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European Commission FP7

Design and Installation of the PGZ1 Experiment at Bure

FORGE Report D5.4 – VER.0

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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.

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Summary

This report describes the objectives, geometry and the first measurements of the in situ experiment PGZ1. PGZ1 is focus on the study of gas propagation in the undisturbed argillites.

This report is the first contribution to the Work Package 5 (deliverable 5.3: design and installation of the PGZ1 experiment at Bure).

Introduction

The PGZ experiments are part of an experimental and demonstration test programme at the Meuse/Haute-Marne Underground Research Laboratory.

One of the objectives of this experimental and demonstration test programme is to study the response of argillites to disturbances caused by a repository. In the PGZ experiments, the subject is the disturbances caused by gases generated by the radiolysis or anoxic corrosion of some of the waste packages and, where applicable, by the corrosion of the repository's steel components, e.g. high-level waste cells. This will particularly include gas transfer in undisturbed and disturbed argillites, as well as transfer through the sealing plugs and at interfaces.

This report contributes to the WP5 (deliverable D5.3: Design and installation of the PGZ1 experiment at Bure). This report describes the PGZ1 experiment since the start of equipment installation in the GED programme unit.

It is intended to show the main dates for installing equipment, the exact geometry and positions of the measuring points, and measurements of the water contents of samples, as well as preliminary measurements and their implications for the rest of the testing programme, for each test.

We first present the objectives and the methods employed for these experiments.

1.1 OBJECTIVES PGZ1

The objectives of PGZ1 are to use gas-injection tests to characterise the formation's internal gas-transfer properties. The goal is to confirm and provide additional support for the parameters and limits of the traditional biphasic model for describing gas transfer:

- Determination of the pressure at which gas can enter the undisturbed argillites and if possible the EDZ (excavation damaged zone),
- Determination of the threshold gas pressure above which pathway dilation occurs,
- Positioning of this threshold with respect to the fracturing pressure.
- Characterisation of the network of microfissures created (reversible or not).

The main objective of PGZ1 is to obtain an understanding and a quantification of the reaction of the undisturbed rock to gas below the fracturing pressure. This gas-injection test in undisturbed rock is identified as "Test PGZ1". Here it is primarily a matter of determining the gas entry pressure and the pressure above which pathway dilation may appear. In the conceptual representation of gas flows in clays it is considered that a mode of transfer exists, above a certain pressure figure. This mode of transfer, previously seen in bentonites, is associated with the opening of pathways for localised percolations.

The second part of the test involves gas fracturing, characterisation of the damage, and a study of the effects of self-healing in the rock.

The test consists of an injection borehole (PGZ1201), a borehole parallel to the injection hole for monitoring interstitial pressures (PGZ1202), and a borehole for monitoring rock deformation (PGZ1031). This borehole is perpendicular to borehole PGZ1201 and located about 1 m above it.

Significant uncertainties remain concerning the predicted orientation of the fracture. Accordingly, after the gas-fracturing stage a final borehole (PGZ1032) designed to measure

interstitial pressures should be drilled: it will enable assessment of the fracture's permeability to water and gas.

1.2 PROGRESS OF INSTALLATION

The following table shows the chronology of the drilling operations and the installation of equipment for Test PGZ1:

Table 1 Chronology of the bore-hole drilling phase of Test PGZ1

	PGZ1031	PGZ1201	PGZ1202
Drilling	July 2-3 2009	July 27-28 2009	July 29-30 2009
Installation of equipment	July 3-6 2009	July 28-29 2009	July 30 2009

The boreholes were cored with air. The external diameter is 76 mm for PGZ1201 and PGZ1202 and 101.3 mm for PGZ1031.

Geologic logging of these boreholes was carried out by GEOTER. The water contents measured in samples from these three boreholes are presented in Paragraph 1.4.1.

- Layouts are given in Appendix 4
- For this test, a sensor for air temperature and relative humidity was installed in the GED drift on August 20, 2009.
- For PGZ1031, a protective cover was installed on the borehole head on July 31 (Appendix 2).
- A gas module was put on place after installation of the equipment near PGZ1201, on October 2nd. Thermal-insulation cladding was placed around the hydraulic lines between the collar of borehole PGZ1201 and the control panel, and between the control panel and the gas module.

1.3 CONFIGURATION AND GEOMETRY OF THE PGZ1

1.3.1 Location of boreholes in drift

PGZ1 is located in the new drift GED of the French URL (see Figure 1).

- Borehole PGZ1031 was drilled in front of the GEX drift. This hole is inclined downwards and fitted with a strain gauge with 20 measuring points.
- Boreholes PGZ1201 and PGZ1202 were drilled in the GED drift at the base of the wall between sliding-ribs 20-21 and 19-20 respectively. These two boreholes are inclined downwards and fitted with two multi-packer completions, each with three intervals.

Appendix 1 and 2 respectively present the location drawing for the GED drift and photos of the boreholes after installation of the equipment.

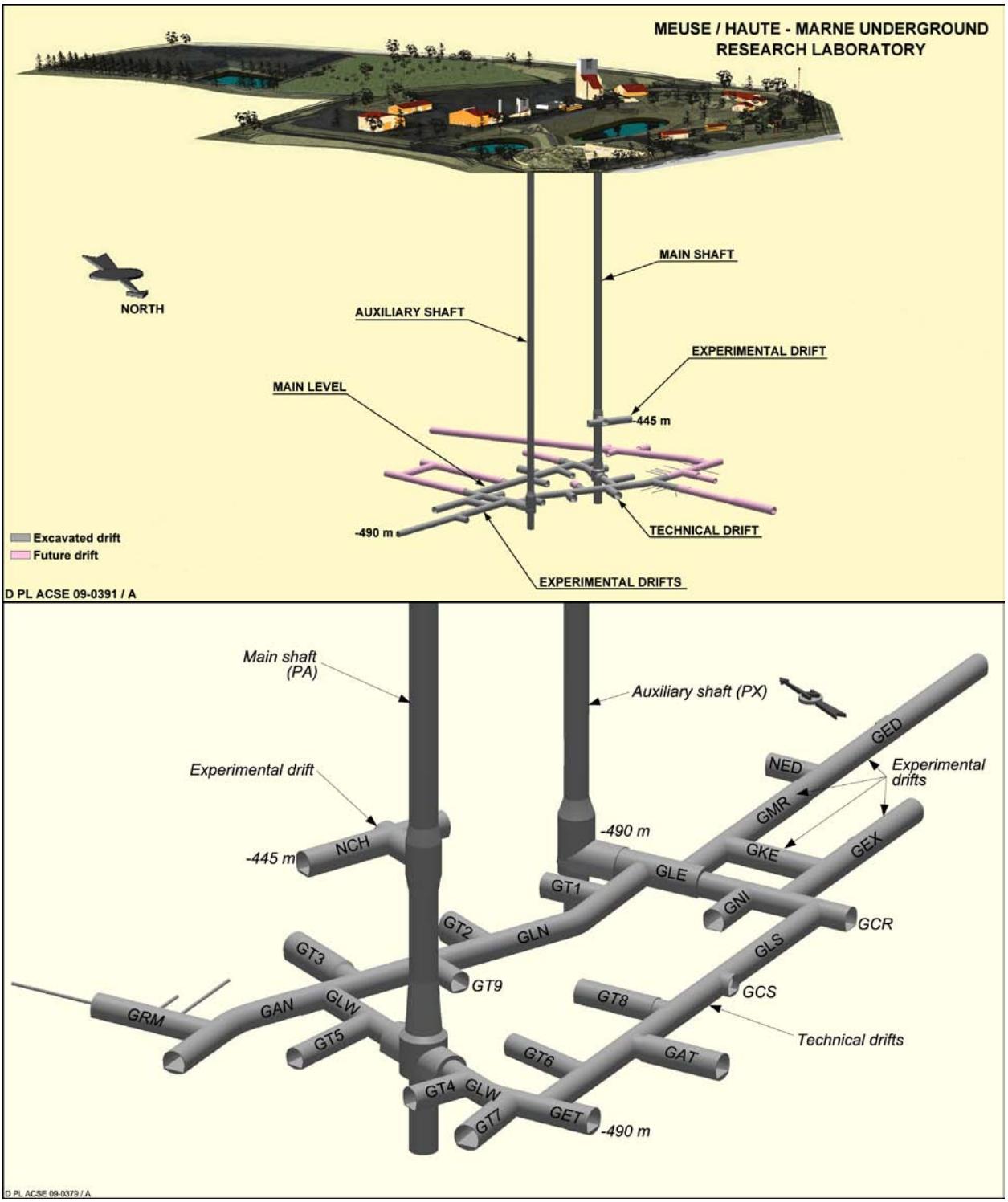


Figure 1 3-D view of the French URL

1.3.2 Geometric configuration of the boreholes

Figure 2 presents a 3-D view of all the PGZ boreholes, notably the holes for Test PGZ1.

