FORGE

Fate Of Repository Gases

European Commission FP7

Progress report on HG-A and HG-C experiments at Mont Terri

FORGE Report D4.10 and D5.6 – VER.0

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Euratom 7th Framework Programme Project: FORGE

EURATOM

Fate of repository gases (FORGE)

The multiple barrier concept is the cornerstone of all proposed schemes for underground disposal of radioactive wastes. The concept invokes a series of barriers, both engineered and natural, between the waste and the surface. Achieving this concept is the primary objective of all disposal programmes, from site appraisal and characterisation to repository design and construction. However, the performance of the repository as a whole (waste, buffer, engineering disturbed zone, host rock), and in particular its gas transport properties, are still poorly understood. Issues still to be adequately examined that relate to understanding basic processes include: dilational versus visco-capillary flow mechanisms; long-term integrity of seals, in particular gas flow along contacts; role of the EDZ as a conduit for preferential flow; laboratory to field up-scaling. Understanding gas generation and migration is thus vital in the quantitative assessment of repositories and is the focus of the research in this integrated, multi-disciplinary project. The FORGE project is a pan-European project with links to international radioactive waste management organisations, regulators and academia, specifically designed to tackle the key research issues associated with the generation and movement of repository gasses. Of particular importance are the long-term performance of bentonite buffers, plastic clays, indurated mudrocks and crystalline formations. Further experimental data are required to reduce uncertainty relating to the quantitative treatment of gas in performance assessment. FORGE will address these issues through a series of laboratory and field-scale experiments, including the development of new methods for up-scaling allowing the optimisation of concepts through detailed scenario analysis. The FORGE partners are committed to training and CPD through a broad portfolio of training opportunities and initiatives which form a significant part of the project.

Further details on the FORGE project and its outcomes can be accessed at www.FORGEproject.org.

Progress Report (Month 24)
For Forge WP4/Task 4.3 and WP5/Task 5.2.2

Date: 30.05.2011

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1 Introduction

This report documents progress regarding the HG-A and HG-C/D experiments at the Mont Terri rock laboratory during the FORGE Project together with relevant information provided to participants in FORGE WP 4.3 and WP 5.2.2. Information relating to the two experiments (HG-A considered within FORGE WP 4.3, HG-C/D considered within FORGE WP 5.2.2) are presented within the same document as there is a significant overlap between the two tasks and some modelling teams are involved in both WP 4.3 and WP 5.2.2. The modelling teams have been working within a joint HG-A/HG-C modelling group coordinated by Nagra.

The document is organised, in four sections:

- Introduction
- Information on the HG-A experiment.
- Information on the HG-C experiment.

A previous report (FORGE Deliverable D4.3/D5.2) presented information on the two experiments corresponding to Project deliverables:

D4.3 Report – compilation of existing data (Mont Terri) WP4.2.1

D5.2 Design, installation and compilation of existing data for the HG-C experiment at Mont Terri WP5.2.2

This short report provides an update on experimental progress and on information provided to the modelling groups.

The HG-A and HG-C/D in-situ experiments and supporting laboratory studies are not funded by the EU, but are presented here as they are the focus of modelling studies by the participants of FORGE Task 4.3 and WP 5.2.2.

2 Information relating to modelling of HG-A

2.1 The HG-A Experiment

The HG-A experiment has been planned as a long-term in-situ test at the Mont Terri URL, aimed at investigating under realistic conditions the hydro-mechanical evolution of a backfilled and sealed tunnel section. Specific objectives of the project are:

- Extension of the conceptual understanding of damage zones around cylindrical excavations (creation and long-term evolution of the EDZ)
- Determination of hydraulic conductivity of the Opalinus Clay on the tunnel scale (upscaling of hydraulic properties from borehole scale to repository scale)
- Investigation of self-sealing processes along the damage zones around backfilled tunnels
- Estimation of typical gas leakage rates from sealed tunnel sections.

