pressure which suggested a hydraulic connection between the interval and the bottom guard zone. At completion of the RI phase there was a total of 709 kPa overpressure.

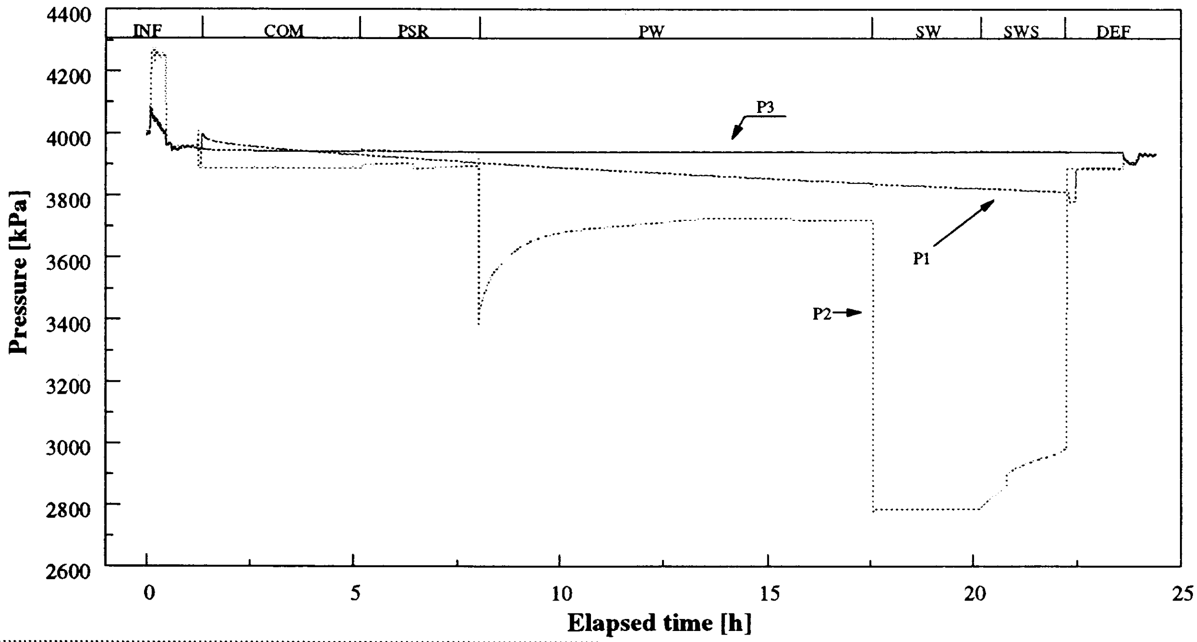
RIS - The subsequent RIS period lasted 14.46 h.

PW3 - The test was concluded with a 2.46 h PW3 phase.

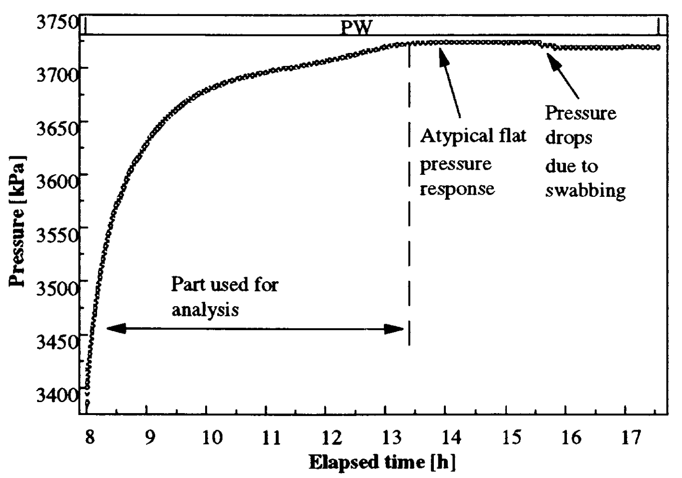
Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The borehole history effects on the test response were relatively significant due to the extensive duration. The log-log diagnostic plots, used to define the flow model, show good formation character beyond the effects of wellbore storage. The reliability of single phase parameters derived from the main production period and subsequent periods is significantly impacted by gas flow. The injection phase shows a non-ideal response.

Packer configuration	Double Packers	
Date of test	18th to 23rd October 1995	
Test interval depth	448.00 to 457.46 m aBH 324.73 to 331.66 m bGL	measured true vertical
Test interval length (measured along the borehole)	9.46 m	
Borehole diameter	4.88 " (= 0.124 m; nominal)	
Geology	324.73 to 331.66 m bGL (true vertical) LOWER CRETACEOUS-Valanginian; Palfris Formation; marly clays interbedded with limestone layers containing calcite veins	
Test objectives defined at start of test	Gas Saturation, Transmissivity, Equivalent Freshwater Head, Flow Model	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	4.0E-09 m^2/s 2E-09 to 6E-09 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	957 m asl 946 to 977 m asl	
Radius of investigation	10 m	
Stabilised temperature at downhole sensor depth	18.0 °C	
Recommended flow model	Wellbore Storage and Skin, Composite, Infinite Lateral Extent	
Recommended two phase flow model	Grant with initial gas saturation of 0.2%	
Factors affecting test analysis	Equipment, Temperature History Gas	No Yes Yes

BOREHOLE SB4a/s - INTERVAL VM12	535.8 - 538.8 m aBH/ 388.2 - 390.4 m bGL

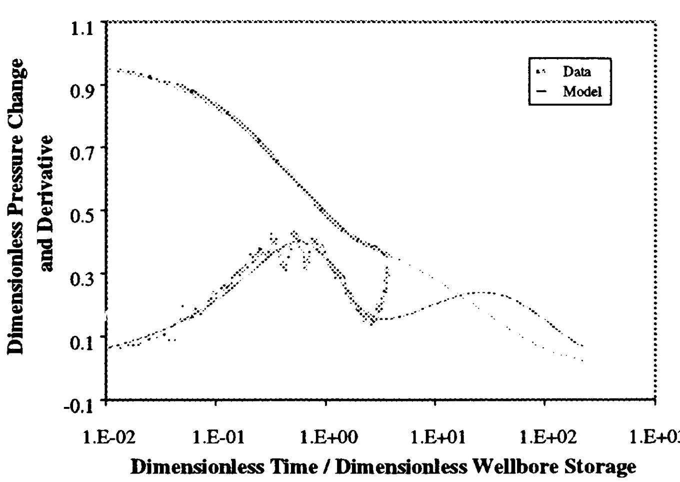


Pressures Measured During VM12



Cartesian Plot of P2 Pressure Response (PW Phase)

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Ramey A Plot for PW phase

TEST SUMMARY BOREHOLE SB4a/s VM12	535.8 to 538.8 m aBH 388.2 to 390.4 m bGL	Reference: NIB 95-15G Standard Analysis

Test Sequence Description: After lowering the tools to circulating depth (1 m below test depth) 2 m^3 of uranin tracered freshwater was circulated down the tubing. At completion of flushing, the tool was moved on test depth and the packers were inflated to 7000 kPa using water.

COM - The shut-in tool remained open for a 3.94 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was flowing from the tubing at a rate of -2.1E-03 l/min at the end of the period.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 2.81 h PSR phase. An initial pressure squeeze of ca. 10 kPa, caused by the operation of the shut in tool, disturbed the early time PSR data. The general upwards trend of the PSR pressure response was indicating a slight above hydrostatic formation initial pressure. At ca. 6.5 h total test elapsed time the swabbing operation caused a ca. 20 kPa pressure jump in the PSR interval pressure response, which made any analysis of this phase for reliable parameters impossible. After this disturbance, it was decided to minimise the duration of the PSR phase and, after the fluid level in the tubing stabilised, carry on with the next phase.

PW - The PW phase was started with the tubing swabbed down to ca. 76 m aBH. The PW period lasted 9.54 h with a total recovery of ca. 65 %. The last 4 h of the phase were showing an atypical flat pressure response, which was additionally disturbed at ca. 15.5 h total test elapsed time by swabbing down to ca. 150 m aBH in preparation for the subsequent SW phase. Only the initial 5.5 h of the phase were analysed. At this stage of the test it was clear that the interval transmissivity was too small and therefore not suitable for the measurement of the gas threshold pressure (air entry pressure). However, in order to second-check the parameters derived from the analysis of the PW phase, it was decided to continue the test with a SW-SWS sequence.

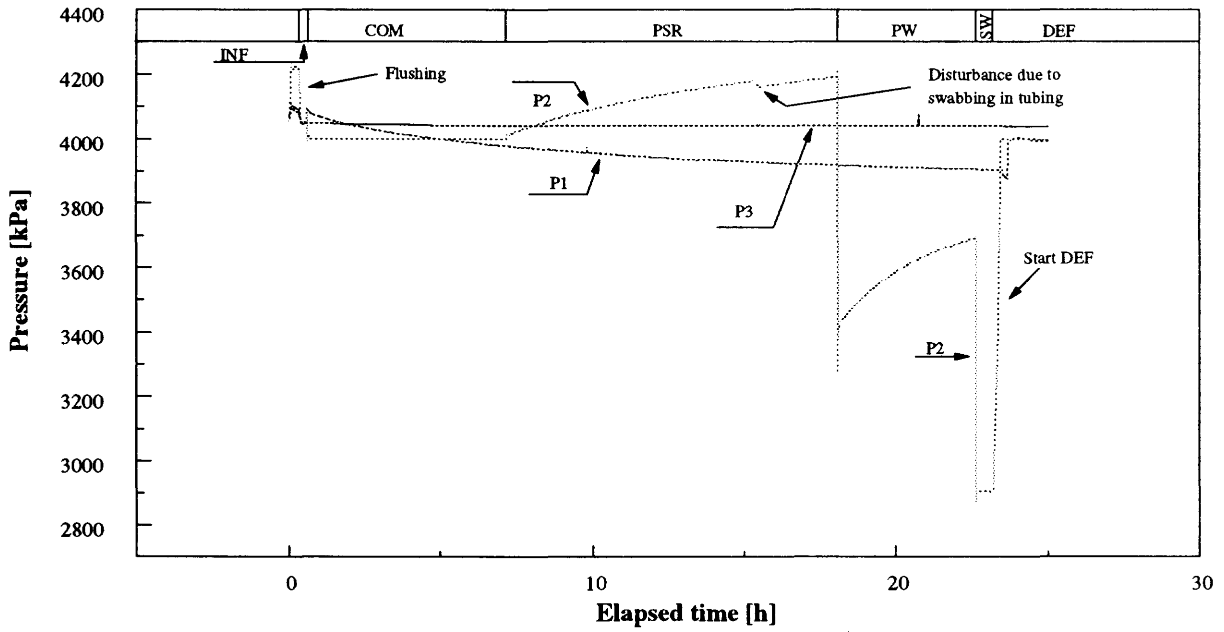
SW - The SW phase lasted 2.63 h and, with exception of a quick pressure recovery of ca. 7 kPa in the first 30 s of the test, did not show any measurable flow from the formation. Due to the very low (not measurable) recovery, the SW phase was not analysable.