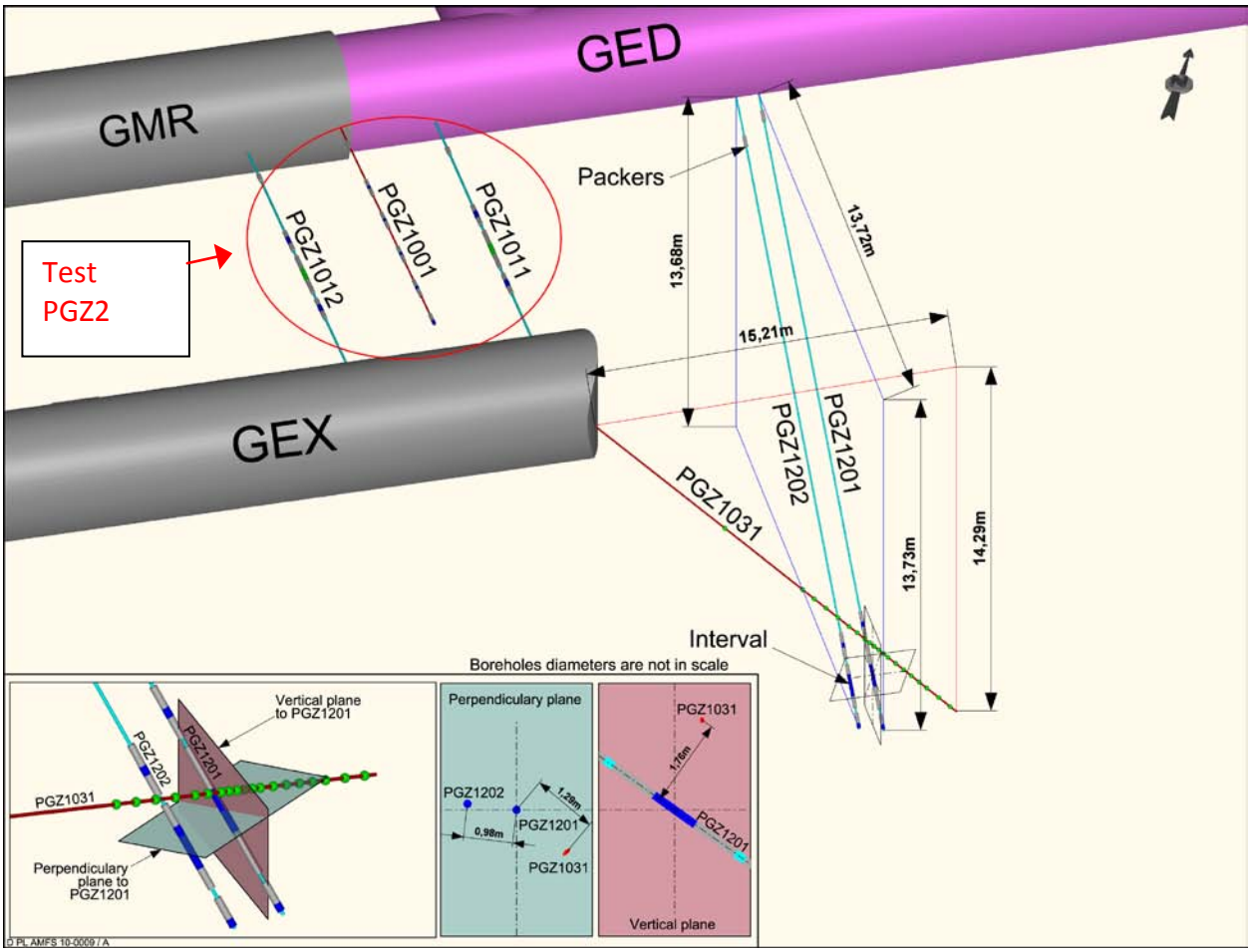


Figure 2 3-D view of the boreholes for the PGZ tests

The table below gives details of the geometry of the boreholes drilled (coordinates of points given in the Lambert 1 coordinate system).

Table 2 Geometry of boreholes in Test PGZ1

		PGZ1031	PGZ1201	PGZ1202
Coordinates of bore-hole mouth	X (m)	823221.037	823223.145	823222.305
	Y (m)	1091617.884	1091643.340	1091642.859
	Z (m)	-125.413	-125.464	-125.527
Diameter (mm)		101.3	76	76
3-D length collar - end (m)		23.27	28.54	28.14
Azimuth (°)		63.1	156.4	156.4
Inclination (°)		-47.8	-35.4	-35.7
Coordinates of end of hole	X (m)	823234.979	823232.456	823231.443
	Y (m)	1091624.957	1091622.030	1091621.920
	Z (m)	-142.656	-142.004	-141.952

In Table 2, the 3-D length corresponds to the length drilled, because the mouth of the borehole represents the physical attack of the drill bit on the wall of the drift.

The coordinates of the bottoms of the holes for PGZ1201 and PGZ1202 have been extrapolated. In fact, survey measurements could not be extended all the way to the bottom of these two holes because they deviated from their initial paths after 23 m and 18 m in PGZ1201 and PGZ1202 respectively. These figures are projections obtained by a linear regression on the last four measured points.

Consequently, the exact positions of the ends of these two bore-holes are unknown. The lengths of the two holes are accurate to about 2 cm, based on a combination of the measurements made by Brisset and by COFOR. The position of the ends of Bore-holes PGZ1201 and PGZ1202 fall within a disk having a radius of 10 cm.

1.3.3 Location of measuring points

1.3.3.1 PGZ1201

Borehole PGZ1201 is equipped with a multi-packer, three-interval completion. Appendix 4 shows the layout installed *in situ*. The injection interval in borehole PGZ1201 (SAGD notation PGZ1201_PRE_02) is one meter long and the other two measurement intervals, which are located on either side of Interval 2, are 0.2 m long.

The positions of the intervals are shown in Table 3 below:

Table 3 Coordinates of measurement intervals in PGZ1201

		X (m)	Y (m)	Z (m)
Interval 3 PGZ1201_PRE_03	Head	823230.869	1091625.659	-139.169
	Middle	823230.904	1091625.580	-139.231
	Foot	823230.938	1091625.501	-139.293
Interval 2 PGZ1201_PRE_02	Head	823231.490	1091624.240	-140.275
	Middle	823231.653	1091623.870	-140.566
	Foot	823231.817	1091623.500	-140.857
Interval 1 PGZ1201_PRE_01	Head	823232.368	1091622.243	-141.840
	Middle	823232.399	1091622.173	-141.894
	Foot	823232.429	1091622.104	-141.948

1.3.3.2 PGZ1202

Borehole PGZ1202 is equipped with a multi-packer, three-interval completion. Appendix 4 shows the layout installed *in situ*. The injection chamber in borehole PGZ1202 (SAGD notation PGZ1202_PRE_02) is one meter long and the other two measurement chambers, which are located on either side of Interval 2, are 0.2 m long.

The positions of the intervals are shown in

Table 4 below:

Table 4 Coordinates of measurement intervals in PGZ1202

		X (m)	Y (m)	Z (m)
Interval 3 PGZ1202_PRE_03	Head	823230.198	1091624.754	-139.701
	Middle	823230.232	1091624.675	-139.764
	Foot	823230.267	1091624.597	-139.826
Interval 2 PGZ1202_PRE_02	Head	823230.650	1091623.715	-140.525
	Middle	823230.811	1091623.345	-140.819
	Foot	823230.972	1091622.974	-141.113
Interval 1 PGZ1202_PRE_01	Head	823231.355	1091622.093	-141.811
	Middle	823231.385	1091622.024	-141.866
	Foot	823231.415	1091621.955	-141.921

1.3.3.3 PGZ1031

Borehole PGZ1031 is equipped with a strain gauge having 30 measurement contacts. Appendix 4 shows the layout installed *in situ*. Table 5 gives the coordinates of the measurement points at the time of installation.

Table 5 Coordinates of the PGZ1031 measuring points at installation

Name of SAGD point	X (m)	Y (m)	Z (m)
PGZ1031_DFO_20	823226.052	1091620.426	-131.590
PGZ1031_DFO_19	823229.048	1091621.942	-135.295
PGZ1031_DFO_18	823229.496	1091622.170	-135.852
PGZ1031_DFO_17	823229.945	1091622.398	-136.408
PGZ1031_DFO_16	823230.394	1091622.625	-136.964
PGZ1031_DFO_15	823230.843	1091622.853	-137.520
PGZ1031_DFO_14	823231.141	1091623.005	-137.891
PGZ1031_DFO_13	823231.440	1091623.157	-138.262
PGZ1031_DFO_12	823231.620	1091623.249	-138.484
PGZ1031_DFO_11	823231.800	1091623.340	-138.706
PGZ1031_DFO_10	823231.979	1091623.431	-138.929
PGZ1031_DFO_09	823232.158	1091623.521	-139.152
PGZ1031_DFO_08	823232.337	1091623.612	-139.375
PGZ1031_DFO_07	823232.635	1091623.764	-139.746
PGZ1031_DFO_06	823232.934	1091623.916	-140.118

PGZ1031_DFO_05	823233.232	1091624.068	-140.489
PGZ1031_DFO_04	823233.531	1091624.220	-140.860
PGZ1031_DFO_03	823233.830	1091624.373	-141.230
PGZ1031_DFO_02	823234.278	1091624.601	-141.787
PGZ1031_DFO_01	823234.727	1091624.829	-142.343

1.3.4 Relative positions of measuring points

Interval 2 in PGZ1201 is the interval where the various hydraulic (water and gas) tests will be performed. The positions of the observation points with respect to this interval are discussed below.

Figure 3 shows the positions of the boreholes for Test PGZ1 on a horizontal plane XY.

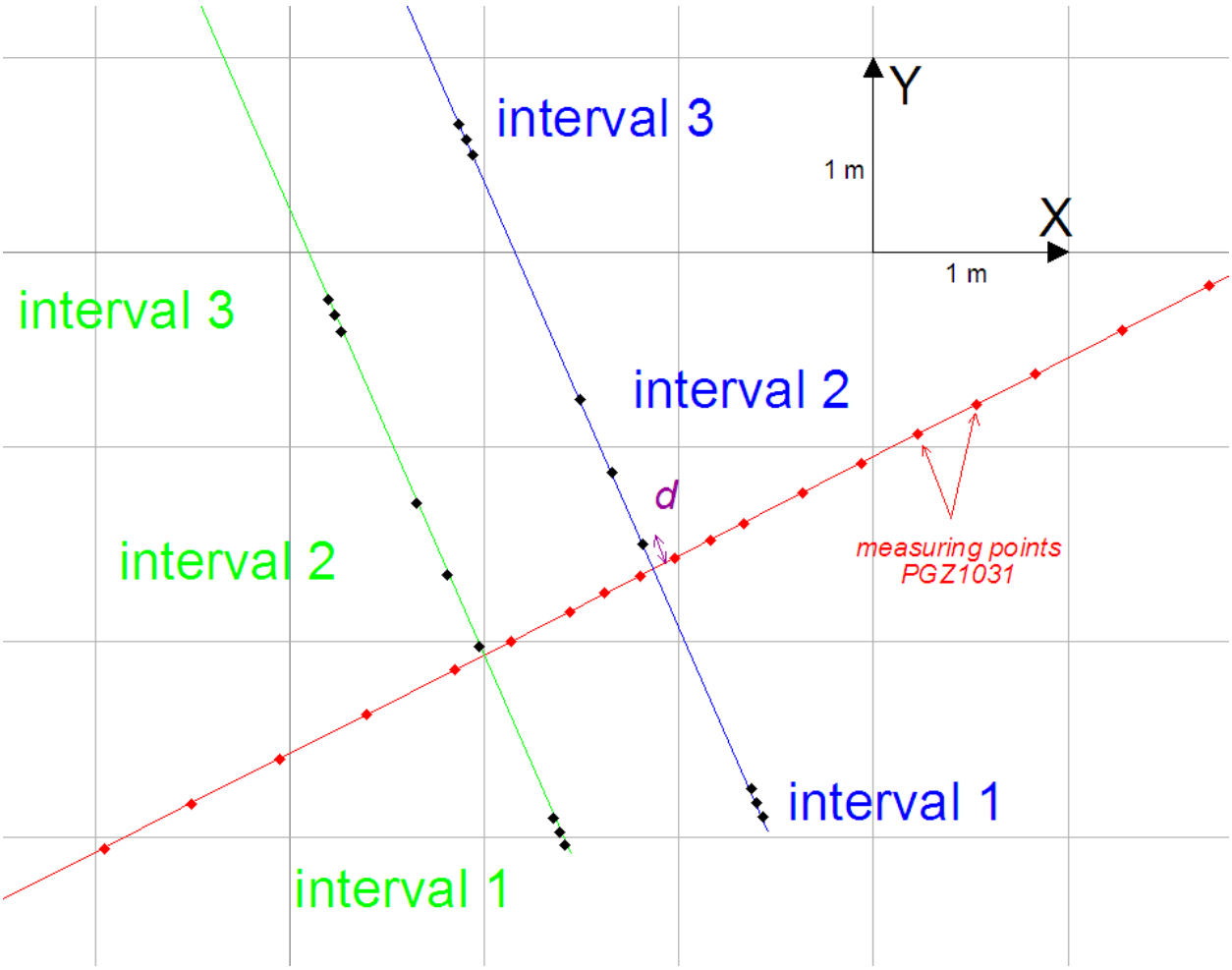


Figure 3 Actual location of measuring points near Interval 2 in borehole PGZ1201, on a horizontal plane XY