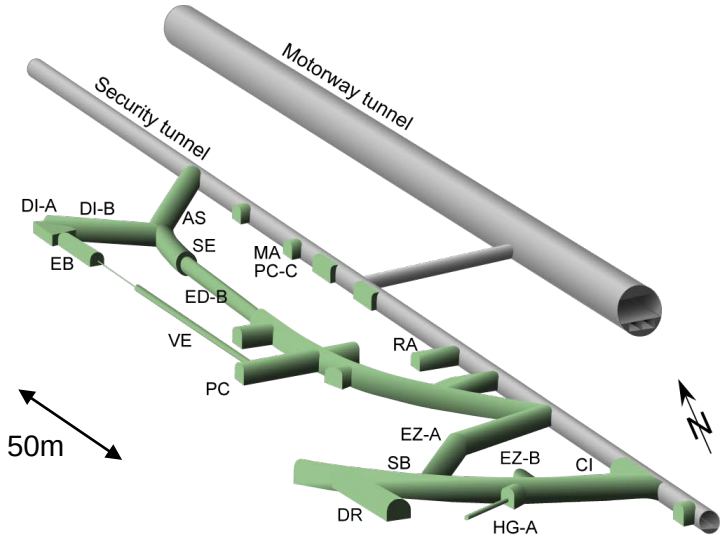

Figure 1: Schematic of Mont Terri URL showing HG-A niche and microtunnel in lower right.

The HG-A experiment is located in a niche off Gallery 04 as shown in Figure 4. The HG-A microtunnel is oriented parallel to the strike of the bedding planes in the Opalinus at that location. In this area of the URL, the shaly facies are composed of marly shales with numerous lenses of grey/white sandy limestones and weakly cemented fine-grained brownish siderite layers.

2.2 Current Status

The experiment has been planned in 6 phases: (i) the excavation of a microtunnel and monitoring of key geotechnical parameters during the open tunnel phase, (ii) backfilling and sealing of the tunnel with a large-size hydraulic packer system (iii) artificial resaturation of the sealed tunnel section, (iv) a series of long-term water injection tests for determining the hydraulic conductivity of the rock on the tunnel scale, (v) gas injection tests and, finally, (vi) the dismantling of the test site. Currently the project is in phase v) having performed the first two gas injections. Data from phases iii) to v) are shown in Figure 2. Data from phase v) only is shown in Figure 3.