SWS - The SWS phase lasted 2.04 h and was disturbed twice by anomalous pressure humps of up to 37 kPa. The origin of these pressure disturbances is unclear and it could not be correlated with any other pressure or temperature measurements in the system.

Comments: The primary test objective of gas threshold pressure was not achieved. Analyses of the initial phases showed the interval transmissivity too low to accurately derive this parameter. Therefore, the test was abandoned. The main goal of interpretation was to corroborate freshwater heads derived in previous analyses of tests which encompassed the VM12 interval. The derived transmissivity is very uncertain due to a radius of investigation on a similar scale as the disturbed zone from drilling effects. Borehole history effects have a relatively significant influence on the test response due to the extensive duration. The log-log diagnostic plots are dominated by anomalies and wellbore storage effects. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The temperature at the P2 sensor depth was relatively stable after the PSR period.

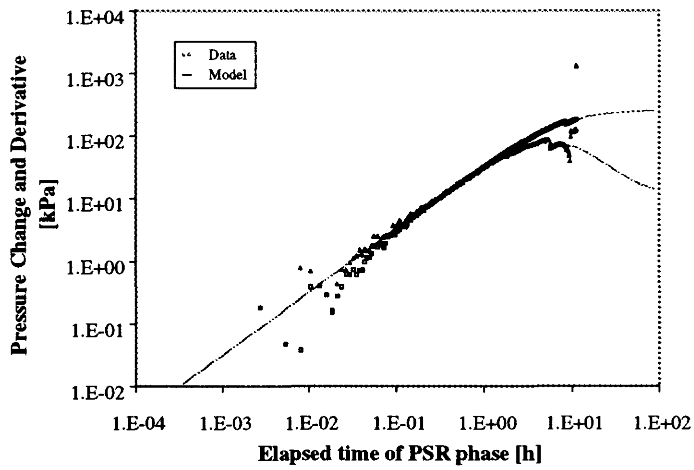
Packer configuration	Double Packers	
Date of test	26th October - 27th October 1995	
Test interval depth	535.80 to 538.80 m aBH 388.21 to 390.35 m bGL	measured true vertical
Test interval length (measured along the borehole)	3.00 m	
Borehole diameter	0.124 m (nominal)	
Geology	535.80 - 538.80 m aBH VALANGINIAN; - Marly clays and limestone marls with calcite veins; 533.1 - 548.6 m aBH ductile shear zone; few calcite vugs	
Test objectives defined at start of test	Transmissivity; Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	3.0E-12 m^2/s 3.0E-13 - 3.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	(943) m asl (test was not optimised for this parameter; see comments) 930 - 960 m asl	
Radius of investigation	< 1m	
Stabilised temperature at P2 depth	20.5 °C	
Recommended flow model	Wellbore Storage and Skin, Composite, Infinite Lateral Extent	
Factors affecting test analysis	Equipment, History, Temperature Gas	Yes No

BOREHOLE SB4a/s - INTERVAL VM13	551.5 - 554.5 m aBH/ 399.4 - 401.5 bGL

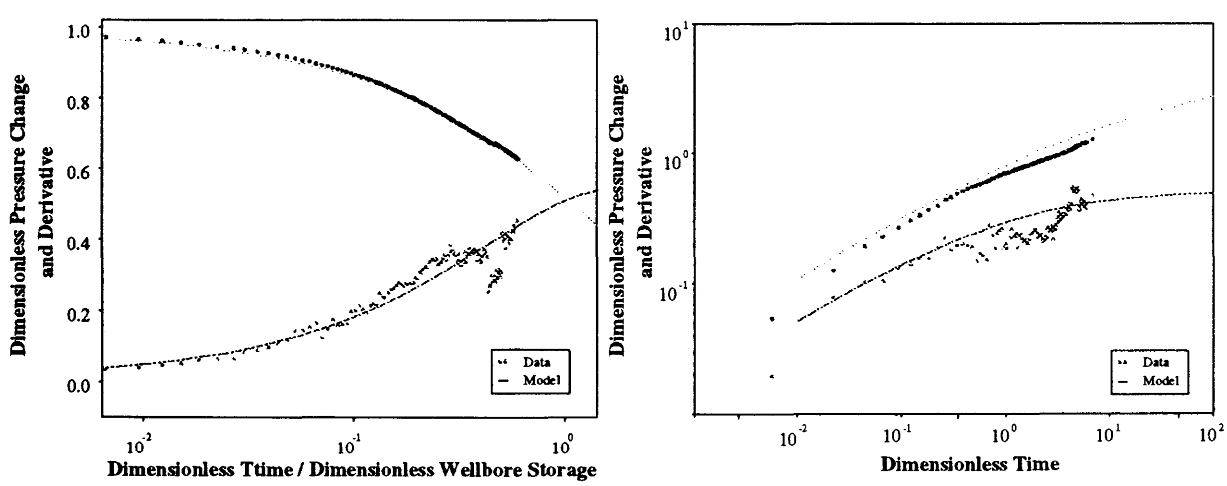


Pressures Measured During VM13

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (PSR Phase)



Ramey A and Deconvoluted Match of PW Phase

TEST SUMMARY BOREHOLE SB4a/s VM13	551.5 to 554.5 m aBH 399.4 to 401.5 m bGL	Reference: NIB 95-15G Standard Analysis

Test Sequence Description:

After moving the tools to 1 metre below the VM13 test depth, 2 m^3 of tracered freshwater was circulated down the tubing. The tools were then moved up to test depth and the packers were inflated to 7000 kPa with water.

COM - The shut-in tool remained open for a 6.48 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining inside the tubing at an average rate of 5.9E-4 l/min.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 10.94 h PSR phase. In contradiction to the declining fluid level during the COM period, the pressure increased, a total of 194 kPa, suggesting a static formation pressure above the hydrostatic conditions of the borehole. In preparation for the subsequent PW phase, fluid was swabbed from the tubing to ca. 96 m below the top of the tubing, measured along the borehole.

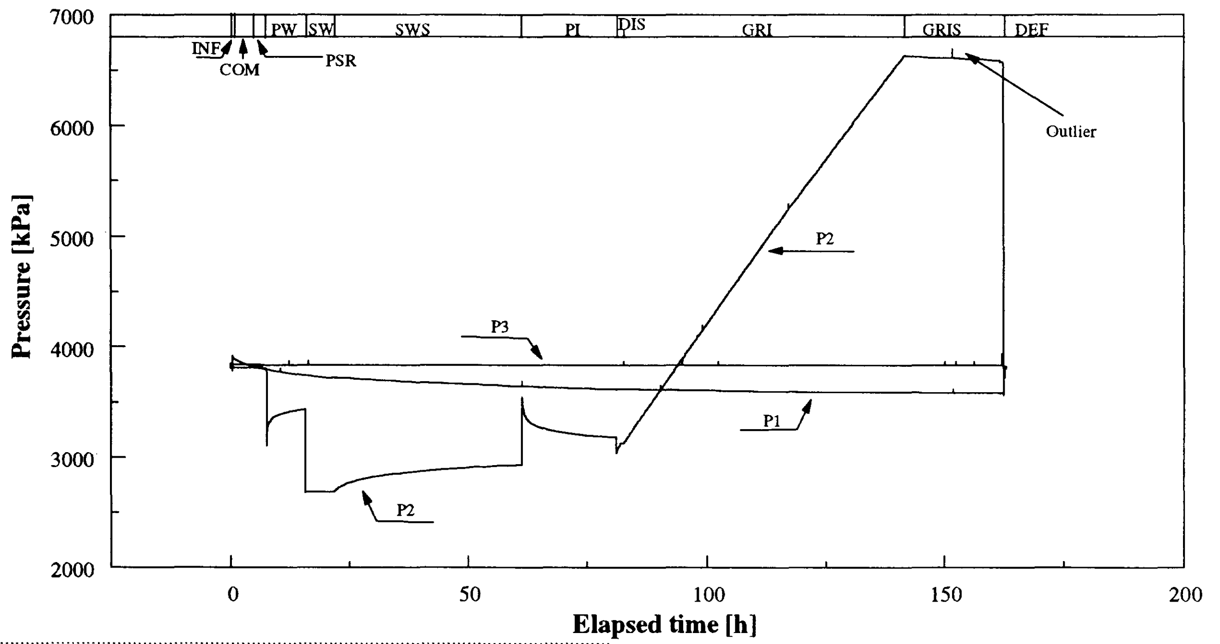
PW - The PW phase lasted 4.53 h with a recovery of 41 % of the total pressure difference at the start indicating a relatively low interval transmissivity. The analysis of the phase confirmed the low interval transmissivity and it was then decided to terminate the test as the primary objective was not considered attainable.

SW - However, an SW period was carried out to further confirm the preliminary analysis results. In preparation for the SW phase, fluid was swabbed to ca.162 m below the top of the tubing, measured along the borehole. Upon opening the shut-in tool, the pressure fell 789 kPa. There was no change in pressure after 25 min. The test was terminated as the primary objective was not attainable with an acceptable level of confidence.

