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Long-term Performance of Engineered Barrier Systems PEBS

EB experiment Contribution of CIEMAT to EB dismantling report. Physical state of the bentonite

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1 Introduction: the EB experiment

The EB experiment (ENRESA 2005), was run by ENRESA at the Mont Terri Underground Research Laboratory in Switzerland, starting in October 2000, with the aim of demonstrating that automated production of a Granular Bentonite Material (GBM) and its emplacement in the upper part of a clay barrier were feasible. The EB niche excavated in the Opalinus clay was 15 m long and had a geometry of a horseshoe section, 2.55 m high and 3 m wide (Figure 1).

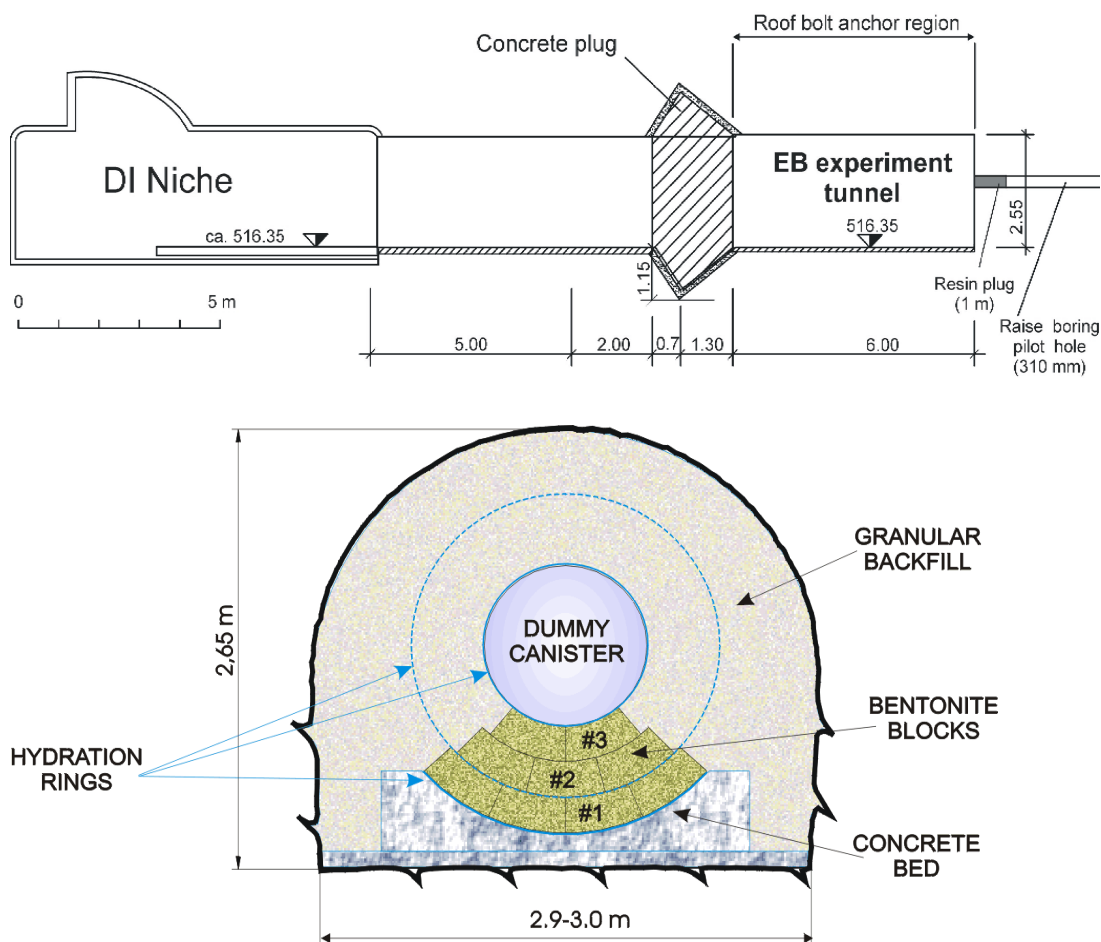


Figure 1: EB niche at Mont Terri URL, longitudinal and cross sections (ENRESA 2005)

According to the measurements performed during installation, in the EB test section an average dry density of 1.36 g/cm^3 of the emplaced GBM was obtained, although some segregation during the emplacement and density inhomogeneities were acknowledged. According to the laboratory characterization of the GBM (ENRESA 2005), for this dry density value it was estimated that the hydraulic conductivity was lower than $5 \cdot 10^{-12} \text{ m/s}$ and the swelling pressure about 1.3 MPa. The artificial hydration of the buffer material started on May 2002 through a series of porous tubes that crossed along the GBM and the bentonite blocks as shown in Figure 2. To enhance the water homogeneous distribution, the concrete bed, the surface of the container and the three rings of bentonite blocks were covered with geotextile. Hydration was carried out with Pearson water coming from a deposit. The Pearson water is a sodium-rich solution and has a composition similar to the Opalinus Clay formation pore water. It has a density of 1.020 g/cm^3 (Pearson 1998) and its chemical composition is indicated in Table I.



Figure 2: Appearance of the concrete and bentonite blocks bed, dummy canister and hydration system before the installation of the GBM (ENRESA 2005)

Table I: Chemical composition of Pearson water (mg/L)

Cl ⁻	SO ₄ ²⁻	HCO ₃ ⁻	Mg ²⁺	Ca ²⁺	Na ⁺	K ⁺	Sr ⁺	pH
10635.90	1354.41	25.75	413.19	1034.06	5550.01	62.95	44.69	7.6

2 Dismantling and sampling

The test run under isothermal conditions (average temperature 16°C) for 10.5 years. The dismantling of the test started on October 2012 with the demolition of the concrete plug, which took almost a month, and went on until February 2013. Figure 3 shows the appearance of the GBM and the bentonite blocks as the test was dismantled, as well as details of the GBM-block contact. The GBM looked completely homogeneous and every void in the barrier had been filled. The contact between the blocks and the GBM was easily recognisable, since the blocks presented a coarse-grained texture, whereas no grains could be identified in the GBM. The pictures show also the numerous tubes and cables that crossed the barrier and the blocks, the appearance of the steel container, the concrete bed and the geotextile layers that separated the three rings of blocks.



Figure 3: Appearance of the GBM (left up), the bentonite blocks (right up), and the GBM-blocks contact (bottom) upon dismantling.

Samples of the GBM, the bentonite blocks, the concrete bed and the concrete plug, the Opalinus clay, and other materials were taken for analysis in the laboratory. Additionally, dry density and water content determinations of the bentonite were performed on site by the AITEMIN team. These determinations were also performed at CIEMAT in bentonite samples that were quickly packed after being taken and sent to CIEMAT laboratories. The packing consisted of a plastic film and two aluminium foil bags that were vacuumed before being closed.

The bentonite samples analysed at CIEMAT laboratories belong to the sampling sections A1-25, CMT1, CMT2, E, B2 and CMT3 (Figure 5). The samples were taken following approximately radii, as shown in Figure 4. Initially only the sections CMT1, CMT2 and CMT3 were to be sampled for CIEMAT (AITEMIN 2012), but once the dismantling started it was decided to take samples from the other sections in order to crosscheck the water content and dry density values obtained on site.

This report summarises the results obtained concerning the physical state of the samples. Additional analyses were performed at CIEMAT, including permeability, thermal conductivity, swelling capacity, geochemical and mineralogical determinations. Those will be reported in separate documents.