1.3.4.1 PGZ1201 – PGZ1202

The initial configuration required that the two boreholes PGZ1201 and PGZ1202 should be parallel and about one meter apart, thereby enabling observation of hydraulic and hydro-mechanical interferences via the intervals for the measurement of interstitial pressure.

The 3-D distance between the central intervals of the PGZ1201 and PGZ1202 completions (Interval 2) is obtained by trigonometry, using the data in Tables 4 and 5.

The distances for the head, middle, and foot of the interval are respectively: 1.023 / 1.025 / 1.027 m. For a borehole radius of 38 mm, the wall-to-wall separations of the boreholes are respectively: 0.948 / 0.949 / 0.951 m.

The actual configuration follows the projected plan in spite of the fact that the two boreholes deviated (they plunged more than expected).

1.3.4.2 PGZ1201 – PGZ1031

Borehole PGZ1031 should enable us to “see" the opening of the fracture created in Interval 2 of PGZ1201. The projected estimation of the fracture's location at this scale is still very difficult, and had been identified as a risk in the design of PGZ1.

The initial configuration predicted that borehole PGZ1031 would pass above Interval 2 in borehole PGZ1201 almost at right angles, so as to allow a "look" at the fracture. In fact, the fracture was supposed to be oriented along Interval 2 of PGZ1201, rising and opening out as it rises.

According to Figure 3, it appears that borehole PGZ1031 is offset with respect to Interval 2 of boreholePGZ1201 by a distance d. This distance is equal to 136 mm. The offset is due to the fact that borehole PGZ1201 plunged more than expected (discrepancy of 40 cm between the theoretical end and the actual end). This offset could not be corrected because the drilling machine had moved before the borehole was surveyed, and it then became impossible to exactly reposition the machine along the axis of the hole. The risk of damaging and losing the borehole was too important, and the choice was made to install the completion in the borehole as it was.

This offset reduces the probability of "seeing" the opening of the fracture via borehole PGZ1031. For all that, the major objectives of this test are to determine the entry pressure of gas into the fresh argillite, and the pressure threshold associated with pathway dilation. The borehole geometry does not compromise these two objectives.

On the other hand, it had been planned to drill a new borehole, PGZ1032, almost parallel to borehole PGZ1031, once the gas fracturing was carried out and the fracture located. If the fracture created is not located by borehole PGZ1031 (no intersection between the fracture and the borehole), the borehole could either not be drilled - which would compromise a portion of the test programme after the gas fracturing - or it could be drilled in a different direction, as yet undetermined. In either case, the decision could only be made at the conclusion of the gas-fracturing phase.

The minimum 3-D distance between the axes of these two boreholes is 1.28 m, or 1.19 m from one bore-hole's wall to the other.

1.3.5 Coordinates for modelling activities

The point located at the middle of interval 2 of PGZ1201 is the reference point. The tables 6 to 8 give the coordinates of the measuring point for each borehole in respect of this reference.

Those coordinates should be used for the modelling activities.

Table 6 Coordinates of measurement intervals in PGZ1201 versus reference point

		X (m)	Y (m)	Z (m)
Interval 3 PGZ1201_PRE_03	Head	-0.784	1.789	1.397
	Middle	-0.749	1.71	1.335
	Foot	-0.715	1.631	1.273
Interval 2 PGZ1201_PRE_02	Head	-0.163	0.37	0.291
	Middle	0	0	0
	Foot	0.164	-0.37	-0.291
Interval 1 PGZ1201_PRE_01	Head	0.715	-1.627	-1.274
	Middle	0.746	-1.697	-1.328
	Foot	0.776	-1.766	-1.382

Table 7 Coordinates of measurement intervals in PGZ1202 versus reference point

		X (m)	Y (m)	Z (m)
Interval 3 PGZ1202_PRE_03	Head	-1.455	0.884	0.865
	Middle	-1.421	0.805	0.802
	Foot	-1.386	0.727	0.74
Interval 2 PGZ1202_PRE_02	Head	-1.003	-0.155	0.041
	Middle	-0.842	-0.525	-0.253
	Foot	-0.681	-0.896	-0.547
Interval 1 PGZ1202_PRE_01	Head	-0.298	-1.777	-1.245
	Middle	-0.268	-1.846	-1.3
	Foot	-0.238	-1.915	-1.355

Table 8 Coordinates of the PGZ1031 measuring points at installation versus reference point

Name of SAGD point	X (m)	Y (m)	Z (m)
PGZ1031_DFO_20	-5.601	-3.444	8.976
PGZ1031_DFO_19	-2.605	-1.928	5.271
PGZ1031_DFO_18	-2.157	-1.7	4.714
PGZ1031_DFO_17	-1.708	-1.472	4.158
PGZ1031_DFO_16	-1.259	-1.245	3.602
PGZ1031_DFO_15	-0.81	-1.017	3.046
PGZ1031_DFO_14	-0.512	-0.865	2.675
PGZ1031_DFO_13	-0.213	-0.713	2.304
PGZ1031_DFO_12	-0.033	-0.621	2.082
PGZ1031_DFO_11	0.147	-0.53	1.86
PGZ1031_DFO_10	0.326	-0.439	1.637
PGZ1031_DFO_09	0.505	-0.349	1.414
PGZ1031_DFO_08	0.684	-0.258	1.191
PGZ1031_DFO_07	0.982	-0.106	0.82
PGZ1031_DFO_06	1.281	0.046	0.448
PGZ1031_DFO_05	1.579	0.198	0.077
PGZ1031_DFO_04	1.878	0.35	-0.294
PGZ1031_DFO_03	2.177	0.503	-0.664
PGZ1031_DFO_02	2.625	0.731	-1.221
PGZ1031_DFO_01	3.074	0.959	-1.777

1.3.6 Sensors in the drift

1.3.6.1 Temperature and relative-humidity sensors in drift

It has been shown that in other boreholes the temperature fluctuations in the drift influenced the pressure measurements in the borehole because in some boreholes the hydraulic lines between the borehole head and the control panel were several meters in length. For Test PGZ1, it is necessary to measure the temperature in the drift because during the gas-injection phase any variations in temperature are reflected in the gas pressure, even though thermal-insulation cladding has been installed (see §1.2).

An air-temperature and a relative-humidity sensor (PGZ1281_TEM_01 and PGZ1281_HUM_01) were installed in the GED drift at sliding-ribs 021GED, under the cable raceways (Figure 4).

Figure 4 Photographs of the temperature and humidity sensor in GED for Test PGZ1

The position of these sensors is not given in the laboratory reference document. Appendix 3 shows the location of these sensors in the plane of the GED drift.

1.3.6.2 GAS MODULE

The gas module is composed by 3 gas flowmeters and one flow controller and a gas pressure sensor:

- Flowmeter 1 (SAGD name PGZ1201_DGZ_01): 0.06 – 3 mln/min
- Flowmeter 2 (SAGD name PGZ1201_DGZ_02): 2 – 100 mln/min
- Flowmeter 3 (SAGD name PGZ1201_DGZ_03): 100 – 5000 mln/min
- Gas pressure sensor (SAGD name PGZ1201_PGZ_01): 0 – 200 bar

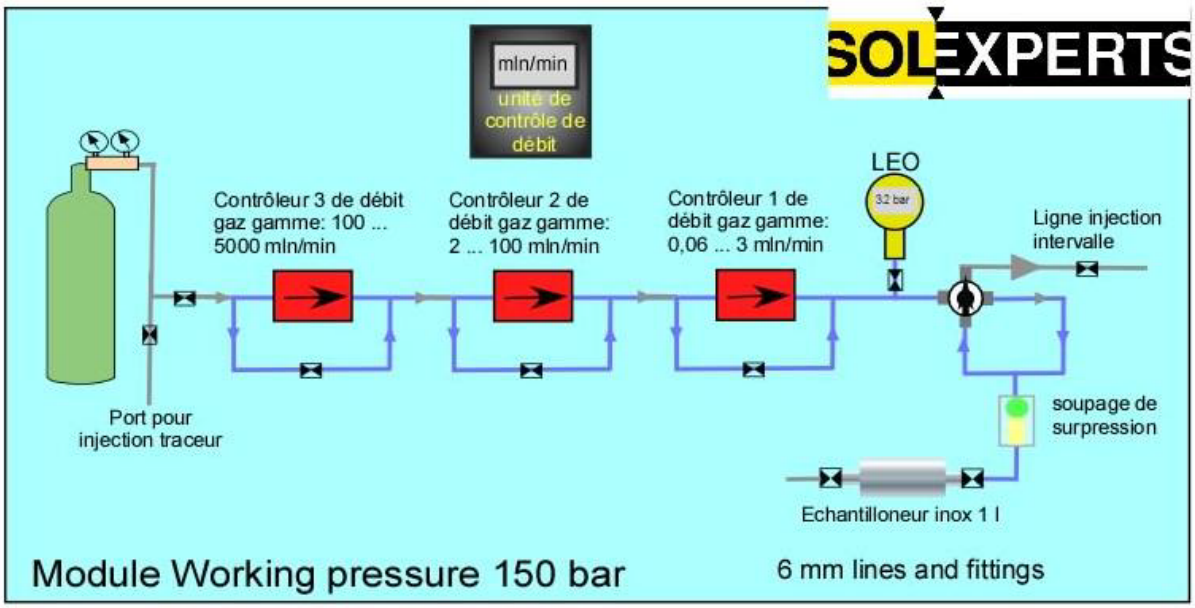


Figure 5 gas module system

The gas used here is nitrogen and the flowrate are given in the standard reference conditions of temperature and pressure for expressing gas volumes, *i.e.* 0 °C (273.15 K) and 101.325 kPa (1 atm).

