P-13-14

# Prototype Repository

## Measurements of water content and density of the retrieved buffer material from deposition hole 5 and 6 and the backfill in the outer section of the Prototype Repository

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June 2014

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*Keywords*: Retrieval, Buffer, Backfill, Bentonite, MX-80.

# Summary

Prototype Repository is a large-scale trial installed at Äspö. The trial consists of six full-scale deposition holes in the TBM-tunnel, depth 450 metre. Each deposition hole is installed with full-scale bentonite buffer (MX-80) and full-scale canister which are equipped with heaters to simulate heat from a canister containing real waist. The trial is divided into two sections, in which the inner section consists of four deposition holes and the outer consisting of two deposition holes. The deposition tunnel is backfilled with a mixture of crushed rock and bentonite (30% bentonite). The trial also includes two concrete plugs which end each section. The trial was installed during the period 2001–2003. Natural wetting from the rock of buffer and backfill continued from that date until the end of year 2010 when Section II was breached.

At the removal of the buffer and backfill samples were taken for further investigations in the laboratory. This report deals with the analyses of the water content and density of the buffer and backfill.

Most of the samples were taken from the buffer in the two deposition holes by core drilling from the upper surface of each installed bentonite block. The cores had a diameter of about 50 mm and a maximum length equal to the original height of the bentonite blocks (about 500 mm).

The excavation of the backfill in the tunnel was made in inclined layers with a backhoe loader. On every 2 meter the excavation stopped and samples were taken for determination of the water content and density of the backfill material, about 100 samples in each section. The samples taken were excavated from the surface with the use of an angle grinder.

The water content of the buffer and backfill was determined by drying a sample at a temperature of 105°C for 24 h and the bulk density was determined by weighing a sample both in the air and immerged in paraffin oil with known density.

The water content, dry density and degree of saturation of the buffer and backfill were then plotted. The plots show that all parts of the buffer had taken up water and the degree of saturation of the buffer varied between 70–100%. Large variation in the dry density of the buffer was also observed.

The measurements of the density and water content for the backfill show that it was fully saturated and that the density varies within the investigated section in such a way that the density close to the rock surface and especially close to the ceiling was low compare to the backfill in the central part of the tunnel.

# Sammanfattning


Prototypförvaret är ett storskaligt försök som installerats på Äspö. Försöket innehåller sex fullskaliga deponeringshål i en TBT-tunnel på djupet 450 m. Deponeringshålen är installerade med fullskaliga bentonitblock av MX-80 och fullskaliga kapslar vilka är utrustade med värmare för att kunna simulera värmen får en riktig kapsel med utbränt bränsle. Försöket är uppdelat i två sektioner där den inre sektionen består av fyra deponeringshål medan den yttre sektionen består av två. Deponeringstunneln är återfylld med ett återfyllningsmaterial som består av 30 % bentonit och 70 % krossat berg. Försöket innehåller också två betongpluggar. Försöket installerade under perioden 2001–2003. Bufferten och återfyllningsmaterialet tog upp vatten från omgivande berg från den tidpunkten till slutet av 2010 då sektion två bröts.

Vid brytningen av bufferten och återfyllningen togs prover för vidare undersökningar i laboratoriet. Denna rapport berör laboratorieanalyserna gjorda för bestämning av densitet och vattenkvot på materialen.

De flesta proverna av bufferten i de två deponeringshålen togs genom kärnborrning från överytan av bentonitblocken. De utborrade kärnorna hade en diameter på ca 50 mm och med en maximal längd lika med den ursprungliga höjden på de installerade blocken (ca 500 mm).

Urgrävningen av återfyllningsmaterialet i tunneln gjorde med hjälp av en traktorgrävare i lutande lager. Varannan meter togs provare på återfyllningsmaterialet, 100 prover i varje sektion, för bestämning av densitet och vattenkvot. Proverna grävdes fram med hjälp av en vinkelslip.

Vattenkvoten på proverna bestämdes genom att torka ett prov i 105 C under 24h och skrymdensiteten bestämdes genom att väga ett prov både i luft och nersänkt i paraffinolja med känd densitet.

Vattenkvoten, torrdensiteten och vattenmättnadsgraden för bufferten och återfyllningen ritades sedan upp i figurer. Figurerna visar att alla delar av bufferten hade tagit upp vatten och att vattenmättnadsgraden för bufferten varierade mellan 70–100 %. Stora variationer i torrdensiteten mellan olika delar av bufferten uppmättes också.

Mätningarna av torrdensitet och vattenkvot hos återfyllningen visade att den var vattenmättad och att densiteten varierade mycket inom de undersökta sektionerna. Torrdensiteten hos återfyllningsmaterialet nära bergytan och då speciellt när tunneltaket var låg i jämfört med den bestämda torrdensiteten i de centrala delarna av tunneln.

# Contents

# 1 Introduction

## 1.1 Background

Prototype Repository is a large-scale trial installed at Äspö. The trial consists of six full-scale deposition holes in the TBM-tunnel, depth 450 metre. Each deposition hole is installed with full-scale bentonite buffer (MX-80) and full-scale canister. The canisters are equipped with heaters to simulate heat from a canister containing spent nuclear fuel. The trial is divided into two sections, in which the inner section (Section I) consists of four deposition holes and the outer section (Section II) consisting of two deposition holes all installed with buffer and canister, see Figure 1-1. The deposition tunnel is backfilled with a mixture of crushed rock and bentonite (30% bentonite). The trial also includes two concrete plugs which end each section.

Furthermore, sensors were installed in the rock, backfill and buffer to monitor pressure build-up and wetting of buffer and backfill. The trial is described in detail by Persson and Broman (2000) and in Svemar and Pusch (2000). The dimensions of the tunnel and the deposition hole are shown in Figure 1-1.

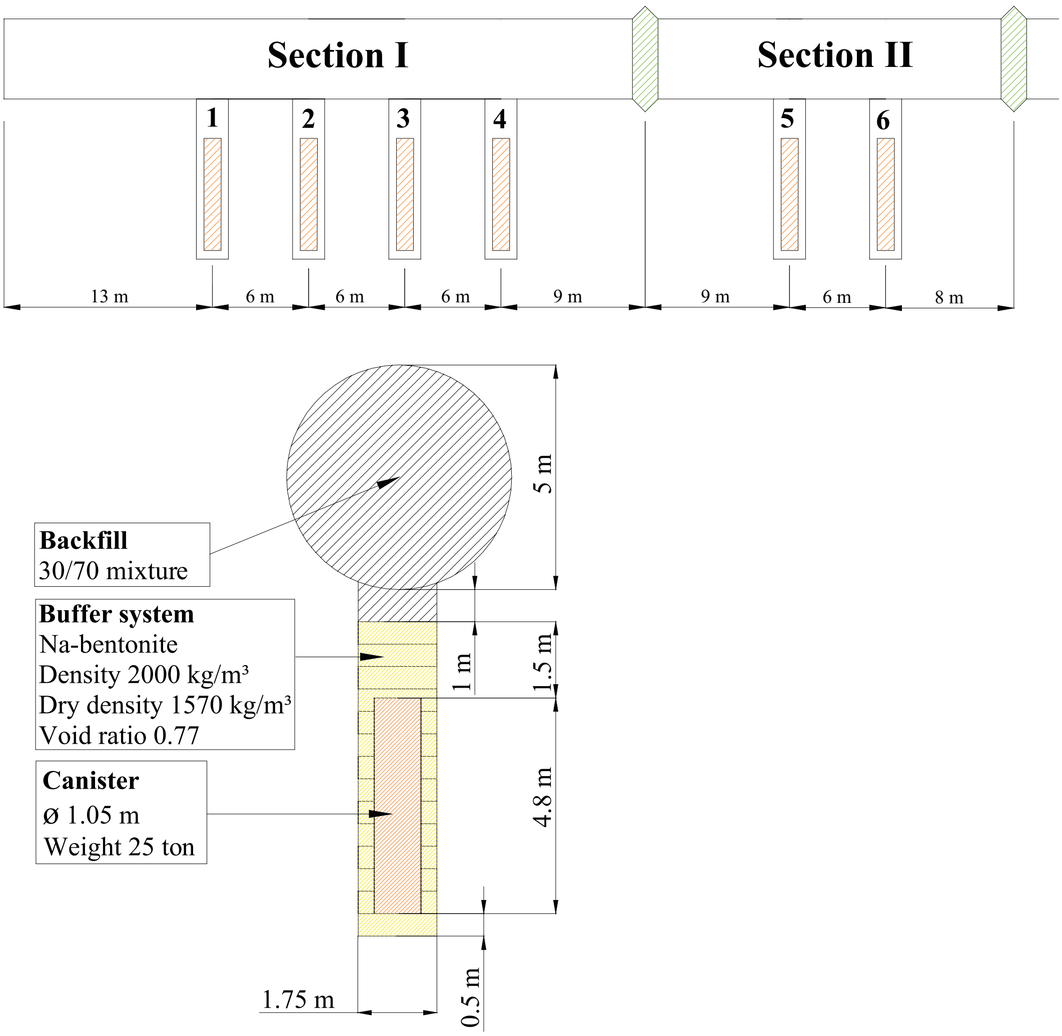


***Figure 1-1.*** *Schematic drawing of the deposition tunnel and the deposition holes of the Prototype Repository.*

The installation of buffer, canister with heater, packing of backfill, and also the making of concrete plugs was done during the autumn of 2001 for section I. Corresponding installations for section II were made during the spring and autumn 2003. Heating of the canisters in the two sections was started successively after filling of the tunnel had reached the deposition holes. The heaters in canister 1 were activated October 3 2001 and respective heaters in canister 6 were activated on May 23 2003. The plug in Section II was completed October 11 2003. The installation of the outer section is described in detail in Johannesson et al. (2004). The manufacturing of the buffer blocks is described in Johannesson (2002) and the manufacturing of the backfill material is described in Gunnarsson et al. (2001) and Gunnarsson (2002).

Natural wetting from the rock of buffer and backfill continued from that date until the end of year 2010 when Section II was breached and retrieved. Natural wetting and heating of Section I still continue as planned.

The canisters were heated with 1,800 W power from May 2003. The power for the canisters was decrease with about 30 W per year. Due to problems with the heaters for the canister in deposition hole 6 two reductions of the power was done with about 200–300 W. The power at the dismantling was about 1,150 W for canister no 6 and about 1,600 W for canister no 5 (Goudarzi 2012).

The buffer around canister no 6 was removed during the period April–July 2011 and the buffer around canister no 5 was removed during the period September–December 2011. The removal of the backfill was done during two periods, February–Mars and July–August 2011. The work with the removal of the buffer and backfill and how the samples were taken are described in a separate report (Johannesson and Hagman 2013).

At the removal of the buffer and backfill samples were taken for further analyses in the laboratory. There are two phases in the analyses of the samples taken from the buffer and backfill.

1. The water content and the density were determined at the Äspö Hard Rock Laboratory just after the samples were taken from the buffer and backfill, which minimized the risk of drying and redistribution of the water in the samples. About 7,000 determinations of water content and density were made on the buffer material, and about 1,000 determinations of the density and water content on the backfill.
2. More advanced investigations of the buffer and backfill such as determination of hydraulic conductivity and swelling pressure, mineralogical changes etc will be made at Clay Technology AB, B+Tech in Helsinki and Micans in Gothenburg. These tests do not require immediate processing of the samples and are reported separately.

The purpose with the investigation is to determine the distribution of the water content and density of the buffer and backfill at the retrieval of the test. The first analyse phase described above and its results are presented in this report. The data will be used for the THM-modelling of the test but also as input for the more advanced laboratory investigations in the second face of the laboratory work. In this report a first attempt to correlate the distribution of the water content and density with the measured water inflow into the deposition holes and the tunnel is also made.

# 2 Execution of the sampling of the buffer

## 2.1 Introduction

Since the buffer was partly saturated from water coming from both the surrounding rock and from backfill above the buffer all initial gaps between the canister and the block and the pellets and the rock has disappeared and thus a swelling pressure toward both the canisters and the surface of the deposition holes was present at the time for the retrieval. It was also assumed that the buffer was not fully saturated and the saturation was not axisymmetric. In order to be able to take the samples and to remove the buffer a combination of core drilling and stitch drilling was used, see Figure 2-1 and Figure 2-2. The technique is described in detail in a separate report (Johannesson and Hagman 2013).

***Figure 2-1.*** *a) The core drilling machines standing on the tunnel floor. b) Holes from cores taken from a buffer block (Johannesson and Hagman 2013).*

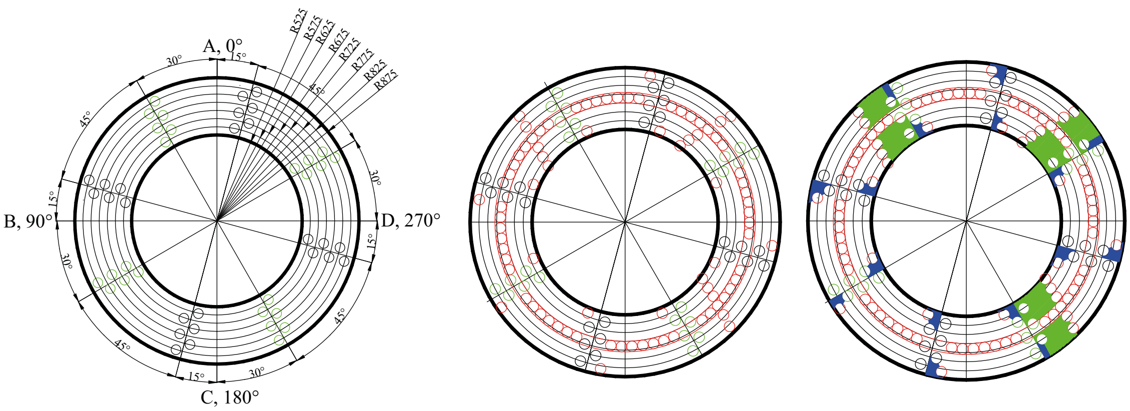


***Figure 2-2.*** *a) The cores taken for determine the density and water content of the buffer. b) The extra cores (red) drilled for loosen the buffer inside the deposition hole. c) The large samples (green) taken from the buffer for further investigations in the lab and the samples (blue) taken for determine the water content and density close to the canister and the rock (Johannesson and Hagman 2013).*

## 2.2 The position of the samples

The designation of the bentonite blocks and the coordinate system used for describing the position of the taken samples are shown in Figure 2-4. With the *z*-axis starting from the cement casting in the bottom of the deposition hole and the angle $\alpha$ counted anti-clockwise from direction A. Direction A and C are placed in the tunnels axial direction with A headed against the end of the tunnel i.e. almost towards West, see Figure 2-3. The position of each sample is defined by three coordinates

1. r-coordinate. The horizontal distance from the centre of the deposition hole.
2. z-coordinate. The distance from the bottom of the deposition hole to the position of the sample.
3. α-coordinate. The horizontal direction where the 0° direction is defined as direction A in Figure 2-4.

The angle α was marked in advance on the wall at the upper part of the deposition hole and furthermore a graduated rulers were placed on the top of the blocks before the sampling started for determining the angle α of the taken samples, see Figure 2-5. The accuracy of the determination is approximately 2°.

The z-coordinate was determined with a laser levelling instrument. The accuracy of this measurement is approximately 1 mm.

The r-coordinate was determined by measuring the distance to the canister and/or to the wall of the deposition hole. The accuracy of this measurement is approximately 5 mm.

## 2.3 Preparation of the samples

Most of the samples were taken in 8 main directions as core drilled samples but also larger sectors of the buffer were taken close to the rock surface and the canister.

The samples taken from the buffer were split up in smaller pieces before determining their water content and density. This was done in most cases within 24 hours after the samples were taken from the buffer blocks. The split was made with a band saw according to the following plan:

- In five directions samples were taken with a radial distance of 5 cm at one depth measured from the top of each block, see Appendix 1. The smaller pieces were named after the core plus a suffix, e.g. Dh5:R7:70:575:A.
- In one direction samples were taken with a radial distance of 2.5 cm at one depth measured from the top of each block, see Appendix 2. The smaller pieces were named after the core plus a suffix, e.g. Dh5:R7: 205:575:Aa–Ab.
- In two directions samples were taken with a radial distance of 5 cm at five depths measured from the top of each block , see Appendix 3. The smaller pieces were named after the core plus a suffix, e.g. Dh5:R7:25:575:A–E.
- Since it was difficult to make a core drilling close to the canister and the wall of the deposition hole larger pieces of the buffer (end sectors) were taken in the same directions as the cores. These are marked with blue in Figure 2-2 c and they were cut in pieces with a thickness of 1 cm in radial direction in order to get a better spatial resolution in the determination of the density and water content in those areas of the buffer. The smaller pieces were named after the end sectors name plus a suffix e.g. Dh5:R7:295:880:A:I for samples taken close to the wall of the deposition hole or Dh5:R7:295:525:A:III for samples taken close to the heater. The suffix number is related to the radial position of the piece in the end sector. The pieces taken closest to the rock surface or heater respectively have the lowest number (I).

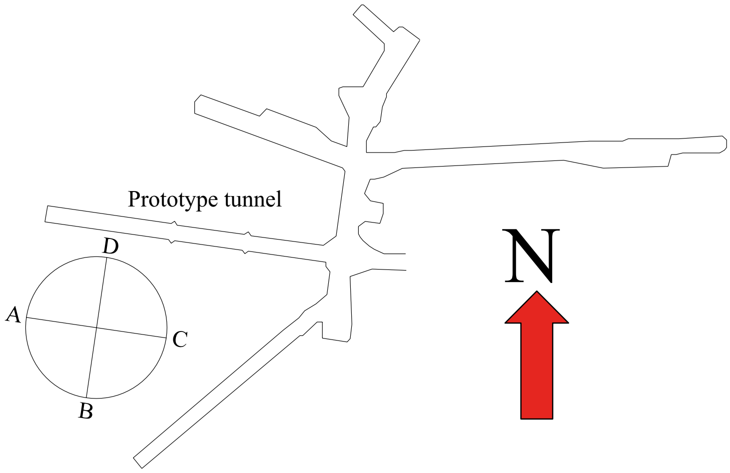


***Figure 2-3.** Äspö HRL, contours of the tunnels at the –450 m level. The directions A...D for the taken samples are marked.*

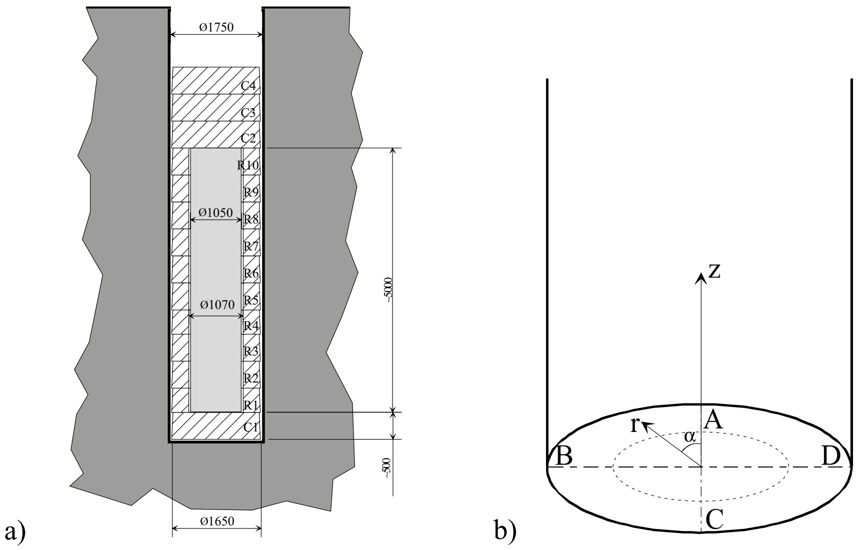


***Figure 2-4.** a) The designation of the bentonite blocks and b) the coordinate system used when describing the positions of the taken samples. 0°is the direction towards the end of the drift and 270° is the direction almost to the north.*

***Figure 2-5.** Graduated rulers placed towards the canister and the rock surface for determining the position of the samples.*

## 2.4 Detemination of density and water content of the samples.

Most of the determining of the water content and the density of the buffer were made within 24 hours after the samples were taken in order to minimize the risk of air drying of the bentonite. The samples were transported wrapped in foils to a surface laboratory at Äspö where small pieces were detached to determine the water content and density. The rest of the samples were restored in the plastic wrapping.