Comments: The primary test objective of air entry pressure was not achieved. Analyses of the initial phases showed the interval transmissivity too low to accurately derive this parameter. Therefore, the test was abandoned. The main goal of interpretation was to corroborate freshwater heads derived in previous analyses of tests which encompassed the VM13 interval. The derived transmissivity should be considered representative of the near wellbore properties, i.e. the disturbed zone due to drilling effects. Borehole history effects have a relatively significant influence on the test response due to the extensive duration. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. The temperature at the P2 sensor depth increased by 2.4°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test. Swabbing activities caused disturbances in the test interval

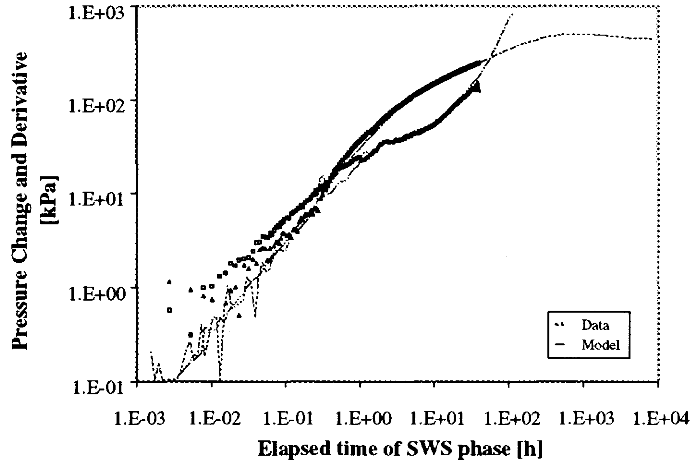
Packer configuration	Double Packers	
Date of test	27th October - 28th October 1995	
Test interval depth	551.50 to 554.50 m aBH 399.35 to 401.47 m bGL	measured true vertical
Test interval length (measured along the borehole)	3.00 m	
Borehole diameter	0.124 m (nominal)	
Geology	551.50 - 554.50 m aBH VALANGINIAN; - Marly clays and limestone marls with calcite veins	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	6.0E-12 m^2/s 6.0E-13 - 6.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	(973) m asl (test was not optimised for this parameter; see comments) 960 - 980 m asl	
Radius of investigation	< 1m	
Stabilised temperature at downhole sensor depth	20.5 °C	
Recommended flow model	Wellbore Storage and Skin Homogeneous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes Yes No

BOREHOLE SB4a/s - INTERVAL VM14	524.7 - 527.7 m aBH/ 380.3 - 382.4 m bGL

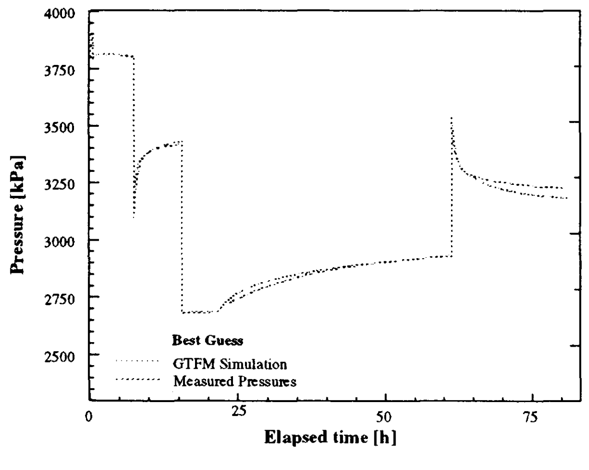


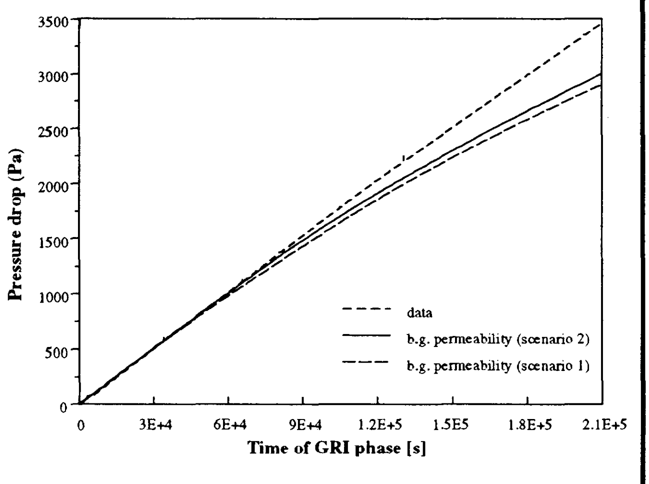
Pressures Measured During VM14

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)





Simulated Response for Hydraulic Parameters (GTFM) and Air Entry Pressure (TOUGH)

<table>
<tr><td>TEST SUMMARY BOREHOLE SB4a/s
VM14</td><td>524.7 to 527.7 m aBH
380.3 to 382.4 m bGL</td><td>Reference: NIB 95-15G
Detailed Analysis</td></tr>
</table>

Test Sequence Description: After deflating the packers for VM13, 2 m^3 of tracered freshwater was circulated down the tubing and then the tools were moved to the VM14 test depth, and subsequently the packers were inflated to 7000 kPa with water.

COM - The shut-in tool remained open for a 3.65 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining inside the tubing at an average rate of -5.0E-4 l/min in the latter part of the period.

PSR - Once the temperature stabilised, the shut-in tool was closed for a 3.32 h PSR phase. There was very little pressure change during the period, a total of 7 kPa; the decreasing trend suggests that the static formation pressure is below the hydrostatic pressure of the borehole. There are two disturbances in the PSR which are attributed to swabbing and airlifting. In preparation for the subsequent PW phase, fluid was swabbed from the tubing to ca. 107 m below the top of the tubing, measured along the borehole.

PW - The PW phase lasted 8.05 h with a recovery of 47 % of the total pressure difference at the start indicating a relatively low interval transmissivity. Fluid was again swabbed from the tubing to ca. 167 m below the top of the tubing, measured along the borehole, in preparation for the SW phase.

SW - Upon opening the shut-in tool, the pressure fell 753 kPa. The SW period lasted 6.13 h with a total recovery of less then 1%.

SWS - In the subsequent SWS phase, the pressure increased to 2931 kPa in 39.67 hours, some 875 kPa less then the end pressure of the PSR period. At this time, it was realised that the static formation pressure was not consistent with previous tests which showed values above the hydrostatic conditions in the borehole.

PI - A PI period was then planned to force the pressure in vicinity of the borehole to the expected static formation pressure based on analyses of the SWS period. In preparation for the PI period, the tubing was filled to ca. 41 m aBH. The PI phase lasted 19.60 h with a total recovery of 59%. At the end of the period, the pressure was 3184 kPa, an equivalent freshwater head of 879 m asl. Once the pressure in the PI phase had recovered to the expected formation pressure, the gas threshold (air entry) part of the test was started.

DIS - The DIS phase lasted 1.48 h with a total of 895 lof gas measured at the surface used to displace 23.7 litres of fluid in the interval. There was no suggestion of gas escaping the interval during this period. The shut-in tool was then closed and the pressure was monitored for approximately 30 min with no measured change.

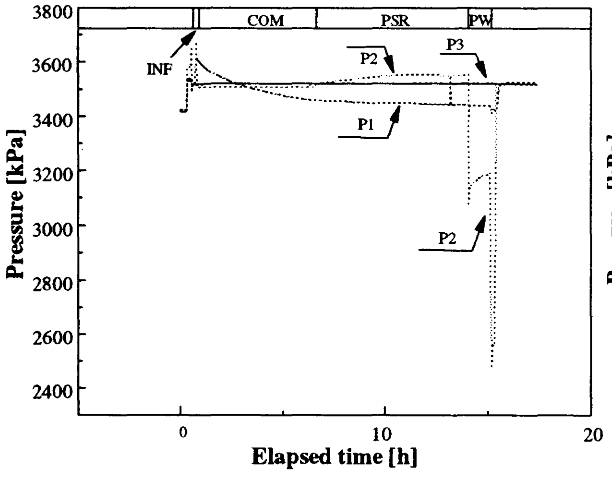
GRI - The subsequent GRI phase lasted approximately 59.02 h with an injection rate of 0.40 l/min. During this period, the pressure increased 3505 kPa above the starting pressure.

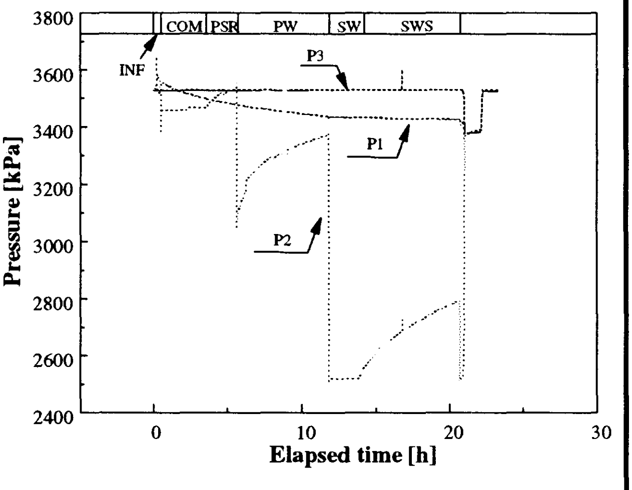
GRIS - In the subsequent 20.23 h GRIS period, the pressure showed a relatively small recovery of 45 kPa.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a significant influence on the test response due to the extensive duration. The log-log diagnostic plots show good formation character beyond the effects of wellbore storage. The temperature at the P2 sensor depth increased by 1.2°C during the INF, COM and PSR phases and was relatively stable for the remainder of the test.

Packer configuration	Double Packers	
Date of test	28th October - 4th November 1995	
Test interval depth	524.70 to 527.70 m aBH 380.29 to 382.43 m bGL	measured true vertical
Test interval length (measured along the borehole)	3.00 m (along borehole)	
Borehole diameter	0.124 m (nominal)	
Geology	524.70 - 527.70 m aBH VALANGINIAN; - Marly clays and limestone marls with calcite veins; ductile shear zone	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	9.0E-12 m^2/s 3.0E-12 - 4.0E-10 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	no values presented no values presented	
Radius of investigation	< 3 m	
Stabilised temperature at downhole sensor depth	20.0 °C	
Recommended flow model	Wellbore Storage and Skin, Composite, Infinite Lateral Extent	
Measured Air-Entry Pressure Two-Phase Flow Parameter Model Brooks-Corey Parameter Residual Liquid Saturation	1342 kPa (inner zone.) Brooks-Corey 2 not determined	2615 kPa (outer zone.)
Factors affecting test analysis	Equipment History, Temperature, Gas	No Yes

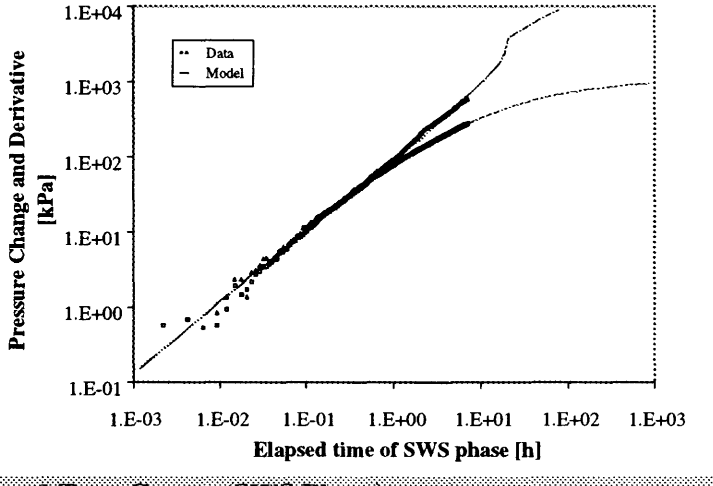
BOREHOLE SB4a/s - INTERVAL VM15	480.0 - 483.0 m aBH/ 347.4 - 349.6 m bGL