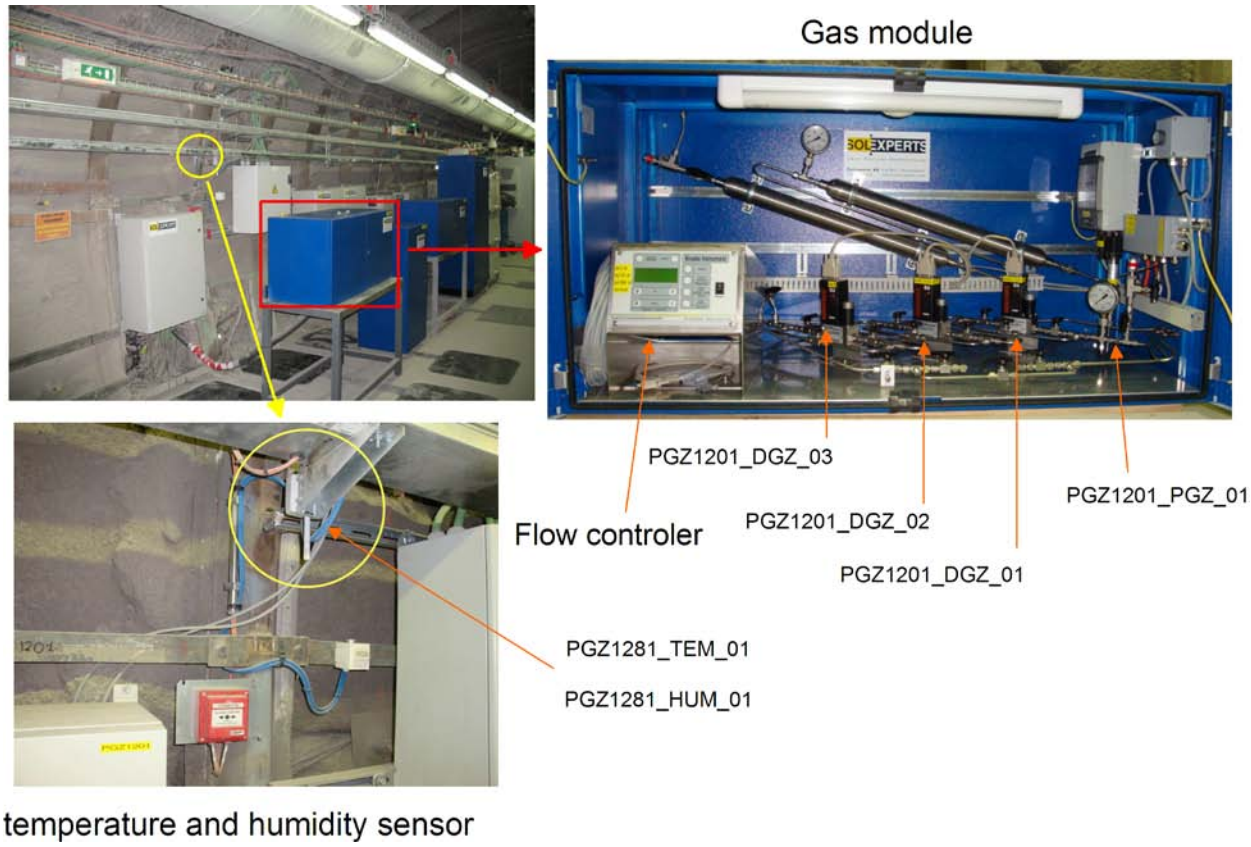


Figure 6 View of the gas module and temperature and humidity sensor in the drift

1.4 MEASUREMENTS

1.4.1 Samples

GEOTER carried out the geologic logging of all the boreholes for the underground laboratory. They packaged the cores from the PGZ boreholes in Cell T1, for laboratories investigations. Table 9 presents details of the packaged cores.

Table 9 List of cores (Cell T1 packaging)

	ANDRA identification	Distance (m) from borehole mouth		Comments
		Head	Foot	
PGZ1201	EST33553	24.77	25.07	Inclined to stratification
	EST33556	25.70	26.00	Inclined to stratification
PGZ1202	EST33651	25.27	25.59	Inclined to stratification
	EST33657	27.52	27.84	Inclined to stratification
PGZ1031	EST33263	17 13	17 43	Inclined to stratification
	EST33271	20.41	20.71	Inclined to stratification
	EST33275	22.32	22.60	Inclined to stratification

GEOTER also measured the water contents in samples from the PGZ1 boreholes.

A first measurement was performed at 105° C for geomechanical purposes, and a second measurement at 150° C for mineralogical and geochemical purposes. After drying in an oven for 24 hours the water content is obtained from the following equation:

$$\text{Hp (\%)} = \frac{\text{wet sample mass (g)} - \text{dry sample mass (g)}}{\text{dry sample mass (g)}} \times 100$$

All of the measurement tables are reported in Appendix 5.

Figures 7 to 9 present the water-content profiles (contents measured at 105 and 150° C) along the PGZ boreholes, against distance from the borehole mouth.

The water contents are more variable (5 to 9%) in the inclined boreholes. A number of factors may explain this difference: lithology-related variations in the clay content of a few percent, air flow during coring, etc.