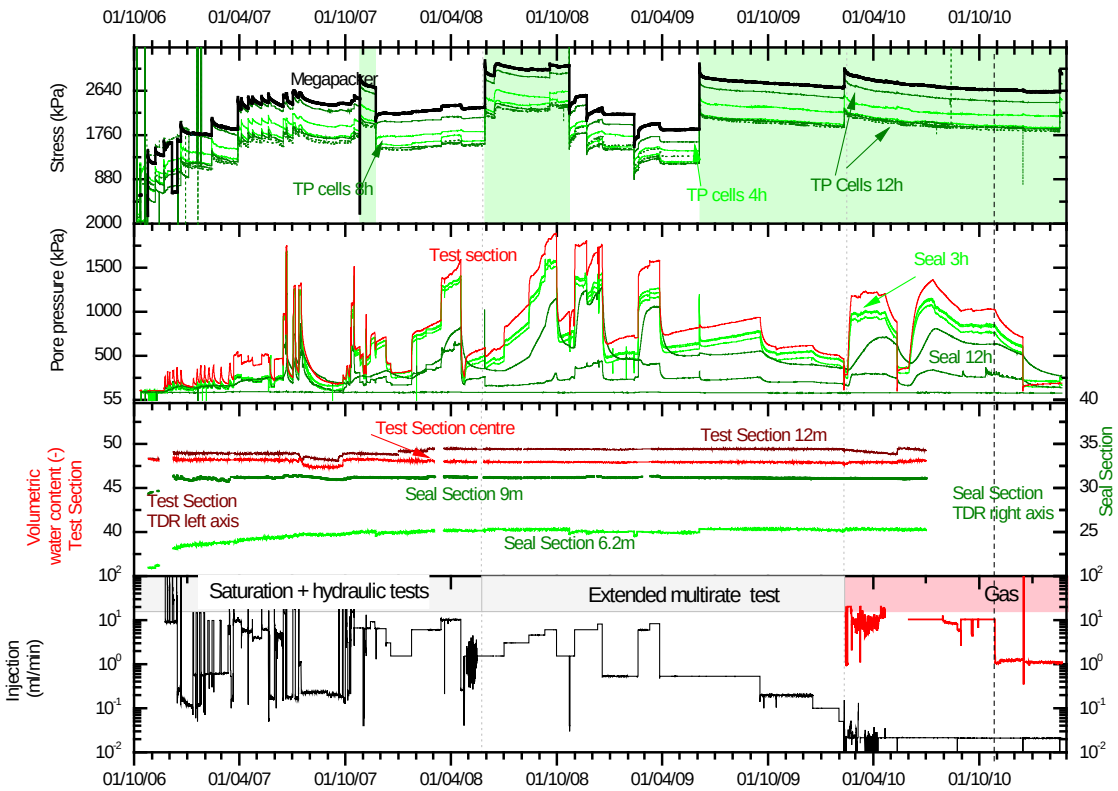

Figure 2 Summary data from HG-A water and gas injection phases (01/10/06-01/02/11)

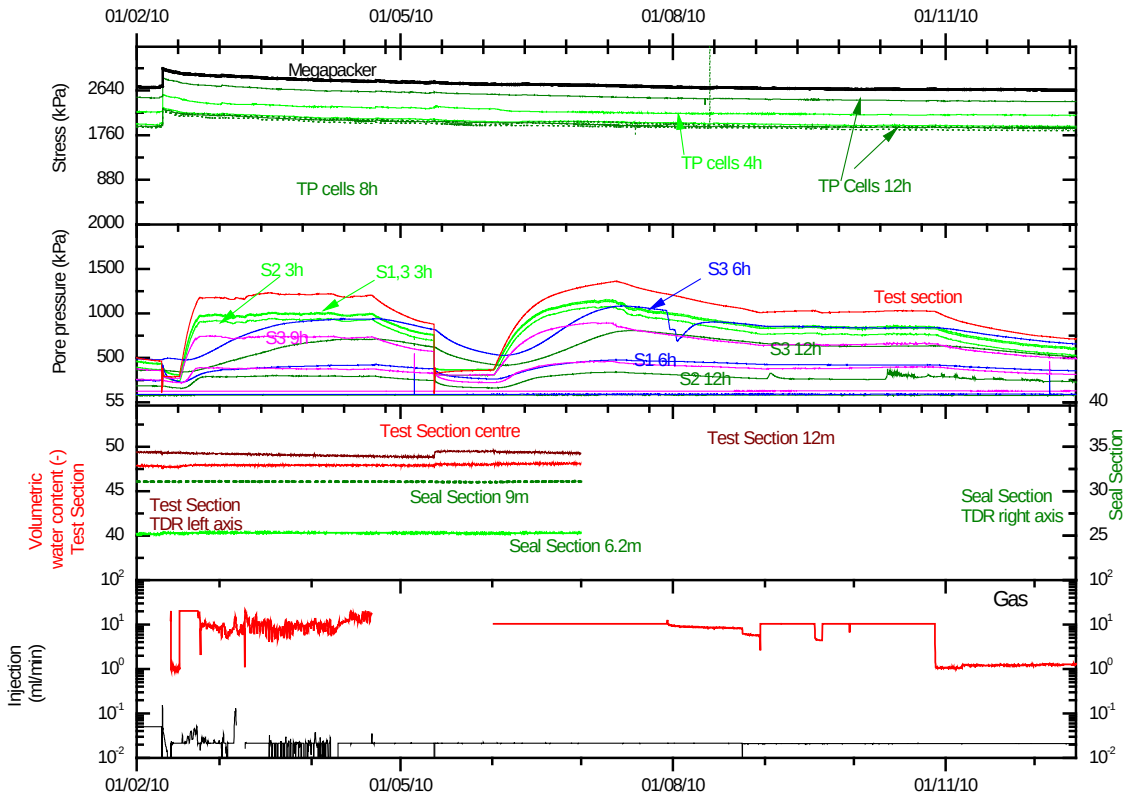

Figure 3 Summary data from HG-A gas injection phases (01/10/06-01/02/11)

2.3 Data Deliveries to Modellers

Deliverable D4.3/5.2 described information provided to modellers up to and including HG-A/HG-C Data Deliverable 4 (February 2010). Since then the following additional material has been provided regarding HG-A:

Data Delivery 6: HG-A Hydro

The contents of this delivery is listed in Appendix A.