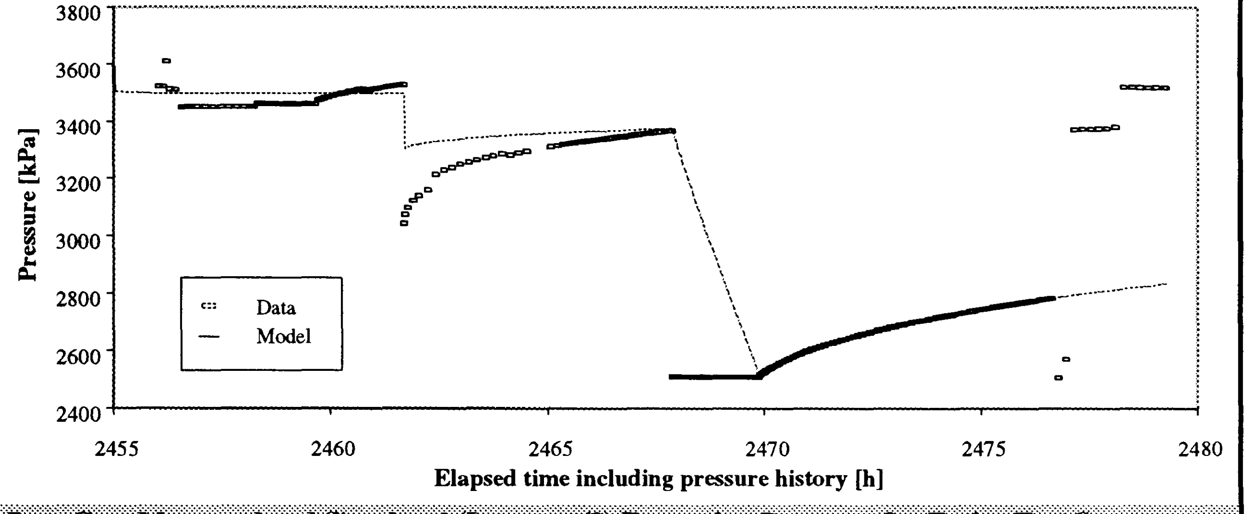


Pressures Measured During First and Second Packer Seats of VM15

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Homogeneous
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Base Case Measured and Simulated (Interpret/2) Formation Response for Entire Test Sequence

TEST SUMMARY BOREHOLE SB4a/s VM15	480.0 to 483.0 m aBH 347.4 to 349.6 m bGL	Reference: NIB 95-15G Standard Analysis

Test Sequence Description: After moving the tools to the VM15 (first packer seat) depth, 1 m^3 of tracered freshwater was circulated down the tubing. The packers were inflated to 7000 kPa with water.

COM1 - The shut-in tool remained open for a 5.84 h compliance period to allow the temperature in the interval to partially equilibrate and also to obtain a first estimate of the historical rate from the change in fluid level inside the tubing. Fluid was declining inside the tubing at an average rate of 7.8E-4 l/min.

PSR1 - Once the temperature stabilised, the shut-in tool was closed for a 7.42 h PSR phase. In contradiction to the declining fluid level during the COM period, the pressure increased, a total of 30 kPa, suggesting a static formation pressure above the hydrostatic conditions of the borehole.

PW - In preparation for the subsequent PW phase, fluid was swabbed from the tubing to ca. 67 m below the top of the tubing, measured along the borehole. The PW phase lasted 1.05 h and was terminated when the lower guard zone pressure response showed that there was communication around the bottom packer.

COM2 - It was decided to move one m deeper and start test VM15. After inflating the packers to 7000 kPa with water the shut-in tool was kept open for a 3.10 h. No fluid level change in the tubing was observed during this period.

PSR2 - The shut-in tool was closed for a 1.98 h PSR period. The pressure showed the same trend as during the first PSR period, it increased by 54 kPa.

PW - Fluid was swabbed out of the tubing down to ca. 70 m aBH in order to prepare for a PW phase. This phase lasted 6.17 h with a recovery of 67%. The analysis of the phase confirmed the low interval transmissivity and it was then decided to terminate the test as the primary objective was not considered attainable. However, an SW period was carried out to further confirm the preliminary analysis results.

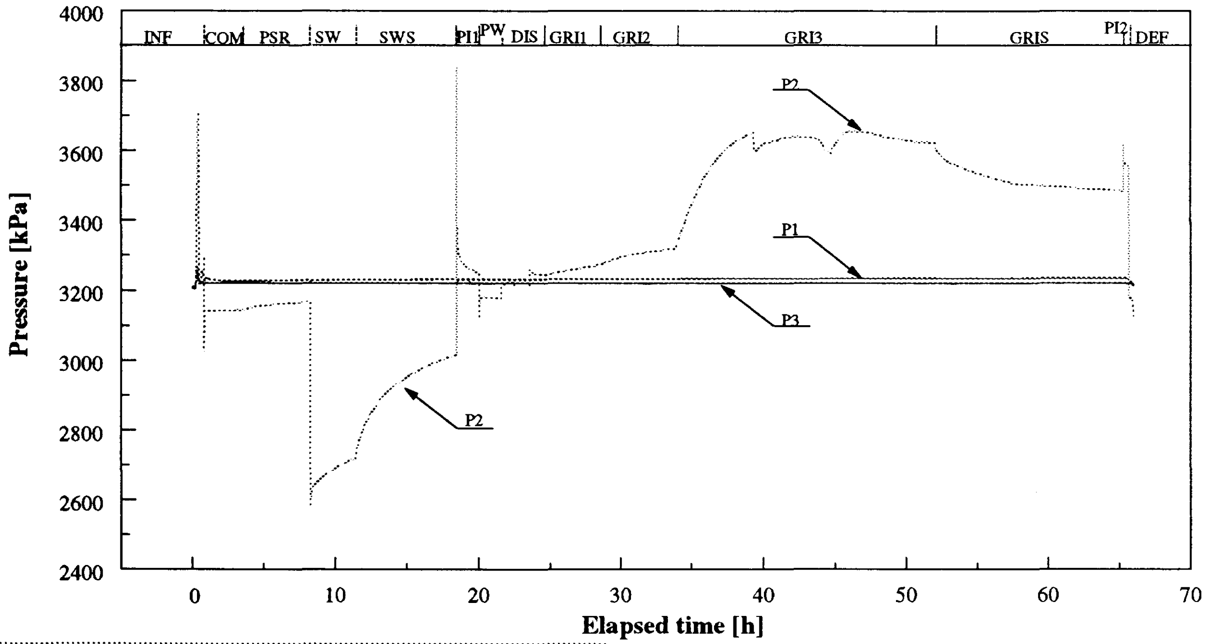
SW - In preparation for the SW phase, fluid was swabbed to ca.149 m below the top of the tubing, measured along the borehole. Upon opening the shut-in tool, the pressure fell 856 kPa. There was no change in pressure after 2.01 h.

SWS - The test was finished with a 6.80 h shut-in period with a pressure recovery of 32%.

Comments: The primary test objective of air entry pressure was not achieved. Analyses of the initial phases showed the interval transmissivity too low to accurately derive this parameter. Therefore, the test was abandoned. The main goal of interpretation was to corroborate freshwater heads derived in previous analyses of tests which encompassed the VM15 interval. The derived transmissivity should be considered representative of the near wellbore properties, i.e. the disturbed zone due to drilling effects. Borehole history effects have a relatively significant influence on the test response due to the extensive duration. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range.

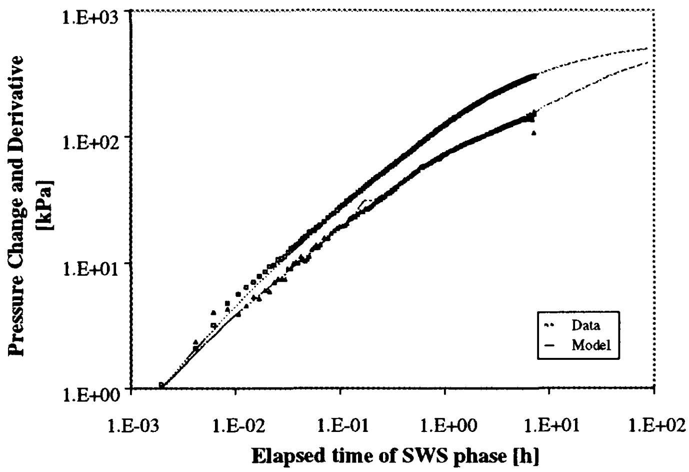
Packer configuration	Double Packers	
Date of test	4th November - 5th November 1995	
Test interval depth	480.00 to 483.00 m aBH 347.38 to 349.55 m bGL	measured true vertical
Test interval length (measured along the borehole)	3.00 m	
Borehole diameter	0.124 m (nominal)	
Geology	480.00 - 483.00 m aBH VALANGINIAN; - Marly clays and limestone marls with calcite veins; open calcite vug at 480.90 m bGL	
Test objectives defined at start of test	Transmissivity; Equivalent Freshwater Head; Flow Model; Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	1.0E-12 m^2/s 1.0E-13 - 1.0E-11 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	(954) m asl (the test was not optimised for this parameter) 950 - 970 m asl	
Radius of investigation	0.4 m	
Stabilised temperature at downhole sensor depth	20.0 °C	
Recommended flow model	Wellbore Storage and Skin Homogeneous Infinite Lateral Extent	
Factors affecting test analysis	Equipment History Temperature Gas	Yes Yes No No