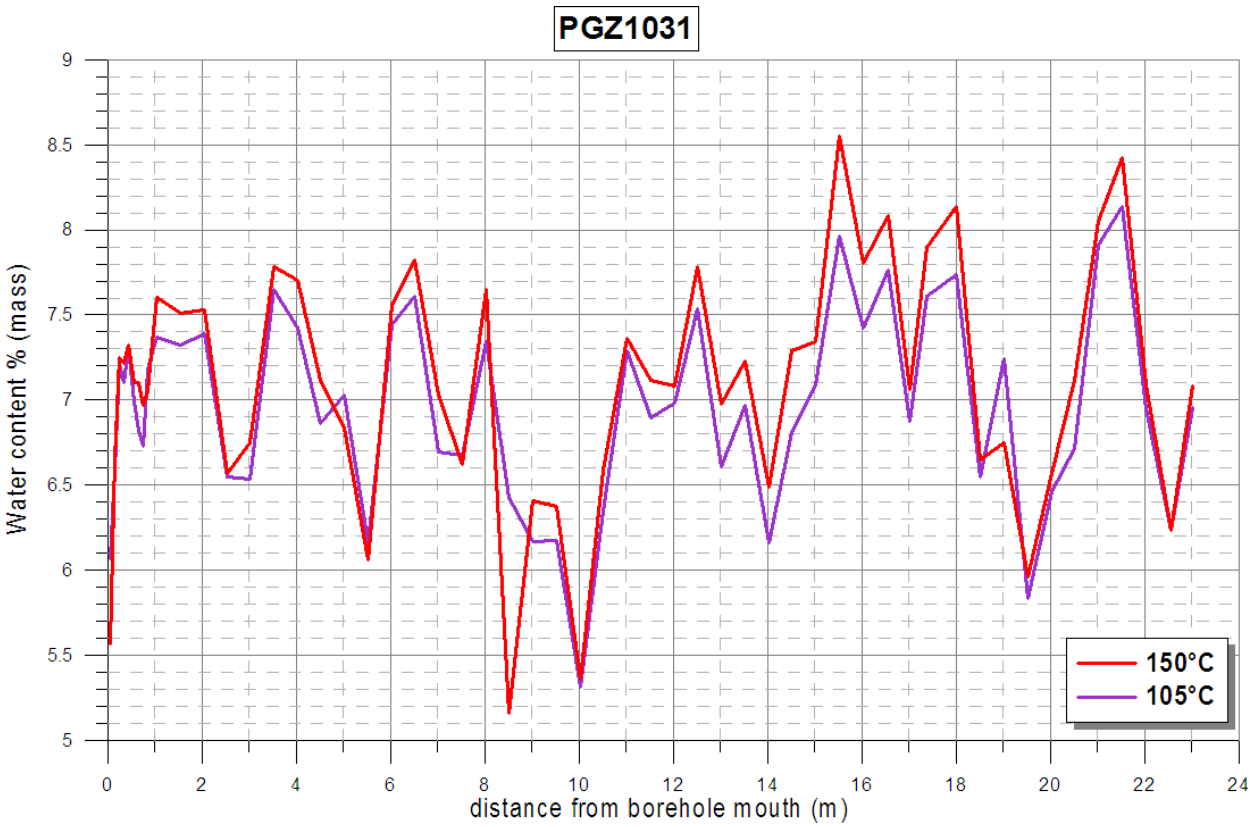


Figure 7 Water-content profile in borehole PGZ1031

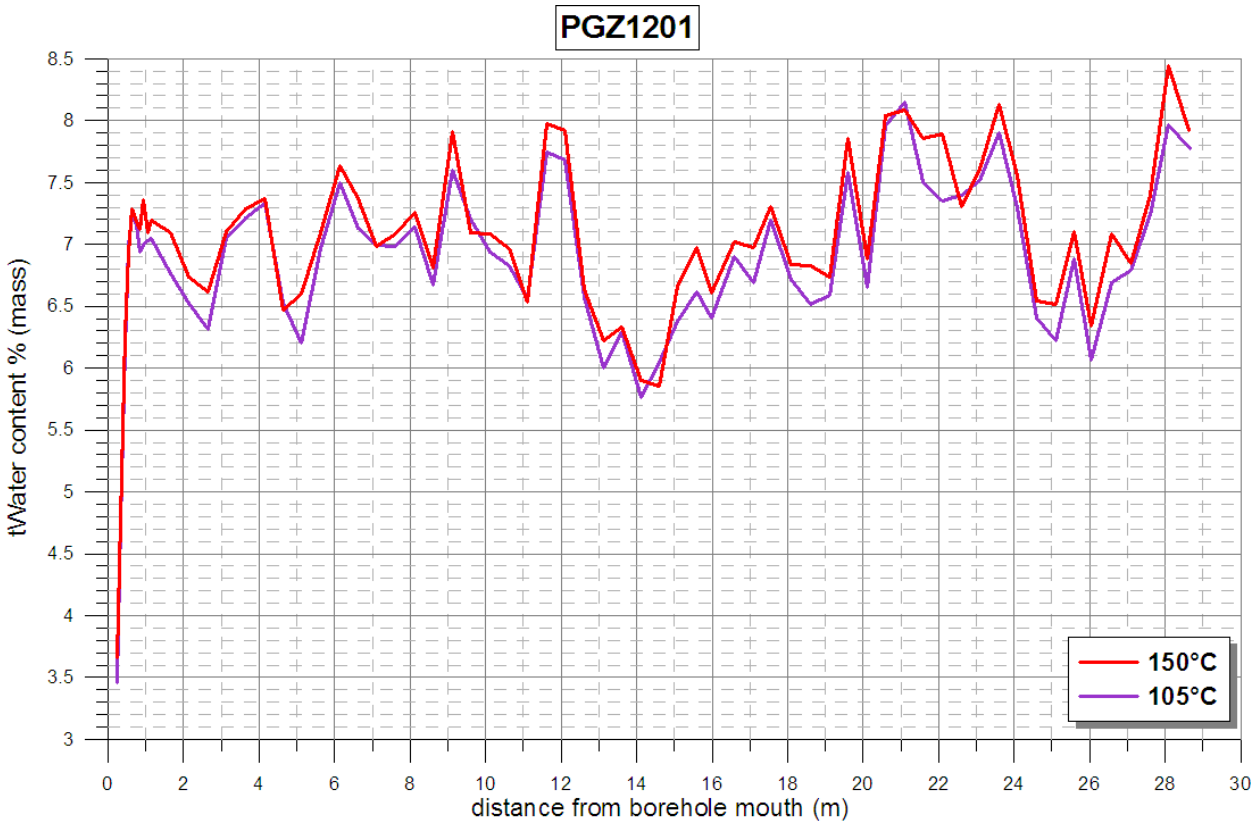


Figure 8 Water-content profile in borehole PGZ1201

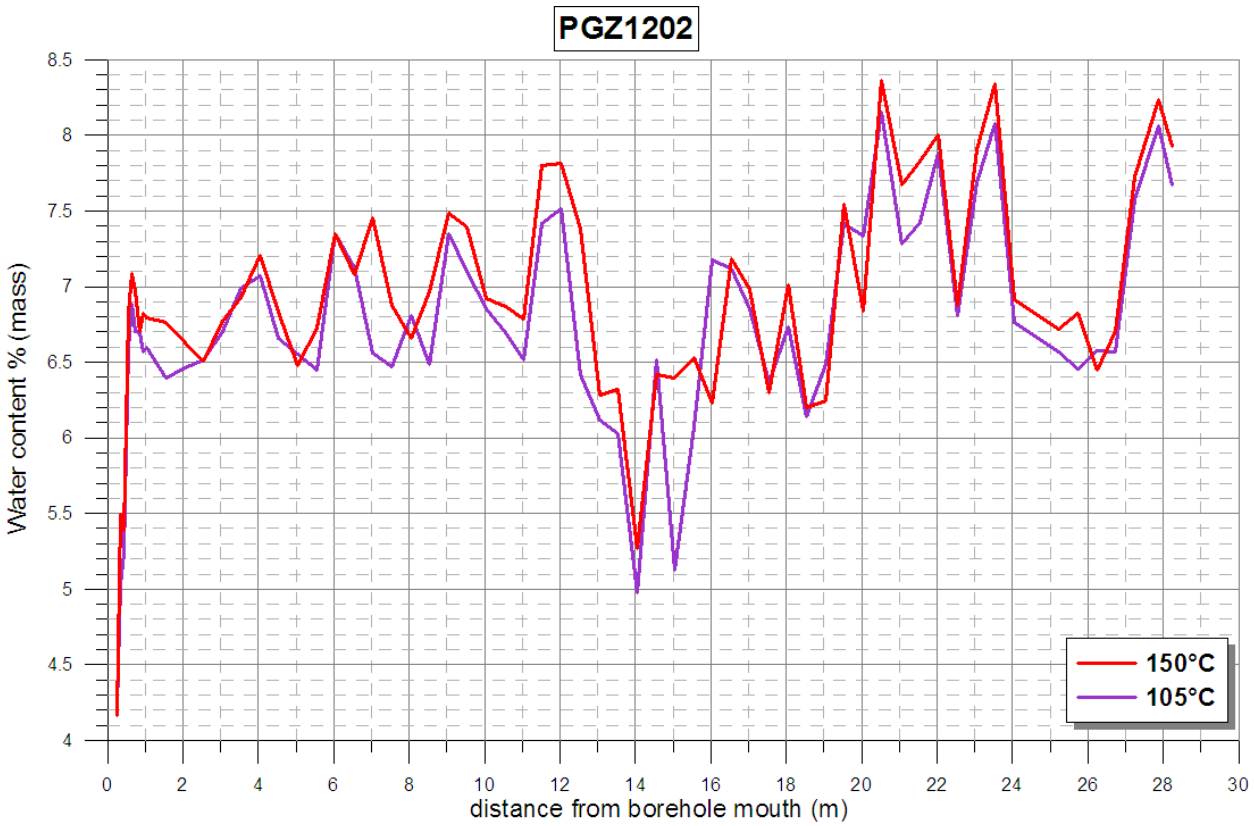


Figure 9 Water-content profile in borehole PGZ1202

1.4.2 Measurement monitoring

This section describes the variations observed in the measurements acquired, from the time the sensors were installed up to mid-November 2009. It does not provide a detailed analysis of the data but presents the significant facts and offers suggestions concerning the phenomena that may be involved in some of the observations.

The borehole temperature measurements, packer pressures, and climatic measurements are not included.

1.4.2.1 Deformation monitoring

Borehole PGZ1031 is fitted with a strain gauge of MAG-X type, supplied by Solexperts. The equipment consists of a guide tube where the measurement contacts are positioned with respect to a reference point in the borehole, and a cemented annulus. This reference point is assumed to be fixed in the borehole. The raw data measured by the system correspond to the distance from this reference point. The processed data presented in the figure below correspond to the relative values of each measurement point with respect to its position when the equipment was installed.

The negative trend of all the measurement points indicates a shortening with respect to the reference point. If we assume that the head is effectively fixed, this means that all of the measurement points are contracting in the direction of the borehole mouth. We are seeing a convergence of the rock-mass toward the GEX drift.

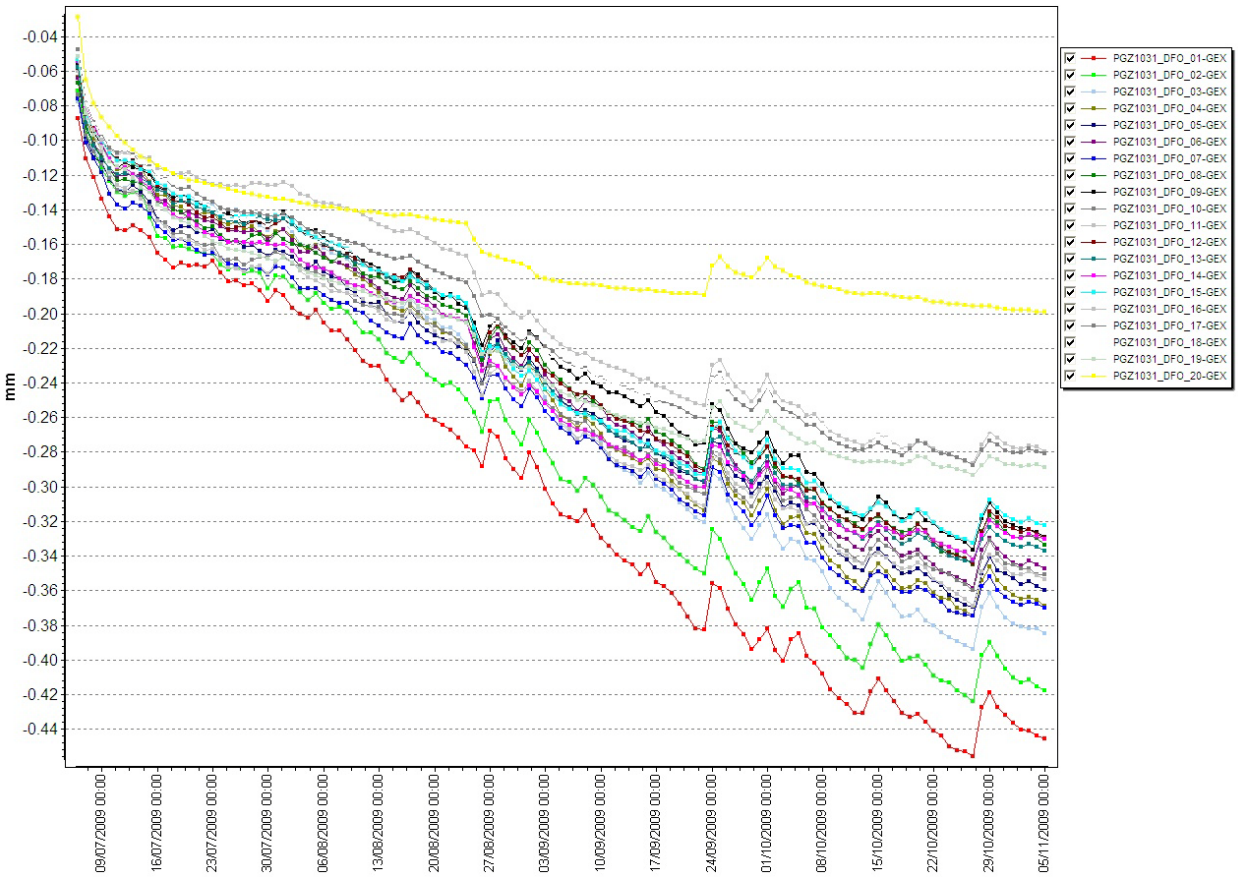


Figure 10 Deformation monitoring in borehole PGZ1031

Since the system is extremely sensitive to shocks at the borehole head, a protective cover was installed on July 31, 2009. This cover was incorrectly attached and failed to prevent shocks to

the borehole head around August 27th, during work in the GEX drift (installation of boreholes PGZ1011 and PGZ1012 see PGZ2 work-package 3). The cover was reattached on September 1, 2009.

Two theories may be considered to explain the fluctuations observed after September 24th:

- the vibrations of the drilling machine during demobilisation of the DIR boreholes in the GEX drift,
- the constant-pressure hydraulic test carried out in interval 2 of borehole PGZ1201.

The first theory is the more probable because the demobilisation operations began on September 21, 2009 and are still in progress (in mid-November).