In adddition to the data deliveries a set of performance measures for model comparison have been defined and distributed to modellers. The aim was to provide a common framework for comparing results from different models and data from the experiment.

A comparison of results (facilitated by Nagra) should allow the development of more general (i.e. not model specific) conclusions regarding the experiments and more generally modelling of gas flow in the undisturbed and disturbed rock.

A list of the suggested performance measures is presented in Appendix B.

3 Information related to modelling HG-C/D

3.1 The HG-C/D Experiment

The layout of the experiment is shown in Figure 3. Four parallel boreholes equipped with Piezometers and Fixed Installed Micrometers (FIMs) are located in the floor of the New Gallery at Mont Terri. The boreholes intersect a bedding parallel feature that was activated within the GS/GPA experiments (Daneshy et al. 2004). The HG-C experiment consisted of step hydraulic pressure tests followed by a step gas pressure test. A fuller description of HG-C and previous experiments (GS/GPA) at the HG-C/D experiment site was presented in a compilation of information provided as Deliverable 5.2.

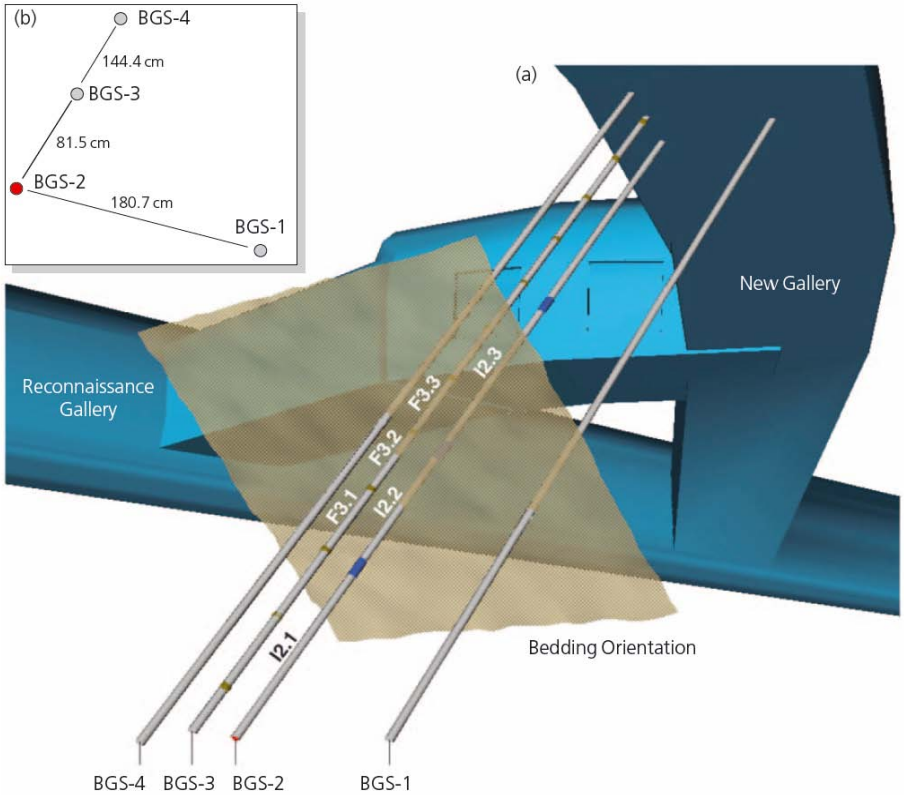

Figure 4 Layout of HG-C experiment at Mont Terri. Situation prior to drilling borehole HG-D1.

3.2 Current Status

A fifth borehole HG-D1 has been drilled as part of a new project (HG-D) to extend the HG-C experiment. The new borehole has been cored, logged and imaged and a triple packer system has been installed. A first phase of hydraulic and gas testing in HG-D1 has now been completed. The pressure monitoring and FIM data from these phases are shown in Figure 5and Figure 6.