The following equipment was used in the laboratory

1. **A band saw** for sawing out pieces from the samples.
2. **A precision balance** with 0–2,000 g range of measurement and a resolution of 0.001 g.
3. **Two ovens** for drying samples at 105°C.

**Determination of water content.**

The determination of the water content was made in the following way:

1. The balance was checked with reference weights before the starting of the measurements.
2. A small baking tin of aluminum was placed on the balance and the weight ($m_{bt}$) was noted in a protocol.
3. The sample was placed in the baking tin and the weight of sample and tin is noted in a protocol ($m_{bt} + m_{bulk}$).
4. The tin with the sample was placed in an oven with a temperature of 105 ˚C for 24 h.
5. After the drying the weight of the baking thin and the sample ( $m_{bt} + m_{solid}$) was measured and noted in a protocol.

The water content of the cut subsamples was determined by drying a sample at a temperature of 105°C for 24 h. The mass of water dried from the sample was determined according to Equation 2-1:

$$m_{water} = m_{bulk} - m_{solid} \tag{2-1}$$

and the water content (w) was calculated according to Equation 2-2.

$$w = \frac{m_{water}}{m_{solid}} \tag{2-2}$$

**Determination of density.**

The bulk density of the samples was determined by weighing the samples both in air and immerged in paraffin oil with known density. The determination was made as follows:

1. A piece of thread was weighed.
2. The sample was weighed hanging on the thread underneath the balance ($m_{bulk}$).
3. The sample was then submerged in the paraffin oil with the density $\rho_{paraffin} = 862.1$ kg/m$^3$ and the weight ($m_{paraffin}$) were noted.

The volume of the sample ($V_{bulk}$) and the density ($\rho_{bulk}$) were calculated according to Equations 2-3 and 2-4.

$$V_{bulk} = (m_{bulk} - m_{paraffine}) / \rho_{paraffine} \tag{2-3}$$

$$\rho_{bulk} = \frac{m_{bulk}}{V_{bulk}} \tag{2-4}$$

The determination of the density described above is made according to SS 027114 (SIS 1989) with the assumption that instead of solvent naphtha paraffin oil was used.

**Calculation of other parameters**

The dry density ($\rho_{dry}$) and the degree of saturation ($S_r$) can be calculated according to Equations 2-5 and 2-6.

$$\rho_{dry} = \frac{\rho_{bulk}}{(1+w)} \tag{2-5}$$

$$S_r = \frac{w \times \rho_{bulk} \times \rho_s / \rho_w}{\rho_s \times (1+w) - \rho_{bulk}} \tag{2-6}$$

For calculating the degree of saturation the values of the density of the solid particles $\rho_s$ = 2,780 kg/m$^3$ (Karnland et al. 2006) for the buffer material and the density of water to $\rho_w$ = 1,000 kg/m$^3$ are used. The density for the solid particles in the backfill (30% bentonite, 70% crushed rock) is stated to $\rho_s$ = 2,688 kg/m$^3$. This density is calculated with the assumption that the solid bentonite particles has a density of 2,780 kg/m$^3$ and the crushed rock particles has a solid density of 2,650 kg/m$^3$ (solid density of sand). The void ratio (e) can be calculated according to Equation 2-7.

$$e = \frac{\rho_s - \rho_{bulk}}{\rho_{bulk} - \rho_w \times S_r} \tag{2-7}$$

# 3 Estimation of the density of different parts of the buffer after installation

Two types of large bentonite blocks, ring shaped blocks around the canister (Block R1–R10) and solid blocks under (Block C1) and above the canister (Block C2–C4), were used for the buffer in the deposition hole. The outer diameter of the bentonite blocks was initially slightly tapered conical and varied between 1,630–1,650 mm. The ring shaped blocks surrounding the canisters had initially an inner diameter of 1,070 mm.

The initial average weight, water content (i.e. the water-solid mass-ratio), density and void ratio of the blocks are listed in Table 3-1 and Table 3-2. The densities were determined by measuring the weight and dimensions of the blocks and the water contents were determined on samples taken at the compaction. The average dry density and water content for all ring shaped blocks used in deposition hole 5 and 6 are 1,770 kg/m$^3$ and 0.173 respectively. Corresponding values for the solid blocks are 1,710 kg/m$^3$ and 0.174. The outer slot between the blocks and the surface of the deposition holes was filled with pellets of bentonite. The filling had an average dry density of 1,060 kg/m$^3$ and with a water content of approximately 0.13.

**Table 3-1. Determined parameters for blocks used in deposition hole 5 of the Prototype Repository.**

| Block No. | Weight (kg) | Water content (%) | Bulk density (kg/m$^3$) | Degree of saturation | Void ratio |
|---|---|---|---|---|---|
| Dh5:C1 | 2,102 | 0.172 | 2,003 | 0.764 | 0.627 |
| Dh5:R1 | 1,248 | 0.170 | 2,070 | 0.829 | 0.572 |
| Dh5:R2 | 1,266 | 0.174 | 2,075 | 0.844 | 0.572 |
| Dh5:R3 | 1,256 | 0.174 | 2,055 | 0.822 | 0.588 |
| Dh5:R4 | 1,274 | 0.173 | 2,107 | 0.878 | 0.548 |
| Dh5:R5 | 1,258 | 0.174 | 2,073 | 0.842 | 0.574 |
| Dh5:R6 | 1,260 | 0.176 | 2,073 | 0.847 | 0.576 |
| Dh5:R7 | 1,278 | 0.169 | 2,073 | 0.829 | 0.568 |
| Dh5:R8 | 1,280 | 0.172 | 2,074 | 0.836 | 0.571 |
| Dh5:R9 | 1,262 | 0.171 | 2,073 | 0.833 | 0.570 |
| Dh5:R10 | 1,256 | 0.171 | 2,072 | 0.832 | 0.571 |
| Dh5:C2 | 2,148 | 0.177 | 2,040 | 0.815 | 0.604 |
| Dh5:C3 | 2,120 | 0.173 | 2,004 | 0.767 | 0.627 |
| Dh5:C4 | 2,110 | 0.173 | 2,002 | 0.766 | 0.629 |

**Table 3-2. Determined parameters for blocks used in deposition hole 6 of the Prototype Repository.**

| Block No. | Weight (kg) | Water content (%) | Bulk density (kg/m$^3$) | Degree of saturation | Void ratio |
|---|---|---|---|---|---|
| Dh6:C1 | 2,128 | 0.173 | 2,004 | 0.766 | 0.627 |
| Dh6:R1 | 1,264 | 0.172 | 2,068 | 0.832 | 0.576 |
| Dh6:R2 | 1,276 | 0.172 | 2,081 | 0.846 | 0.566 |
| Dh6:R3 | 1,260 | 0.175 | 2,083 | 0.856 | 0.568 |
| Dh6:R4 | 1,250 | 0.178 | 2,088 | 0.871 | 0.568 |
| Dh6:R5 | 1,258 | 0.175 | 2,070 | 0.841 | 0.577 |
| Dh6:R6 | 1,256 | 0.172 | 2,077 | 0.842 | 0.569 |
| Dh6:R7 | 1,264 | 0.171 | 2,067 | 0.828 | 0.575 |
| Dh6:R8 | 1,272 | 0.173 | 2,072 | 0.838 | 0.574 |
| Dh6:R9 | 1,270 | 0.172 | 2,085 | 0.849 | 0.563 |
| Dh6:R10 | 1,274 | 0.171 | 2,070 | 0.832 | 0.573 |
| Dh6:C2 | 2,150 | 0.180 | 2,035 | 0.818 | 0.613 |
| Dh6:C3 | 2,110 | 0.170 | 2,000 | 0.755 | 0.626 |
| Dh6:C4 | 2,136 | 0.174 | 2,005 | 0.770 | 0.627 |

# 4 Results of measured densities and water content of the buffer in depostion hole 6

Measurements of density and water content in the 14 investigated blocks with the surrounding pellets filled outer gap were made in 8 radial lines (see Section 2.2). The water content and density of the buffer were determined in more than 3,800 positions in the test parcel.

In the following sections the results from the measurements of the density and water content are described for all of the investigated blocks with surrounding pellets. The results are also compared with measured water inflow pattern and the fractures observed before the installation, see Figure 4-1.

The results for all of the investigated blocks are provided in Appendix 4–17.

| Borehole | Q 1999-12-20 – 1999-12-22 (l/min) | Q 2000-03-21 – 2000-03-27 (l/min) | Q 2000-07-13 – 2000-07-26 (l/min) |
|---|---|---|---|
| DA3545G01 | 0.00610 +/- 0.00031 | 0.00270 +/- 0.00008 | 0.00740 +/- 0.00022 |

| Mapped feature in DA3545G01, see *Fig 5-20* | Q 2000-02-25 – 2000-03-31 (l/min) |
|---|---|
| 1 | 5.45E-6 |
| 2 | 4.16E-5 |
| 3 | 2.17E-4 |
| 4 | 3.85E-5 |
| 5 | 0 |
| 6 | 2.03E-5 |
| 7 | 2.24E-4 |
| 8 | 3.96E-6 |
| 9 | 3.22E-5 |
| 10 | 1.16E-5 |
| SUM | 5.95E-4 |

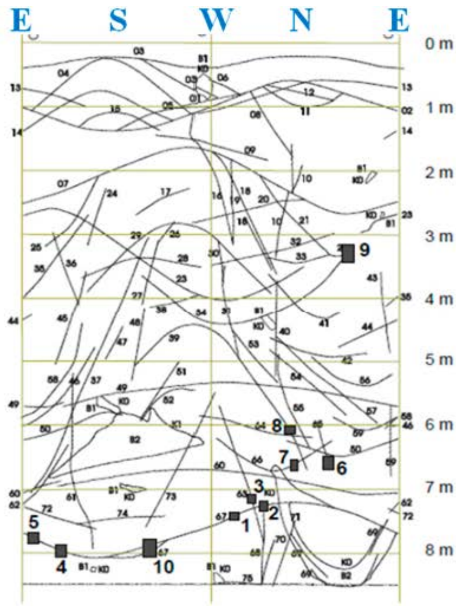


***Figure 4-1.*** *Observed fractures and water inflow into deposition hole 6 (Rhén and Forsmark 2001).*

## 4.1 Measurements below the heater (block C1)

The measured water content, dry density, degree of saturation and void ratio for block C1 and its surrounding pellets filled outer slot are shown in Appendix 4. The results are plotted as function of the radial distance from the centre of the deposition hole in eight directions (50, 150, 250, 350 and 450 degrees). The coordinate system is described in Section 2.2. Furthermore in two of the eighth directions also measurements are made at different depths from the upper surface of the block (50, 150, 250, 350 and 450 mm from the top of the block). The initial conditions of the buffer are plotted in the same figures. The following observations can be made:

- Very small differences in the results can be seen between the eight directions i.e. the saturation of the block is axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the block and the pellets has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased and the dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation close to the surface of the deposition hole is about 97% while the degree of saturation in the central part of the buffer is about 95%.
- The observed water bearing fractures (No 4 and 10) have not affected the water uptake of the buffer, see Figure 4-2. The highest water content was observed in direction north. About 500 mm above the installed blocks in the north-west direction a cluster of water baring fractures have been defined. These fractures might have influenced the somewhat higher water content towards the north.

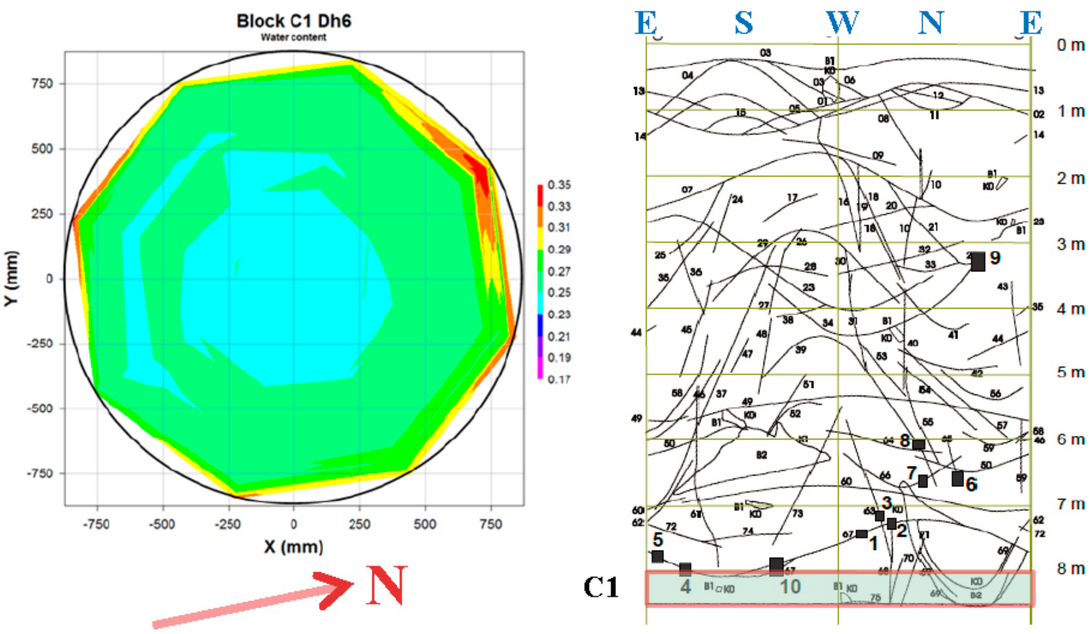


*Figure 4-2. Contour plots of the water content of block C1 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

## 4.2 Measurements at the level of the canister (R1–R10)

The measured water content, dry density, degree of saturation and void ratio for the blocks R1–R10 and their surrounding pellets filled outer slot are shown in Appendix 5-14, where also the initial conditions of the buffer are shown. The results are plotted in the same way as described in Section 4.1. In the following sections the data from the determination of the water uptake for each of the ring shaped blocks are commented.

### 4.2.1 Block R1

The following observations can be made about water uptake for block R1, see Appendix 5:

- Small differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer toward north-west (direction 300°) especially close to the rock surface.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 98% expect for some parts close to the canister surface where the calculated degree of saturation is about 95%.
- It seems that the water bearing fractures No1, No2 and No3 (in north-west direction) have affected the water uptake of the buffer, see Figure 4-3.

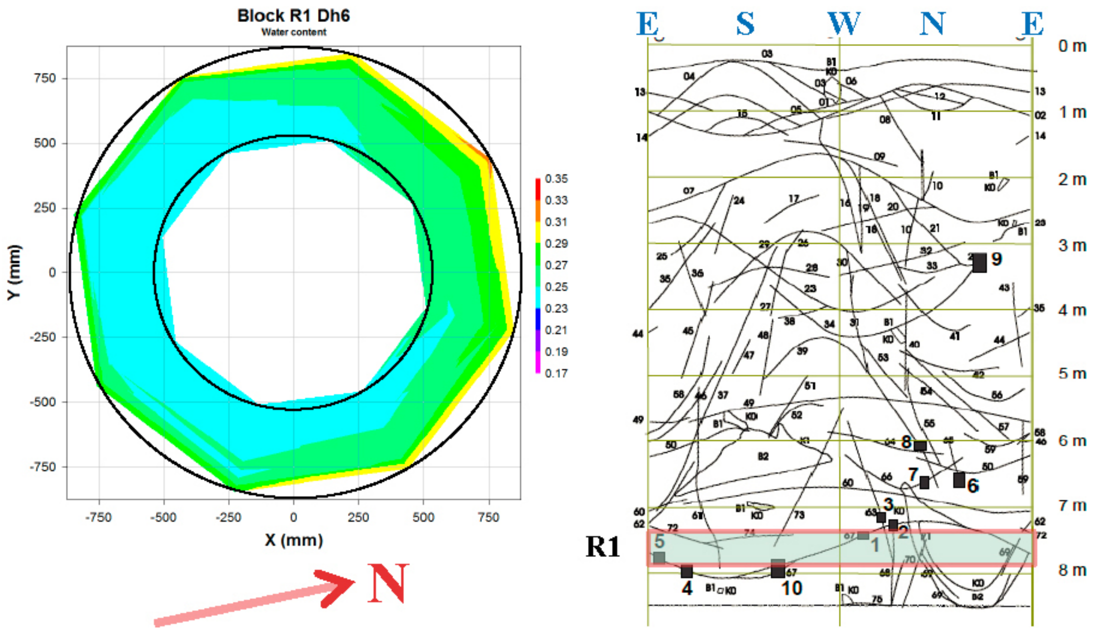


*Figure 4-3. Contour plots of the water content of block R1 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.2 Block R2

The following observations can be made about water uptake for block R2, see Appendix 6:

- Small differences in the measured/calculated results can be seen between the eight directions and there is a tendency that more water has been taken up by the buffer toward north-west (direction 290°) especially close to the rock surface.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 98% expect for some parts close to the canister surface where the calculated degree of saturation is about 95%.
- It seems that the water bearing fractures No1, No2 and No3 (in north-west direction) have affected the water uptake of the buffer, see Figure 4-4.

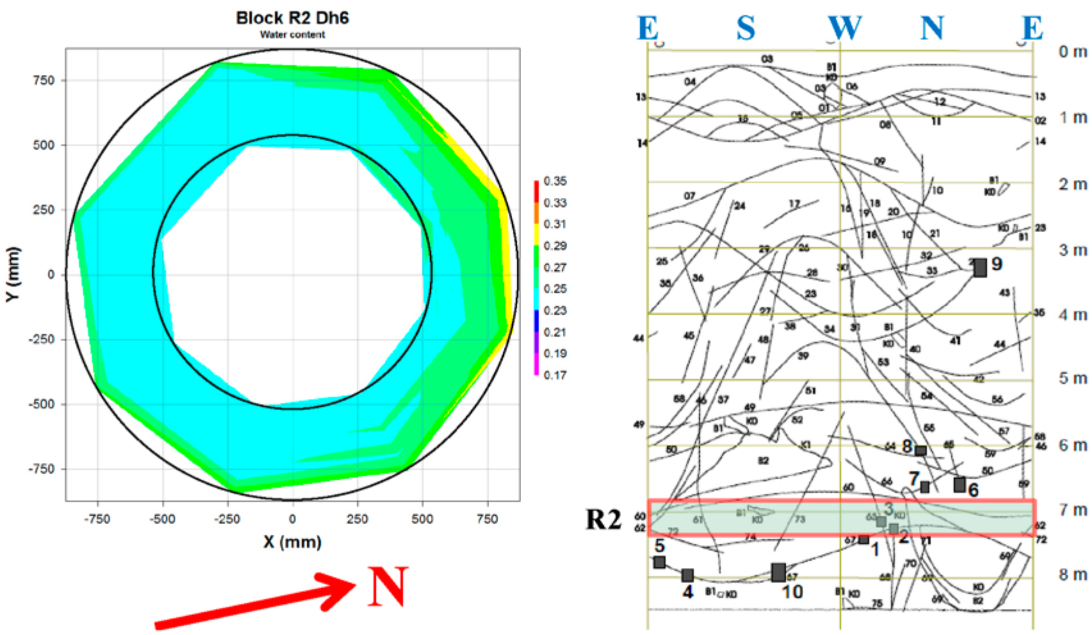


*Figure 4-4. Contour plots of the water content of block R2 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.3 Block R3

The following observations can be made about water uptake for block R3, see Appendix 7:

- There is a tendency that more water has been taken up by the buffer towards north (direction 255°–300°) especially close to the rock surface. The water content of the bentonite close to the wall of the deposition hole varies between 26% and 31%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north, about 1,500 kg/m$^3$ while the highest dry densities of the pellets filling were measured towards east, about 1,600 kg/m$^3$.
- The degree of saturation of the buffer is about 98% expect for some parts close to the canister surface where the calculated degree of saturation is about 95%.
- It seems that the water bearing fractures No6 and No7 (in north direction) have affected the water uptake of the buffer i.e. the water content of the buffer is higher towards the directions of the fractures, see Figure 4-5.