1.4.2.2 Pressure monitoring in PGZ 1201 and PGZ1202

Figure 11 and Figure 12 show the monitoring of pressures in boreholes PGZ1201 and PGZ1202.

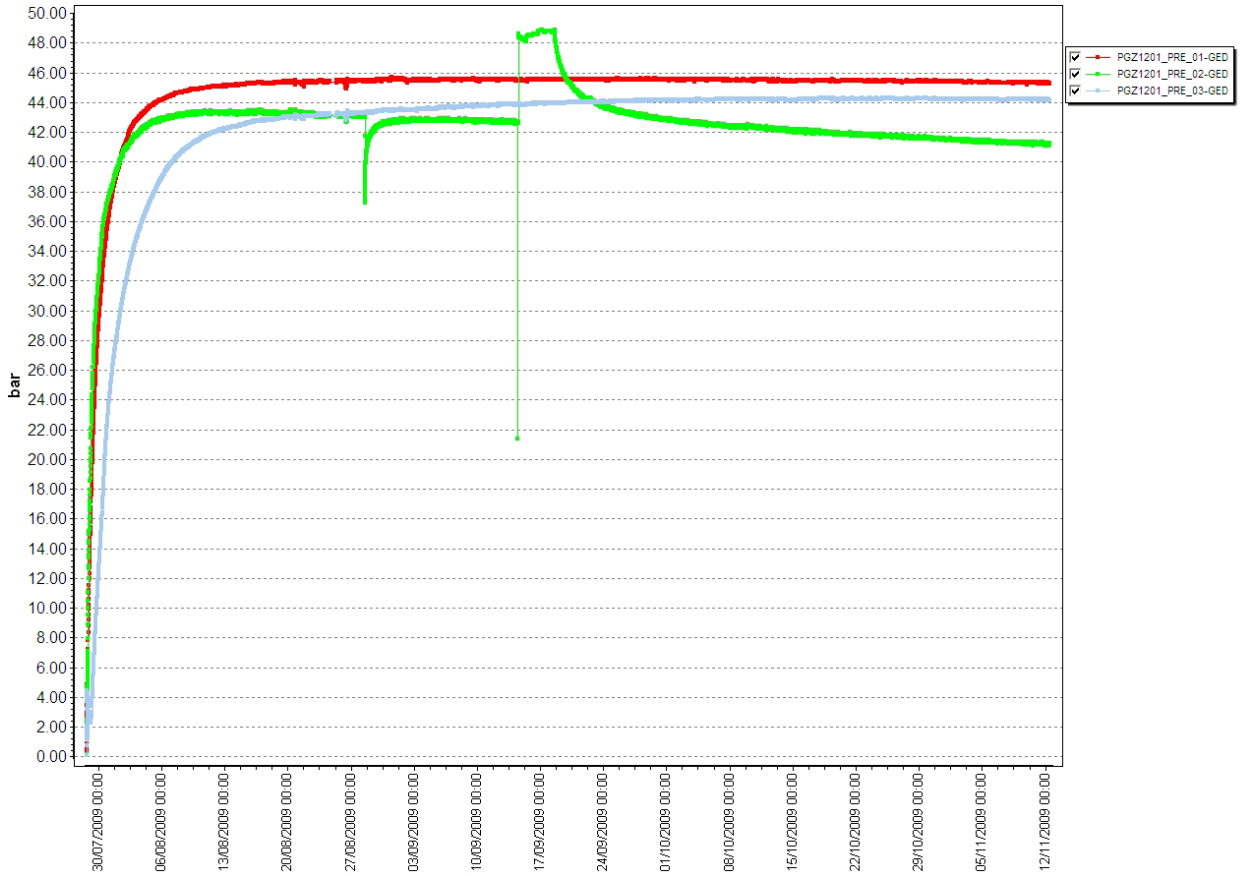


Figure 11 Pressure monitoring in borehole PGZ1201

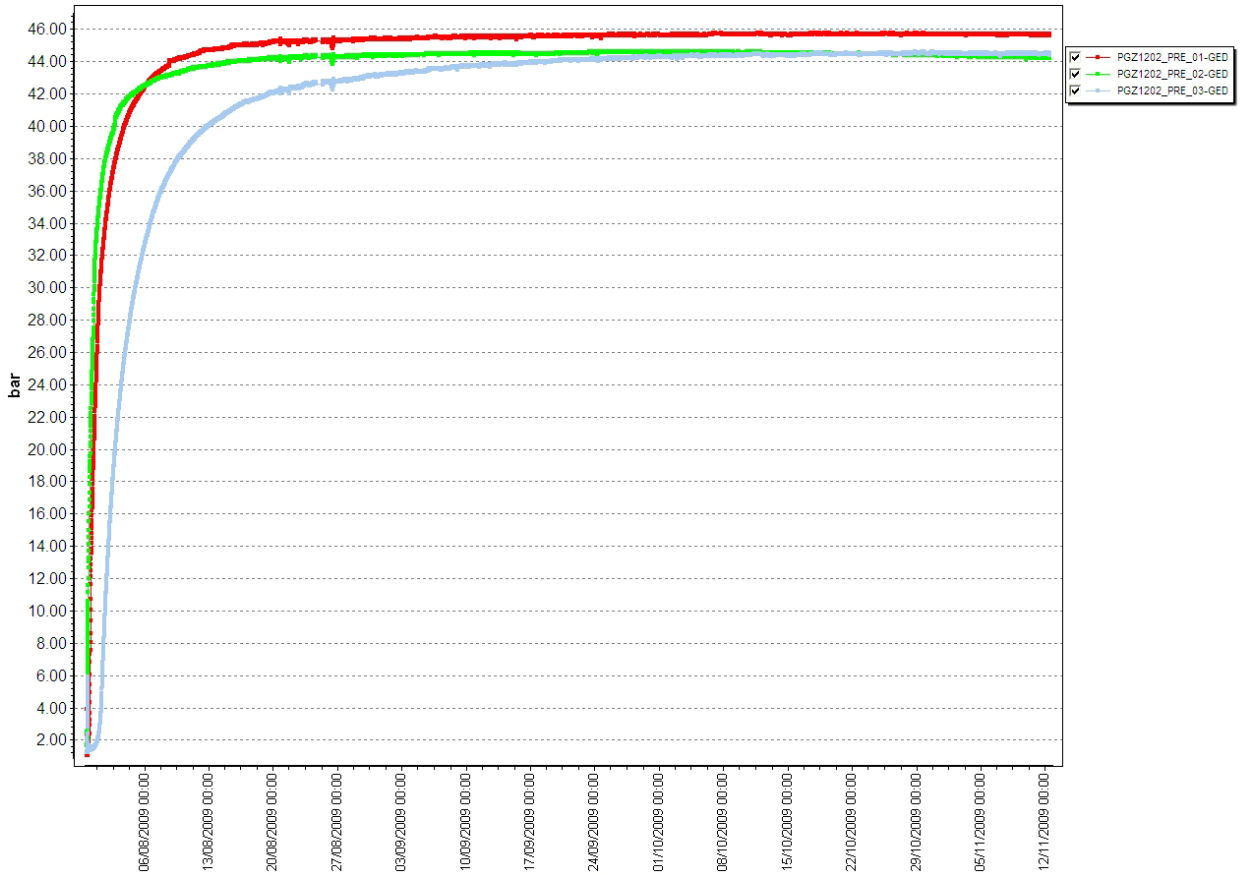


Figure 12 Pressure monitoring in borehole PGZ1202

After 10 to 20 days, the interstitial pressures have reached a level of pseudo-stability. The levels are fairly well stabilised in intervals 1 to 3 of borehole PGZ1202. For the other intervals, after a stabilisation phase we see a more or less appreciable decrease in the pressure. This is clearly visible for interval 2 of borehole PGZ1201.

Since this decrease is observed in several of the measurement chambers and in two different boreholes, a leak problem on a hydraulic line or a drift in the sensor can be eliminated. The nearest other borehole is PGZ1031; it is located 1.19 m from interval 2 of borehole PGZ1201. This borehole consists of an annulus cemented up to the surface, with a permeability of about 10^{-7} m/s. Application of hydrostatic pressure within the annulus in borehole PGZ1031 causes an hydraulic disturbance equivalent to drainage. This balancing effect should be transient.

In an another experiment PEP in the URL, a hydro-mechanical interference was identified between boreholes PEP1002 and PEP1003 (0.6 m apart) during the drilling of borehole PEP1002, borehole PEP1003 having been drilled 52 days earlier. On the other hand, for boreholes PEP2001 and PEP2002, located in the drift at -445 m, no interference was observed between the two boreholes either during the drilling of borehole PEP2002, which took place 31 days after the drilling of PEP2001, or during an 11-month constant-pressure test on Interval 4 in PEP2001. The distance between the No. 4 Intervals in PEP2001 and PEP2002 is 1 m.

In interval 2 of borehole PGZ1201, two hydraulic tests were performed: a pulse test under negative pressure and then a constant-pressure test under positive pressure. Interpretation of the two hydraulic tests gives a permeability for the undisrturbed rock (external zone) of 1.1 10^{-13} m/s and a storage coefficient of 3.10^{-6} 1/m. At this point in the analysis, the confidence

interval for the permeability is not available. Adjustments were carried out using a radial-composite model[1].

1.5 CONTINUATION OF TEST PGZ1

The pressures in boreholes PGZ1201 and PGZ1202 continue to be monitored. The injection of gas will begin only in early February, without waiting for the pressures to return to equilibrium.

The gas-injection programme should follow the programme:

- The first sequence of gas injection should enable characterisation of the rock's properties as regards reversible behaviour. The maximum pressure of the injected gas must remain below the fracturing pressure, estimated to be 12 MPa,
- The second sequence aims to provide confirmation for the formation's parameters as regards reversible behaviour, and then produce gas fracturing of the rock,
- Depending on the results obtained, borehole PGZ1032 will be drilled to assess the permeability of the fracture to gas, by means of a final sequence of injection.

The first sequence consists of a series of pneumatic tests at constant flow (nitrogen), separated by recovery periods. This injection procedure offers better possibilities for interpretation than do constant-pressure tests for determining changes in the flow model by means of diagnostic plots. The estimated flows for use in the tests range between $1x10^{-8}$ kg/sec and $1x10^{-5}$ kg/sec, (~0.5 - 500 ml/min).

The subsequent sequences will be based on the same type of test series but they will be adjusted according to feedback from experience in the first injection sequence.