The injection interval HG-D1i2 is located in an “undisturbed “ part of the rock thought not to be affected by the GS/GPA hydrofracture. Pressure data show a small response to hydraulic testing in GS2 and one interval of GS1. A more significant response to gas testing has been observed in GS1PE1 (bottom of GS1). Some problems have been encountered with FIM data and it is believed that at least 2 of the FIM sensors is no defective. However possible response to gas injection are visible in 2 of the GS3 FIMs.

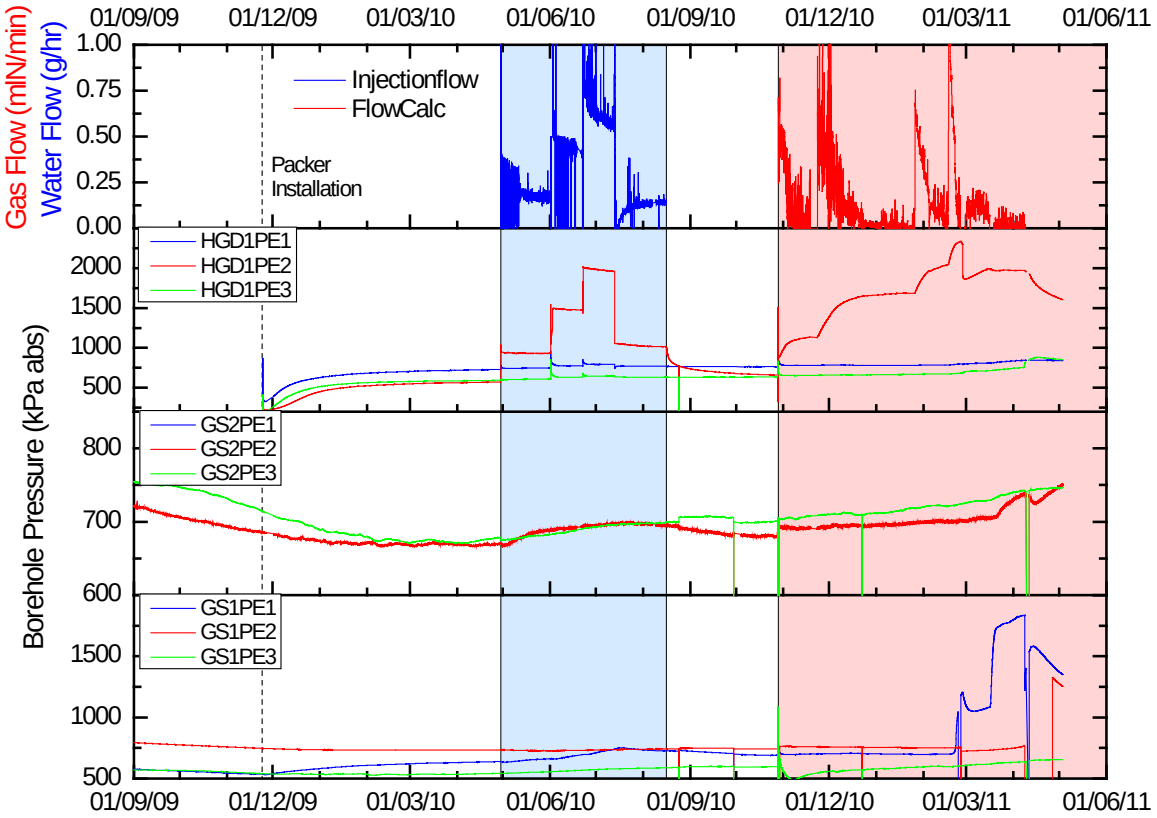

Figure 5 Overview of pressure and flow data from hydraulic and gas testing in HG-D1.