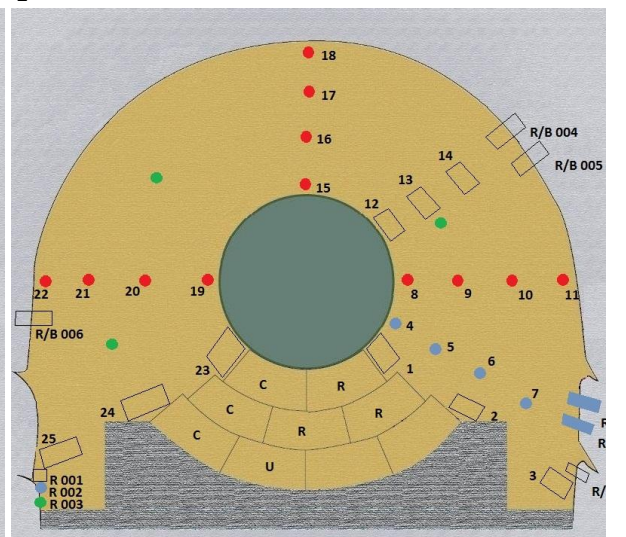
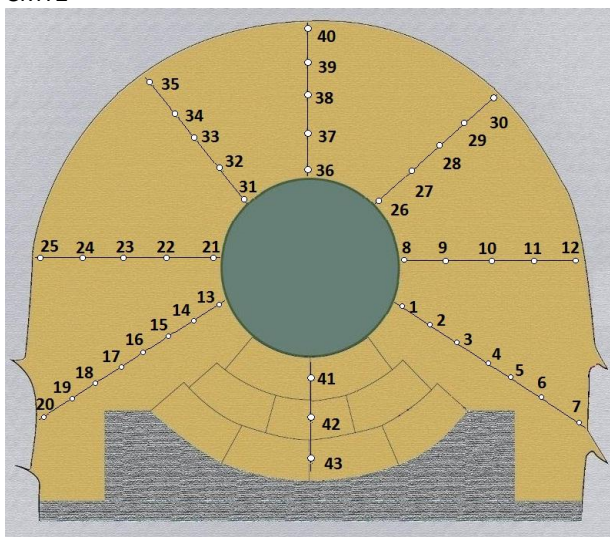
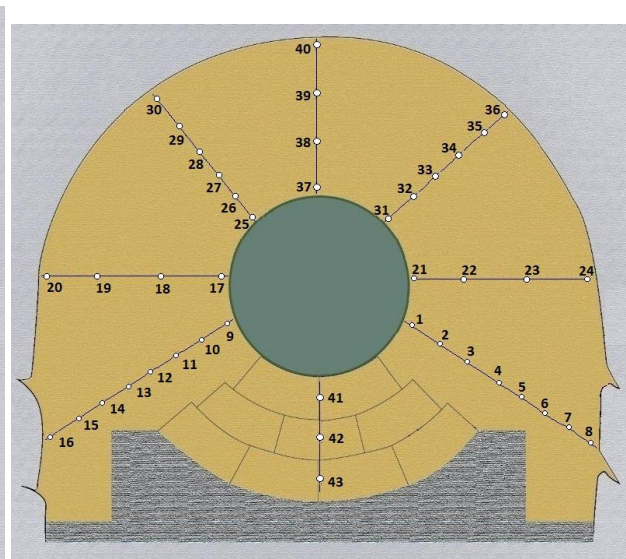
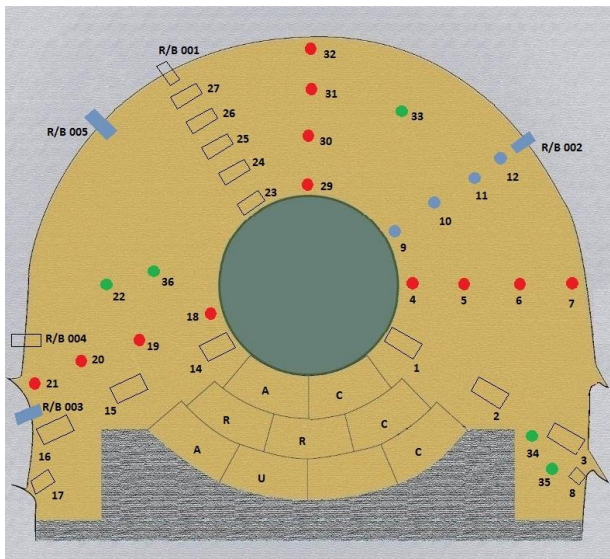
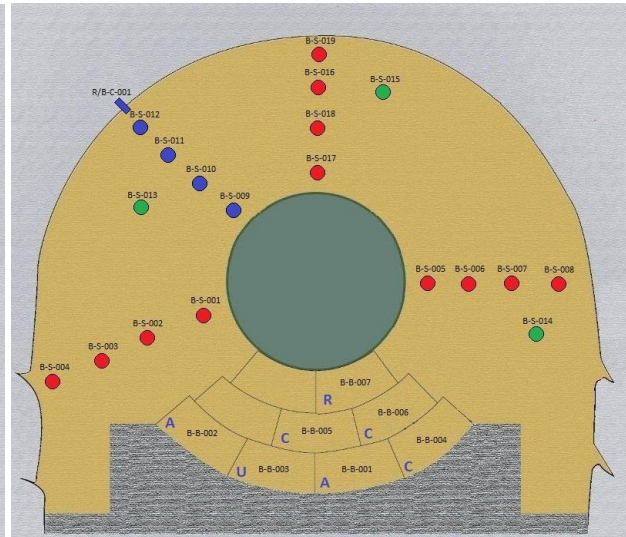
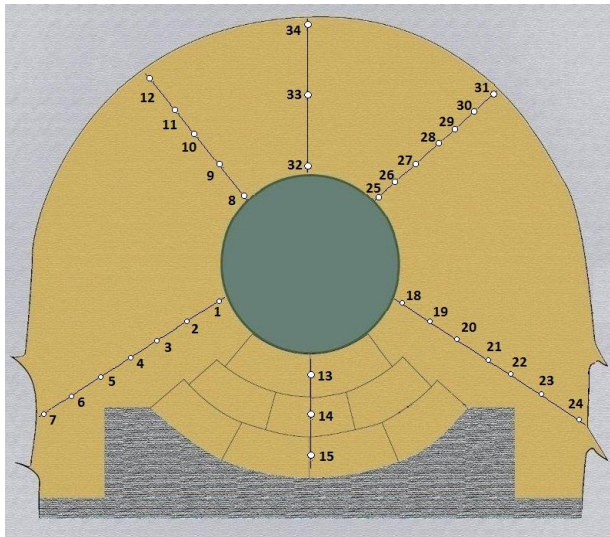
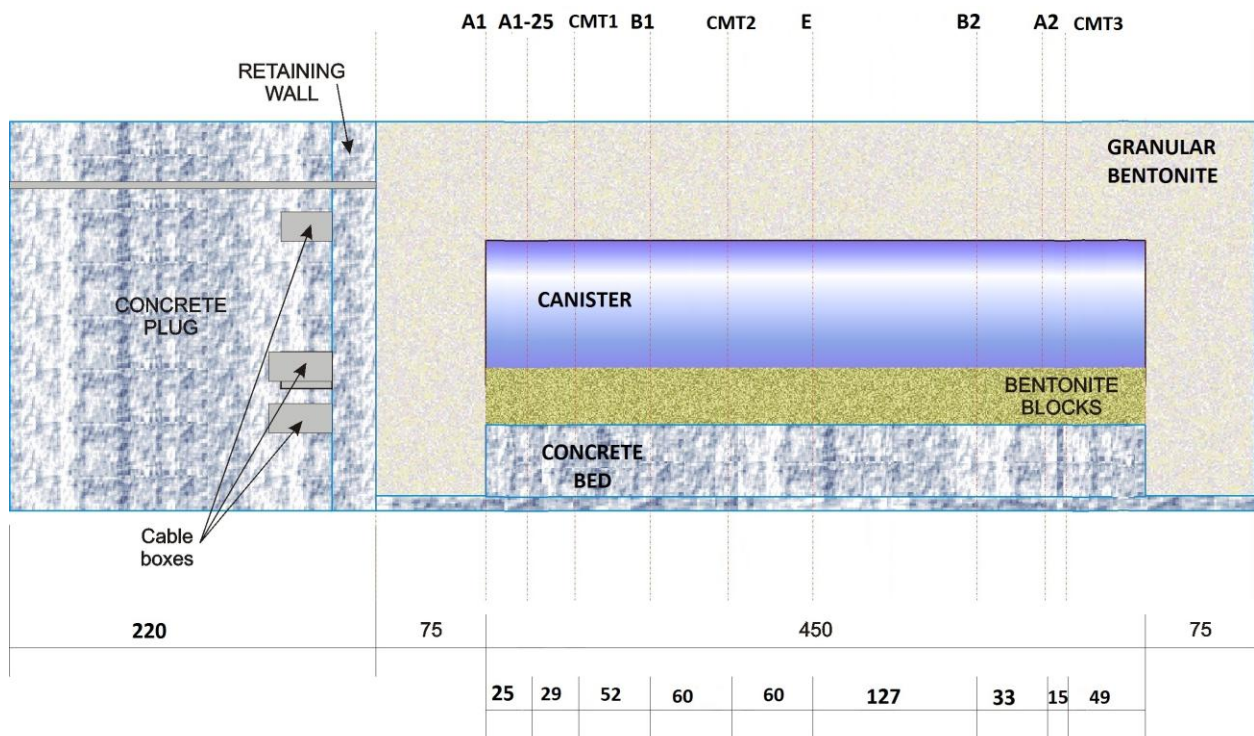


Figure 4: Cross section of the sampling sections showing the location of the bentonite samples (in sections CMT1, CMT2 and CMT3 the GBM samples sent to CIEMAT are indicated with red circles or a rectangle and the blocks with a C) (AITEMIN 2012)



All dimensions in cm

Figure 5: Bentonite sampling sections (AITEMIN 2012)

3 Material

The GBM used in the EB experiment was prepared from FEBEX bentonite dried and milled in a three-step process to produce a fine grade powder with a water content of 3.3%. Later, a commercial plant with an in-line highly automated briquetting process produced coarse (>7 mm) and fine (0.4-2 mm) grained materials with dry densities of 2.11 and 2.13 g/cm³, respectively. These two grain size fractions were subsequently combined after several trials to produce a material with a granulometric Simonis curve, which was used for the *in situ* emplacement (ENRESA 2005). On the other hand, the blocks used came from the series that was manufactured for the FEBEX *in situ* test in 1997, and had a dry density of 1.69 g/cm³ and a water content of 14.4%.

The physico-chemical properties of the FEBEX bentonite, as well as its most relevant thermo-hydro-mechanical and geochemical characteristics obtained during the projects FEBEX I and II were summarised in the final report of the project (ENRESA 2006). The FEBEX bentonite was extracted from the Cortijo de Archidona deposit (Almería, Spain). The processing at the factory consisted of disaggregation and gently grinding, drying at 60°C and sieving by 5 mm, and this was the material used for the laboratory characterisation.

The montmorillonite content of the FEBEX bentonite is above 90 wt.%. The smectitic phases are actually made up of a smectite-illite mixed layer, with 10-15 wt.% of illite layers. Besides, the bentonite contains variable quantities of quartz, plagioclase, K-felspar, calcite, and cristobalite-trydimite. The liquid limit of the bentonite is 102±4%, the plastic limit 53±3%, the specific gravity 2.70±0.04, and 67±3 percent of particles are smaller than 2 µm. The hygroscopic water content is 13.7±1.3 percent. The total specific surface area obtained using the Keeling hygroscopicity method is 725 m²/g. The cation exchange capacity is 102±4 meq/100g, the main exchangeable cations being calcium, magnesium and sodium. The predominant soluble ions are chloride, sulphate, bicarbonate and sodium.

4 Methodology of laboratory tests

Until their analysis, the samples sent from Mont Terri were kept at CIEMAT facilities in a storage room in which the temperature was between 7 and 16°C and the relative humidity between 70 and 90%. The samples were taken one at a time out of the storage room and unpacked in the laboratory. The size and condition of the samples was very variable. Most of the blocks kept their original shape, but some of them came in pieces (Figure 6). Overall, the samples from the GBM looked homogeneous, but occasionally they presented blue spots or areas of different grain size (Figure 7).