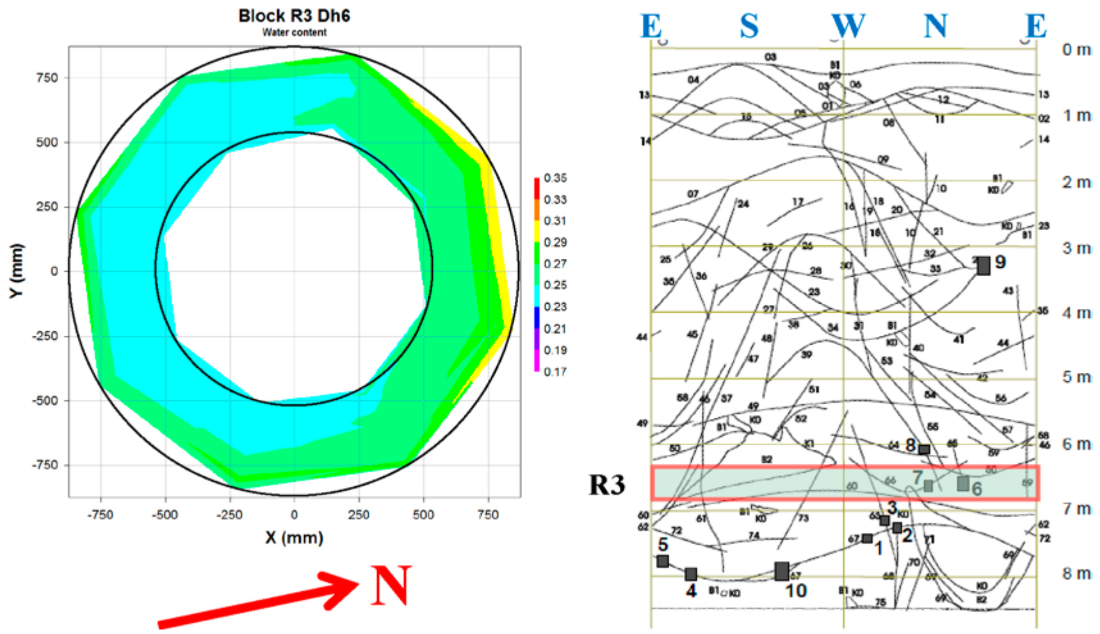


*Figure 4-5.* *Contour plots of the water content of block R3 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.4 Block R4

The following observations can be made about water uptake for block R4, see Appendix 8:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-west (direction 255°–345°) especially close to the rock surface. The water content of the bentonite close to the wall of the deposition hole varies between 27% and 31%.
- Differences in the measured water content can be seen between different levels in the buffer for direction 255°. The water content is increasing with the depth i.e. towards the water bearing fracture No7 and No6, see Figure 4-5.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state. The lowest densities of the pellets were measured towards the north, about 1,475 kg/m$^3$ while the highest densities of the pellets filling were measured towards east, about 1,575 kg/m$^3$.
- The degree of saturation of the buffer is about 97% expect for some parts close to the canister surface where the calculated degree of saturation varies between 90–95%.
- It seems that the water bearing fractures No8 and No7 (in north-west direction) have affected the water uptake of the buffer, see Figure 4-6.

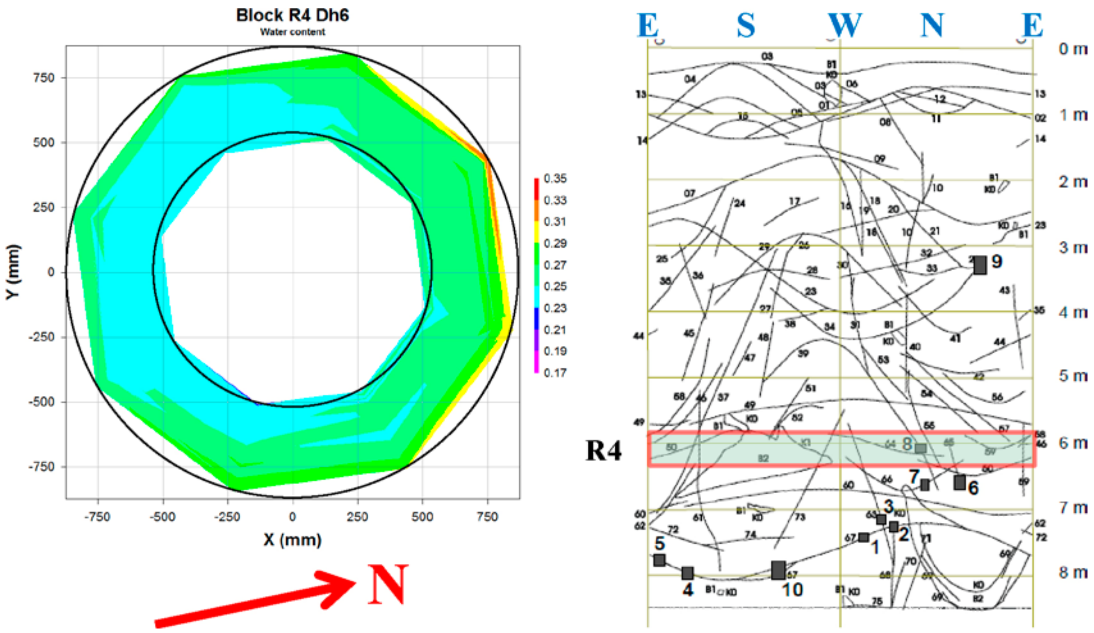


***Figure 4-6.*** *Contour plots of the water content of block R4 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.5 Block R5

The following observations can be made about water uptake for block R5, see Appendix 9:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-west (direction 255°–345°) especially close to the rock surface. The water content of the bentonite close to the wall of the deposition hole varies between 27% and 31%.
- Differences in the measured water content can be seen between different levels in the buffer for direction 255°. The water content is increasing with the depth i.e. towards the water bearing fracture No7 and No6, see Figure 4-6.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state. The lowest densities of the pellets were measured towards the north, about 1,475 kg/m$^3$ while the highest densities of the pellets filling were measured towards east, about 1,575 kg/m$^3$.
- The degree of saturation of the buffer is about 97% expect for some parts close to the canister surface where the calculated degree of saturation varies between 90–95%.
- It seems that the water bearing fracture No8 and No7 (in north-west direction) have affected the water uptake of the buffer, see Figure 4-7.

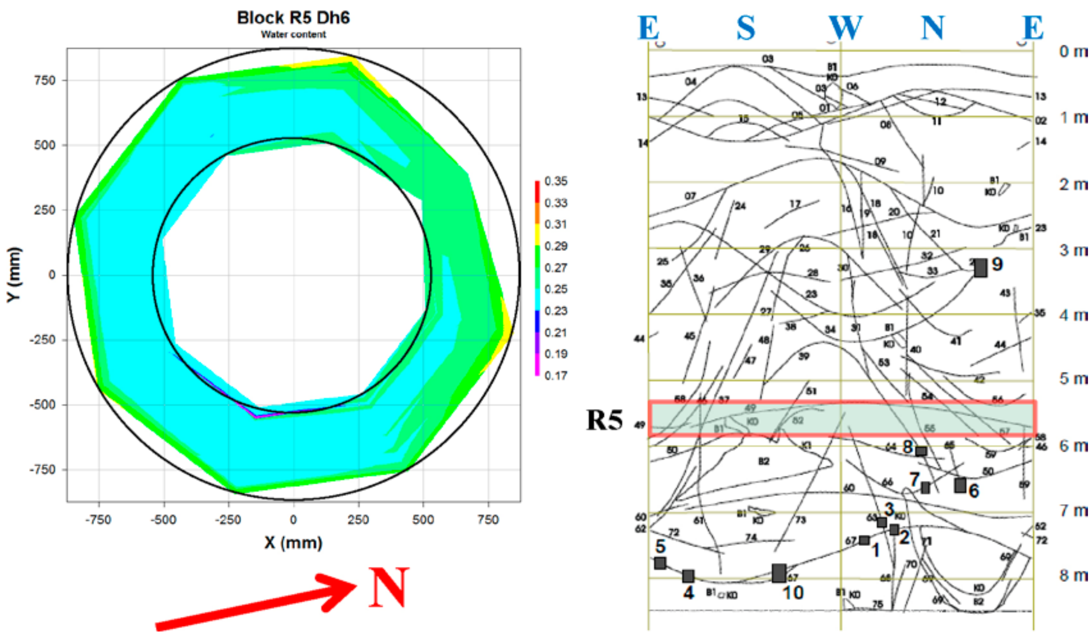


***Figure 4-7.*** *Contour plots of the water content of block R5 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.6 Block R6

The following observations can be made about water uptake for block R6, see Appendix 10:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-west (direction 290°–335°) especially close to the rock surface. The water content of the buffer close to the wall of the deposition hole varies between 26% and 31%. In the central part of the block the water content varies between 23% and 26%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north, about 1,480 kg/m$^3$ while the highest densities of the pellets filling were measured towards east, about 1,580 kg/m$^3$.
- The degree of saturation of the buffer varies between 95–100%.
- It seems that the water bearing fracture No8 and No7 (in north-west direction) have affected the water uptake of the buffer, see Figure 4-8.

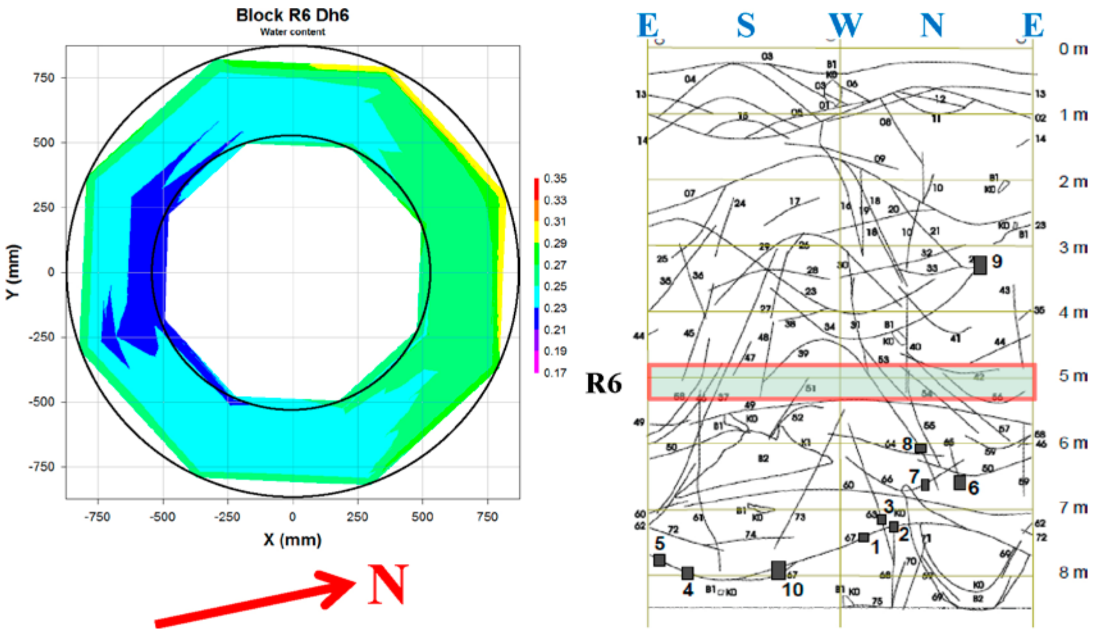


***Figure 4-8.** Contour plots of the water content of block R6 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.7 Block R7

The following observations can be made about water uptake for block R7, see Appendix 11:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-east (direction 210°–300°) especially close to the rock surface. The water content of the buffer close to the wall of the deposition hole varies between 26% and 28%. In the central part of the block the water content varies between 22% and 27%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north, about 1,500 kg/m$^3$. The dry density in the central part of the block varies between 1,700 kg/m$^3$ (towards east) and 1,600 kg/m$^3$ (towards north).
- The degree of saturation of the buffer varies between 90-100%.
- The driest parts of the buffer (marked with blue in Figure 4-9) are observed towards the south. Very small amount of fractures were observed in this direction.

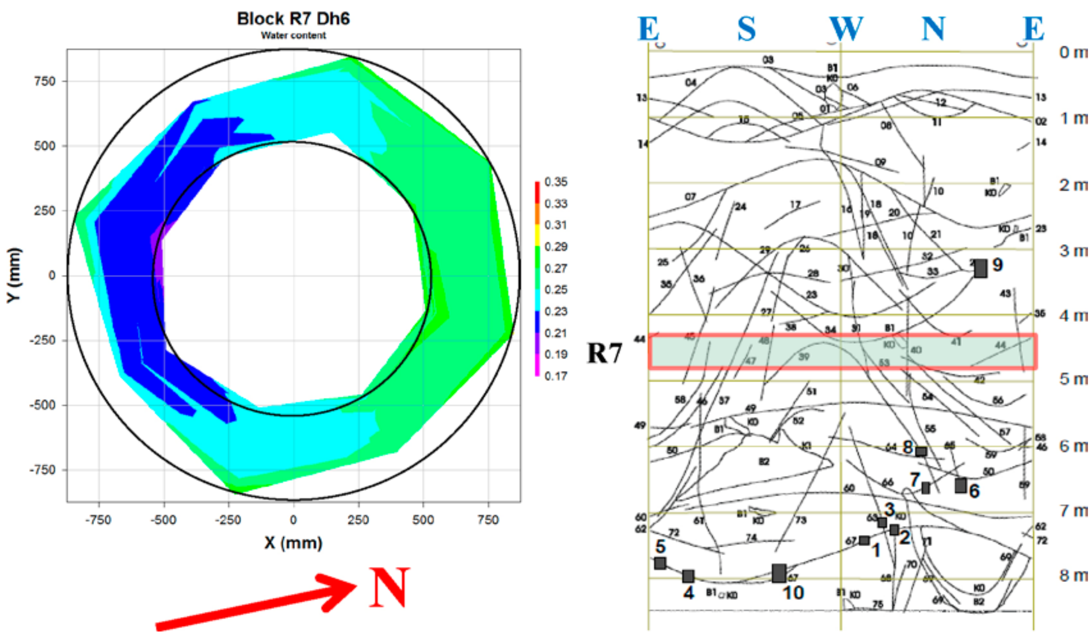


***Figure 4-9.*** *Contour plots of the water content of block R7 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.8 Block R8

The following observations can be made about water uptake for block R8, see Appendix 12:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-east (direction 210°–255°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 25% and 34%. In the central part of the block the water content varies between 21% and 28%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling, towards the canister and in the directions north-east (210°–300°). The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north-east, about 1,400 kg/m$^3$. The dry density in the central part of the block varies between 1,710 kg/m$^3$ and 1,550 kg/m$^3$.
- The degree of saturation of the buffer varies between 90–100%.
- The driest parts of the buffer (marked with blue in Figure 4-10) are observed towards the south. Very small amount of fractures were observed in this direction. The wettest parts of the buffer are observed towards the north-east close to the water bearing fracture No9 about 0.5 m above the upper surface of the block.

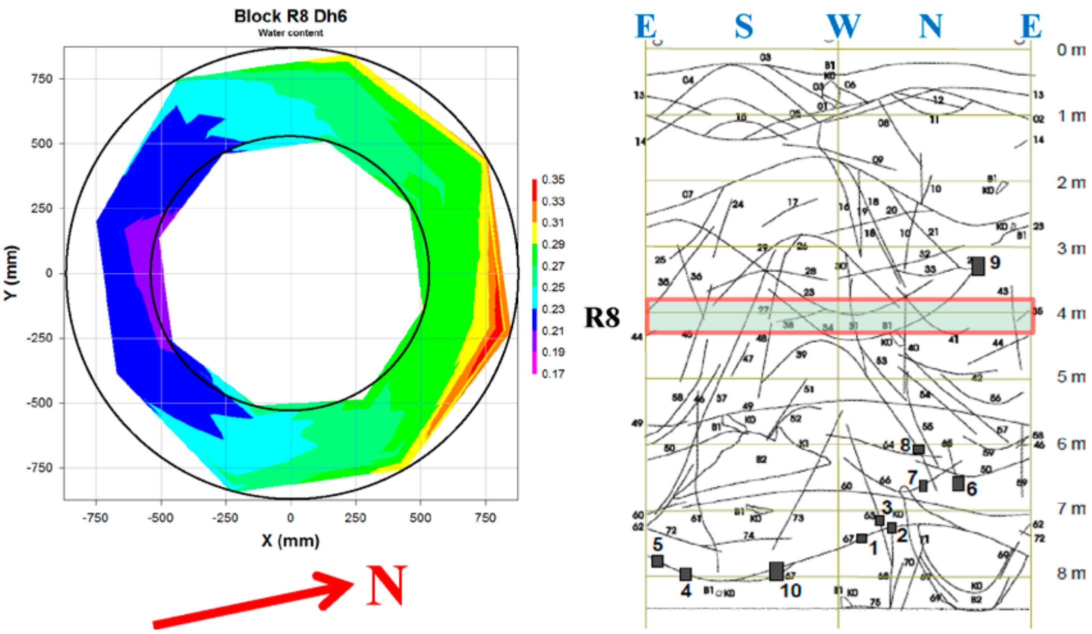


*Figure 4-10. Contour plots of the water content of block R8 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.9 Block R9

The following observations can be made about water uptake for block R9, see Appendix 13:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-east (direction 245°–290°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 22% and 32%. In the central part of the block the water content varies between 20% and 30%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling, towards the canister and in the directions north-east (245°–290°). The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north-east, about 1,450 kg/m$^3$. The dry density in the central part of the block varies between 1,700 kg/m$^3$ and 1,550 kg/m$^3$.
- The degree of saturation of the buffer varies between 85–100%.
- The driest parts of the buffer (marked with blue in Figure 4-11) are observed towards the south. Very small amount of fractures were observed in this direction. The wettest parts of the buffer are observed towards the north-east close to the water bearing fracture No9.

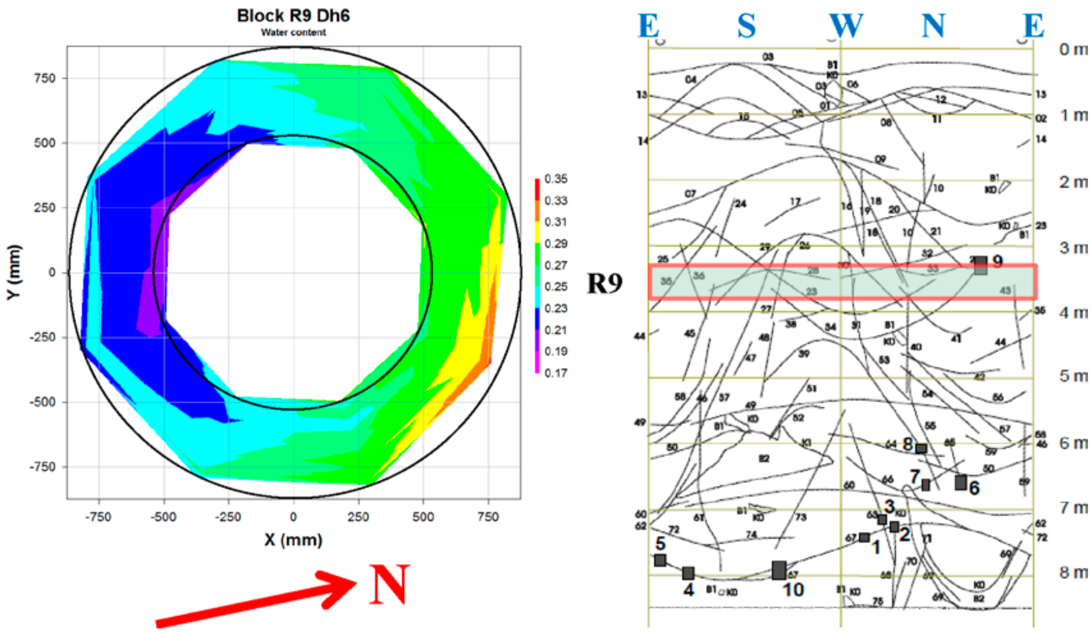


*Figure 4-11. Contour plots of the water content of block R9 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.2.10 Block R10

The following observations can be made about water uptake for block R10, see Appendix 14:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-east (direction 200°–290°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 23% and 33%. In the central part of the block the water content varies between 23% and 27%.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling, towards the canister and in the directions north-east (200°–290°). The dry density of the pellets filling has increased compared to the initial state. The lowest dry densities of the pellets were measured towards the north-west, about 1,400 kg/m$^3$. The dry density in the central part of the block varies between 1,650 kg/m$^3$ and 1,500 kg/m$^3$.
- The degree of saturation of the buffer varies between 85–100%.
- The driest parts of the buffer (marked with blue in Figure 4-12) are observed towards the south. Very small amount of fractures were observed in this direction. The wettest parts of the buffer are observed towards the north-east close to the water bearing fracture No9.