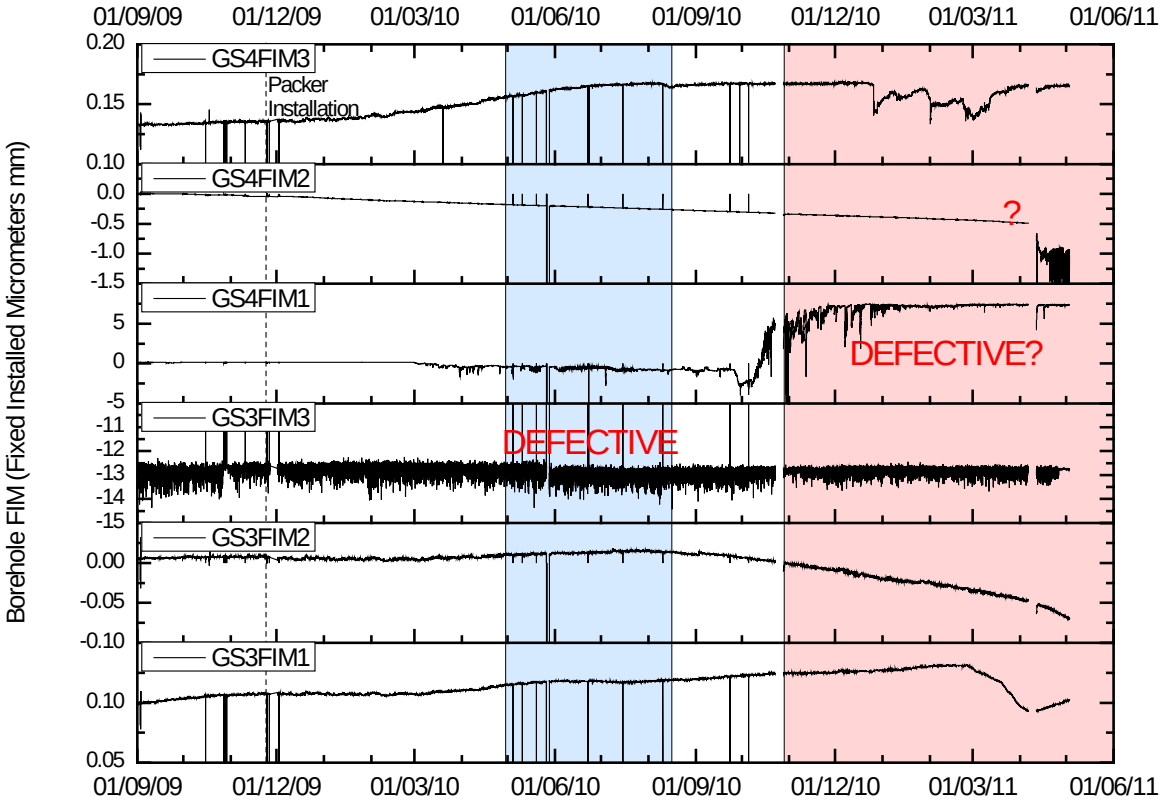

Figure 6 Overview of FIM data from hydraulic and gas testing in HG-D1.

3.3 Data Deliveries to Modellers

Deliverable D4.3/5.2 described information provided to modellers up to and including HG-A/HG-C Data Delivery 4 (February 2010). Since then the following additional material has been provided regarding HG-C/D.

Data Delivery 5: Data from the GS/GPA tests

Data Delivery 7: HG-D data

The contents of these deliveries are listed in Appendix C.

To facilitate possible "blind prediction" studies by GRS for the HG-D experiment. Monitoring system response data has been stripped from the data included in Data Delivery 7 and a set of model comparison measures were suggested (see Appendix D).

It is planned to provide the full dataset to the modellers when any blind prediction activities have been completed.

References

Daneshy, A., Blümling, P., Marschall, P., Zuidema, P. (2004). Interpretation of Field Experiments and Observation of Fracturing Process. SPE 86486 presented at the SPE International Symposium and Exhibition on Formation Damage Control held in Lafayette, Louisiana, U.S.A., 18–20 February 2004.

Appendix A Description of HG-A Data Deliveries (March 2010 on)

FORGE HG-A Data Package 6

Task 2 Hydro-Mechanical model of the HG-A experiment (EDZ creation & evolution)

The data covers the period needed for all of Task 2. Within the task description the hydromechanical modelling has been split into three steps as set out in the table below. For completeness Data Package 6 includes the data already sent out in Data Package 1 (from 18/02/05-31/12/05).