Figure 6: Appearance of blocks after unpacking

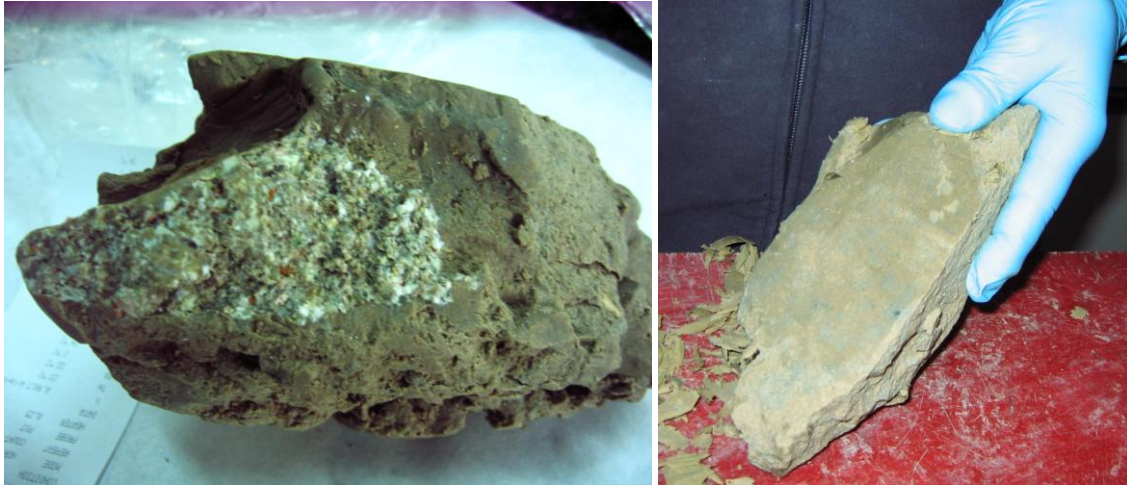


Figure 7: Appearance of some GBM samples

The samples for the water content and dry density determinations were prepared by trimming regular specimens of the right size, with volumes of between 6 and 13 cm³ (Figure 8). Two specimens were trimmed and analysed from each GBM sample. The subsamples from the blocks were taken at three different distances from the container (up, middle, down), and for each distance at least two specimens were used. To section the blocks, knives and hammers were used (Figure 9). The process of trimming took some minutes, and during this time some drying of the sample could have taken place, because the samples remained exposed to drier room conditions than those in the barrier. This was evaluated and the results obtained are shown in the section “Methodology impact on results”.



Figure 8: Trimming of a sample in the laboratory for water content and dry density determination



Figure 9: Sectioning of blocks to obtain subsamples

The gravimetric water content (w) is defined as the ratio between the weight of water and the weight of dry solid expressed as a percentage. The weight of water was determined as the difference between the weight of the sample and its weight after oven drying at 110°C for 48 h (weight of solid). Dry density (ρ_d) is defined as the ratio between the weight of the dry sample and the volume occupied by it prior to drying. The volume of the specimens was determined by immersing them in a recipient containing mercury and by weighing the mercury displaced, as established in UNE Standard 7045 “Determination of soil porosity”. The same samples whose volumes had been determined were used for the water content determination. Additionally, in some cases larger samples were used just for water content determination.

In some samples the relative humidity and temperature were measured using either a capacitive sensor or a psychrometer (Figure 10, Figure 11). Since the degree of saturation of the samples was very high, the measurement range of the capacitive sensors was not suitable, because their accuracy for relative humidities between 90 and 100% is 2%. Consequently, it was decided to use exclusively psychrometers. In both cases the sensors were inserted in holes drilled in the bentonite and sealed with the bentonite itself. The samples were kept wrapped in plastic films or in bags to avoid water content lost during the measurements. The equilibration time for the capacitive sensors was less than 2 hours and for the psychrometers of at least 24 hours. The suction in the pores of the sample (s , in MPa) is related to the relative humidity (RH, %) and the temperature (T , absolute temperature) measured by the sensors by means of Kelvin’s law:

$$s = -10^6 \frac{R \times T}{V_w} \ln \left(\frac{RH}{100} \right) \quad [1]$$

where R is the universal constant of the gases (8.3143 J/mol·K) and V_w is the molar volume of the water ($1.80 \cdot 10^{-5} \text{ m}^3/\text{mol}$).



Figure 10: Insertion of capacitive sensors in blocks for measurement of RH and T



Figure 11: Measurement of relative humidity and temperature with psychrometers

Thermal conductivity measurements, mercury intrusion porosimetry tests, determination of the specific surface area and measurement of the basal spacing of the smectite were done also in all the subsamples, but the results are reported elsewhere.

5 Results

5.1 METHODOLOGY IMPACT ON RESULTS

Since most of the samples analysed had very high water contents, much higher than hygroscopic, their manipulation at laboratory conditions (temperature of $22 \pm 1^\circ\text{C}$, relative humidity of $35 \pm 6\%$, corresponding to a suction of $146 \pm 24 \text{ MPa}$) could imply certain drying. In order to determine how this drying could affect the values of water content obtained, some samples were let after unpacking in room conditions and their weight change was checked periodically, before putting the samples in the oven to determine their dry mass. The evolution of their water content during exposure to laboratory conditions is shown in Figure 12, and in

Figure 13 in terms of percent water content loss. In the latter the average results of a similar test performed on site by AITEMIN during the dismantling are shown. In this case the ambient conditions were different, since the relative humidity and temperature at the gallery of the Mont Terri URL where the determinations were done were 48% and 17°C. The preparation of the samples for dry density and water content measurements took on average less than 20 minutes. According to Figure 13 this would mean that the decrease of water content during manipulation in the laboratory could be of between 0.7 and 1.5%. This could imply a certain decrease in the degrees of saturation obtained, of 2% in the worst cases.

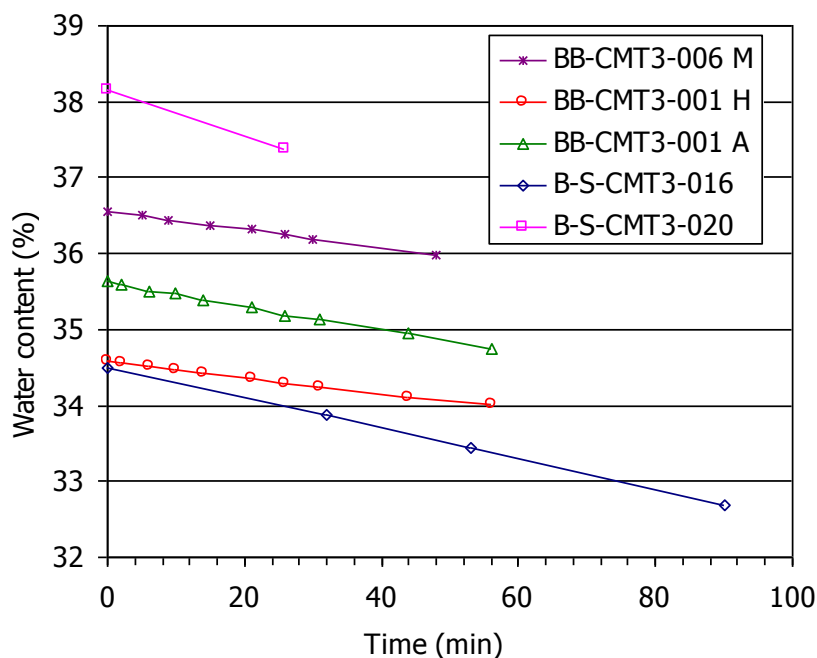


Figure 12: Evolution of water content in samples kept at laboratory conditions after unpacking

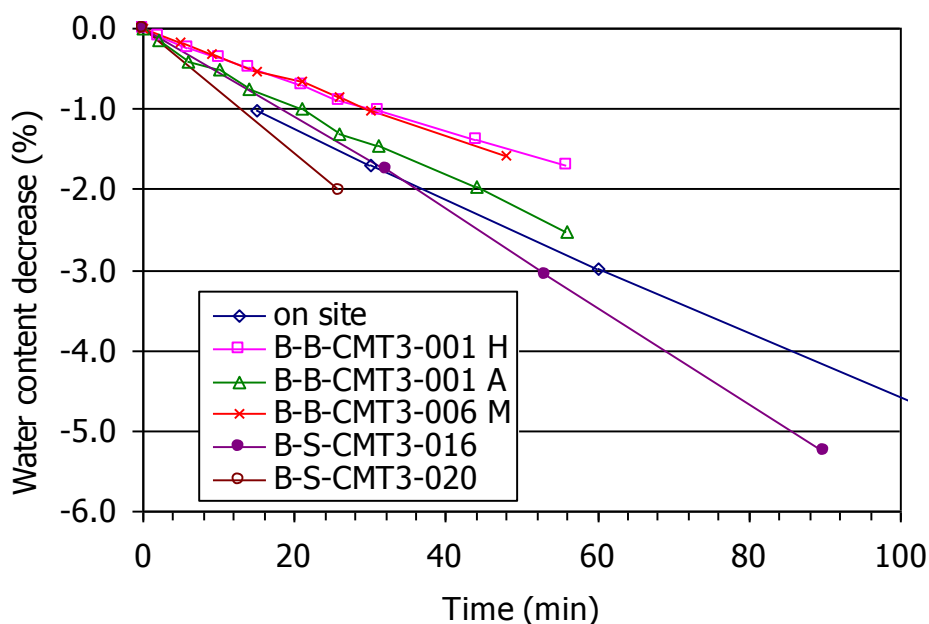


Figure 13: Decrease of water content in samples exposed to room conditions at CIEMAT's laboratory and on site (average of several data of AITEMIN)

5.2 SIZE OF BLOCKS

Some of the blocks received were measured upon unpacking, in order to compare their dimensions to the original ones and evaluate their deformation. The results obtained are shown in Table II according to the key given in Figure 14. The expansion of all the blocks is clear, particularly in those of section CMT1, which is the one closer to the concrete plug. In this section the height of the samples increased up to a 56%, which indicates the longitudinal expansion of the bentonite bed. In the two other sections the average height increase was of 4%. The other dimensions increased also between 6 and 14% in section CMT1. The dimension c increased an average of 7% in sections CMT2 and CMT3, indicating the uplift of the canister.

When these measurements are compared with those taken by AITEMIN during dismantling (also included in the Table), it is observed that the measurements taken in the laboratory are larger, which could mean that the expansion of the blocks continued after excavation. The difference between both measurements is particularly large for the blocks in sections CMT2 and CMT3. At these two sections the GBM was removed long before the blocks were extracted, and this would have allowed more time for them to swell once the overload of the GBM was removed. Besides, the time between excavation and sampling at the laboratory was longer for the blocks in section CMT3.