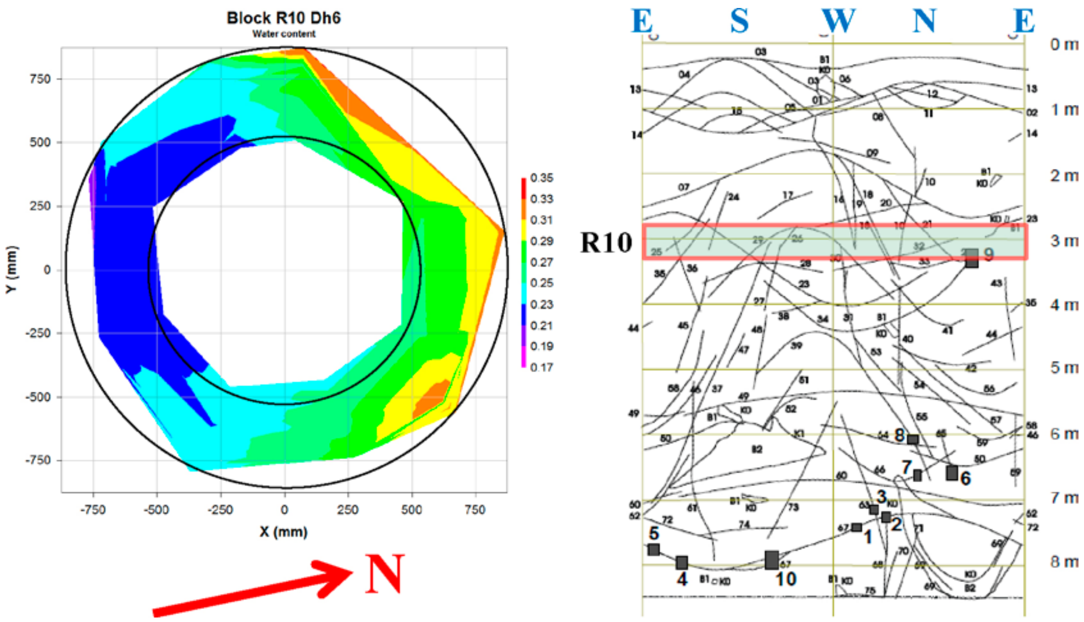


*Figure 4-12. Contour plots of the water content of block R10 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

## 4.3 Measurements above the canister (block C2–C4)

The measured water content, dry density, degree of saturation and void ratio for the blocks C2–C4 and their surrounding pellets filled outer slot are shown in Appendices 15–17, where also the initial conditions of the buffer are shown. The results are plotted in the same way as described in Section 4.1. In the following sections the data from the determination of the water uptake for each of the solid blocks above the canister are commented.

### 4.3.1 Block C2

The following observations can be made about water uptake for block C2, see Appendix 15:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north-west (direction 300°–345°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 23% and 35%. In the central part of the block is the water content about 22%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 85% in the central part of the block and about 100% close to the wall of the deposition hole.

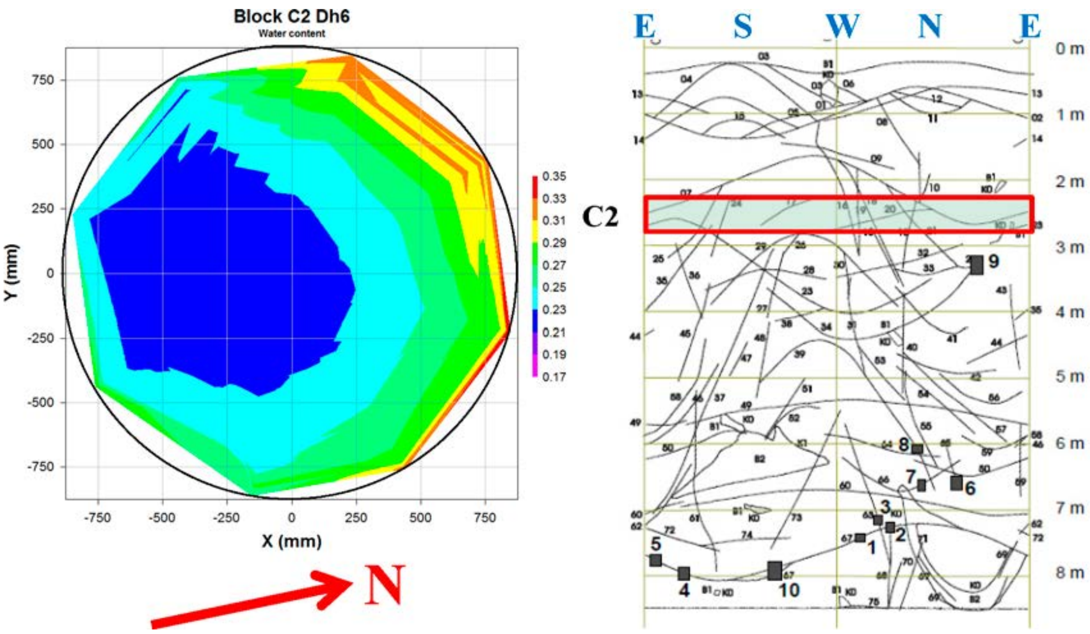


*Figure 4-13. Contour plots of the water content of block C2 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.3.2 Block C3

The following observations can be made about water uptake for block C3, see Appendix 16:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards north (direction 200°–345°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 27% and 37%, see Appendix 16. In the central part of the block is the water content about 24%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 85% in the central part of the block and about 100% close to the wall of the deposition hole.

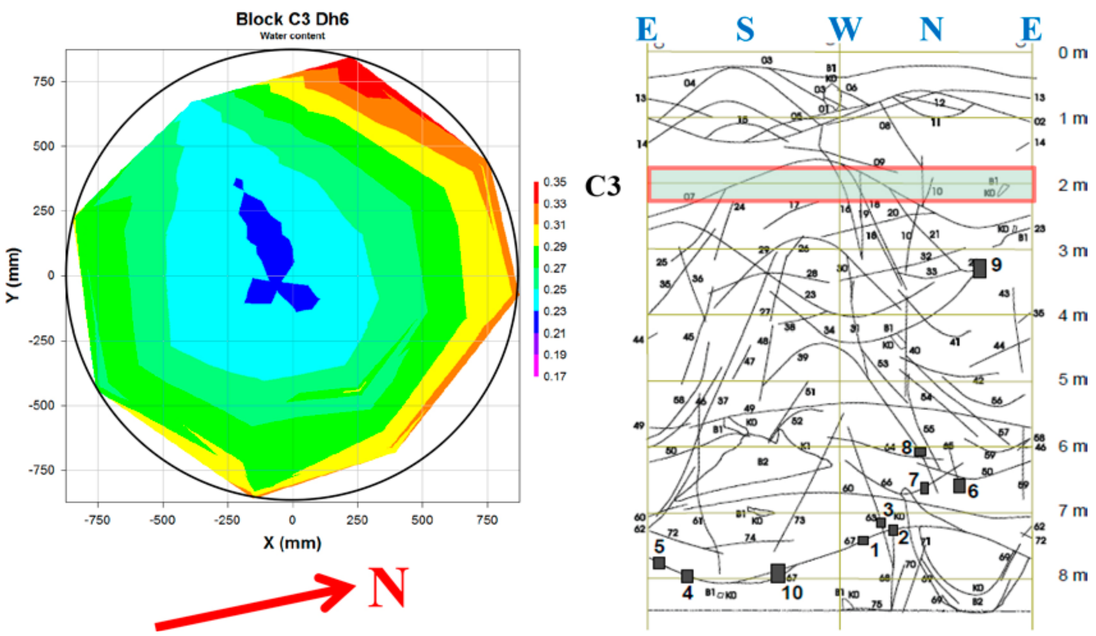


*Figure 4-14.* *Contour plots of the water content of block C3 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

### 4.3.3 Block C4

The following observations can be made about water uptake for block C4, see Appendix 17:

- No differences in the measured/calculated results can be seen between the eight directions. The water content of the buffer close to the wall of the deposition hole varies between 35% and 45%. In the central part of the block is the water content about 37%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- Large differences in the measured/calculated results can be seen between different levels in the block. The water content is much higher at the top of the block compared to the bottom of it. At the centre of the block the water content varies between 37% and 25%. The dry density at the centre of the block varies between 1,350 kg/m$^3$ at the upper part of the block up to 1,570 kg/m$^3$ at the bottom of the block.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 90–100%.

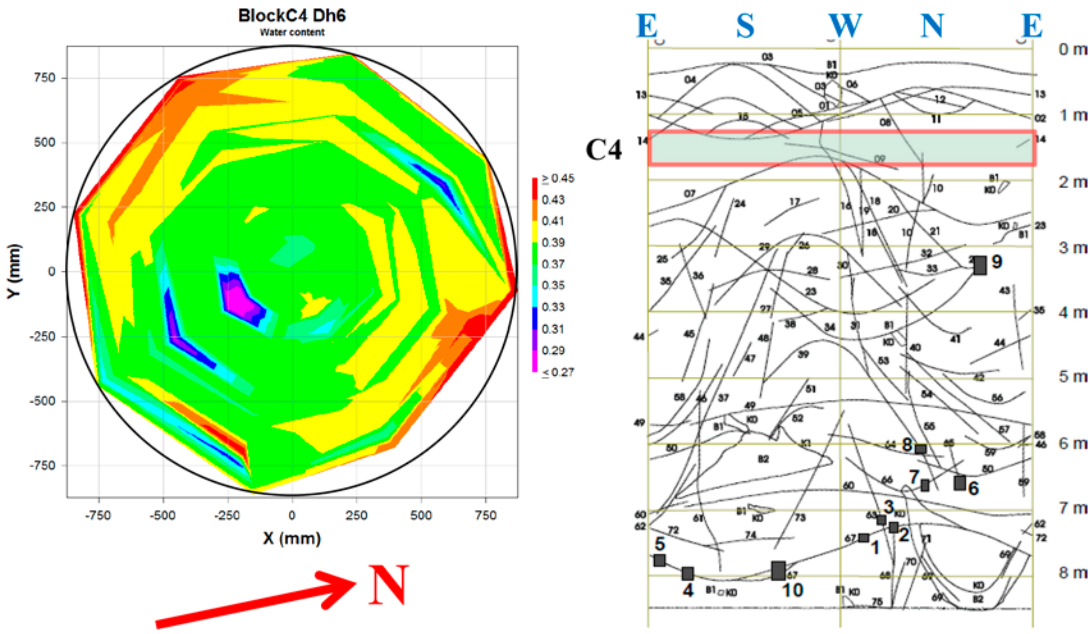


***Figure 4-15.*** *Contour plots of the water content of block C4 in deposition hole 6 together with the observed fractures on the wall of the deposition hole.*

## 4.4 Contour plots of measured results

Contour plots of the measured and calculated variables water content, dry density and degree of saturation were made using an interpolation program. Before these plots were made, data which obviously were wrong (density and water content) were removed. All date are however shown in the figures of the individual profiles of the water content and density obtained in the blocks and pellets. These plots are provided in the Appendices 4–17 for the individual bentonite blocks with the surrounding pellets. More extensive sampling of the buffer were made in two direction, i.e. the water content and density were measured on several levels in each of the blocks for direction ca 30° and direction 255°. The data from these determinations are plotted as contour plots, see Figure 4-16 and Figure 4-17. The following conclusions can be made from the figures:

- The buffer is close to fully saturated in both profiles on the canister level i.e. between the canister and the surface of the deposition hole as well as underneath the canister.
- The degree of saturation is relatively low on the upper surface (top) of the canister especial in the centre of the deposition hole.
- The degree of saturation is high at the upper surface of the most upper block, block C4.
- The dry density is higher as an average for the buffer in direction 30° compare to the direction 255°.
- The water content is lower as an average for the buffer in direction 30° compare to the direction 255°.

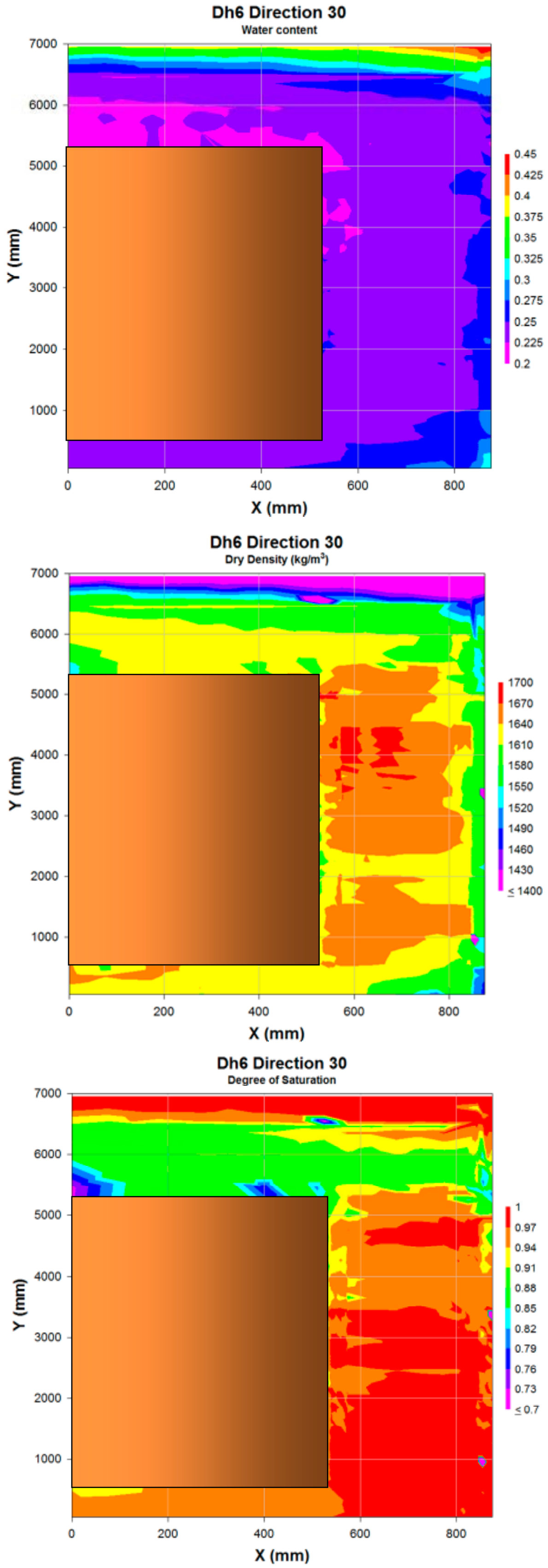


***Figure 4-16.*** *Contour plots of the water content, dry density and degree of saturation for the buffer in deposition hole 6 direction 30°.*

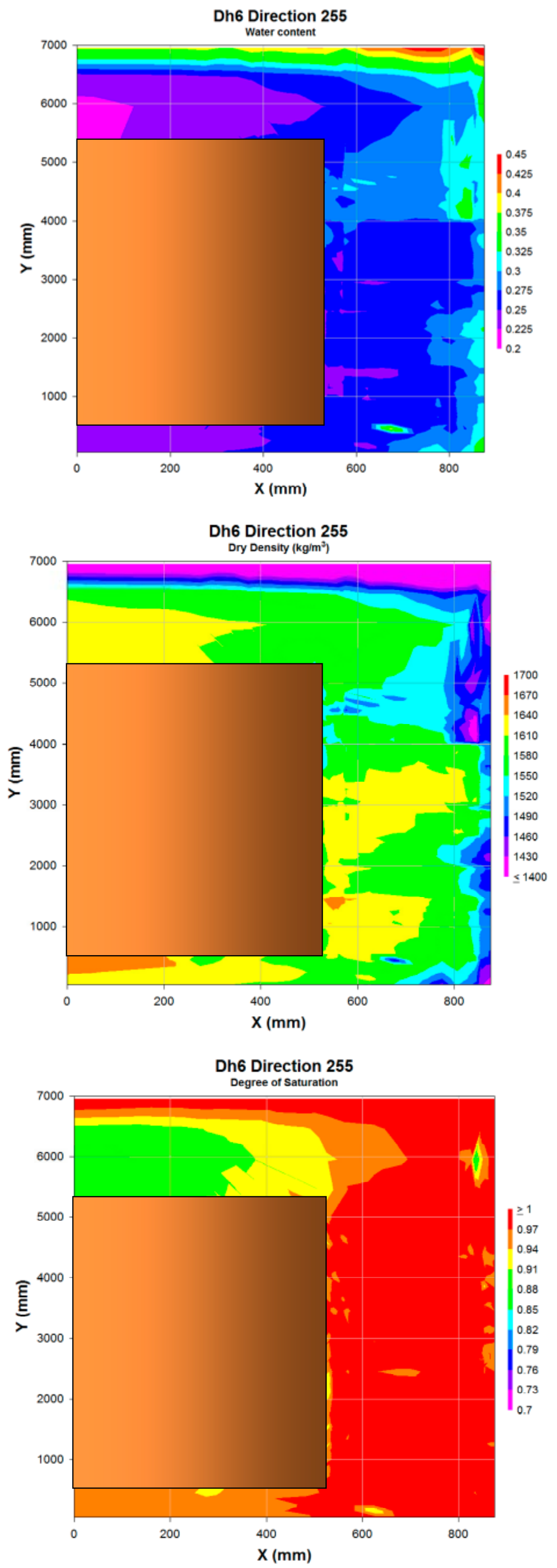


***Figure 4-17.*** *Contour plots of the water content, dry density and degree of saturation for the buffer in deposition hole 6 direction 255°.*

# 5 Results of measured densities and water content of the buffer in depostion hole 5

Measurements of density and water content in the 14 investigated blocks with the surrounding pellets filled outer gap were made in 8 radial lines (see Section 2.2). The water content and density of the buffer were determined in more than 4,000 positions in the test parcel.

In the following sections the results from the measurements of the density and water content are described for all of the investigated blocks with surrounding pellets. The results are also compared with measured water inflow pattern and the observed fractures observed before the installation, see Figure 5-1.