Table 1: Task 2 Steps and data packages

Step	Description	Data Package	Approximate period
1	EDZ Creation	1st data package data & this data package	18/02/05 - 07/03/05
2	EDZ Evolution during open tunnel phase	Data Package 6	07/03/05 - 06/06/06
3	Response to saturation and hydraulic testing	Data Package 6	06/07/06 - 01/02/10

Task 3: Design optimization of gas injection phase

The data package also covers the initial period of gas testing - a relatively low gas rate injection into the tunnel section where pressure was controlled to ensure no hydromechanical effects. The data can be used to calibrate or test existing models.

Interpolated field data

Field measurements have been linearly interpolated onto a 1hr time step to simplify data processing by the modellers. Even given this significant data reduction the dataset now contains approximately 47000 records. Raw data sampled at 2-5 minute intervals is also available if required.

The data is provided in a single Microsoft Excel (2007) workbook called HGAField1hr.xlsx. The file is large ~55Mb.

Data Trend Reports

Data trend reports describe the data acquired and significant test events during the period covered. They also identify instrumentation problems that may affect data quality. The data trend reports covering the period from 01/01/2006 to 03/06/2010 are included in the data package. Files sizes can be large due the inclusion of detailed plots of instrument response.

Data Trend Report	Period Covered	Size (Mb)
HGA-Data Trend Report-3_draft1_complete	01/01/2006-31/03/2006	9
HGA-Data Trend Report-4_complete	01/04/2006-30/09/2006	14
TN 2007-21_HGA_Data Trend Report 5	01/10/2006-30/06/2007	4
TN 2008-04_HGA_Data Trend Report 6	01/07/2007-30/06/2008	4
TN 2009-02_HGA_Data Trend Report 7 Phase14_V1	01/07/2008-30/06/2009	4
TN 2010-13_HGA_Data Trend Report 8 Phase15_final	01/07/2009-30/06/2010	4

Appendix B Suggested HG-A Model Comparison Measures

HG-A Excavation and evolution: From excavation to start of saturation				
Form	Property	Location	Time	Comment
Time history	Pressure (kPa)	B-A02PE1-PE3 B-A03PE1-PE3	17/02/05- 08/10/06	
Time history	Displacement (m)	B-A05DE01-4 B-A07DE01-4		
Section Snapshot	Water pressure (kPa)	Vertical plane YL=7.5 (seal)	25/02/05, 08/10/06	End of excavation and prior to start of saturation
Section Snapshot	Volumetric Strain (-)	Vertical plane YL=7.5 (seal)	25/02/05, 08/10/06	
Section Snapshot	Plasticity/failed zone	Vertical plane YL=7.5 (seal)	25/02/05, 08/10/06	
HG-A Saturation and Hydraulic Testing: From start of saturation to test-section degassing				
Form	Property	Location	Time	Comment
Time history	Pressure (kPa)	M-PECeiling M-PES1-3,6,9,12h M-PES2-3,6,9,12h M-PES3-3,6,9,12h	09/10/06- 08/02/10	
Time history	Displacement (m)	B-A05DE01-6 B-A07DE01-6		
Time history	Stress (MPa)	B-A21-23		Biaxial stress around borehole
Time history	Deformation (mm)	M-EH,M-EV		Zero at start of saturation
Section Snapshot	Water pressure (kPa)	Vertical plane YL=7.5 (seal)		Start of saturation+ Selected times
HG-A Gas Injection: From test section degassing to end of Gas Injection 3				
Form	Property	Location	Time	Comment
Time history	Pressure (kPa)	M-PECeiling M-PES1-3,6,9,12h M-PES2-3,6,9,12h M-PES3-3,6,9,12h	09/02/10- to be defined	
Time history	Displacement (m)	B-A05DE01-5 B-A07DE01-7		
Time history	Stress (MPa)	B-A21-23		Biaxial stress around borehole
Time history	Deformation (mm)	M-EH,M-EV		Zero at start of saturation

Section Snapshot	Water pressure (kPa)	Vertical plane YL=7.5 (seal)		
Section Snapshot	Saturation (-)	Vertical plane YL=7.5 (seal)		

Appendix C Description of HG-C Data Deliveries (March 2010 on)