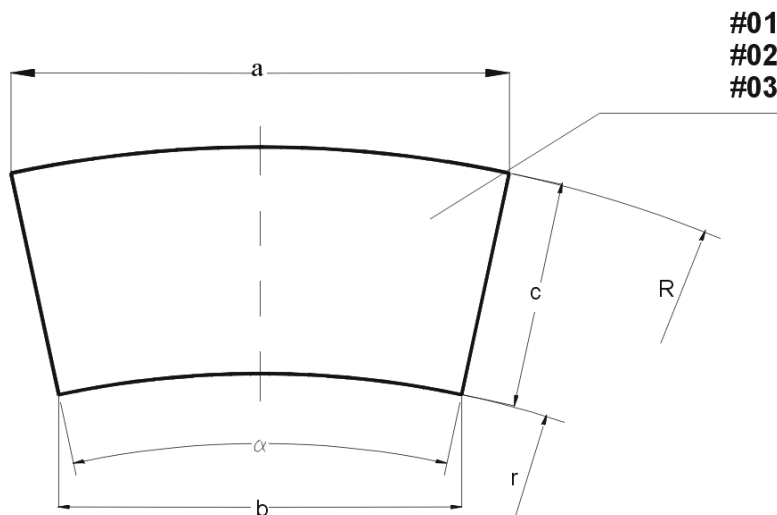


Figure 14: Block dimensions (ENRESA 2005)

Table II: Dimensions of the blocks sampled in the laboratory (refer to Figure 1 and Figure 14). The initial height (h) was 12.5 cm and the dimension c 21.4 cm for all types of blocks

Reference	Block Type	Initial (cm)		Final (cm)				
		a	b	h	a	b	c	c ^a
B-B-CMT1-006	2	47.3	36.1	16.0	51	41	24.3	24.3
B-B-CMT1-004	1	47.0	38.0	19.5	50	45	23.8	22.0
B-B-CMT2-002	3			12.8			22.0	22.0
B-B-CMT2-005	2			13.0			23.0	21.0
B-B-CMT2-009	1			13.0			23.0	21.0
B-B-CMT3-006	1			13.0			23.0	21.8

^a taken on site during dismantling

5.3 DRY DENSITY AND WATER CONTENT

The samples for the water content and density determinations were taken following approximately sampling radii in the GBM, as shown in Figure 4. The results are shown in the Tables in Appendix 1 and are plotted in terms of water content, dry density and degree of saturation as a function of the distance to the container axis in Figure 15 to Figure 17. The points joint by lines in these Figures belong to the same sampling radius. Each point is the average of two measurements. As the dismantling operation started it was observed that the bottom part of the barrier, particularly the zones closer to the concrete bed, looked wetter than the rest of the GBM, and it was decided to analyse also samples taken from this part of the barrier and not belonging to any particular radius. These are the samples having higher water contents (higher than 45%) and lower dry densities and located farther away from the container axis in Figure 15 and Figure 16. In general, only the sampling radii located in the lower half of the barrier showed a trend to higher water contents towards the external part of the barrier, *i.e.* towards the bottom. In the sampling radii located in the upper half of the barrier, no trend with respect to water content or dry density was observed. Regarding the degrees of saturation, no trends along the GBM were observed, most of the values being between 96 and 100%.

The results obtained in bentonite blocks are detailed in Tables in Appendix 1 and plotted in Figure 18 and Figure 19. Each point in the Figures is the average of two or three measurements. In sections CMT1 and CMT2 the water content tended to increase and the dry densities to decrease towards the bottom, that is, away from the container and towards the concrete bed. However, in section CMT3 these trends were not observed. In terms of degree of saturation there are not clear spatial trends. The values measured were between 95 and 101%.

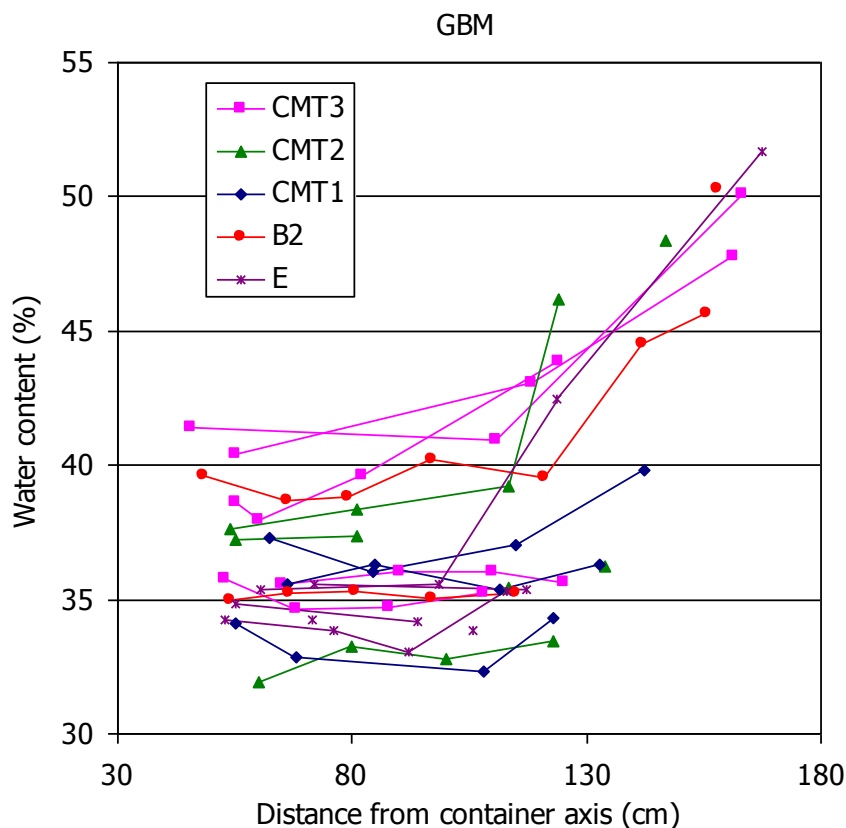


Figure 15: Water content of GBM samples from different sampling sections as measured in the laboratory

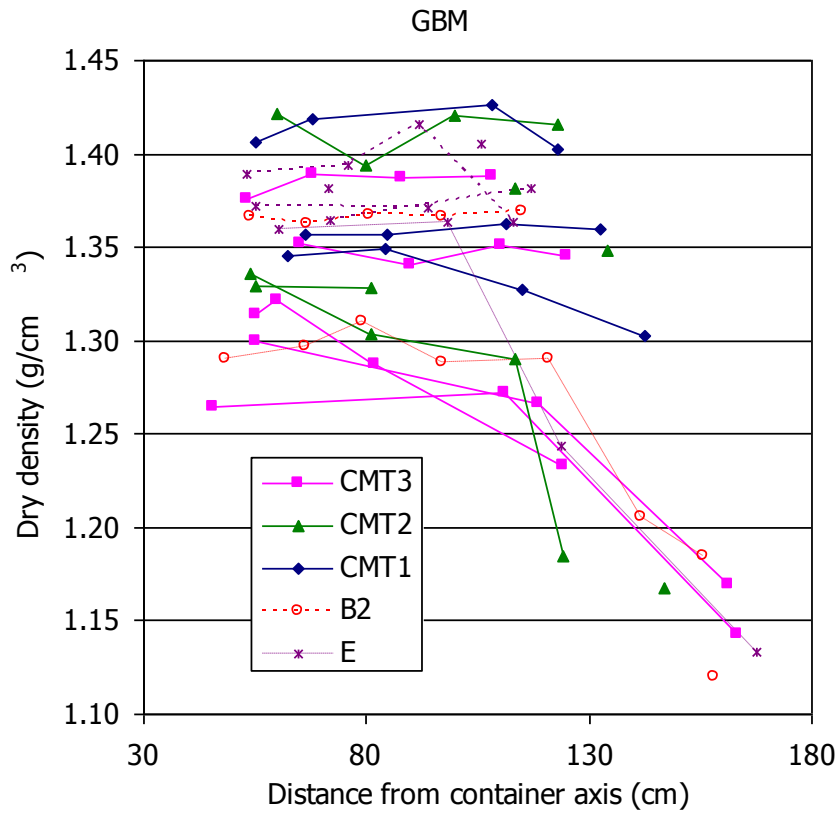


Figure 16: Dry density of GBM samples from different sampling sections as measured in the laboratory

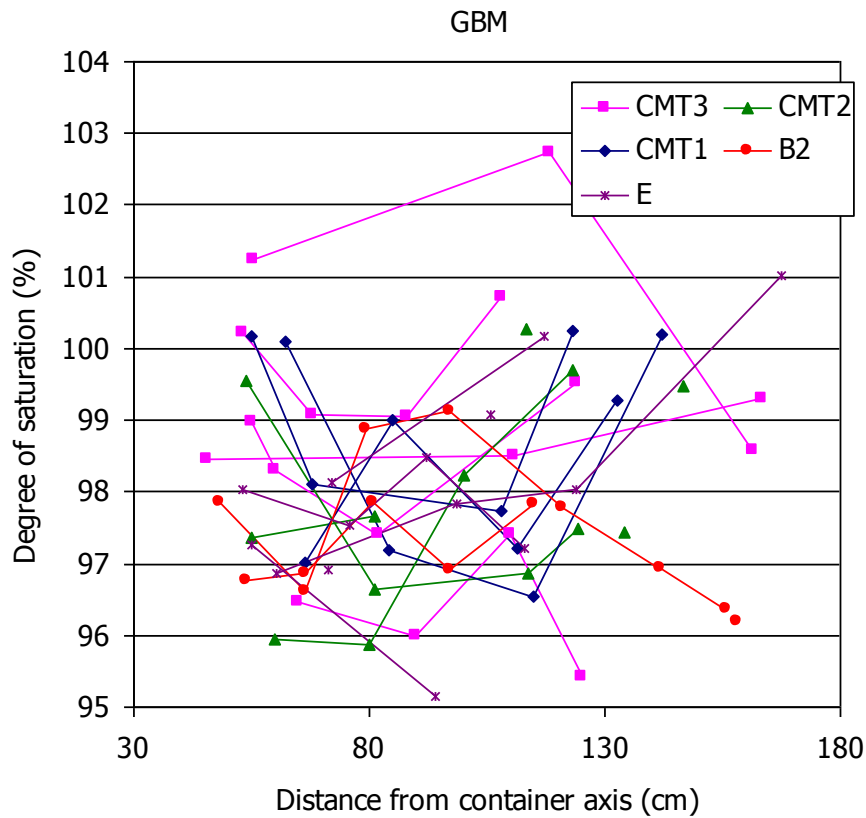


Figure 17: Degree of saturation of GBM samples from different sampling sections as measured in the laboratory