BOREHOLE SB4a/s - INTERVAL VM16	441.5 - 444.5 m aBH/ 320.0 - 322.2 m bGL

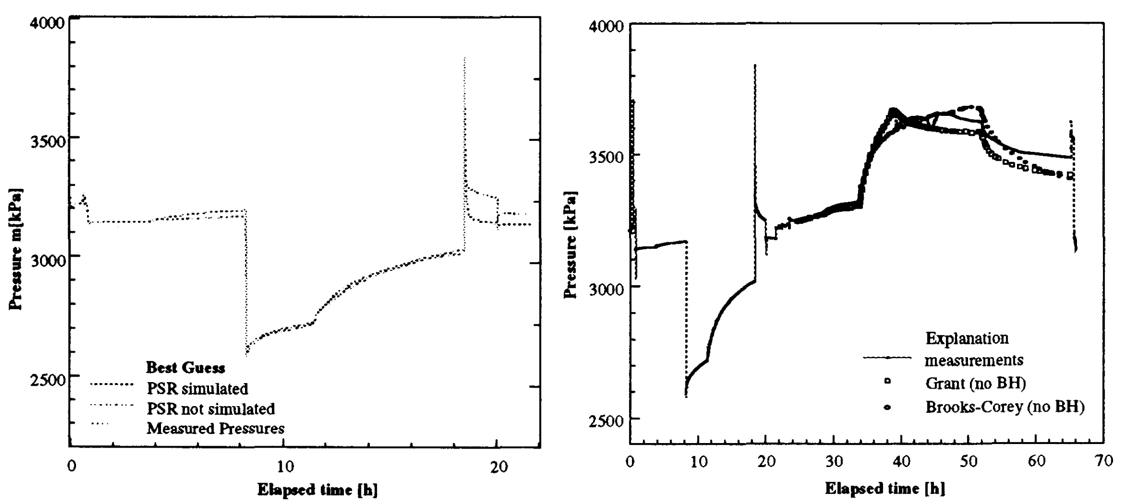


Pressures Measured During VM16

Flow Model:
Inner Boundary: Wellbore Storage and Skin
Formation: Composite
Outer Boundary: Infinite Lateral Extent



Representative Log-Log Diagnostic Plot and Type Curves (SWS Phase)



Simulated Response for Hydraulic Parameters (GTFM) and Air Entry Pressure (TOUGH)

TEST SUMMARY BOREHOLE SB4a/s VM16	441.5 to 444.5 m aBH 320.0 to 322.2 m bGL	Reference: NIB 95-15G Detailed Analysis

Test Sequence Description: After lowering the tools to testing depth 2 m^3 of uranin tracered freshwater was circulated down the tubing. At completion of flushing the packers were inflated to 7000 kPa using water.
COM - The shut-in tool remained open for a 3.01 h compliance period. A ca. 11 m swabb was taken at the beginning of COM in order to avoid freezing of fluid inside the tubing. Fluid was flowing from the formation at a rate of 5.5-03 l/min at the end of the period.
PSR - Once the temperature stabilised, the shut-in tool was closed for a 4.40 h PSR phase.
SW - The tubing was swabbed down to ca. 97 m aBH and, after fluid equilibrium in the tubing was achieved, the SW phase was initiated by opening the shut-in tool. The SW phase lasted 3.16 h and showed a recovery of ca. 30 %. It is likely that gas escaped the interval during this phase.
SWS - The subsequent SWS phase lasted 7.01 h and showed good recovery to a final pressure of 3016 kPa.
PI1 & PW - Subsequently, a pulse injection phase lasting 1.59 h and a pulse withdrawal phase lasting 1.51 h were conducted in order to measure the wellbore storage coefficient of the system and expedite the pressure equilibration to the expected static formation pressure. The PW phase showed a 'roll over' at late times.
DIS - The interval displacement of water with gas lasted 3.07 h. During this time a total amount of 24.5 l of water were displaced and measured at the surface using a calibrated cylinder, a total amount of 1308 l of gas was injected. Several pressure anomalies occurred during the displacement procedure. At the end of DIS gas bubbles were observed at the surface, flowing out of the tubing, which suggests that the gas front reached the top of screen in the interval and a part of the injected gas escaped through the tubing at surface.
GRI1, 2 & 3 - After exchanging the interval, the shut-in tool was closed and a constant rate gas injection phase (GRI1) at a rate of 0.23 l/min was started. Since the interval pressure was increasing too slowly (ca. 8 kPa/h) it was decided after 4.1 h to increase the injection rate to 0.45 l/min (GRI2). A deviation of the pressure response from the wellbore storage unit slope line occurred during GRI2 after ca. 1 h phase elapsed time, at a pressure difference of 14.22 kPa (calculated from the start pressure of GRI2). The injection rate was increased a third time (GRI3) to 3 l/min. GRI3 lasted 18.2 h. At ca 40 h total test elapsed time (ca. 5 h GRI3 elapsed time) the interval pressure dropped sharply by ca. 50 kPa. For the remainder of the phase the pressure continued behaving inconsistently with the expected formation response. This anomaly was possibly caused by rock mechanical phenomena such as opening of fractures.
GRIS - A shut-in period (GRIS) was subsequently conducted by closing the injection line at surface. The GRIS phase lasted 13.27 h and shown an anomalous pressure response during the last ca. 6 h of the period.
PI2 - The test was concluded with a brief pulse injection phase (PI2) lasting 0.35 h.

Comments: All test objectives were achieved. Function checks of downhole gauges and flowmeters showed the readings to be within the expected range. Borehole history effects have a significant influence on the test response due to the extensive duration. The temperature at the P2 sensor depth increased by 1.5°C during the INF, COM and PSR phases and was relatively stable thereafter.

Packer configuration	Double Packers	
Date of test	5th November - 8th November 1995	
Test interval depth	441.50 to 444.50 m aBH 319.95 to 322.16 m bGL	measured true vertical
Test interval length (measured along the borehole)	3.00 m	
Borehole diameter	0.124 m (nominal)	
Geology	441.50 - 444.50 m aBH VALANGINIAN; - Marly clays and limestone marls with calcite veins; open calcite vugs at 441.80 - 442.2 m aBH	
Test objectives defined at start of test	Transmissivity, Equivalent Freshwater Head, Flow Model, Air Entry Pressure	
Downhole fluid sampling	No	
Best estimate of transmissivity Confidence interval of transmissivity	7.0E-09 m^2/s 2.0E-09 - 2.0E-08 m^2/s	
Best estimate of freshwater head Confidence interval of freshwater head	941 m asl 938 - 952 m asl	
Radius of investigation	< 40 m	
Stabilised temperature at downhole sensor depth	18.0 °C	
Recommended flow model	Wellbore Storage and Skin, Composite, Infinite Lateral Extent	
Measured Air-Entry Pressure Two-Phase Flow Parameter Model Brooks-Corey Parameter Residual Liquid Saturation	110 kPa (inner zone) Grant 2 0.25	240 kPa (outer zone)
Factors affecting test analysis	Equipment, Temperature History, Gas	No Yes

APPENDIX D: QUALITY ASSURANCE / QUALITY CONTROL DOCUMENTATION WITH EXAMPLES

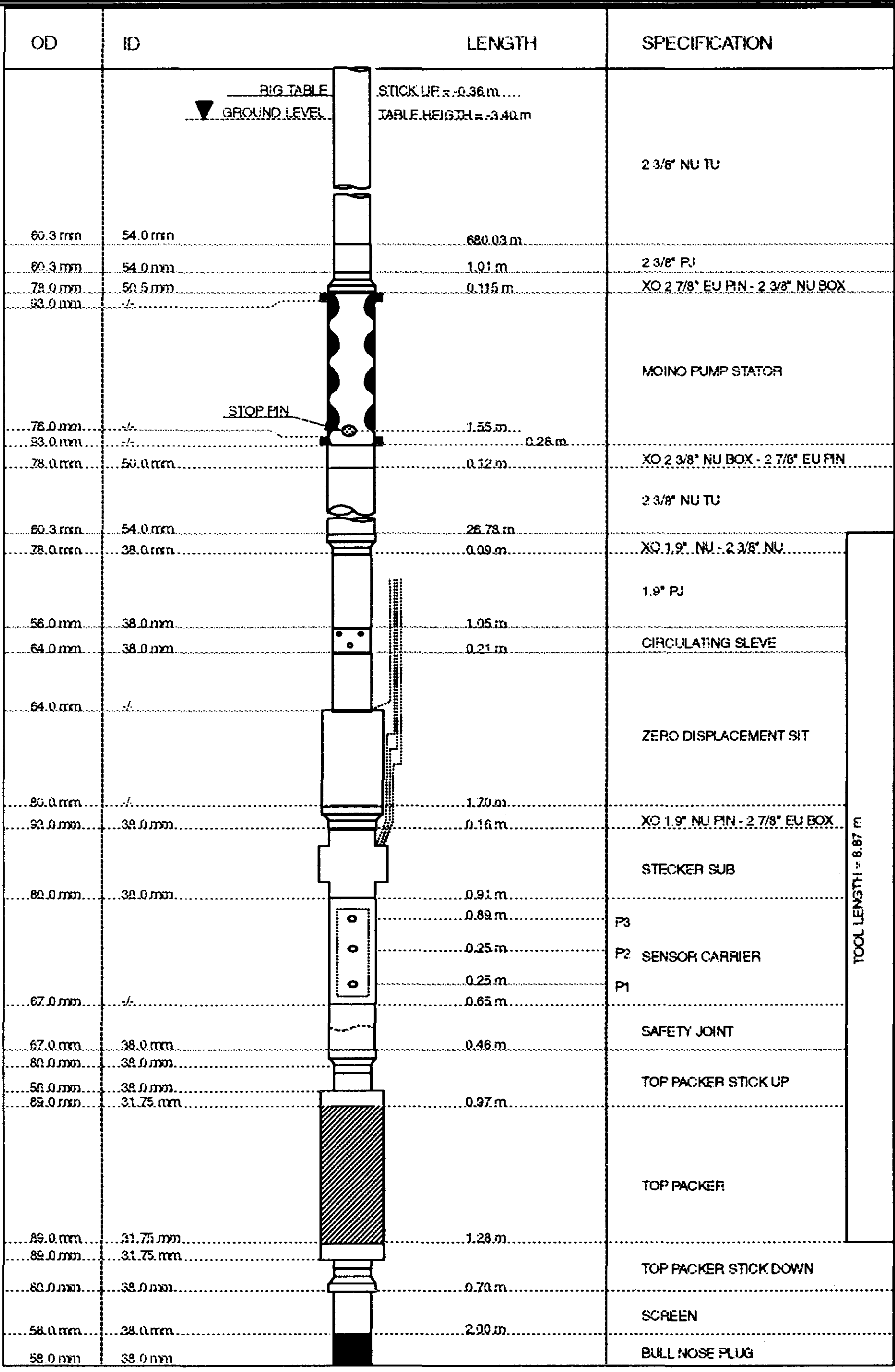
Project: NAGRA WLB
SB4a/s - Test VM14 **Testing Logbook**