Table 10 presents the detailed programme for the first sequence of gas injection

Table 10 Gas-injection programme for the first sequence

Test sequence	Test	Duration [d]	Cumulative Duration [d]	flow rate [kg-air/sec] 1)	Comment
GAZ1	RI1	10	10	1 E-08	
	RIS1	15-20	25-30	-	
	RI2	10	35-40	2 E-08	
	RIS2	20-30	55-70	-	
	RI3	10	65-80	4 E-08	
	RIS3	30-60 2)	95-140	-	Min. duration 30 days (double)
	RI4	10	105-150	6 E-08	
	RIS4	40-60	145-210	-	
	RI5	10	155-220	1 E-07	1st dilation test

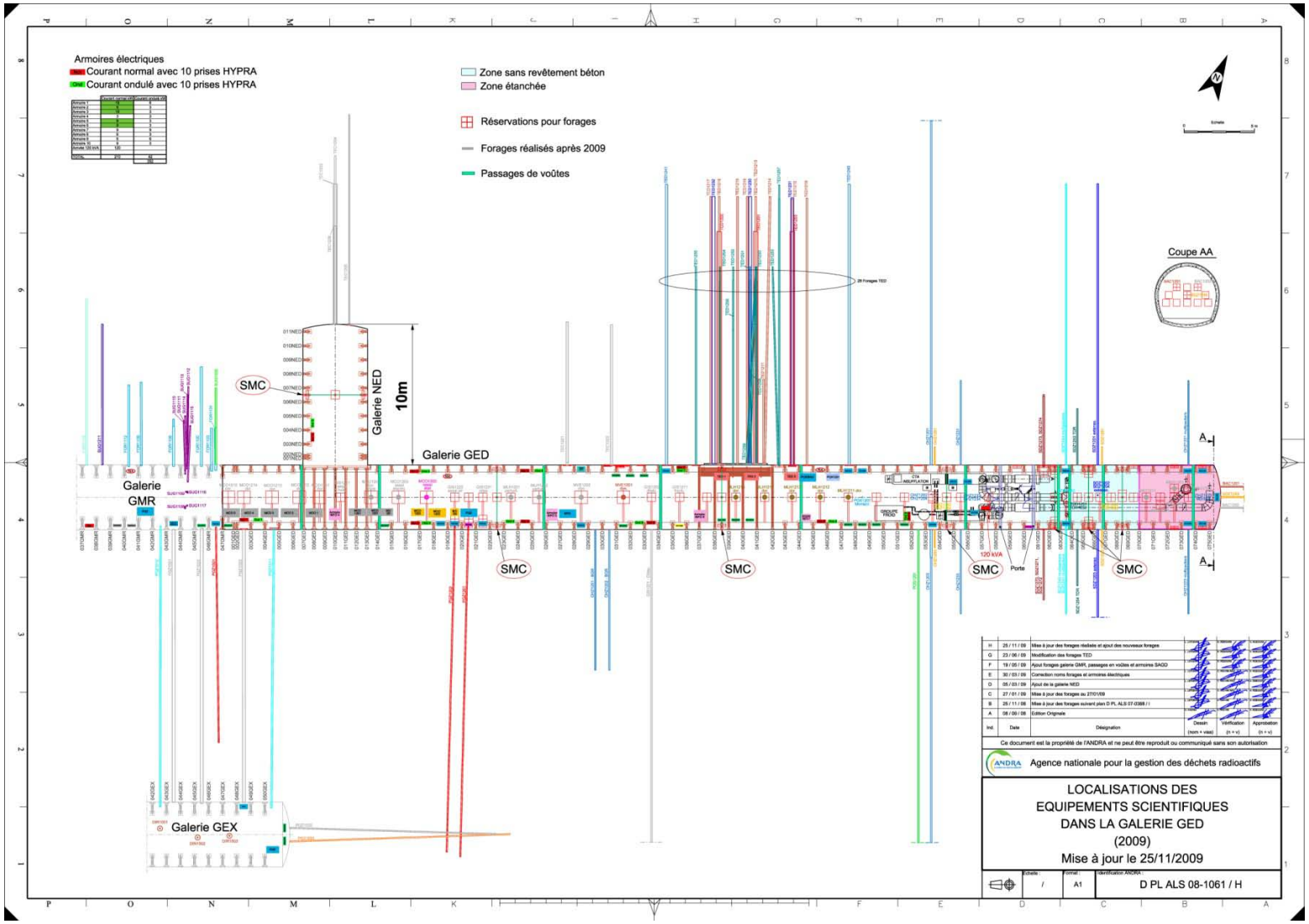
[1] When using a radial-composite model the internal zone is restricted to a maximum distance of 10 cm from the wall of the borehole (rd<0.1 m + bore-hole radius). In the presence of a formation that is assumed to be completely saturated and undisturbed, the storage coefficients should fall between $1 \cdot 10^{-6}$ and $3 \cdot 10^{-6}$ 1/m (reference values for undisturbed Callovo-Oxfordian). In the event of a possible desaturation, or of damage to the formation in the intervals, the storage coefficients may vary up to the level of the porosity (~15% for argillite).

	RIS5	60 [2)]	215-280-	-	
	RI6	10	225-290	2 E-07	2nd dilation test
	RIS6	60 [2)]	285-350	-	End of Gas Series 1

1) Corresponding mass flow rate: from 0.5 to 210 ml/min (standard at. conditions)
2) The dimensioning calculations were performed using 15-day recoveries, but a reliable definition of the flow model would require a longer duration (30 to 60 days).

Under this programme, the first test sequence, GAZ1, would cover a period of about 290 to 350 days (10-12 months).

Appendix 1 GED map



Appendix 2 Photographs

Borehole PGZ1201 free after drilling

installation

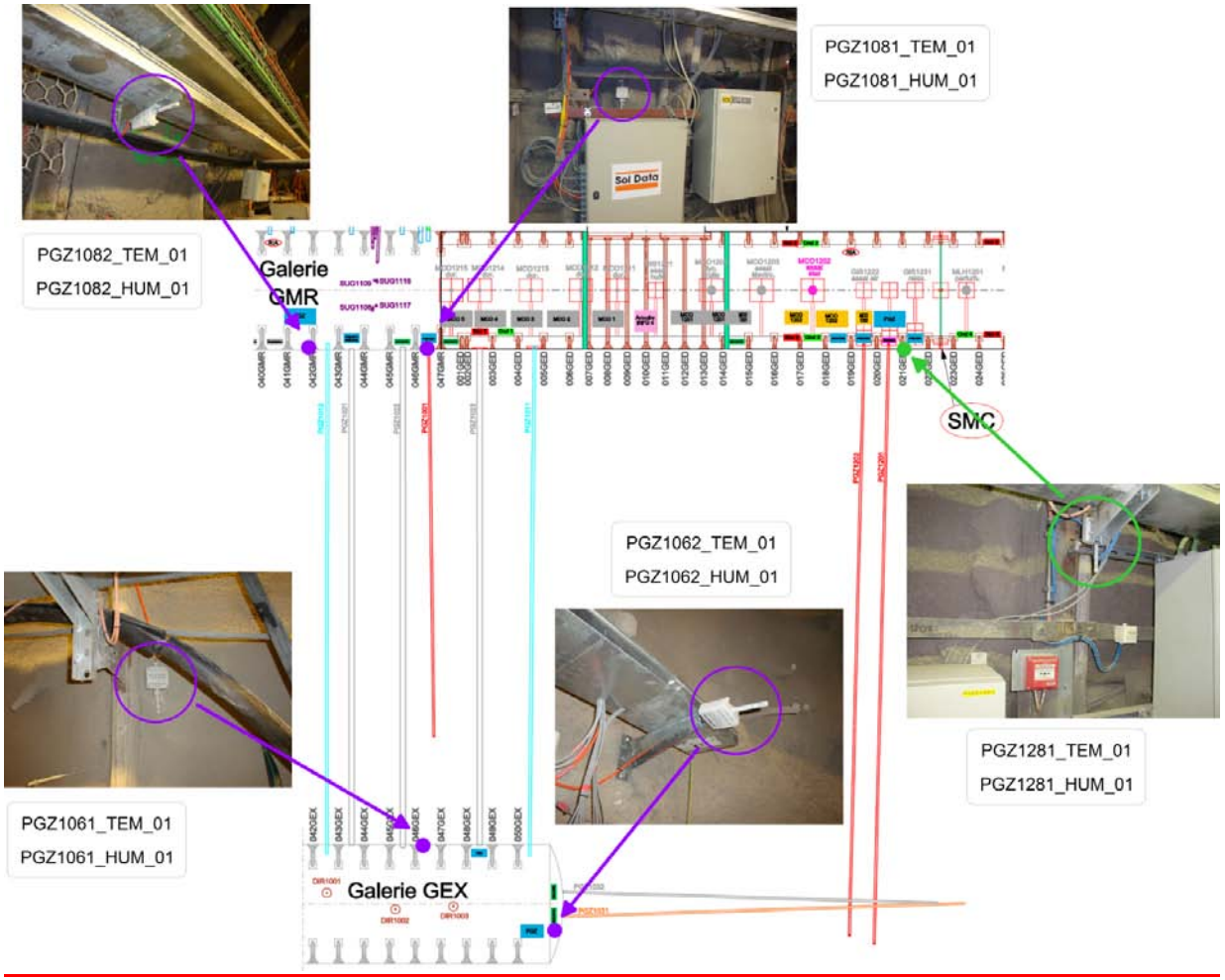
installation of the multipacker system in PGZ1201