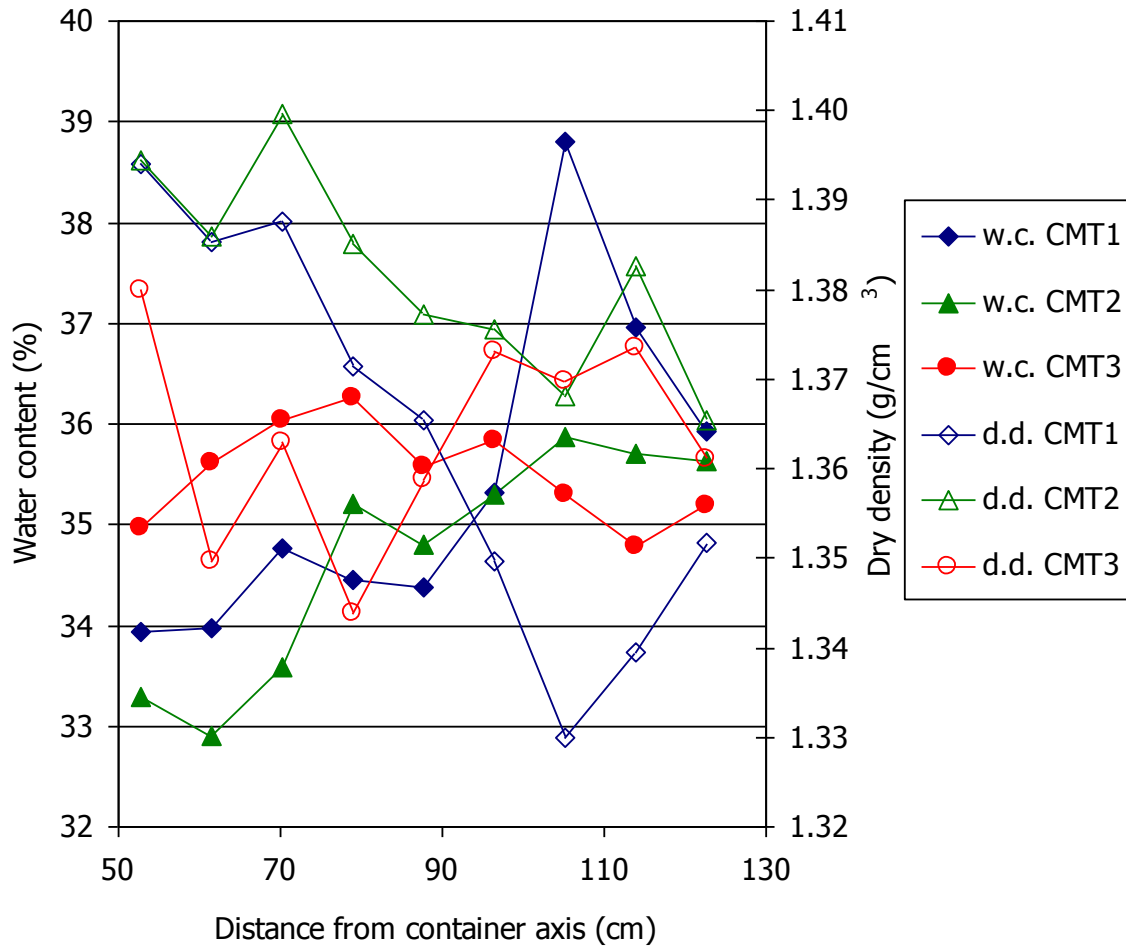


Figure 18: Water contents and dry densities measured in blocks from three sampling sections

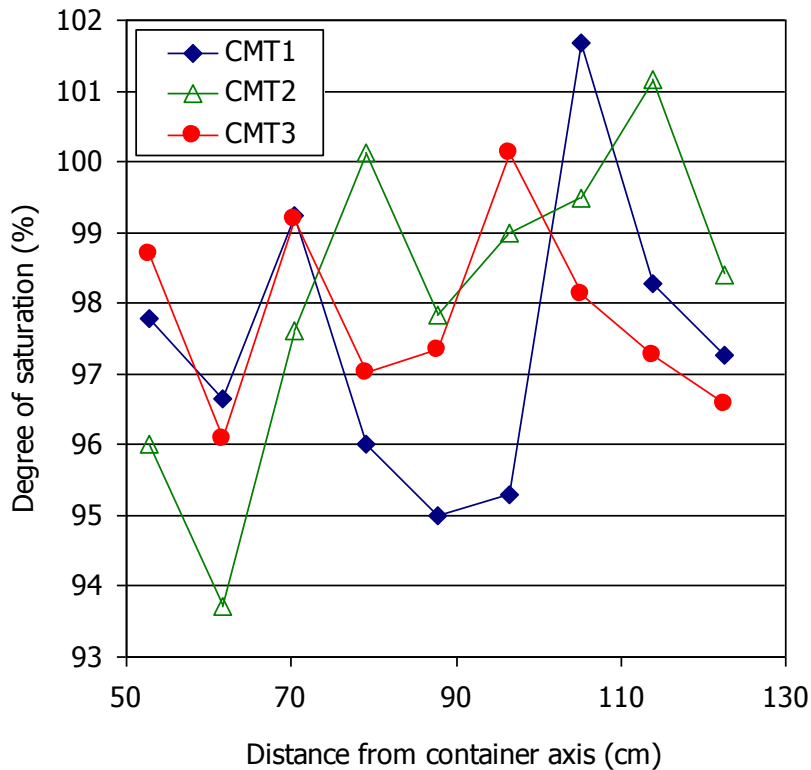


Figure 19: Degrees of saturation measured in blocks from three sampling sections

Table III shows average values for each sampling section grouped according to the position of the samples in the barrier: upper, intermediate and lower part of the GBM and blocks. These values are also plotted in Figure 20 to Figure 22. Inside the GBM the water content increased clearly towards the bottom, while the dry density decreased. These changes were not reflected in the degrees of saturation, which did not show any clear spatial trend. The deviations with respect to the average values were higher towards the bottom of the GBM because the increase in water content towards the bottom was sharper in the lower part of the GBM. The average values for the blocks were between those of the bottom and the upper part of the GBM and were similar for the three sampling sections. On the other hand, there were differences among sections in the GBM, and it seems that the average water content of the GBM increased towards the bottom part of the gallery (from section CMT1 to CMT3).

Table III: Average values according to the position of the samples in each section

Position	# samples	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)
CMT1 GBM upper	4	1.42±0.01	33.4±1.0	99±1
CMT1 GBM intermediate	4	1.36±0.00	35.9±0.05	98±1
CMT1 GBM lower	4	1.33±0.02	37.5±1.6	99±2
CMT1 blocks	12	1.36±0.02	35.4±1.6	97±2
CMT2 GBM upper	5	1.41±0.02	33.4±1.3	98±2
CMT2 GBM intermediate	5	1.35±0.02	36.6±1.0	98±1
CMT2 GBM lower	4	1.24±0.07	43.0±5.0	98±1
CMT2 blocks	12	1.38±0.01	34.7±1.1	98±2
CMT3 GBM upper	5	1.39±0.01	35.0±0.5	99±1
CMT3 GBM intermediate	8	1.32±0.04	37.9±2.8	97±2
CMT3 GBM lower	6	1.24±0.06	44.1±3.9	100±2
CMT3 blocks	12	1.36±0.01	35.5±0.5	98±1
A1_25 GBM lower	7	1.34±0.03	37.2±1.9	99±2
E GBM upper	6	1.39±0.02	34.2±0.7	98±1
E GBM intermediate	4	1.37±0.01	35.2±0.7	98±2
E GBM lower	4	1.27±0.11	41.3±7.7	99±2
B2 GBM upper	5	1.37±0.00	35.2±0.2	97±1
B2 GBM lower	8	1.25±0.07	42.2±4.2	98±1

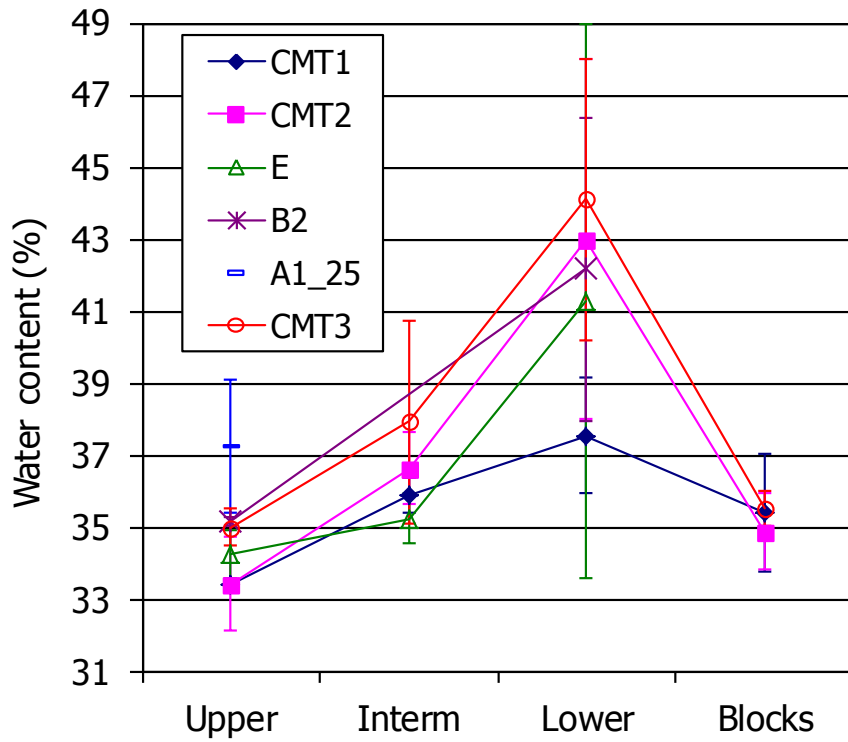


Figure 20: Average water content measured in the laboratory according to the position of the samples in the barrier and the sampling section