Golder Associates

Date	Time	Event	Comment
The interval was cored from 07:00 on 28.07.95 to 11:30 on 28.07.95. Borehole SB4a/s is being drilled at a target deviation of 45 ° from the vertical. All reported depths are measured along the borehole (m aBH) unless otherwise noted. The surface pumping pressure for the circulation of mud while drilling through the interval varied between 27 and 29 bar, this pressure does not include the additional pressure exerted on the interval from the fluid in the borehole. The mud density was measured at the surface while drilling through the interval and shown to be between 1072 and 1073 g/cm^3. A total of 940 litres of fluid was lost to the formation while drilling from 521.20 to 532.60 m aBH. Daily flow check showed -0.3 and -2.3 l/min. At completion of coring to 532.60, fluid was circulated in the borehole and then tools were removed to the surface. The fluid level in the borehole was monitored for 64 minutes and was decreasing at an equivalent rate of -0.03 l/min. Tests VM5 to VM8 were performed and then the sequence of coring and testing continued to the total depth (858.20 m aBH). Tests VM5, VM6, VM7 and VM8 all encompass the VM14 interval. After completion of the single packer tests in the bottom approximately 120 m, geophysical surveys were performed and a followed by a 'round trip' to 'clean-up' the borehole. Test VM11 (448.00 to 457.46 m aBH) was performed between 18.10.95 and 24.10.95. A second 'round trip' was then performed. Tests VM12 (26 to 27.10.95) and VM13 (27 to 28.10.95) were then carried out.			
28.10.95	02:25	No measurable inflow during SW period of test VM13, remove PAA and fill tubing in preparation for deflation	**End Test VM13 (551.50 to 554.50 m aBH)**, transmissivity considered too low to perform a gas threshold pressure test
	02:50	Complete filling tubing, start packer deflation	
	05:00	Lower packer deflated, waiting for upper packer to deflate	
	06:15	Pull on test string, packers free	
	06:20	Start circulating tracered freshwater into tubing	
	06:40	Complete flushing with 2 m^3, close SIT and move up to test depth	
	07:20	On test depth	
	07:23	Start BASYS	**Start Test VM14 (524.70 to 527.70 m aBH)**
	07:28	Fill annulus	<u>Check Gauges</u> P1: 3850 kPa P2: 3847 kPa P3 3845 kPa Equivalent density = 1007 to 1008 g/cm^3 Foralith measurements show the mud density to be 1040 g/cm^3 on the 17.10.95. Readings are considered reasonable as flushing activities lower the density.

TESTING DATA FORM 1S - TOOL CONFIGURATION

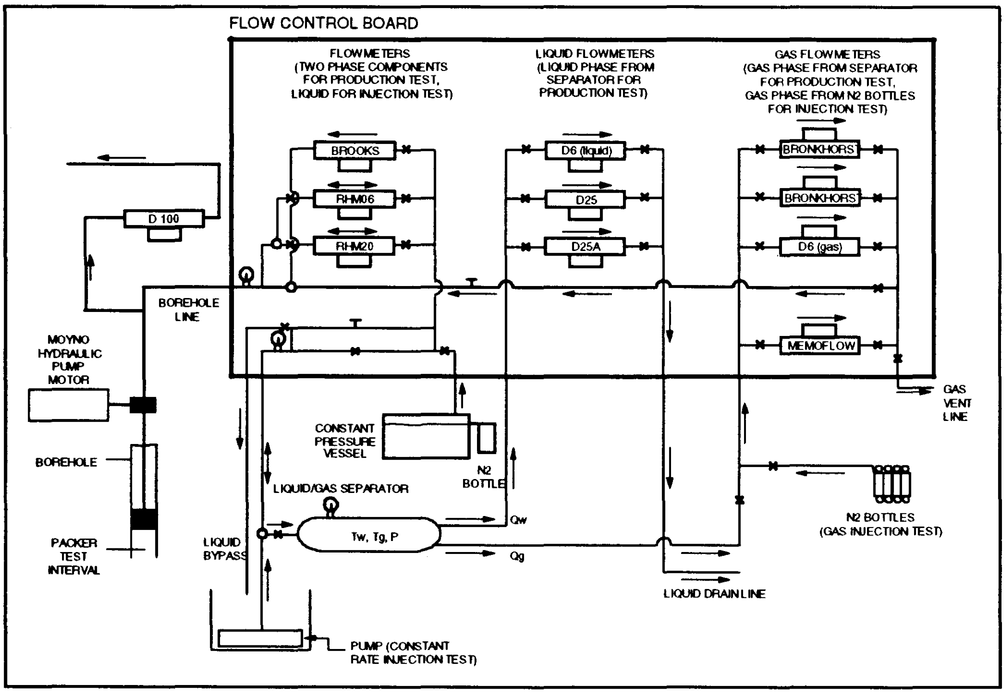
Project	Location	Date
NAGRA - Wellenberg	Wellenberg, Canton Nidwalden	10.09.95
Well name	**Test name**	**Engineer**
SB4a/s	T2	Wozniewicz/Enachescu



Reference point	Well depth [m bGL]	Last Permanent Casing depth [m bGL]
Ground Level (GL) - Elevation 942.3 m asl	740.00	416.00
UPLS [m bGL]	**Interval length [m]**	**Stickup [m bGL]**
715.00	25.00	-0.36

TESTING DATA FORM 1F -GENERALISED LAYOUT OF SURFACE EQUIPMENT

Project	Location	Date
NAGRA - Wellenberg	Wellenberg, Canton Nidwalden	28.10.95
Well name	**Test name**	**Engineer**
SB4a/s	VM14	Enachescu / J. Wozniewicz



Gauge	Output Range	Calibrated Range	Offset	Multiplier
BROOKS (F3)	2-100 g/h	0-5 V	0.10204	19.6
RHM06 (F2)	0-10 kg/min	0-10 V	0	1
Brooks 5850 E Series (B1)	0-30 l/min	0-5 V	0	6
D6 (D6-1; liquid)	0-900 g/min	4-20 mA / 500 Ohm	-2	112.5
Micromotion D25 (D25-1)	0-18 kg/min	4-20 mA / 500 Ohm	-2	2.25
Micrmotion D25A (D25-2)	0-5000 g/min	4-20 mA / 500 Ohm	-2	625
BRONKHORST - 1 (F4)	0-10 l/min N2	0-5 V	0	2
BRONKHORST - 2 (F6)	0-50 l/min N2	0-5 V	0	10
D6 (D6-2; gas)	0-50 g/min	4-20 mA / 500 Ohm	-2	6.25
MEMOFLO (Memflo)	0-10 l/min	0-5 V	0	2
D100 (D100)	0-100 l/min	4-20 mA / 500 Ohm	To be calibrated	
Brooks 5850 E Series (B2)	0-30 l/min	0-5 V	0	6
Brooks 5850 TR Series (B3)	0-10 l/min	0-5 V	0	1
Pseparator (P-SEP)	0-30 bar	0-10 V	0	3
Pmanifold (P-MAN)	0-34.474 bar	0-2 V	2	17.237
Tubing Pressure (PAA)	0-6 bar	4-20 mA / 250 Ohm	-0.52921	129.1485
Tubing Pressure (PTX-W2)	0-10 bar	4-20 mA / 250 Ohm	-0.66701	254.2625

Two phase separator used	No
Pumping equipment used	No
Flowmeters used	2 Brooks 5850 E Series gas flowmeters in parallel (B1 & B2 BASYS channel names); Brooks 5850 TR series (B3 BASYS channel name) used for gas injection
Constant pressure vessel used	No
Gas injection equipment used	The gas injection line to the interval contained 2 check valves that did not open until the pressure in the line exceeded the pressure in the interval
Additional gauges used	PAA pressure gauge for tubing pressure measurements

Note: The device name in BASYS file is shown in parenthesis.

TESTING DATA FORM 2 PERTINENT TEST INFORMATION

Project NAGRA WELLENBERG	Location Wellenberg, Canton Nidwalden	Date 28.10.95
Well name SB4a/s	Test name VM14	Engineer C. Enachescu / J. Wozniewicz

Reference point (Note: Depths reported are measured along borehole unless otherwise noted) Ground Level

Latitude 673 252	Longitude 192 213	Elevation [m asl] 942.3 m asl

Drilling method Core drilling

Target well inclination [°] 45	Nominal well diameter [mm] 124.00	Well depth [m aBH] 858.20
Casing shoe depth [m aBH]	Cement shoe depth [m aBH]	Casing OD [inch]
84.40 10 3/4"		10 3/4"
178.30 8 5/8"	178.30	8 5/8"
416.00 5.5"	416.00	5.5"

Tubing ID [mm] 50.7	Tubing specific capacity [litres/m length] 2.019

Start drilling 10.05.95 at 13:00	Stop drilling 27.09.95 at 09:40	Drilling through interval top 28.07.95 at 07:00	Drilling through interval bottom 28.07.95 at 11:30

Start geophysics 08.10.95	End geophysics 17.10.95

Geophysical methods Schlumberger deviation measurements and other logs prior to testing. The target deviation is 45°. Fluid logging conducted as well prior to test

Start testing 28.10.95 at 07:23	End testing 04.11.95 at 01:43

Packer assembly configuration 3 1\2" Double Packer

UPLS [m aBH] (depths not corrected for borehole inclination) 524.70	Top of interval [m aBH] 524.70
LPUS [m aBH] 527.70	Base of interval [m aBH] 527.70
LPLS [m aBH] 528.98	Well depth [m aBH] 858.20
Interval length [m] 3.00	Interval volume [m3] 0.04
Guard zone length [m] 329.22	Guard zone volume [m3] 3.98

Packer size ["] 3 1/2	Seal length [m] 1.28	Inflation pressure [kPa] 7000	Inflation fluid Water

Gauge description Serial number 505 (calibrated 0 to 2000 psi)

P1 depth [m aBH] 521.34	P2 depth [m aBH] 521.09	P3 depth [m aBH] 520.84

Shut-in tool type Zero displacement, pressure activated

Pumping equipment N/A

Flow control board - flowmeter used 2 Brooks 5850 E Series gas flowmeters in parallel (B1 & B2 BASYS channel names); Brooks 5850 TR series (B3 BASYS channel name) used for gas injection

Mud losses while drilling through interval . The mud density was measured at the surface while drilling through the interval and shown to be between 1072 and 1073 g/cm^3. A total of 940 litres of fluid was lost to the formation while drilling from 521.20 to 532.60 m aBH. Daily flow check showed -0.3 and -2.3 l/min.	Mud pressure while drilling through interval [bar] 27 to 29 (GEMAG)
Mud viscosity [Pa s] not measured	Mud density [kg/m3] 1040 (Foralith;17.10.95); 1007 (P2 gauge check prior to test)

Other activities prior to test The interval was cored from 07:00 on 28.07.95 to 11:30 on 28.07.95. Borehole SB4a/s is being drilled at a target deviation of 45 ° from the vertical. All reported depths are measured along the borehole (m aBH) unless otherwise noted. The fluid level in the borehole was monitored for 64 minutes and was decreasing at an equivalent rate of -0.03 l/min. Tests VM5 to VM8 were performed and then the sequence of coring and testing continued to the total depth (858.20 m aBH). Tests VM5, VM6, VM7 and VM8 all encompass the VM14 interval. After completion of the single packer tests in the bottom approximately 120 m, geophysical surveys were performed and a followed by a 'round trip' to 'clean-up' the borehole. Test VM11 (448.00 to 457.46 m aBH) was performed between 18.10.95 and 24.10.95. A second 'round trip' was then performed. Tests VM12 (26 to 27.10.95) and VM13 (27 to 28.10.95) were then carried out.