View of the gas module

View of the final set-up of PGZ1 in the GED drift

Borehole head of PGZ1031	PGZ1031 cover

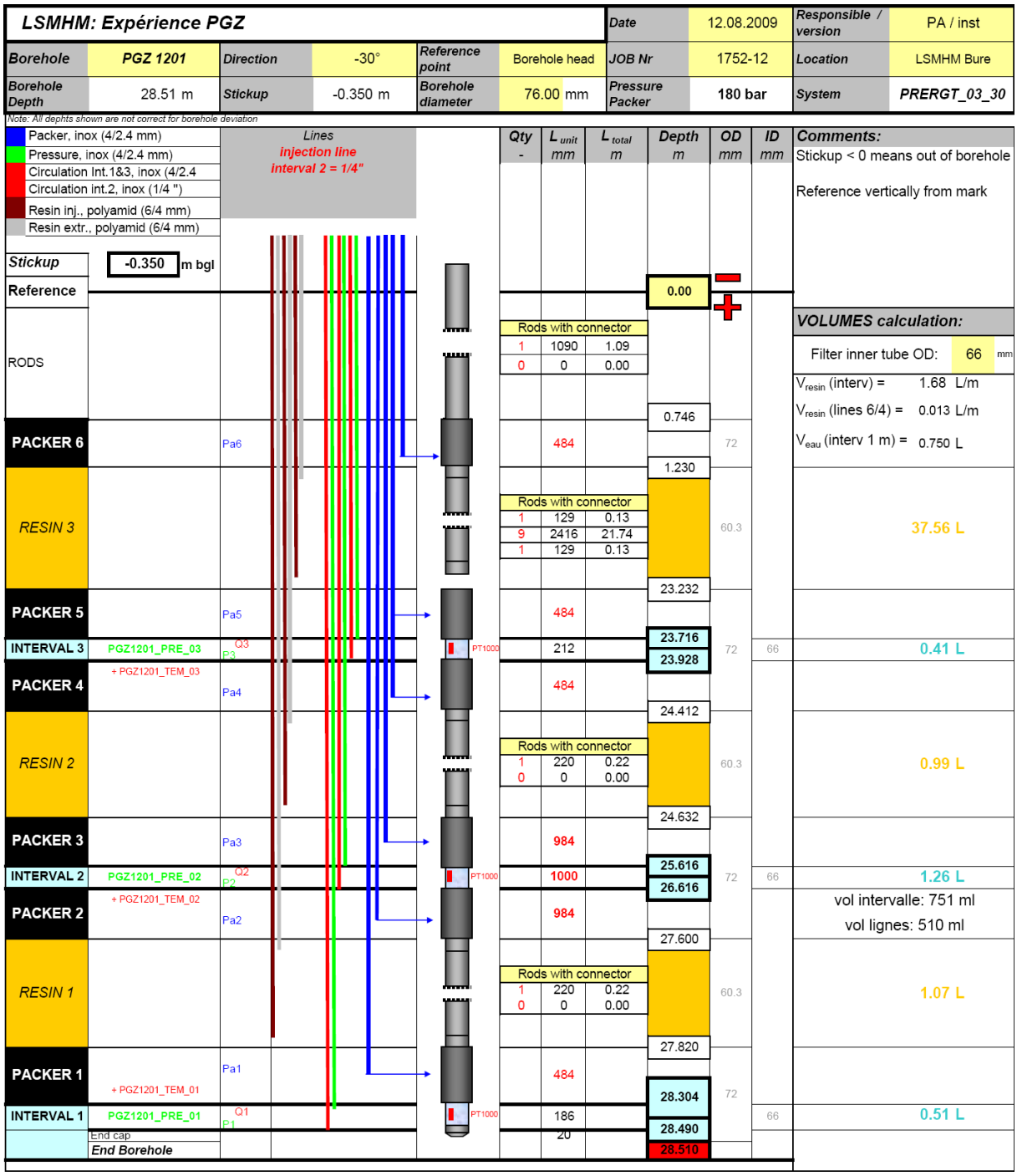
Appendix 3 Location of the temperature and relative-humidity sensors for PGZ1 and PGZ2



Appendix 4 Layouts

Distances are given in reference to the borehole head. The borehole head is an imaginary point which represents the intersection between the borehole axis and the vertical plane from a geodesic target. This geodesic target is located near the borehole at wall.

PGZ1201



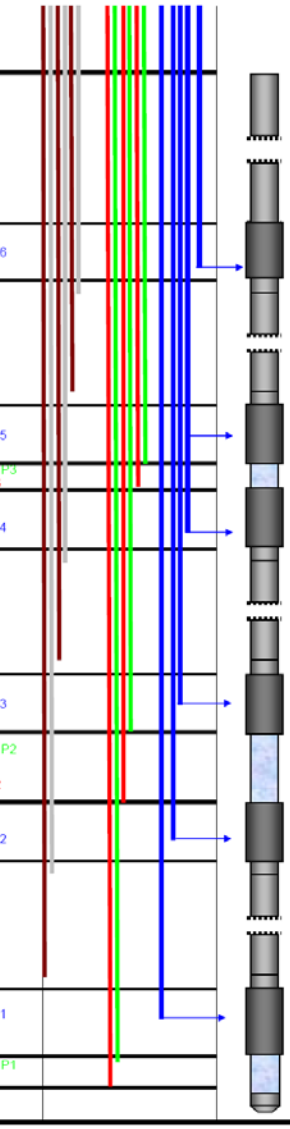
PGZ1202

LSMHM: Expérience PGZ						Date	12.08.2009	Responsible / version	PA / inst
Borehole	PGZ 1202	Direction	-30°	Reference point	Borehole head	JOB Nr	1752-16	Location	LSMHM Bure
Borehole Depth	28.28 m	Stickup	-0.140 m	Borehole diameter	76.00 mm	Pressure Packer	180 bar	System	PRERGT_03_30

Note: All depths shown are not correct for borehole deviation

Packer, inox (4/2.4 mm)
Pressure, inox (4/2.4 mm)
Circulation, inox (4/2.4 mm)
Resin inj., polyamid (6/4 mm)
Resin extr., polyamid (6/4 mm)

Stickup -0.140 m bgl



			Qty -	L_{unit} mm	L_{total} m	Depth m	OD mm	ID mm	Comments:
Reference						0.000			Stickup < 0 means out of borehole Reference vertically from mark
RODS			Rods with connector 1 0	1889 0	1.89 0.00				VOLUMES calculation: Filter inner tube OD: 66 mm V_{resin} (interv) = 1.68 L/m V_{resin} (lines 6/4) = 0.013 L/m V_{eau} (interv 1 m) = 0.725 L
PACKER 6		Pa6		484		1.749 2.233	72		
RESIN 3			Rods with connector 9 1	2387 258	21.483 0.258		60.3		37.14 L
PACKER 5		Pa5		484		23.974			
INTERVAL 3	PGZ1202_PRE_03	P3 Q3		212		24.458 24.670	72	66	0.42 L
PACKER 4		Pa4		484		25.154			
RESIN 2			Rods with connector 1 0	220 0	0.22 0.00		60.3		1.01 L
PACKER 3		Pa3		484		25.374			
INTERVAL 2	PGZ1202_PRE_02	P2 Q2		1000		25.858 26.858	72	66	1.00 L
PACKER 2		Pa2		484		27.342			vol intervalle: 725 ml vol lignes: 271 ml
RESIN 1			Rods with connector 1 0	220 0	0.22 0.00		60.3		1.06 L
PACKER 1		Pa1		484		27.562			
INTERVAL 1	PGZ1202_PRE_01	P1 Q1		186		28.046	72	66	0.50 L
	End cap			20		28.232			
	End system					28.252			

PGZ1031

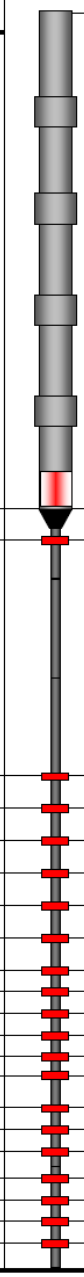
LSMHM, Exp PGZ Galerie GEX						Date	01.04.2009	Project Leader	J. Prouvot
Borehole	PGZ1031	Direction	-45°	Reference point	Geodesic target	JOB Nr	1833-3	Location	GEX, Bure FR
Borehole Depth	23.38 m	Stickup	m	Borehole diameter	101.30 mm	UP	PGZ	System	MagX Spec.

Note: All dephts shown are not correct for borehole deviation

A1	22.86 m	A8	18.86 m	A15	16.36 m
A2	22.11 m	A9	18.56 m	A16	15.61 m
A3	21.36 m	A10	18.26 m	A17	14.86 m
A4	20.86 m	A11	17.96 m	A18	14.11 m
A5	20.36 m	A12	17.66 m	A19	13.36 m
A6	19.86 m	A13	17.36 m	A20	8.36 m
A7	19.36 m	A14	16.86 m		

Stickup -0.325 m bgl

Geodesic target



Lines	Qty -	L_{unit} mm	L_{total} m	Depth m	OD mm	ID mm
		325		0.00		
	Rods with connector					
	4	2000	8.000		70	55.5
	1	325	0.325			
HEAD				8.00		
Diameter reduction		360	0.36			
ANCHOR 20 PGZ1031_DFO_20				8.36		
			5.00			
	Rods with connector					
	1	1000	1.000		30	11.9
	7	2000	14.000			
	1	380	0.380			
ANCHOR 19 PGZ1031_DFO_19				13.36		
			0.75			
ANCHOR 18 PGZ1031_DFO_18				14.11		
			0.75			
ANCHOR 17 PGZ1031_DFO_17				14.86		
			0.75			
ANCHOR 16 PGZ1031_DFO_16				15.61		
			0.75			
ANCHOR 15 PGZ1031_DFO_15				16.36		
			0.50			
ANCHOR 14 PGZ1031_DFO_14				16.86		
			0.50			
ANCHOR 13 PGZ1031_DFO_13				17.36		
			0.30			
ANCHOR 12 PGZ1031_DFO_12				17.66		
			0.30			
ANCHOR 11 PGZ1031_DFO_11				17.96		
			0.30			
ANCHOR 10 PGZ1031_DFO_10				18.26		
			0.30			
ANCHOR 09 PGZ1031_DFO_09				18.56		
			0.30			
ANCHOR 08 PGZ1031_DFO_08				18.86		
			0.50			
ANCHOR 07 PGZ1031_DFO_07				19.36		
			0.50			
ANCHOR 06 PGZ1031_DFO_06				19.86		
			0.50			
ANCHOR 05 PGZ1031_DFO_05				20.36		
			0.50			
ANCHOR 04 PGZ1031_DFO_04				20.86		
			0.50			
ANCHOR 03 PGZ1031_DFO_03				21.36		
			0.75			
ANCHOR 02 PGZ1031_DFO_02				22.11		
			0.75			
ANCHOR 01 PGZ1031_DFO_01				22.86		
			0.52	23.38		
End Borehole						

Comments:

Stickup < 0 means out of reference point

Reference is at borehole **head** on the vertical plan of the geodesic target

RALLONGE 7cm

Appendix 5 Water contents data

All distance are given in respect from borehole mouth

PGZ1031

PGZ1201

PGZ1202

Glossary

PGZ: experiment in the URL. French acronym for perturbation induced by gas experiment.

PEP: experiment in the URL. French acronym for pressure and permeability characterisation experiment.

DIR: experiment in the URL. French acronym for radionuclide diffusion experiment.

SAGD: french acronym for the data acquisition system in the URL.

Borehole head: the borehole head is an imaginary point which represents the intersection between the borehole axis and a vertical plan. This plane could be taken from a geodesic target at wall or between two inner sliding-ribs.

Borehole mouth: the borehole mouth represents the attack of a drilling machine in the wall.