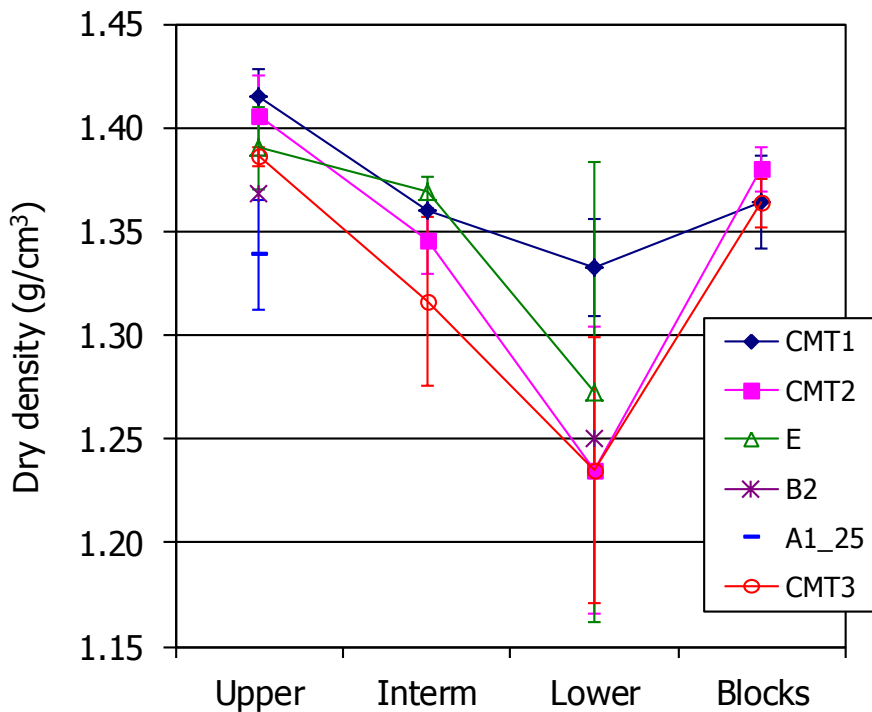


Figure 21: Average dry density measured in the laboratory according to the position of the samples in the barrier and the sampling section

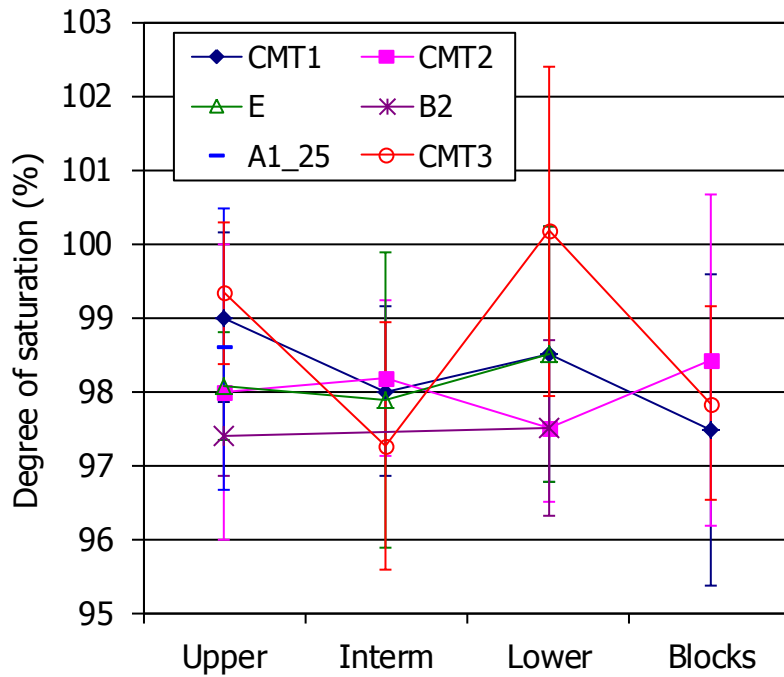


Figure 22: Average degree of saturation measured in the laboratory according to the position of the samples in the barrier and the sampling section

The results for the GBM are plotted again in Figure 23 and Figure 24 as a function of the coordinate y indicating the positions of the samples. The origin for this coordinate is the middle point of the bottom of the gallery. The trend for the water content to increase and the dry density to decrease towards the bottom is very clear and can even be fit to a potential expression.

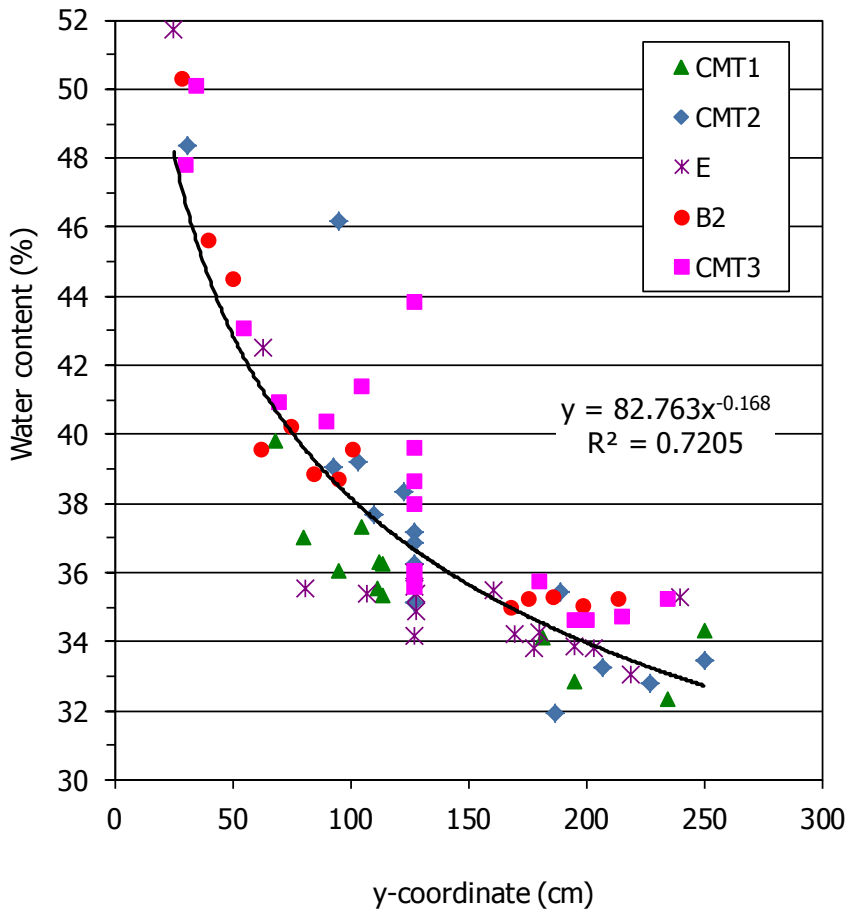


Figure 23: Water content measured in the GBM of different sections as a function of coordinate y

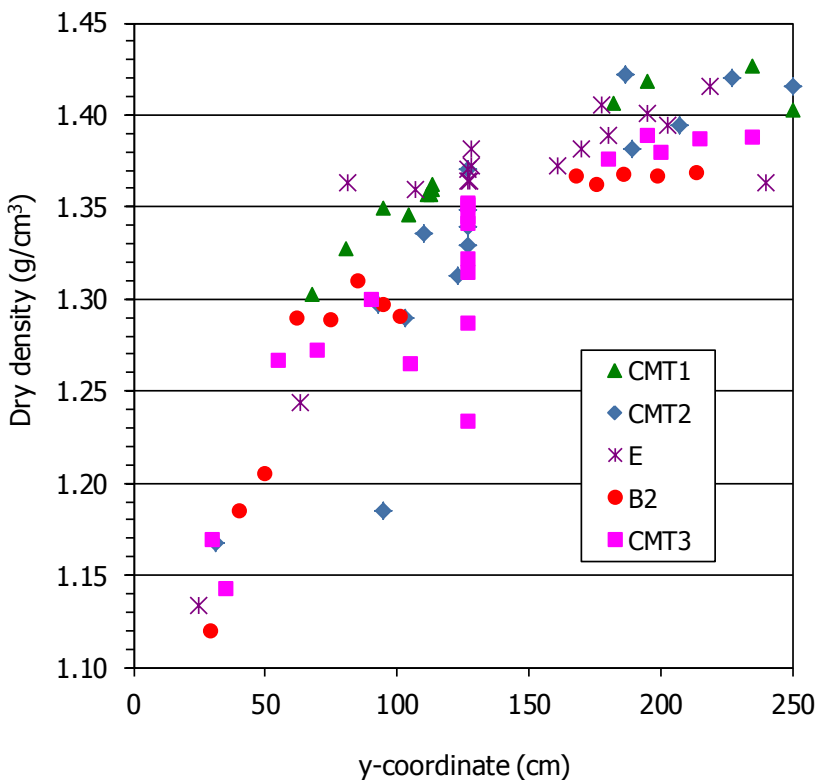


Figure 24: Dry density measured in the GBM of different sections as a function of coordinate y

5.4 LABORATORY SUCTION MEASUREMENTS

The suction of the samples was computed with Equation 1 from the relative humidity and temperature measured in the laboratory in samples of the blocks and the GBM. The values obtained with the psychrometers, which ranged between 2.1 and 4.7 MPa, are plotted in Figure 25 as a function of the water content of the bentonite for the different kinds of samples. Despite the large dispersion, the suction is seen to decrease with water content, and no difference could be found between the GBM and the blocks. The relationship between suction and dry density was inverse (Figure 26), but no clear relation with the degree of saturation could be verified.