Measured flow rate in tubing during COM [l/min]: -5.00E-04 (see testing logbook for details)	Duration of wellbore history [h] 2208 (time from drilling through top of interval to start of test)

Annulus and guard zone information The P1 and P3 pressures declined steadily throughout the test with no suggestion of packer bypass. The P3 pressure declined from 3844 kPa at start of the test to 3834 kPa at packer deflation. The P1 pressure declined from 3910 kPa at start of test to 3584 kPa at packer deflation. Fluid was flowing from the annulus throughout the test at an average rate of approximately 1.1E-02 l/min.

Geology marly clays and limestone marls, ductile shear zone

Test objective (s)

Transmissivity	Initial pressure	Flow geometry	Gas threshold pressure	Residual Gas Saturation
Yes	Yes	Yes	Yes(Primary)	No

TESTING DATA FORM 3 - TRANSDUCER BENCH TEST

Project NAGRA WELLENBERG	Location Wellenberg, Canton Nidwalden	Date 25.10.95
Well name SB4a/s	Test name VM14	Engineer C. Enachescu/J. Wozniewicz

Transducer description	Output units
0 to 2000 psi Full Scale (Serial Number 505)	kPa

P1 #	P2 #	P3 #
44383	44372	44374
P1 multiplier N/A	P2 multiplier N/A	P3 multiplier N/A

Pretest bench test (Date:25.10.95)

Measurement conditions (P and T)	Sampling rate
100 kPa, 14°C	10 seconds

Nr.	P1	P2	P3	Nr.	P1	P2	P3
1	99.41	98.85	99.08	6	99.44	98.95	99.14
2	99.41	98.90	99.13	7	99.48	98.96	99.16
3	99.43	98.90	99.12	8	99.47	98.98	99.13
4	99.44	98.92	99.13	9	99.47	98.96	99.12
5	99.43	98.87	99.20	10	99.46	98.96	99.13

P1 average	P2 average	P3 average
99.45	98.93	99.13
Zero adjust shift P1 +0.55	Zero adjust shift P2 +1.07	Zero adjust shift P3 +0.87

1. Zero adjust	Sampling rate
N/A	10 sec

Nr.	P1	P2	P3	Nr.	P1	P2	P3
1	99.8408	100.041	99.7919	6	99.8544	100.058	99.7817
2	99.8348	100.064	99.7697	7	99.8646	100.037	99.7795
3	99.8647	100.093	99.7415	8	99.8411	100.040	99.7750
4	99.8403	100.047	99.7925	9	99.8387	100.004	99.7647
5	99.8302	100.093	99.7654	10	99.8475	100.064	99.7437

P1 average	P2 average	P3 average
99.8457 kPa	100.0541 kPa	99.77056 kPa
Zero adjust shift P1 N/A	Zero adjust shift P2 N/A	Zero adjust shift P3 N/A

2. Zero adjust	Sampling rate
N/A	N/A

Nr.	P1	P2	P3	Nr.	P1	P2	P3
1	-	-	-	6	-	-	-
2	-	-	-	7	-	-	-
3	-	-	-	8	-	-	-
4	-	-	-	9	-	-	-
5	-	-	-	10	-	-	-

P1 average	P2 average	P3 average
N/A	N/A	N/A

After test bench test (Date:09.11.95) -

Measurement conditions	Sampling rate
100 kPa, 13°C	10 s

Nr.	P1	P2	P3	Nr.	P1	P2	P3
1	98.0845	98.7316	98.1756	6	98.0705	98.5969	98.1777
2	98.1082	98.7089	98.1907	7	98.0686	98.5645	98.1792
3	98.1012	98.6619	98.1661	8	98.0967	98.5756	98.1562
4	98.0788	98.6255	98.1414	9	98.0663	98.5753	98.1566
5	98.0851	98.6347	98.1718	10	98.0819	98.5657	98.1648

P1 average	P2 average	P3 average
98.0842 kPa	98.6241 kPa	98.1680 kPa

Golder Associates

Project	Location	Date
NAGRA WELLENBERG	Wellenberg, Canton Nidwalden	2.12.94
Well name	Test name	Engineer
SB4a	VM1	C. Enachescu/J. Wozniewicz

1. Flowmeter

Flowmeter description			Output units		
RHM06			kg/min		
Flowmeter serial #			Calibration device		
13840994			Calibrated by manufacture prior to testing		
Multiplier			Shift		
2.25			No shift except to zero adjust prior to the start of test		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1	2.6	2.97	3	2.8	2.91
2	2.8	2.93	4	2.8	2.86
Multiplier			Shift		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1			3		
2			4		

2. Flowmeter

Flowmeter description			Output units		
Micro Motion			Kg/min		
Flowmeter serial #			Calibration device		
21140			Calibrated by manufacture prior to testing		
Multiplier			Shift		
2.25			N/A		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1	2.6	2.63	3	2.8	2.74
2	2.8	2.76	4	2.8	2.70
Multiplier			Shif		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1			3		
2			4		

3. Flowmeter

Flowmeter description			Output units		
Flowmeter serial #			Calibration device		
Multiplier			Shift		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1	N/A	N/A	3		
2			4		
Multiplier			Shift		
Nr	Manual measurement value	Flowmeter value	Nr	Manual measurement value	Flowmeter value
1			3		
2			4		

Tally List 3 1/2" Double Packer

TOOL	8.87	TU 14	8.92	TU 32	8.92	TU 50	8.94				
TU 1	8.93	TU 15	8.93	TU 33	8.92	TU 51	8.94				
TU 2	8.94	TU 16	8.93	TU 34	8.92	TU 52	8.88				
TU 3	8.91	TU 17	8.92	TU 35	8.93	TU 53	8.92				
XO	0.12	TU 18	8.93	TU 36	8.93	TU 54	8.93				
STATOR	1.83	TU 19	8.93	TU 37	8.93	TU 55	8.93				
XO	0.12	TU 20	8.92	TU 38	8.92	TU 56	8.93				
PJ 0	1.01	TU 21	8.92	TU 39	8.93	TU 57	8.92				
TU 4	8.92	TU 22	8.91	TU 40	8.93	PJ 1	3.03				
TU 5	8.92	TU 23	8.93	TU 41	8.93	PJ 2	3.03				
TU 6	8.91	TU 24	8.93	TU 42	8.95	PJ 3	2.00				
TU 7	8.93	TU 25	8.92	TU 43	8.93						
TU 8	8.93	TU 26	8.92	TU 44	8.92						
TU 9	8.92	TU 27	8.92	TU 45	8.93						
TU 10	8.93	TU 28	8.92	TU 46	8.94						
TU 11	8.90	TU 29	8.91	TU 47	8.94						
TU 12	8.92	TU 30	8.92	TU 48	8.94						
TU 13	8.93	TU 31	8.93	TU 49	8.93						
	127.94		160.61		160.74		79.45		0.00		0.00
							TOTAL STRING LENGTH:				528.74

Note:

Interval: 0.7 m upper packer stick down+ 0.5 m 1.9" TU+1.5 m 1.9"TU(bottom 10 cm perforated)+0.30 m packer stick up

All depths shown are measued along the borehole.

Table height and stick up measured along borehole angle.

Tally List Sucker Rods:

ROTOR	1.73	SR 17	9.08	SR 35	9.09						
PJ 1	0.74	SR 18	9.11	SR 36	9.12						
SR 1	9.12	SR 19	9.07	SR 37	9.13						
SR 2	9.11	SR 20	9.13	SR 38	9.10						
SR 3	9.11	SR 21	9.13	SR 39	9.11						
SR 4	9.10	SR 22	9.11	SR 40	9.06						
SR 5	9.07	SR 23	9.06	SR 41	9.11						
SR 6	9.07	SR 24	9.09	SR 42	9.07						
SR 7	9.12	SR 25	9.10	SR 43	9.08						
SR 8	9.13	SR 26	9.11	SR 44	9.13						
SR 9	9.12	SR 27	9.06	SR 45	9.12						
SR 10	9.12	SR 28	9.10	PJ 2	1.23						
SR 11	9.13	SR 29	9.10	PJ 3	1.86						
SR 12	9.12	SR 30	9.13								
SR 13	9.13	SR 31	9.11								
SR 14	9.05	SR 32	9.13								
SR 15	9.11	SR 33	9.12								
SR 16	9.12	SR 34	9.08								
	148.20		163.82		103.21		0.00		0.00		0.00
							TOTAL STRING LENGTH:				415.23

table height:	-3.40	m aBH	stop pin (length):	492.69	m
stick up:	-0.64	m below Table	stop pin (depth):	488.65	m aBH
upper packer lower seal:	524.70	m aBH	stick up sucker rods:	-0.20	m
lower packer upper seal:	527.70	m aBH	max. length sucker rods:	492.39	m
final depth:	858.20	m aBH	min length sucker rods:	491.89	m
interval length:	3.00	m	distance stop pin - rotor:	77.66	m
borehole radius:	0.062	m	target inclination	45.00	Deg
interval volume:	0.04	m3	assumed mud density:	1020.00	kg/m^3
depth p3:	520.84	m aBH	expected p3 reading:	3785.14	kPa
depth p2:	521.09	m aBH	expected p2 reading:	3786.91	kPa
depth p1:	521.34	m aBH	expected p1 reading:	3788.68	kPa

MASTER TESTING DATA FORM (MTDF) G-2 Golder Associates COLENCO POWER CONSULTING

Project / Borehole		Test		Test date & start time	
NAGRA WLB - SB4a/s		VM1		01.07.95, 14:25	
Task	**Subtask**	**Completed by Date**	**Signature**	**Checked by Date**	**Signature**
A - Data acquisition	**GA+BOT**				
A 1	Pressure transducer bench test (Form 3) GA+BOT				
A 2	Flowmeter bench test (Form 4) GA+BOT				
A3	Inspection of Core and Caliper info (NAGRA)+GA				
A4	Tally list (Form 5) GA+BOT				
A5	Tool layout (Form 1S) GA+BOT				
A6	Pertinent information (Form 2) GA				
A7	Test design and calculations GA				
A8	Testing Log Book GA				
A9	Data backup / Test completed GA				
B - Quick Look Report (QLR)	**GA**				
B1	Data preparation GA				
B2	Test analysis GA				
B3	Tables GA				
B4	Comments GA				
B5	Drafting GA				
B6	QA - documents GA				
B7	Data management GA				
B8	Data backup GA				
B9	Copy sent to NAGRA GA				
B10	Data transfer to NAGRA GA				