FORGE HG-C/D Data Package 5

This data package contained reports descriping the GS/GPA testing:

- TN2000-06: GS and GP-A Experiments:Mobilisation and Borehole Instrumentation of BGS-1 and BGS-2
- TN2000-07: GP-A Experiment: Pre-frac hydraulic and gas longterm tests n borehole BGS-2.
- TN2000-08: GS and GP-A Experiments: Report on long term testing (water and gas) in boreholes BGS-2 (active) and BGS-1 (observation).
- TN2000-10:GS Experiment: hydraulic fracturing in BGS-2

FORGE HG-C/D Data Package 7

HG-C Subtask 2: Dataset update, predictive modelling/analysis of the new tests (HG-D borehole)

The data covers the period needed for modelling of the hydraulic testing in the HG-D borehole from 01/07/09-28/10/10. A further data package will be provided regarding the planned gas injection.

Data Package contents

Field data

Field data from the existing HG-C boreholes (pressure monitoring and FIM) and the new HG-D borehole have been included in a spreadsheet using a similar format to previous HG-C data (Data Package 4). Data from the main test periods have been removed (apart from the measured head in the injection interval) to allow blind prediction. A version of the spreadsheet with all data will be distributed at a later date.

Hydraulic Testing Report

A Quick Look Report describing the data acquired and significant test events during the period covered is included. They also identify instrumentation problems that may affect data quality

File	Period Covered	Size (Mb)
TN2010-46_HG-D_Phase15_final –nodata.pdf	24/11/09-28/11/10	>1
HG-DData010709-281010 TEST D1PE2Only.xls	01/07/09-28/10/10	7Mb

Appendix D Suggested HG-C/D Model Comparison Measures

HG-C hydraulic Testing				
Time history	Pressure (kPa)	GS1PE1-3 GS2PE1-3	14/12/06 17:49- 14/05/07 00:00	Start of hydraulic test and post shut-in
Time history	Deformation (μm)	GS3FIM1-3 GS4FIM1-3		
Section Snapshot	Water pressure (kPa)	Vertical Planes GS2-GS1 GS2-GS4	14/12/06 17:49 20/12/06 12:16 10/01/06 14:34 18/01/07 13:28 12/02/07 15:43 28/02/07 16:16 08/03/07 09:15 21/03/07 11:28 21/03/07 11:28 04/04/07 09:14 16/04/07 09:00 27/04/07 12:26	Start of each test phase + Shutin
HG-C Gas testing				
Time history	Pressure (kPa)	GS1PE1-3 GS2PE1-3	05/02/08 17:33- 19/09/08 00:00	
Time history	Deformation (μm)	GS3FIM1-3 GS4FIM1-3		
Section Snapshot	Water pressure (kPa)	Vertical Planes GS2-GS1 GS2-GS4	05/02/08 17:33 05/03/08 14:34 02/04/08 12:29 15/05/08 12:40 01/07/08 11:20 19/09/08 00:00	Start of each test phase + end
Section Snapshot	Gas pressure (kPa)	Vertical Planes GS2-GS1 GS2-GS4		
Section Snapshot	Water saturation (-)	Vertical Planes GS2-GS1 GS2-GS4		
HG-D hydraulic Testing				
Time history	Pressure (kPa)	GS1PE1-3 GS2PE1-3	To be defined	
Time history	Deformation (μm)	GS3FIM1-3 GS4FIM1-3		

HG-D Gas testing				
Time history	Pressure (kPa)	GS1PE1-3 GS2PE1-3	To be defined	
Time history	Deformation (μm)	GS3FIM1-3 GS4FIM1-3		
Section Snapshot	Water pressure (kPa)	Plane around BGS-2i1		
Section Snapshot	Water pressure (kPa)	Vertical Planes GS2-GS1 GS2-GS4		
Section Snapshot	Gas pressure (kPa)	Vertical Planes GS2-GS1 GS2-GS4		
Section Snapshot	Water saturation (-)	Vertical Planes GS2-GS1 GS2-GS4		

Not all sensors were working throughout the experiment time it was thought simplest to ask for all for the comparison rather than switch between instruments for each test phase.