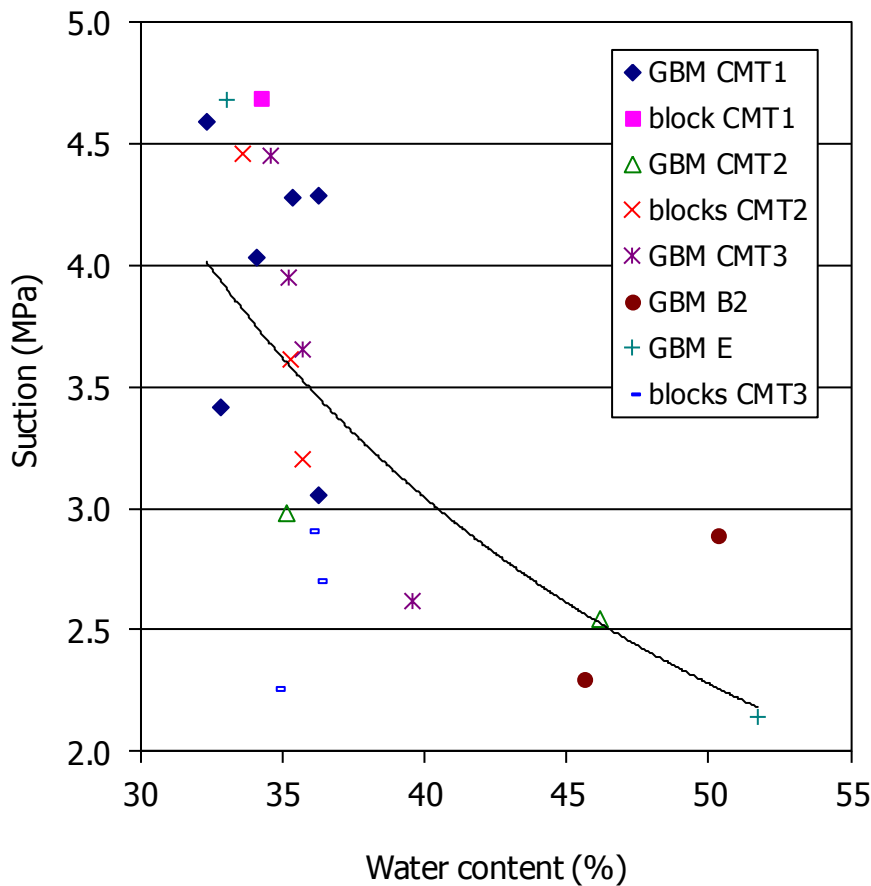


Figure 25: Suction computed from the psychrometer measurements in samples from different sampling sections as a function of the water content of the samples

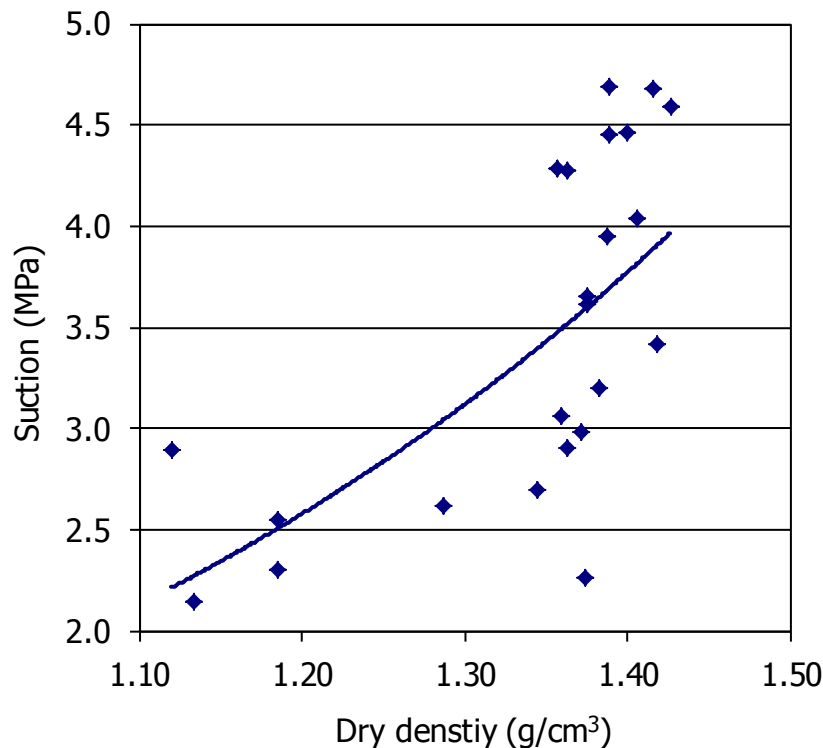


Figure 26: Suction computed from the psychrometer measurements in samples from different sampling sections as a function of the dry density of the samples

5.5 COMPARISON OF ON SITE AND LABORATORY DETERMINATIONS

A few samples from section A1_25 were cut in two, and one half was analysed on site by the AITEMIN team and the other half at CIEMAT laboratories, with the aim of fine tuning the on-site measurement methods. The results obtained by both are shown in Figure 27, where it can be observed that the water contents obtained in the laboratory were a 3.8% higher than those obtained on site and, consequently, the dry densities were lower (a 1.1%). This proved that the packing methods were good enough to keep the physical conditions of the samples upon extraction.

Additionally, twin samples were taken in sections E and B2, one of them was analysed on site and the other one was sent to CIEMAT. A total of 13 samples from section B2 (Table A- IX) and 17 from section E (Table A- VIII) were analysed. For section B2 the water contents obtained in the laboratory were on average a 0.7% higher than those obtained on site, and the dry densities a 0.2% higher. For section E the water contents obtained in the laboratory were on average the same as those obtained on site and the dry densities a 1.4% higher. The differences are very small, particularly regarding water content, consequently they are not considered significant.

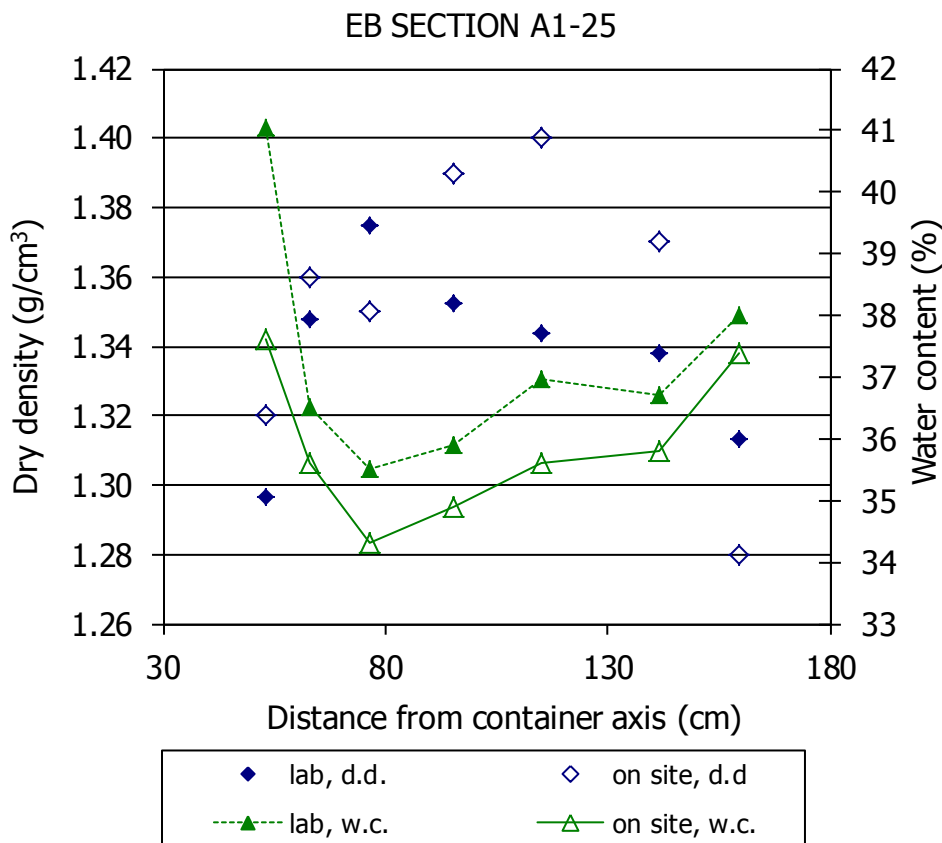


Figure 27: Water content and dry density measured in samples from section A1_25 on site and in the laboratory

Conclusions

This report summarises the physical characterisation performed at CIEMAT laboratories of bentonite samples taken during the EB experiment dismantling. Water content, dry density and degree of saturation values have been presented, along with some suction measurements.

The water contents ranged between 33 and 43% and the dry densities between 1.42 and 1.24 g/cm³, with a clear trend for the water content to increase towards the bottom part of the barrier. Two factors could have played a role in this distribution. Firstly, during the installation of the GBM segregation occurred, the finer grains accumulating at the bottom, which would cause an initial density gradient in the barrier, with lower density at the bottom. Secondly, the effect of gravity on the water distribution seems to have been relevant. The accumulation of water in the lower part of the barrier took place probably at the beginning of the experiment, favoured by the higher initial porosity of the barrier bottom. The higher water contents in these zones were accompanied by a further reduction in dry densities, consequence of swelling. This swelling seems to have been irreversible, since the density difference among different parts of the barrier remained after 10 years of operation. The blocks had water contents similar to those of the adjacent GBM, and their density decreased from an initial value of 1.7 g/cm³ to values close to 1.4 g/cm³, similar to the average values found in the GBM. The increase in the dimensions of the blocks confirms that they swelled during the test and also after dismantling, when the pressures were released. The blocks closer to the concrete plug swelled mainly in the longitudinal direction, whereas in the rest of sections the change in blocks' vertical dimensions indicates the uplift of the canister.

The degrees of saturation of the barrier ranged between 95 and 101%. It is considered that the average pore water density in the barrier is close to 1.0 g/cm^3 due to the low average dry density of the bentonite.

Concerning the average values of water content and dry density there are not important differences among the different sampling sections.

The comparison between the values obtained on site and in the laboratory has shown a very good agreement, but all these observations have to be confirmed with the on site measurements, which involve a larger number of samples.