MASTER TESTING DATA FORM (MTDF) G-12 Golder Associates COLENCO POWER CONSULTING

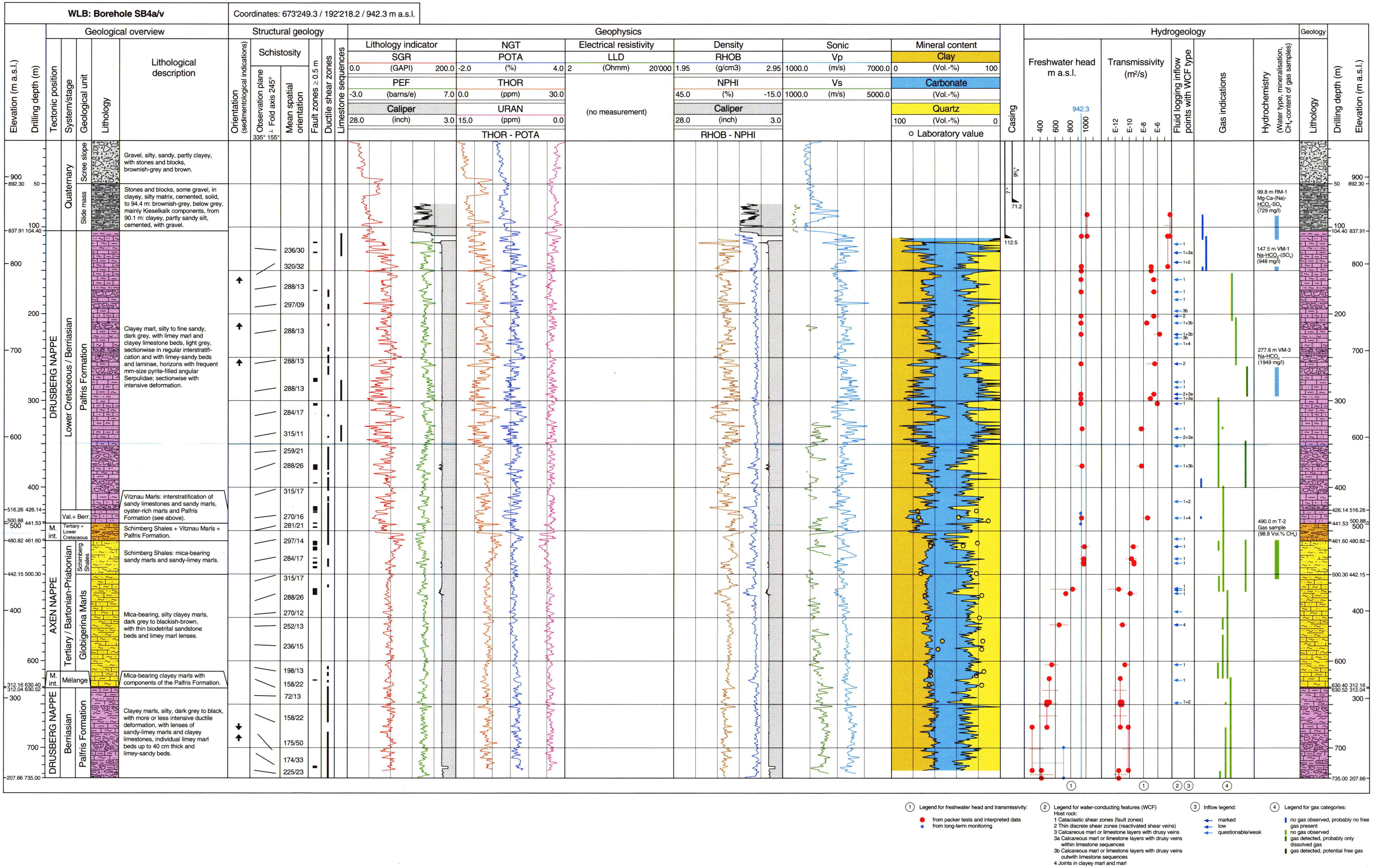
Project / Borehole		Test		Test date & start time	
NAGRA WLB - SB4a/s		VM1		01.07.95, 14:25	

Task	Subtask	Completed by Date	Signature	Checked by Date	Signature
D - QLR QC CPC					
D1	Test documentation CPC				
D2	Analysis assumptions CPC				
D3	Interpretations CPC				
D4	Parameter calculations CPC				
D5	Internal consistency CPC				
D6	QC - report CPC				
E - QLR approved and accepted NAGRA PL					
F - QLR documents sent to Celle GA					
G - Test classification NAGRA PL					
STANDARD INTERPRETATION BY GA / CPC TO BE DONE: YES / NO					
H - Standard Analysis GA+CPC					
H1	Transfer QLR-QC doc. and comments to GA NAGRA				
H2	QLR-QC comments addressed GA				
H3	Fast GTFM analysis CPC				
H4	Transfer GTFM analysis doc. to GA CPC				
H5	Additional Standard Analysis GA+CPC				
H6	Confidence limits assigned to QLR results GA+CPC				
H7	QLR analysis incorporated in: IR.: VM1-4/ NAGRA NIB: 95-15A GA				
I - Standard Analysis approved and accepted NAGRA PL					

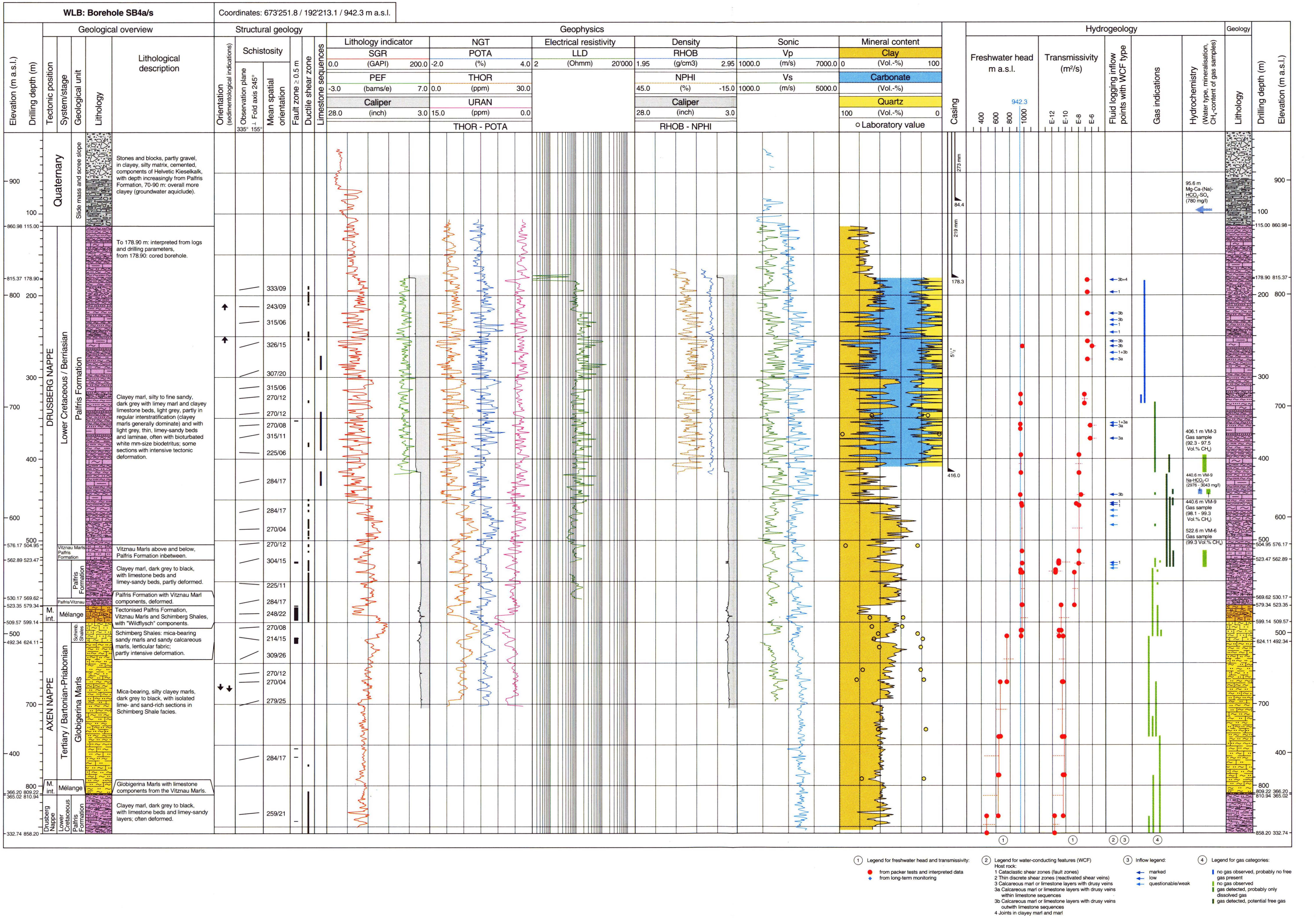
MASTER TESTING DATA FORM (MTDF) G-4 Golder Associates COLENCO POWER CONSULTING

Project / Borehole		Test		Test date & start time	
NAGRA WLB - SB4a/s		VM1		14.06.95, 22:00	
Task	**Subtask**	**Completed by Date**	**Signature**	**Checked by Date**	**Signature**
DETAILED INTERPRETATION BY GA / CPC TO BE DONE: YES / NO					
J - Detailed Analysis (IR)	**CA+CPC**				
J1	Test analysis GA				
J2	Sensitivity analysis GA				
J3	Tables GA				
J4	Comments (to section 8,9 inc.) GA				
J5	QA - documents GA				
J6	Transfer draft to CPC GA				
J7	GTFM analysis CPC				
J8	Transfer GTFM-results to GA CPC				
J9	Final comments GA+CPC				
J10	Report review by Golder Celle GA				
J11	Incorporate review comments GA				
J12	Results of other tests performed in interval GA+CPC				
J13	Data management GA				
J14	Data backup GA				
J15	Copy sent to NAGRA GA				
K - IR approved and accepted	**NAGRA PL**				

APPENDIX E: SUMMARY OF GEOLOGIC, GEOPHYSICAL AND HYDROGEOLOGICAL DATA FOR SB4A/VERTICAL AND SB4A/SLANTED



Composite log of borehole SB4a/v E2



Composite log of borehole SB4a/s E3