The results for all of the investigated blocks are provided in Appendix 18–31.

| Borehole | Q 1999-12-23 – 2000-01-10 (l/min) | Q 2000-03-21 – 2000-03-27 (l/min) | Q 2000-07-16 – 2000-07-26 (l/min) |
|---|---|---|---|
| DA3551G01 | 0.00270 +/- 0.00014 | 0.00155 +/- 0.00005 | 0.00160 +/- 0.00005 |

| Mapped feature in DA3551G01, see *Fig 5-19* | Q 2000-02-25 – 2000-03-31 (l/min) |
|---|---|
| 1 | 2.84E-5 |
| 2 | 2.59E-5 |
| 3 | 3.49E-5 |
| 4 | 8.63E-6 |
| 5 | 1.94E-5 |
| 6 | 1.05E-5 |
| 7 | 1.12E-4 |
| 8 | 1.19E-4 |
| 9 | 0 |
| SUM | 3.59E-4 |

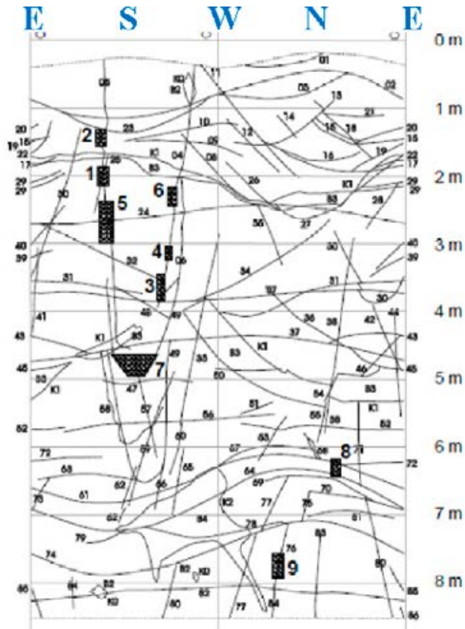


***Figure 5-1.*** *Observed fractures and water inflow into deposition hole 5 (Rhén and Forsmark 2001).*

## 5.1 Measurements below the canister (block C1)

The measured water content, dry density, degree of saturation and void ratio for block C1 and its surrounding pellets filled outer slot are shown in Appendix 18. The results are plotted as function of the radial distance from the centre of the deposition hole in eight directions (25, 70, 115, 160, 205, 250, 295, 340 degrees). The coordinate system is described in Section 2.2. Furthermore in two of the eighth directions also measurements are made at different depths from the upper surface of the block (50, 150, 250, 350 and 450 mm from the top of the block). The initial conditions of the buffer are plotted in the same figures. The following observations can be made:

- Differences in the measured/calculated results can be seen between the eight directions i.e. the saturation of the buffer is not axisymmetric.
- Differences in the measured/calculated results can be seen between different levels in the block. The water content is higher towards the bottom of the deposition hole compared to the upper part of the block close to the bottom of the canister.
- The water content has increased in most parts of the block and the pellets. In the central part of the section the water content is similar to the initial water content of the block.
- The dry density of the outer parts of the block has decreased, while the density in the central part of the block is similar to the initial dry density. The dry density of the pellets filling has increased compared to its initial state.
- The degree of saturation close to the surface of the deposition hole varies between 85–97% while the degree of saturation in the central part of the block is about 80%.
- The observed water bearing fracture No 9 has affected the water uptake of the buffer, see Figure 5-2. The highest water content was observed in direction north-west.

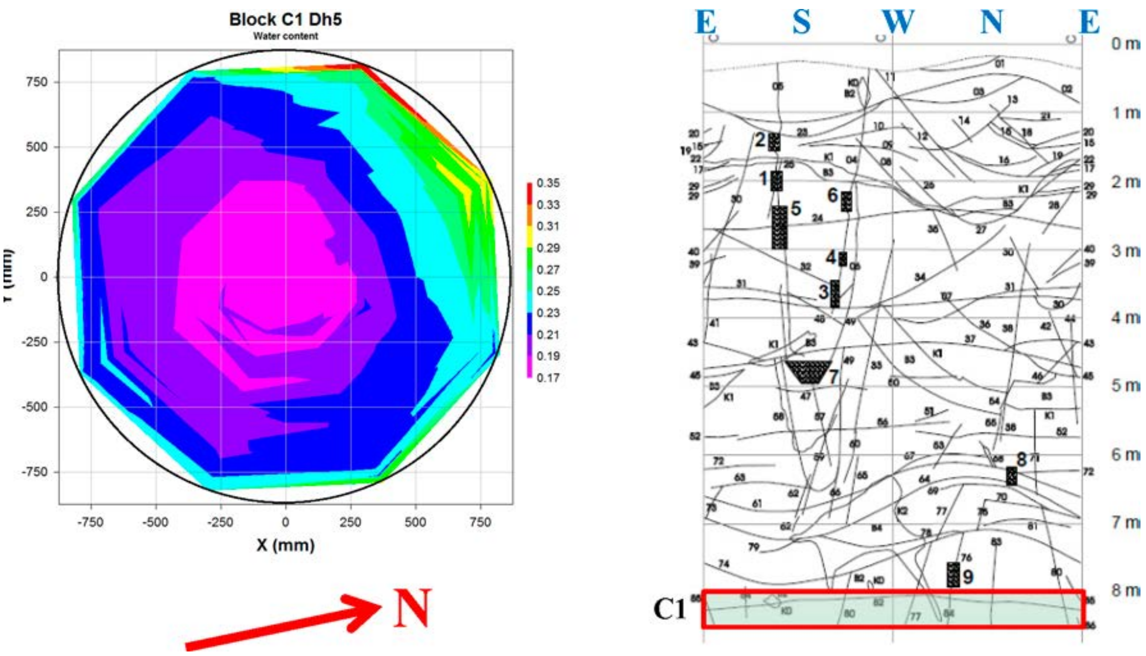


*Figure 5-2. Contour plots of the water content of block C1 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

## 5.2 Measurements at the level of the canister (R1–R10)

The measured water content, dry density, degree of saturation and void ratio for the blocks R1–R10 and their surrounding pellets filled outer slot are shown in Appendix 19–28, where also the initial conditions of the buffer are shown. The results are plotted in the same way as described in Section 5.1. In the following sections the data from the determination of the water uptake for each of the ring shaped blocks are commented.

### 5.2.1 Block R1

The following observations can be made about water uptake for block R1, see Appendix 19:

- Small differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer toward north-west (direction 295°) especially close to the rock surface.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 90–100% except for some points in the pellets filled slot where the degree of saturation is somewhat lower.
- It seems that the water bearing fracture No9 (in north-west direction) has affected the water uptake of the buffer, see Figure 5-3.

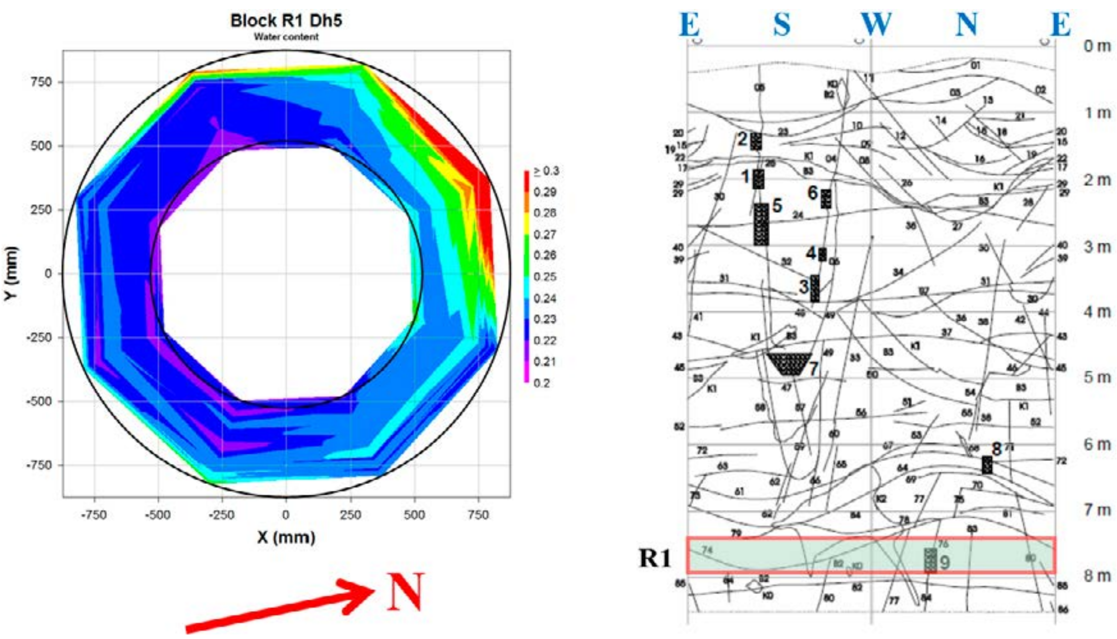


*__Figure 5-3.__ Contour plots of the water content of block R1 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.2 Block R2

The following observations can be made about water uptake for block R2, see Appendix 20:

- Small differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer toward north-west (direction 295°) especially close to the rock surface.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 95–100%.
- It seems that the water bearing fracture No9 (in north-west direction) has to some extend affected the water uptake of the buffer, see Figure 5-4.

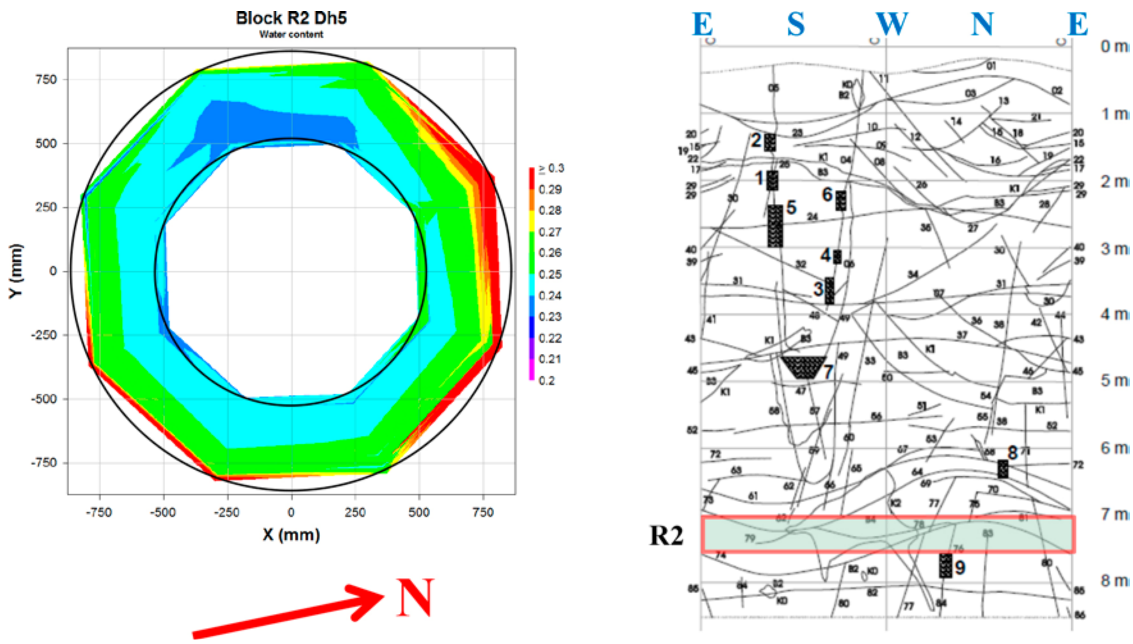


*Figure 5-4. Contour plots of the water content of block R2 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.3 Block R3

The following observations can be made about water uptake for block R3, see Appendix 21:

- Small differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer toward north-east (direction 205°–250°) and towards south-east (direction 7°0) especially close to the rock surface.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 95–100% except for some parts of the buffer very close to the canister surface.
- The water bearing fracture No8 (in north-east direction) has to some extend affected the water uptake of the buffer especially in the pellets filled outer slot, see Figure 5-5.

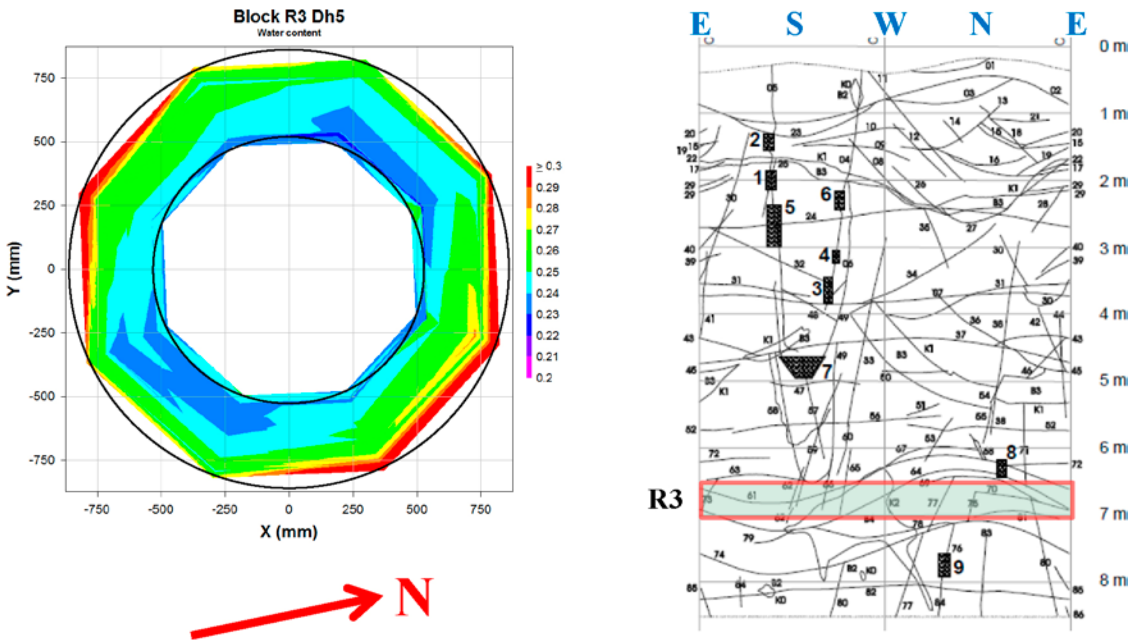


***Figure 5-5.*** *Contour plots of the water content of block R3 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.4 Block R4

The following observations can be made about water uptake for block R4, see Appendix 22:

- Small differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer toward south-east (direction 25°–115°).
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 95–100% except for some parts of the buffer very close to the canister surface where the degree of saturation is low.
- The wettest part of the buffer is towards the south-west direction, see Figure 5-6. No observations of water bearing fractures have been noted in that direction.

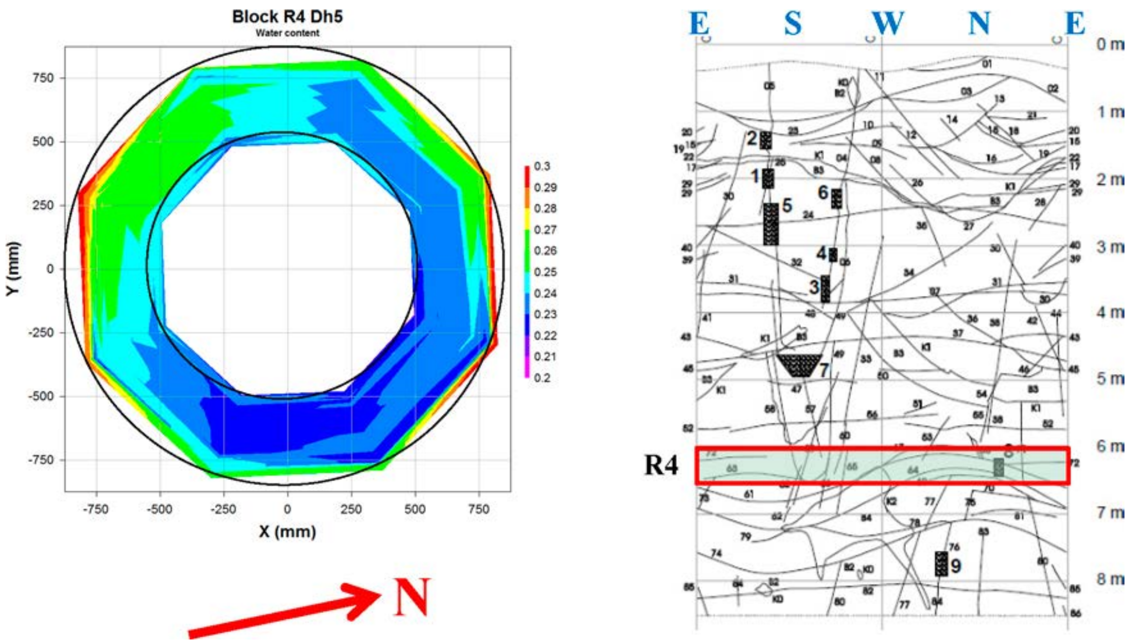


*Figure 5-6. Contour plots of the water content of block R4 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.5 Block R5

The following observations can be made about water uptake for block R5, see Appendix 23:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 90–100%.
- The wettest part of the buffer is towards the south-west direction, see Figure 5-7. The position of the water bearing fracture No7 is in that direction and about 1 meter above the block but it might although has affected the water uptake.

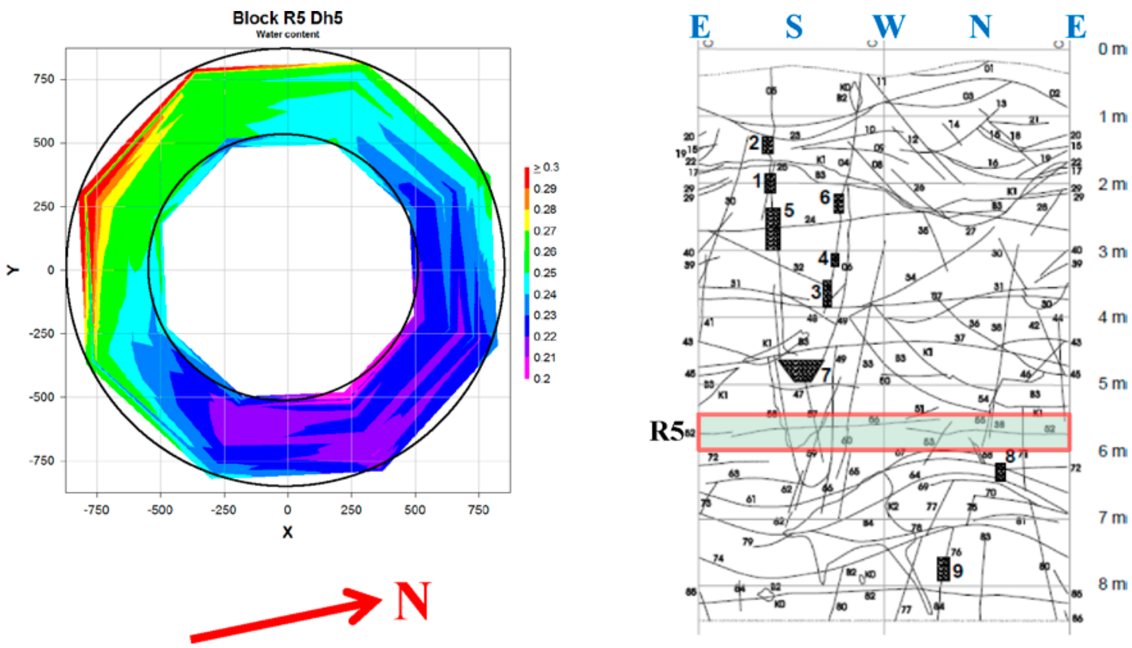


***Figure 5-7.*** *Contour plots of the water content of block R5 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.6 Block R6

The following observations can be made about water uptake for block R6, see Appendix 24:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 85–100% in the block while in some part of the pellets the degree of saturation is as low as 75%.
- The wettest part of the buffer is towards the south-west direction where the water bearing fracture No7 is situated, see Figure 5-8.

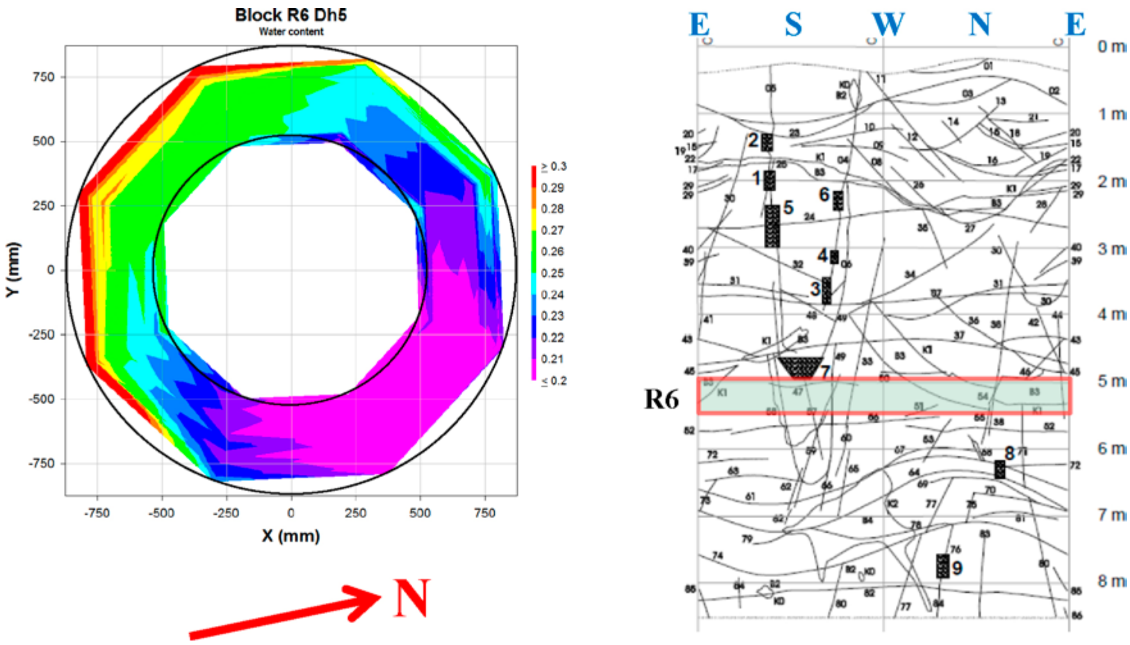


***Figure 5-8.*** *Contour plots of the water content of block R6 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.7 Block R7

The following observations can be made about water uptake for block R7, see Appendix 25:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 85–100% in the block while in some part of the pellets the degree of saturation is as low as 75%.
- The wettest part of the buffer is towards the south-west direction where the water bearing fracture No7 is situated, see Figure 5-9.