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Appendix 1 Laboratory measurements

Table A- I: Values measured in the laboratory in GBM samples from section A1_25 (z=320)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)
B-S-A1_25-018	49	107	53	1.30	41.0	102
B-S-A1_25-019	57	100	63	1.35	36.5	98
B-S-A1_25-020	67	90	77	1.38	35.5	100
B-S-A1_25-021	83	80	95	1.35	35.9	97
B-S-A1_25-022	100	70	115	1.34	37.0	99
B-S-A1_25-023	125	60	142	1.34	36.7	97
B-S-A1_25-024	140	50	160	1.31	38.0	97
Average				1.34±0.03	37.2±1.9	99±2

^a Approximate distance to canister centre

Table A- II: Values measured in the laboratory in block samples (two or three measurements per sample, average specimen volume 10±2 cm³) from section CMT1 (z=355)

Sample reference	Position ^a (cm)	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)	Suction (MPa)
B-B-CMT1-007	53	1.39	33.9	98	4.7 ^c
	62	1.39	34.0	97	
	70	1.39	34.8	99	
B-B-CMT1-006	79	1.37	34.4	96	
	88	1.37	34.4	95	
	96	1.35	35.3	95	
B-B-CMT1-004	105	1.33	38.8	102	
	114	1.34	37.0	98	0 ^b
	123	1.35	35.9	97	0.5 ^b
Average		1.36±0.02	35.4±1.6	97±2	

^a Approximate distance to canister centre; ^b Measured in the laboratory with capacitive sensors; ^c Measured in the laboratory with psychrometers

Table A- III: Values measured in the laboratory in block samples (two or three measurements per sample, average specimen volume 11±2 cm³) from section CMT2 (z=460)

Sample reference	Position ^a (cm)	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-B-CMT2-002	53	1.39	33.3	96	
	62	1.39	32.9	94	
	70	1.40	33.6	98	4.5
B-B-CMT2-005	79	1.39	35.2	100	
	88	1.38	34.8	98	
	96	1.38	35.3	99	3.6
B-B-CMT2-009	105	1.37	35.9	99	
	114	1.38	35.7	101	
	123	1.37	35.6	98	3.2
Average		1.38±0.01	34.7±1.1	98±2	

^a Approximate distance to canister centre; ^b Measured in the laboratory with capacitive sensors

Table A- IV: Values measured in the laboratory in block samples (two or three measurements per sample, average specimen volume $10\pm 1 \text{ cm}^3$) from section CMT3 (z=650)

Sample reference	Position ^a (cm)	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-B-CMT3-001	53	1.38	35.0	99	
	62	1.35	35.6	96	
	70	1.36	36.0	99	2.9
B-B-CMT3-003	79	1.34	36.3	97	2.7
	88	1.36	35.6	97	
	96	1.37	35.8	100	
B-B-CMT3-006	105	1.37	35.3	98	
	114	1.37	34.8	97	2.3
	123	1.36	35.2	97	
Average		1.36±0.01	35.5±0.5	98±1	

^a Approximate distance to canister centre; ^b Measured in the laboratory with capacitive sensors; ^c Measured in the laboratory with psychrometers

Table A- V: Values measured in the laboratory in GBM samples (two measurements per sample, average specimen volume $12\pm 3 \text{ cm}^3$) from section CMT1 (z=349)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm ³)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-S-CMT1-001	-58	105	62	1.35	37.3	100	
B-S-CMT1-002	-78	95	84	1.35	36.0	97	
B-S-CMT1-003	-105	81	115	1.33	37.0	97	
B-S-CMT1-004	-130	68	142	1.30	39.8	100	2.0 ^b
B-S-CMT1-005	65	112	66	1.36	35.6	97	
B-S-CMT1-006	84	113	85	1.36	36.3	99	1.2 ^b / 4.3 ^c
B-S-CMT1-007	111	114	111	1.36	35.3	97	4.3 ^c
B-S-CMT1-008	132	114	133	1.36	36.3	99	3.1 ^c
B-S-CMT1-017	0	182	55	1.41	34.1	100	4.0 ^c
B-S-CMT1-018	0	195	68	1.42	32.8	98	3.4 ^c
B-S-CMT1-016	0	235	108	1.43	32.3	98	
B-S-CMT1-019	0	250	123	1.40	34.3	100	2.2 ^b / 4.6 ^c
Average				1.37±0.04	35.6±2.0	99±1	

^a Approximate distance to canister centre; ^b Measured in the laboratory with capacitive sensors; ^c Measured in the laboratory with psychrometers

Table A- VI: Values measured in the laboratory in GBM samples (two measurements per sample, average specimen volume $8\pm 1 \text{ cm}^3$) from section CMT2 ($z=460$)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm^3)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-S-CMT2-004	55	127	55	1.33	37.2	97	
B-S-CMT2-005	81	127	81	1.33	37.4	98	
B-S-CMT2-006	107	127	107	1.37	35.1	98	3.0
B-S-CMT2-007	134	127	134	1.35	36.2	97	
B-S-CMT2-018	-53	110	56	1.34	37.7	100	
B-S-CMT2-019	-81	123	81	1.30	38.3	97	
B-S-CMT2-020	-111	103	114	1.29	39.2	97	
B-S-CMT2-021	-120	95	124	1.18	46.2	97	3.4
B-S-CMT2-029	0	187	60	1.42	32.0	96	
B-S-CMT2-030	0	207	80	1.39	33.3	96	
B-S-CMT2-031	0	227	100	1.42	32.8	98	
B-S-CMT2-032	0	250	123	1.42	33.5	100	
B-S-CMT2-026	95	189	113	1.38	35.5	100	
Average				1.35 \pm 0.07	36.4 \pm 3.7	98 \pm 1	
B-S-CMT2-017	-129	31	161	1.17	48.3	99	

^a Approximate distance to canister centre; ^b Measured in the laboratory with psychrometers

Table A- VII: Values measured in the laboratory in GBM samples (two measurements per sample, average specimen volume $9\pm 1 \text{ cm}^3$) from section CMT3 ($z=695$)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm^3)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-S-CMT3-008	65	127	65	1.35	35.6	96	
B-S-CMT3-009	90	127	90	1.34	36.0	96	
B-S-CMT3-010	110	127	110	1.35	36.0	97	
B-S-CMT3-011	125	127	125	1.34	35.6	95	
B-S-CMT3-014	65	200	98	1.38	34.6	98	
B-S-CMT3-015	0	180	53	1.38	35.7	100	3.7
B-S-CMT3-016	0	195	68	1.39	34.6	99	4.5
B-S-CMT3-017	0	215	88	1.39	34.7	99	
B-S-CMT3-018	0	235	108	1.39	35.3	101	4.0
B-S-CMT3-019	-55	127	55	1.31	38.7	99	
B-S-CMT3-020	-60	127	60	1.32	38.0	98	
B-S-CMT3-021	-82	127	82	1.29	39.6	97	2.6
B-S-CMT3-022	-124	127	124	1.23	43.8	100	
Average ^c				1.34 \pm 0.05	36.8 \pm 2.6	98 \pm 2	
B-S-CMT3-001	41	90	55	1.30	41.3	103	
B-S-CMT3-002	94	55	118	1.27	43.1	103	
B-S-CMT3-003	129	30	161	1.17	47.8	99	
B-S-CMT3-023	-40	105	46	1.26	41.4	98	
B-S-CMT3-024	-95	70	111	1.27	40.9	99	
B-S-CMT3-025	-135	35	163	1.14	50.1	99	
Average ^d				1.31 \pm 0.07	39.3 \pm 4.6	99 \pm 2	

^a Approximate distance to canister centre; ^b Measured in the laboratory with psychrometers; ^c Samples from the 3 sampling radii in the half upper part of the GBM; ^d Samples from the 5 sampling radii

Table A- VIII: Values measured in the laboratory in GBM samples (two measurements per sample, average specimen volume $7\pm 1 \text{ cm}^3$) from section E ($z=520$)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm^3)	Water content (%)	Degree of saturation (%)	Suction ^b (MPa)
B-S-E-017	-67	128	67	1.37	34.9	97	
B-S-E-019	-112	127	112	1.37	34.2	95	
B-S-E-022	80	128	80	1.36	35.6	98	
B-S-E-023	94	127	94	1.36	36.0	99	
B-S-E-024	132	128	132	1.38	35.4	100	
B-S-E-028	68	161	76	1.37	35.5	99	
B-S-E-029	96	178	109	1.41	33.8	99	
B-S-E-032	-57	170	71	1.38	34.2	97	
B-S-E-034	-80	195	105	1.40	33.9	99	
B-S-E-037	0	180	53	1.39	34.3	98	
B-S-E-038	0	203	76	1.39	33.8	98	
B-S-E-039	0	219	92	1.42	33.1	98	4.7
B-S-E-040	0	240	113	1.36	35.3	97	
Average ^c				1.38 ± 0.02	34.6 ± 0.9	98 ± 1	
B-S-E-010	-57	107	60	1.36	35.4	97	
B-S-E-012	-87	81	98	1.36	35.5	98	
B-S-E-014	-106	63	124	1.24	42.5	98	
B-S-E-016	-133	25	168	1.13	51.7	101	2.1
Average ^d				1.36 ± 0.07	36.2 ± 4.5	98 ± 1	

^a Approximate distance to canister centre; ^b Measured in the laboratory with psychrometers; ^c Samples from the half upper part of the GBM; ^d Samples from all the sampling radii

Table A- IX: Values measured in the laboratory in GBM samples (two measurements per sample, average specimen volume $8\pm 2 \text{ cm}^3$) from section B2 ($z=647$)

Sample reference	x	y	Position ^a (cm)	Dry density (g/cm^3)	Water content (%)	Degree of saturation (%)	Suction (MPa)
B-S-B2-031	-35	168	54	1.37	35.0	97	
B-S-B2-032	-45	176	67	1.36	35.2	97	2.0 ^b
B-S-B2-033	-55	186	81	1.37	35.3	98	
B-S-B2-034	-65	199	97	1.37	35.0	97	1.2 ^b
B-S-B2-035	-75	214	115	1.37	35.2	98	
Average ^d				1.37 ± 0.00	35.2 ± 0.2	97 ± 1	
B-S-B2-001	48	101	55	1.29	39.6	98	
B-S-B2-002	58	95	66	1.30	38.7	97	
B-S-B2-003	67	85	79	1.31	38.8	99	
B-S-B2-004	82	75	97	1.29	40.2	99	
B-S-B2-005	102	62	121	1.29	39.6	98	
B-S-B2-006	119	50	142	1.21	44.5	97	
B-S-B2-007	129	40	156	1.19	45.6	96	2.3 ^c
B-S-B2-020	-124	29	158	1.12	50.3	96	2.9 ^c
Average ^e				1.25 ± 0.07	42.2 ± 4.2	97 ± 1	

^a Approximate distance to canister centre; ^b Measured in the laboratory with capacitive sensors; ^c Measured in the laboratory with psychrometers; ^d Samples from the half upper part of the GBM; ^e Samples from the half lower part of the GBM