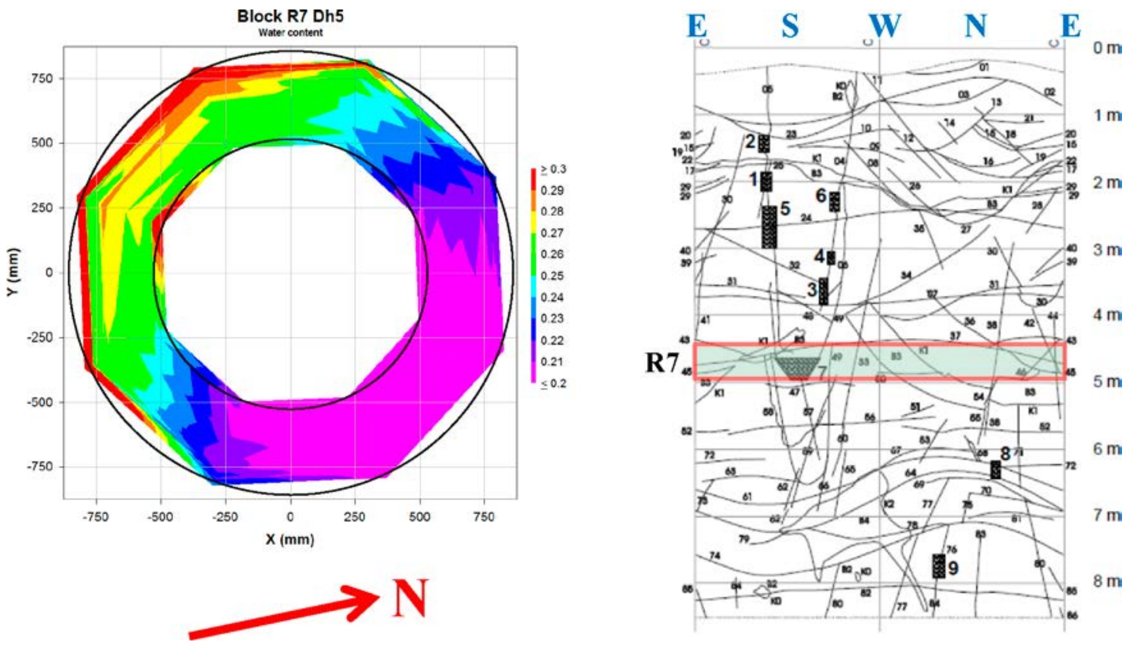


*__Figure 5-9.__ Contour plots of the water content of block R7 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.8 Block R8

The following observations can be made about water uptake for block R8, see Appendix 26:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 85–100% in the block while in some part of the pellets the degree of saturation is as low as 80%.
- The wettest part of the buffer is towards the south-west direction where the water bearing fractures No7 and No3 are situated, see Figure 5-10.

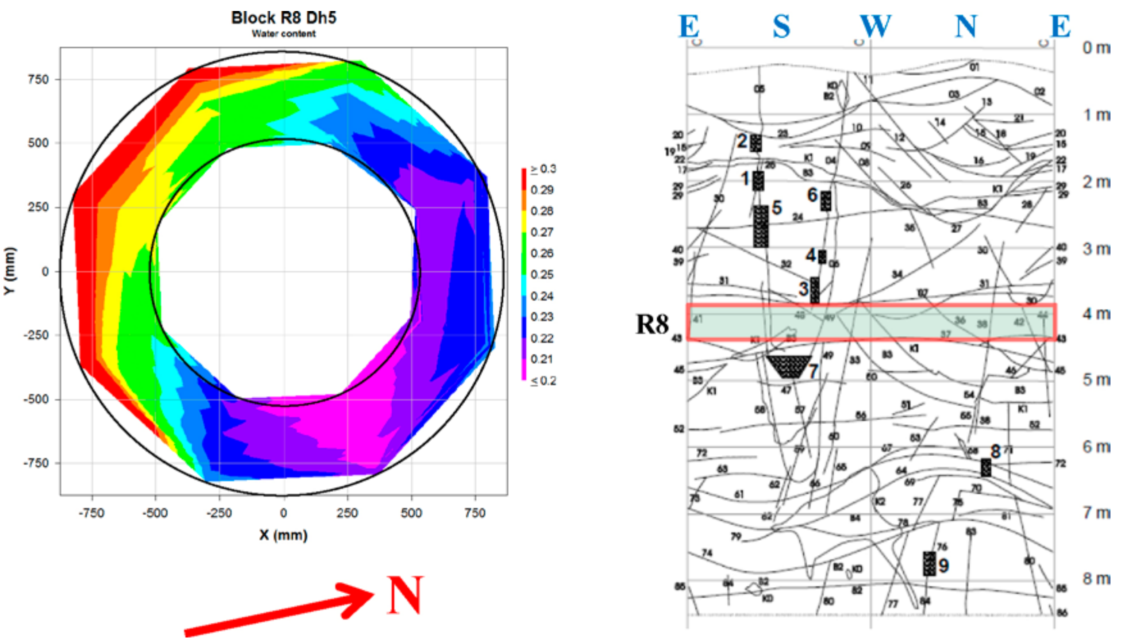


***Figure 5-10.*** *Contour plots of the water content of block R8 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.2.9 Block R9

The following observations can be made about water uptake for block R9, see Appendix 27:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling and also towards the canister. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer varies between 85–100% in the block while in some part of the pellets the degree of saturation is as low as almost 80%.
- The wettest part of the buffer is towards the south-west direction where the water bearing fractures No3 and No4 are situated, see Figure 5-11.

### 5.2.10 Block R10

For this block a smaller amount of samples were taken for the determination of the density and water content of the buffer compared to the rest of the blocks in this deposition hole, due to the fact that at this section of the deposition hole, samples of the canister were also taken. At this work the buffer was removed before the buffer samples were taken. The following observations can be made about water uptake for block R10, see Appendix 28:

- Large differences in the measured/calculated results can be seen between the eight directions i.e. the water uptake is not axisymmetric.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state
- The degree of saturation of the buffer varies between 85–100%.

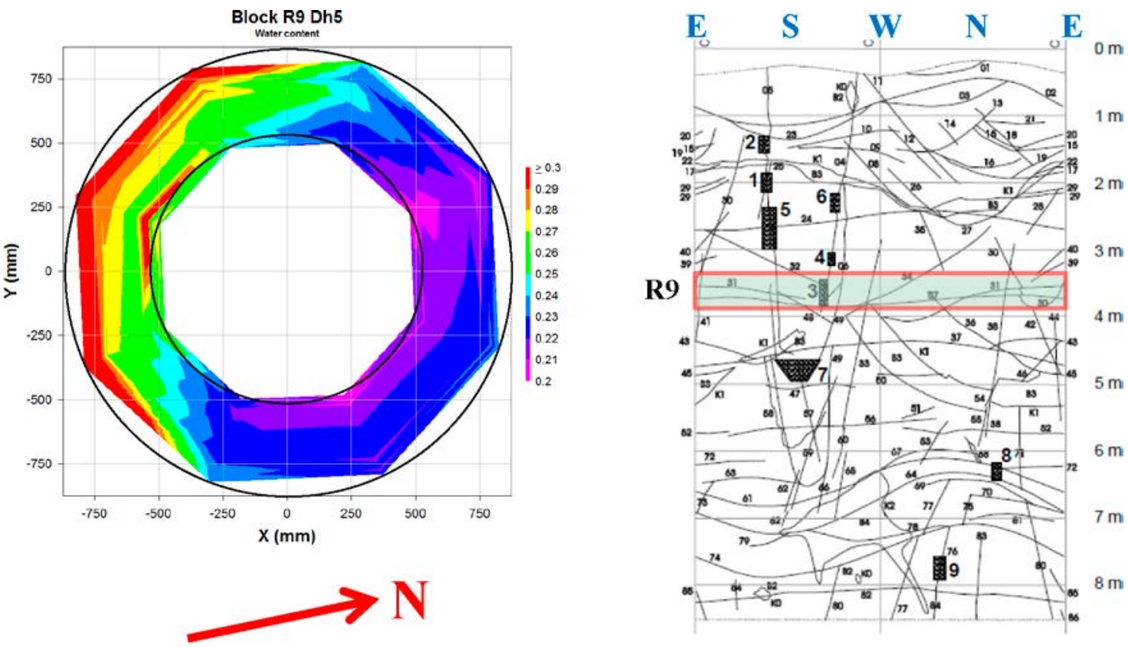


*Figure 5-11. Contour plots of the water content of block R9 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

## 5.3 Measurements above the canister (block C2–C4)

The measured water content, dry density, degree of saturation and void ratio for the blocks C2–C4 and their surrounding pellets filled outer slot are shown in Appendices 29–31, where also the initial conditions of the buffer are shown. The results are plotted in the same way as described in Section 5.1. In the following sections the data from the determination of the water uptake for each of the ring shaped blocks are commented.

### 5.3.1 Block C2

The following observations can be made about water uptake for block C2, see Appendix 29:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards south (direction 25°–115°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 22% and 40%. In the central part of the block is the water content about 22%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 85% in the central part of the block and about 100% close to the wall of the deposition hole.
- Very small differences in the measured/calculated results can be seen between different levels of the buffer.
- The wettest part of the buffer is towards the south direction where the water bearing fracture No5 is situated, see Figure 5-12.

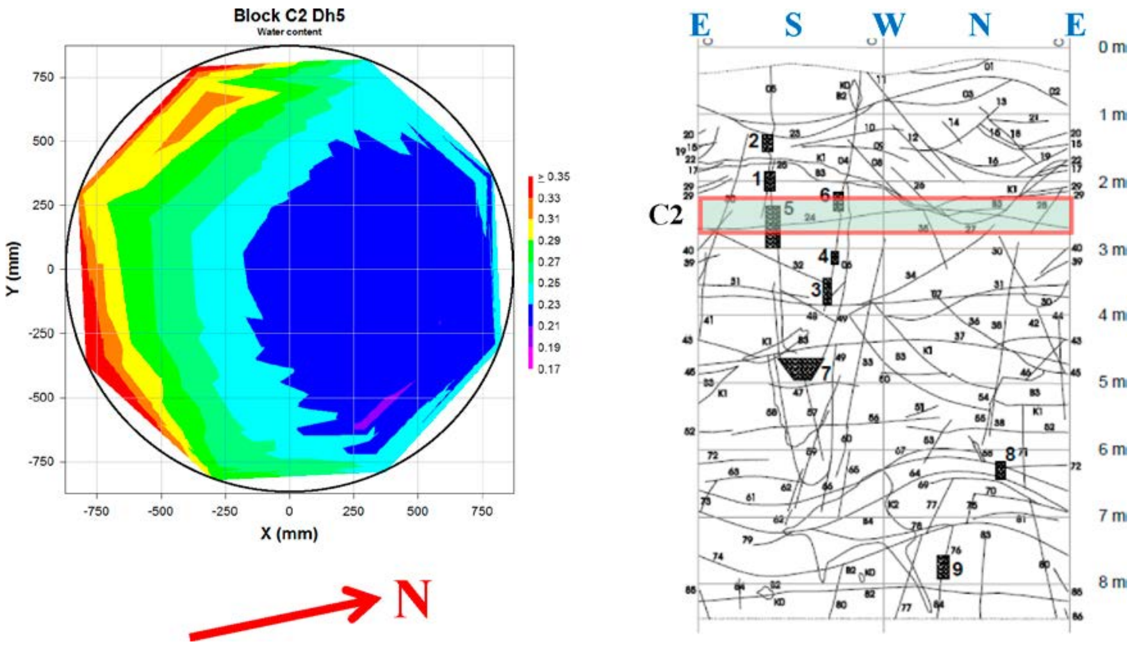


*Figure 5-12. Contour plots of the water content of block C2 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.3.2 Block C3

The following observations can be made about water uptake for block C3, see Appendix 30:

- Differences in the measured/calculated results can be seen between the eight directions. There is a tendency that more water has been taken up by the buffer towards south (direction 25°–115°) for all part of the buffer. The water content of the buffer close to the wall of the deposition hole varies between 23% and 37%. In the central part of the block is the water content about 23%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 85% in the central part of the block and about 100% close to the wall of the deposition hole.
- Small differences in the measured/calculated results can be seen between different levels in the block. The lowest part of the block has taken up more water compare to the upper part.
- The wettest part of the buffer is towards the south-east direction where the water bearing fractures No1 and No2 is situated, see Figure 5-13.

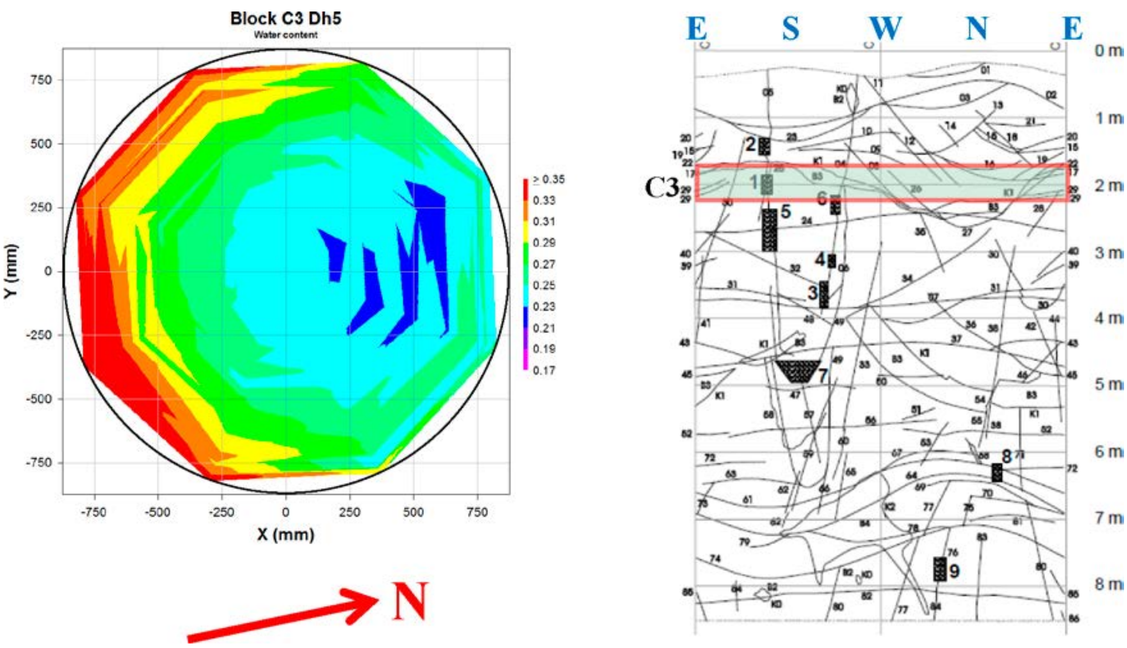


***Figure 5-13.*** *Contour plots of the water content of block C3 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

### 5.3.3 Block C4

The following observations can be made about water uptake for block C4, see Appendix 31:

- The water content of the buffer varies between 25% and 45%. In the central part of the block the water content is about 35%.
- The water content in the buffer has increased at all measuring points compared to the initial values.
- The dry density of all parts of the block has decreased compared to the initial state. This is more pronounced close to the pellets filling. The dry density of the pellets filling has increased compared to the initial state.
- The degree of saturation of the buffer is about 90–100%.
- Large differences in the measured/calculated results can be seen between different levels in the block. The upper part of the block has taken up more water compare to the lower part. This indicates that the block has been wetted from the backfill material placed in the deposition hole on top of the block.
- All parts of the buffer seems to have been wetted evenly except for two anomalies in direction north and west where the water content of the buffer is lower compare to the rest of the block, see Figure 5-14.

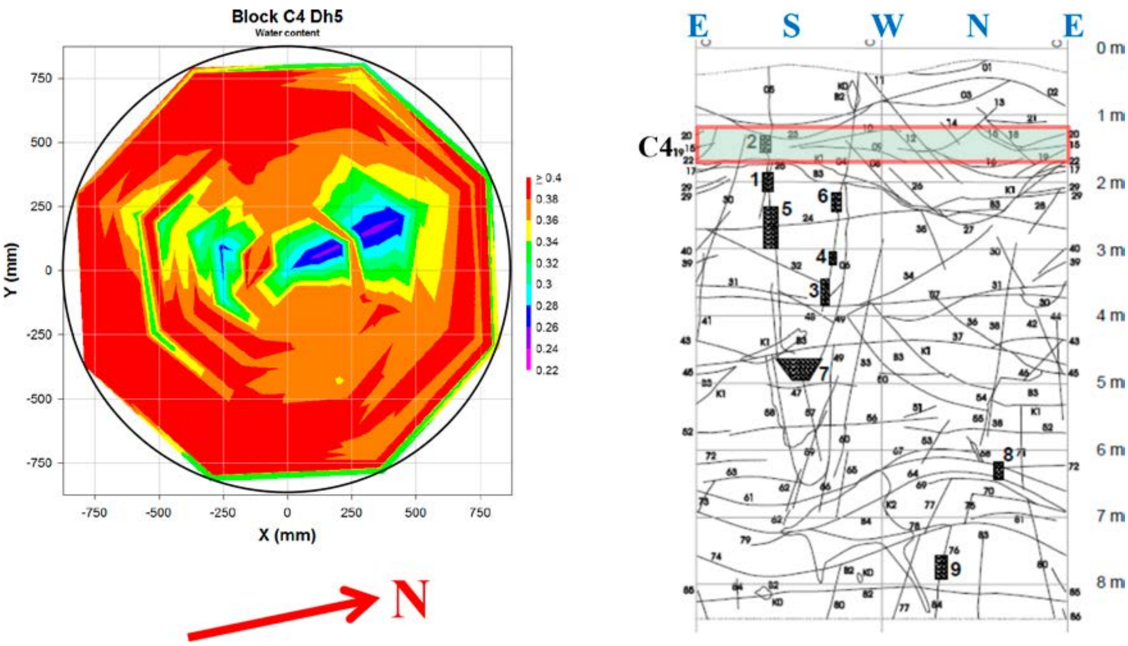


*Figure 5-14. Contour plots of the water content of block C4 in deposition hole 5 together with the observed fractures on the wall of the deposition hole.*

## 5.4 Contour plots of measured results

Contour plots of the measured and calculated variables water content, dry density and degree of saturation were made using an interpolation program. Before these plots were made, data which obviously was wrong (density and water content) were removed. These plots are provided in the Appendices 18–31 for the individual bentonite blocks with the surrounding pellets. More extensive sampling of the buffer were made in two direction, i.e. the water content and density were measured on several levels in each of the blocks for direction ca 25° and direction 250°. The data from these determinations are plotted as contour plots, see Figure 5-15 and Figure 5-16. The white parts of the figures imply that samples were not taken at those locations. The following conclusions can be made from the figures:

- The buffer is close to fully saturated for the profile for direction 25° at the canister level while the degree of saturation is lower for direction 250° especially at the distance 3,000–4,000 mm from the bottom of the deposition hole.
- The degree of saturation is relatively low close to the upper surface of the canister.
- The degree of saturation is high at the upper surface of the most upper block, block C4.
- The dry density is higher as an average for the buffer in direction 250° compare to the direction 25°.
- The water content is lower as an average for the buffer in direction 250° compare to the direction 25°.

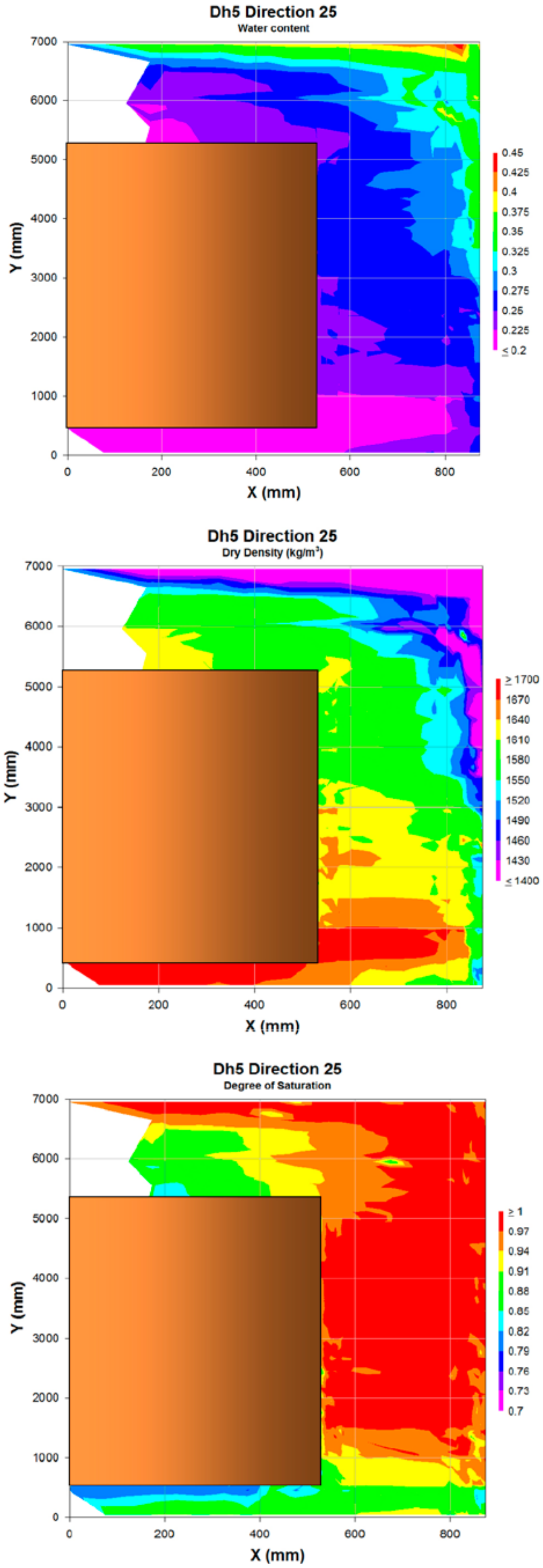


***Figure 5-15.*** *Contour plots of the water content, dry density and degree of saturation for the buffer in deposition hole 5 direction 25°.*

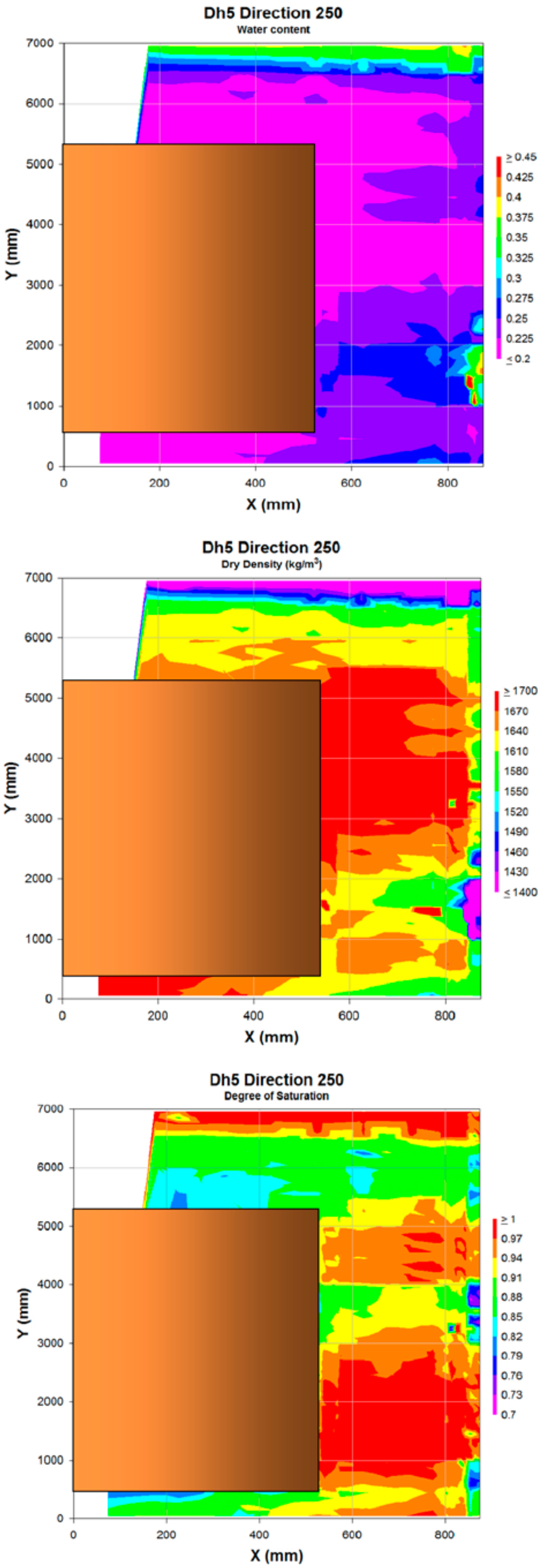


***Figure 5-16.*** *Contour plots of the water content, dry density and degree of saturation for the buffer in deposition hole 5 direction 250°.*

# 6 Execution of the sampling of the backfill

## 6.1 Introduction

The excavation of the backfill in the tunnel was made in inclined layers with a backhoe loader. On every 2 meter the excavation stopped and samples were taken for determination of the water content and density of the backfill material, see Figure 6-1a. In order to be able to stand on the surface of the backfill, when taking samples, steel rods were pushed into the backfill and platforms were placed on them. In order to get well defined cuts on the surface of the backfill and as "undisturbed" samples as possible, they were excavated from the surface with the use of an angle grinder. The samples were wrapped in plastic and transported to the lab for determining of its water content and density.

The same technique was used for taken samples of the backfill inside the deposition holes and also for these samples the position were determined with geodetic surveying, see Figure 6-1b.

## 6.2 The position of the taken samples

Samples were taken on every 2 meter of the backfilled tunnel. The total amount of samples was about 1,000. The coordinate of each of the taken samples were determined by geodetic surveying. The positions of the samples were described in the Äspö 1996 coordinate system and also recalculated according to the local coordinate system described in Figure 6-2.

The coordinate *y* starts at the entrance on ground level, which means that the tunnel ends at y = 3,599.8. The *y*-axis runs in the centre of the tunnel, which means that the tunnel walls intersect the *z* and *x*-axes at +/–2.5 m. The z-coordinate is determined positive upwards and the x-coordinate is determined positive to the right when facing the end of the tunnel. The coordinates were used at the presentation of the density and water content of the material, see Section 8.

a) b)

***Figure 6-1.*** *a) Sampling of the backfill material in a tunnel section. b) Sampling of the backfill material inside the deposition hole.*

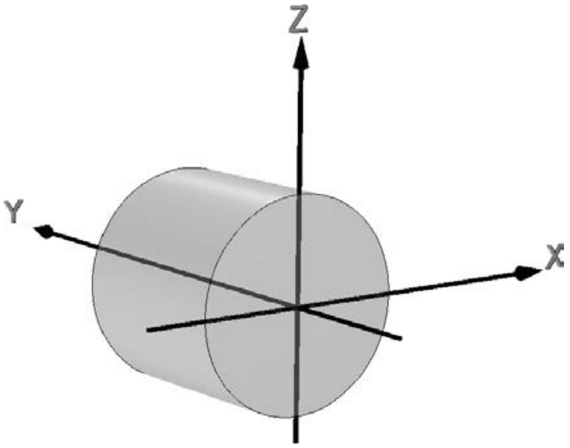


*Figure 6-2. Coordinate system of the tunnel. The coordinate y starts at the entrance of the Äspö tunnel on the ground level.*

## 6.3 Preparation of the samples

The taken samples were wrapped in plastic and transported to the laboratory on the ground level. From the samples then smaller pieces on which the density and the water content were determined were cut out. The rest of the samples were then wrapped in plastic and stored.

## 6.4 Determination of density and water content of the samples

The determination of the water content and density were made within 48 hours after the samples were taken from the site in order to minimize the risk of drying of the samples and thus changes in both the determined water content and density. The technique for determining the water content and density were the same as those uses for the buffer, i.e. the water content of the samples were determined by drying the samples in an oven with a temperature of 105°C for 24 hours and the bulk density was determined by weighting the samples in air and emerged in paraffin oil with known density. The techniques are described in detail in Section 2.4.

# 7 Mesurement of density and water content of the backfill after installation

The backfill material was compacted in situ in inclined layers with the use of vibrating slop compactor attached on a backhoe loader at the installation of the test. The material consisted of 30% bentonite and 70% crushed rock. The rock was originated from the TMB boring of the Prototype tunnel. It was crushed to a maximum grain size of 20 mm. The bentonite originated from Milos in Greece (Silver and Baryte Ores Mining Co was sodium converted before it was shipped to Luleå in Sweden where it was dried and grounded and thereafter mixed with the crushed rock at Äspö in a paddle mixer. The composition and the production of the backfill material are described in detail in Gunnarsson et al. (2001) and Gunnarsson (2002). The density and water content in average for each of the installed layers are shown in Figure 7-1. The figure is indicating that the average dry density of the backfill was lower towards the inner plug. The average density of all of the layers was about 1,750 kg/m$^3$ and the average water content was about 14%. The expected water content at saturation, as an average, is thus about 21.5%. Test made at the installation indicated that the density of the backfill was lower close to the rock surface of the tunnel, especial close to the ceiling, compared to the central part of the tunnel, see Figure 7-2.

The backfill inside the two deposition holes were compacted with a hand held device in layers with a thickness of 10 cm. The average dry density ($\rho_d$) of the backfill inside deposition hole 6 was 1,830 kg/m$^3$ with water content (w) of about 12.8%. Corresponding values for the backfill in deposition hole 5 was $\rho_d$ = 1,770 kg/m$^3$ and w = 15.0%.

Measurements of the inflow together with mapping of the fractures in the tunnel were made before the installation of the test (Rhén and Forsmark 2001). The outcome from this is shown in Figure 7-3. The figure indicates that the inflow to the tunnel is larger close to the outer plug.

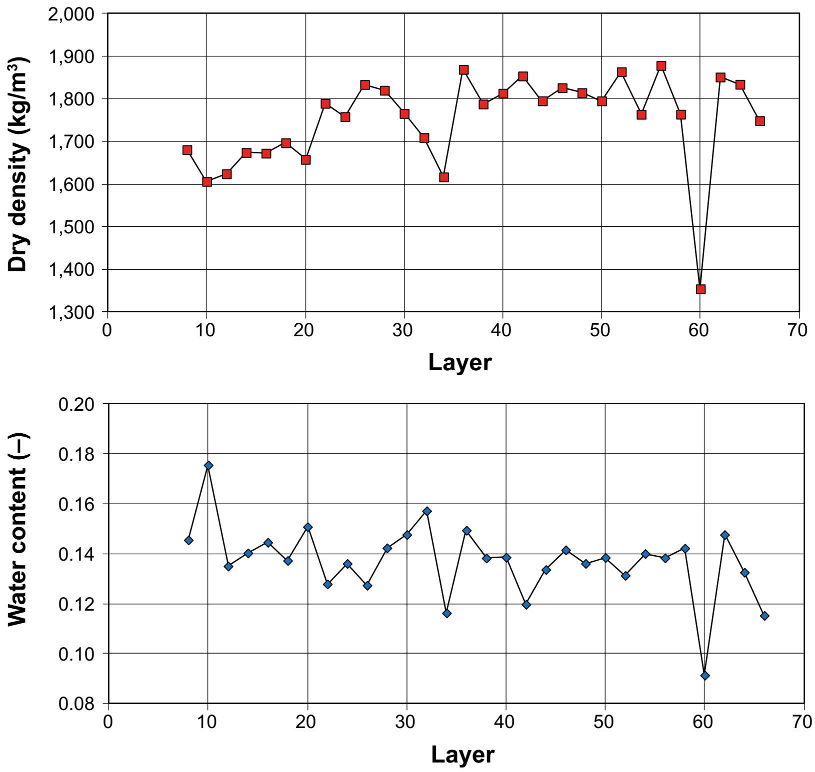


*Figure 7-1. The average dry density (upper) and water content (lower) of the installed layers of backfill in Section II (Johannesson et al. 2004).*

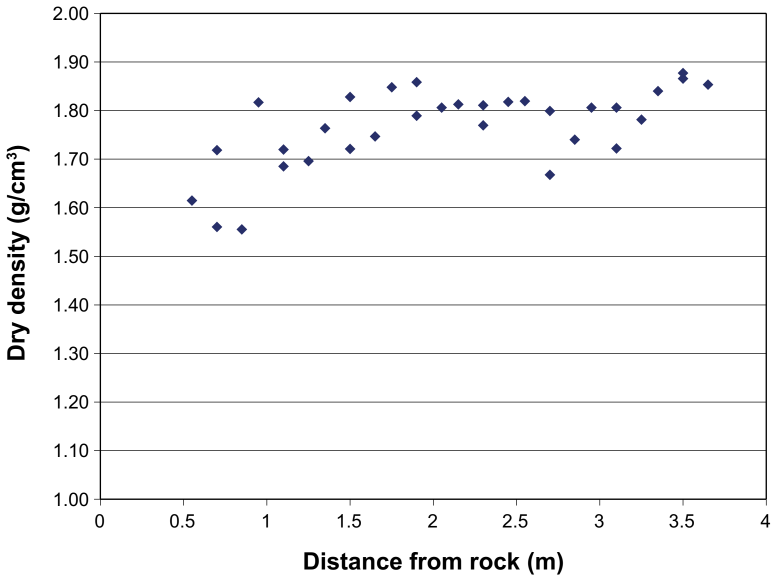


***Figure 7-2.** The dry density of the backfill for one profile in layer 48 as a function of the distance from the rock surface in Section II (from Johannesson et al. 2004).*

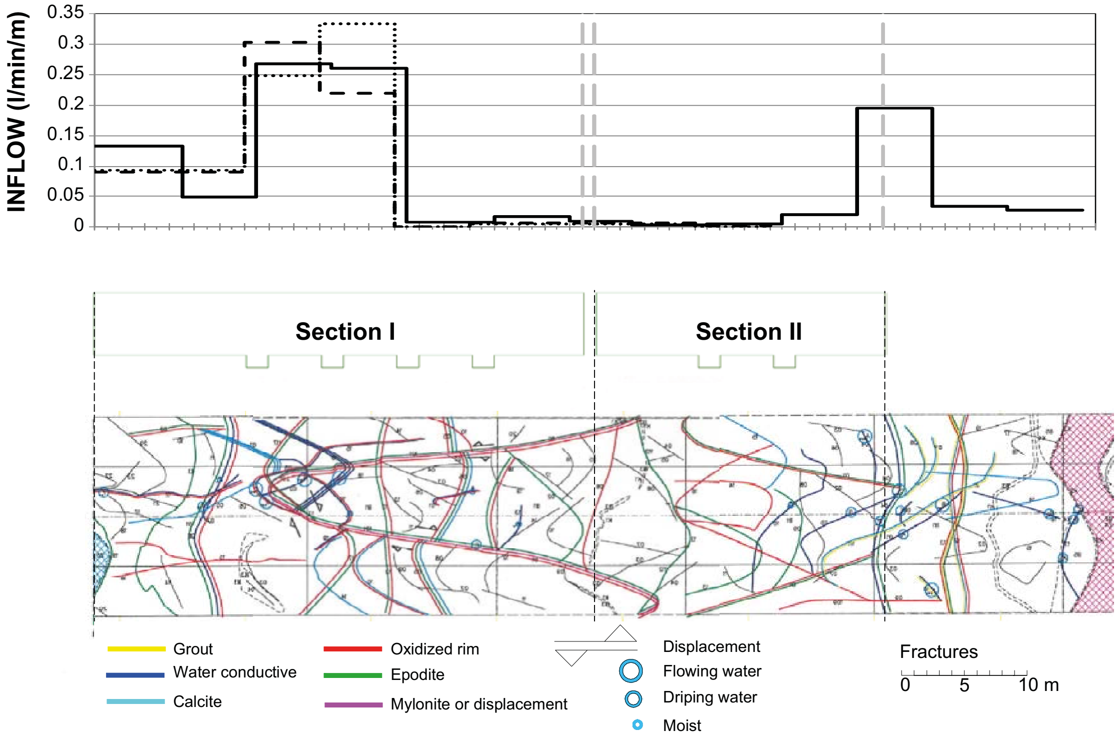


***Figure 7-3.** The measured inflow and the mapping of the fractures in the Prototype tunnel (Rhén and Forsmark 2001).*

# 8 Results of measured densities and water content of the backfill

## 8.1 Backfill in the upper part of the deposition holes

The density and water content in average of the backfill inside the two deposition holes both at the installation and at the retrieval are summarised in Table 8-1. The density at the installation was measured with a gamma probe (Campel Pacific MC-3 Port probe). The technique used and the values from these measurements are described in Johannesson et al. (2004) while the methods used at the retrieval are described in Section 6.4. The backfill material inside the deposition holes had an initial height of about 1.00 m. From the measured average density it is possible to make a rough calculation of the compression of the backfill inside the deposition holes caused by the upward swelling of the buffer. The outcomes from these calculations are also shown in Table 8-1. The figures indicate that the deformations of the backfill inside the two deposition holes are small compared to the observed deformation of the upper surface of the bentonite (156 mm in deposition hole 5 and 178 mm in deposition hole 6 (Johannesson and Hagman 2013) and thus most of the compression of the backfill can be located to the backfill in the tunnel.

## 8.2 Backfill in the tunnel

With the data from the measurement of the water content and the density it is possible to calculate the dry density and the degree of saturation. This data can be plotted as contour plots as shown in Figure 8-1. The data from the 11 sections are summarized in Appendixes 32–41. The plots are indicating that the backfill has a low density and high water content close to the rock surface, especially close to the roof. The plots of the degree of saturation are indicating that there are some spots which have a divergent value compared to surrounding parts. This can be explained by the fact that the backfill material is rather heterogenic and the degree of saturation was calculated from the measurement of water content and density which were determined on two different samples although they are taken from the same spot in the backfill.

From the measurements on the investigated sections an average density, water content and degree of saturation can be calculated. The data from these calculations are shown in Table 8-2 and Figure 8-2. The data are indicating that the backfill is fully saturated in average and that there is a tendency that the dry density is increasing towards the outer plug. Furthermore the average dry densities are significantly lower than the density measured at the installation, c.f. Figure 7-1. An explanation to this might be that, at the installation the density was not measured directly. Instead a nuclear gauge probe and a penetrometer were used for interpretation of the density of the filling (Johannesson et al. 2004).

**Table 8-1. Average water content and dry density of the backfill material inside the two deposition holes in section II of the Prototype Repository.**

| Deposition hole | At installation Dry density (kg/m$^3$) | At installation Water content | At retrieval Dry density (kg/m$^3$) | At retrieval Water content | Deformation |
|---|---|---|---|---|---|
| DA3545G01 (Dh 6) | 1,770 | 0.150 | 1,796 | 0.180 | ~14 mm |
| DA3551G01 (Dh 5) | 1,830 | 0.128 | 1,814 | 0.178 | ~0 mm |

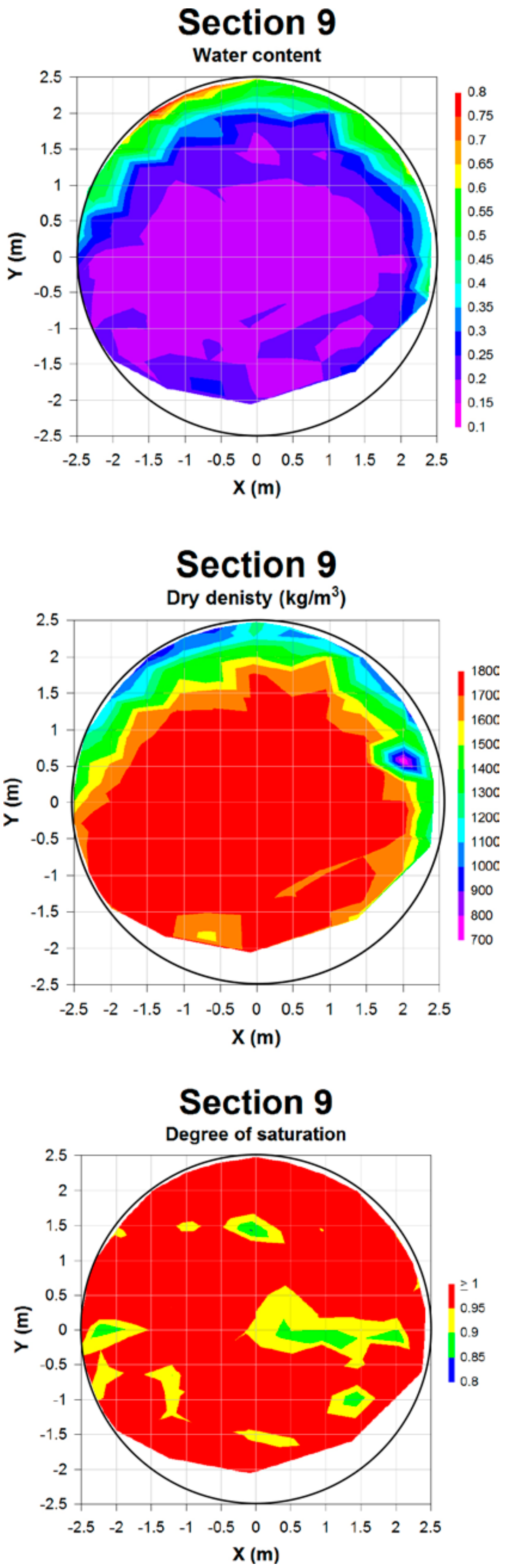


***Figure 8-1.*** *The measured water content, dry density and degree of saturation of the backfill material in section 9.*

**Table 8-2. The average water content, dry density, void ratio and degree of saturation for the 11 investigated sections and the backfill towards the two plugs.**

| Section No | Water cont. | Dry dens. (kg/m³) | Void ratio | Degree of sat. |
|---|---|---|---|---|
| Plugg 2 | 0.23 | 1,690 | 0.62 | 1.00 |
| 1 | 0.24 | 1,653 | 0.65 | 0.99 |
| 2 | 0.26 | 1,623 | 0.68 | 1.01 |
| 3 | 0.27 | 1,581 | 0.74 | 0.98 |
| 4 | 0.24 | 1,655 | 0.65 | 1.00 |
| 5 | 0.25 | 1,639 | 0.67 | 1.00 |
| 6 | 0.26 | 1,593 | 0.72 | 0.98 |
| 7 | 0.23 | 1,666 | 0.62 | 0.99 |
| 8 | 0.28 | 1,583 | 0.75 | 0.98 |
| 9 | 0.29 | 1,567 | 0.77 | 1.00 |
| 10 | 0.28 | 1,575 | 0.78 | 0.99 |
| 11 | 0.26 | 1,591 | 0.71 | 0.99 |
| Plugg 1 | 0.30 | 1,570 | 0.80 | 0.99 |

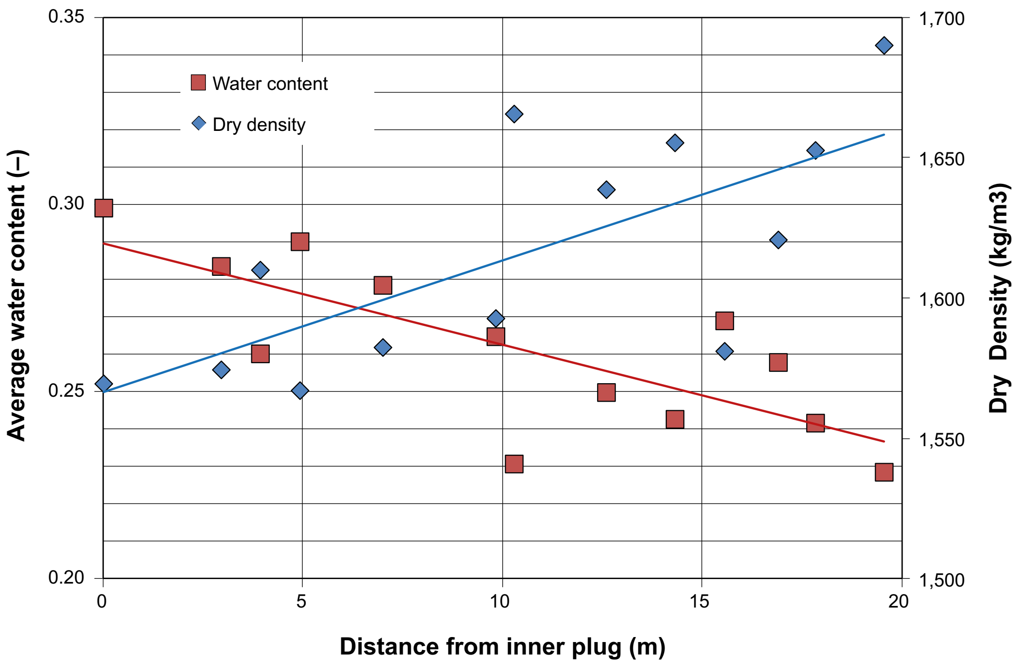


***Figure 8-2.*** *The average density and water content of the backfill material as function of the distance from the inner plug.*

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# Appendices

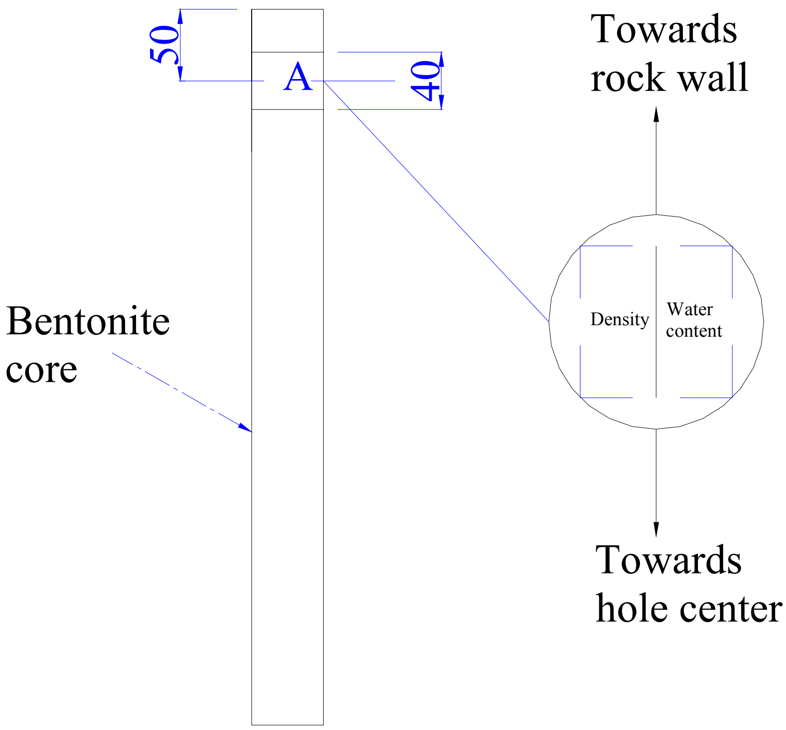
1. Sample from cores in Section A1–A5.
2. Sample from cores in Section B1.
3. Sample from cores in Section C1–C2.
4. Results from measurements made in block C1 in Dh 6.
5. Results from measurements made in block R1 in Dh 6.
6. Results from measurements made in block R2 in Dh 6.
7. Results from measurements made in block R3 in Dh 6.
8. Results from measurements made in block R4 in Dh 6.
9. Results from measurements made in block R5 in Dh 6.
10. Results from measurements made in block R6 in Dh 6.
11. Results from measurements made in block R7 in Dh 6.
12. Results from measurements made in block R8 in Dh 6.
13. Results from measurements made in block R9 in Dh 6.
14. Results from measurements made in block R10 in Dh 6.
15. Results from measurements made in block C2 in Dh 6.
16. Results from measurements made in block C3 in Dh 6.
17. Results from measurements made in block C4 in Dh 6.
18. Results from measurements made in block C1 in Dh 5.
19. Results from measurements made in block R1 in Dh 5.
20. Results from measurements made in block R2 in Dh 5.
21. Results from measurements made in block R3 in Dh 5.
22. Results from measurements made in block R4 in Dh 5.
23. Results from measurements made in block R5 in Dh 5.
24. Results from measurements made in block R6 in Dh 5.
25. Results from measurements made in block R7 in Dh 5.
26. Results from measurements made in block R8 in Dh 5.
27. Results from measurements made in block R9 in Dh 5.
28. Results from measurements made in block R10 in Dh 5.
29. Results from measurements made in block C2 in Dh 5.
30. Results from measurements made in block C3 in Dh 5.
31. Results from measurements made in block C4 in Dh 5.
32. Results from measurements made in Section 1 of the backfill.
33. Results from measurements made in Section 2 of the backfill.
34. Results from measurements made in Section 3 of the backfill.
35. Results from measurements made in Section 4 of the backfill.
36. Results from measurements made in Section 5 of the backfill.
37. Results from measurements made in Section 6 of the backfill.

38. Results from measurements made in Section 7 of the backfill.
39. Results from measurements made in Section 8 of the backfill.
40. Results from measurements made in Section 9 of the backfill.
41. Results from measurements made in Section 10 of the backfill.
42. Results from measurements made in Section 11 of the backfill.

## Samples from cores in Section A1–A5

| RevNo | Revision note | Date | Signnature | Checked |
|---|---|---|---|---|

# Section A1-A5 : Density and water content /5 cm radial direction . One level.

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Tel: 046-286 2570

Sampling

Prototype Repository | Edetion | Sheet

## Samples from cores in Section B1

| RevNo | Revision note | Date | Signnature | Checked |
|---|---|---|---|---|

Section B1: Density and water content /2.5 cm radial direction . One level.

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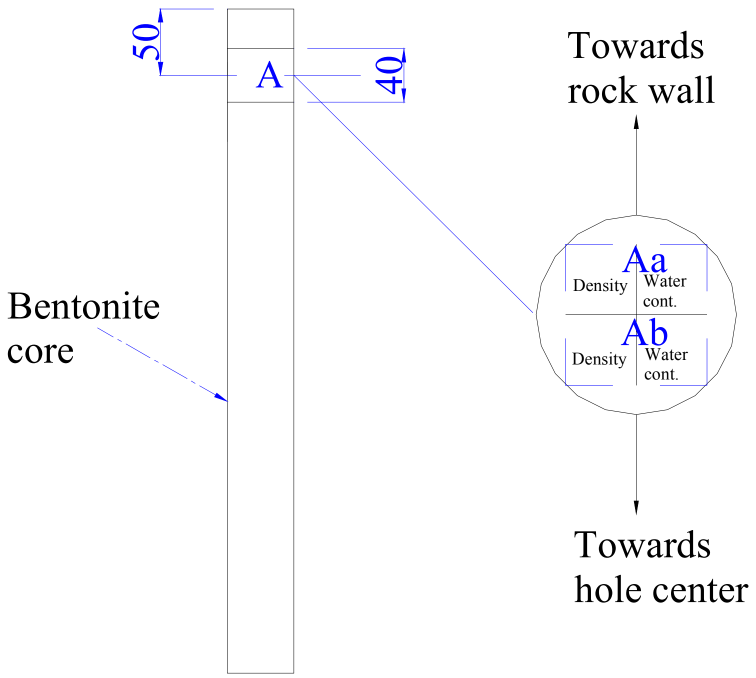


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| LEJ | LEJ | | | 110411 | |

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Sampling

Prototype Repository

| Edetion | Sheet |
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## Samples from cores in Section C1–C2

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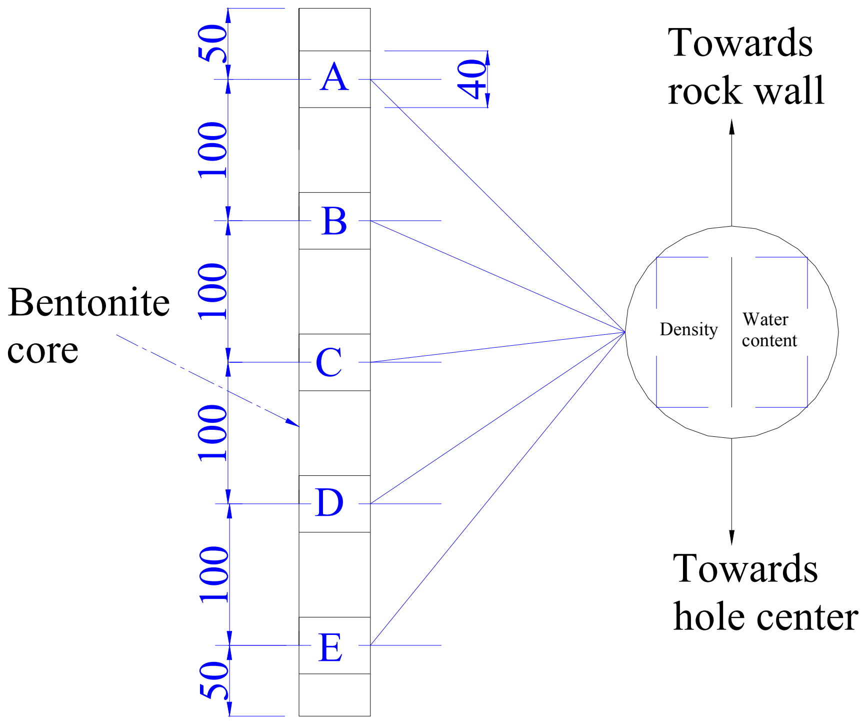


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|---|---|---|---|
| Clay Technology AB<br>Ideon 223 70, Lund<br>Tel: 046-286 2570 | Sampling | | |
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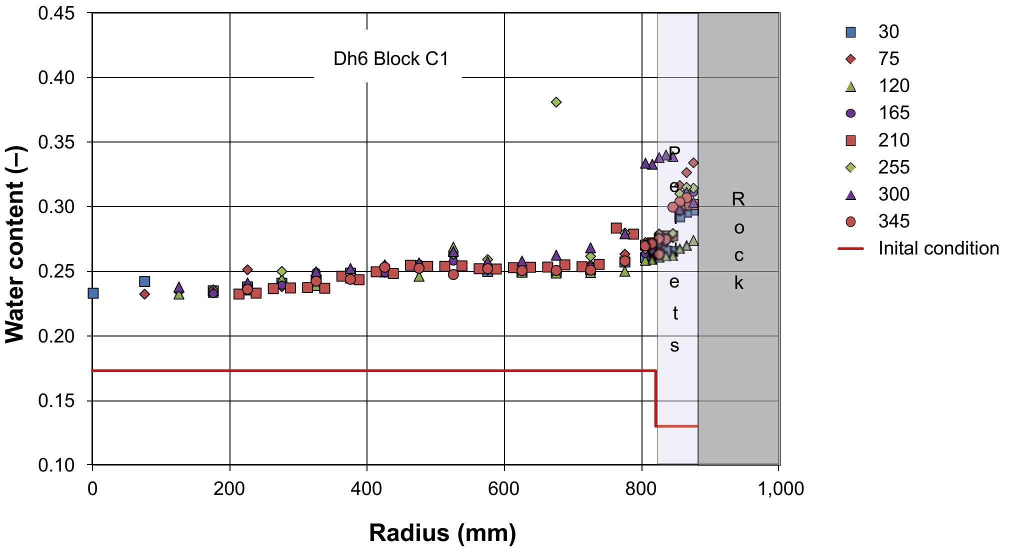
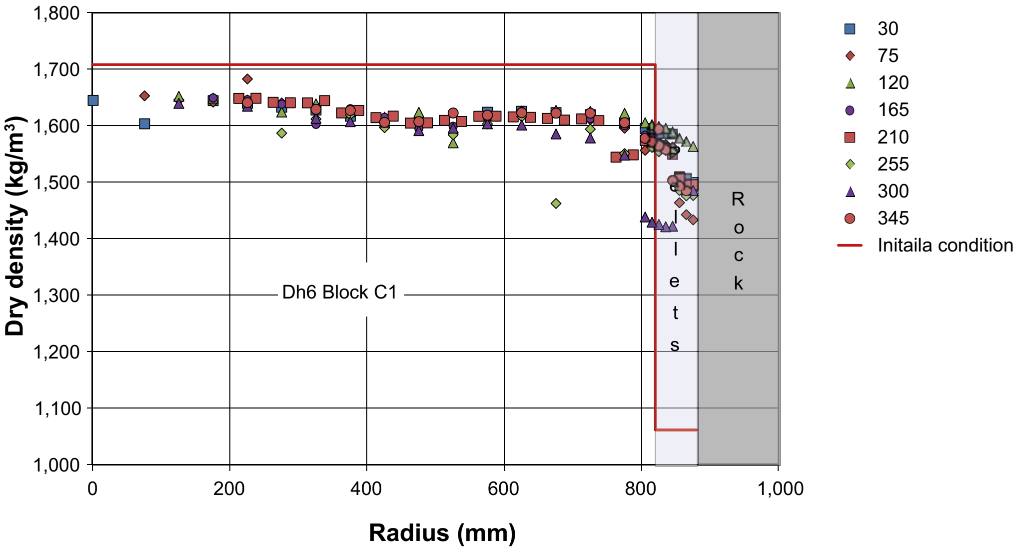
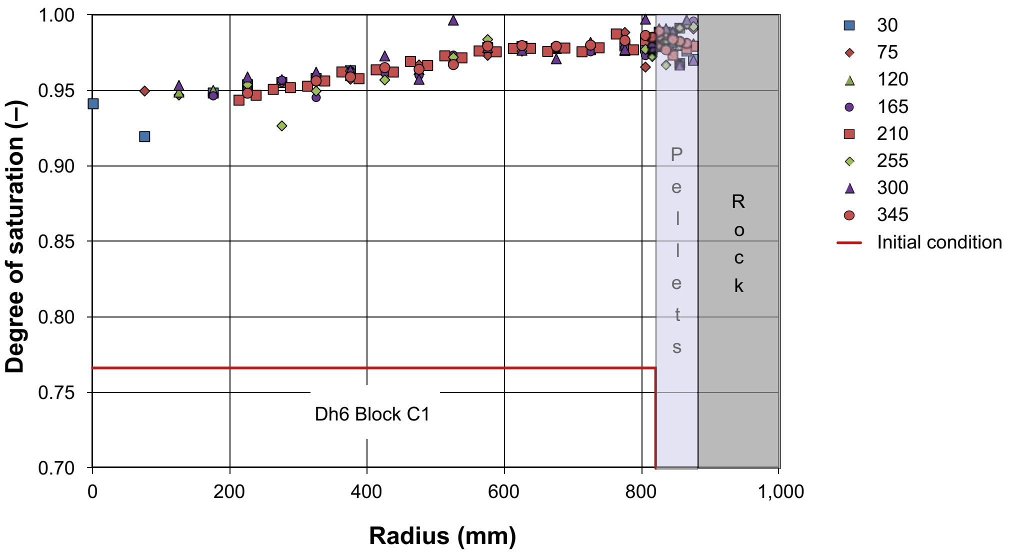
# Appendix 4

## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block C1, Dh 6



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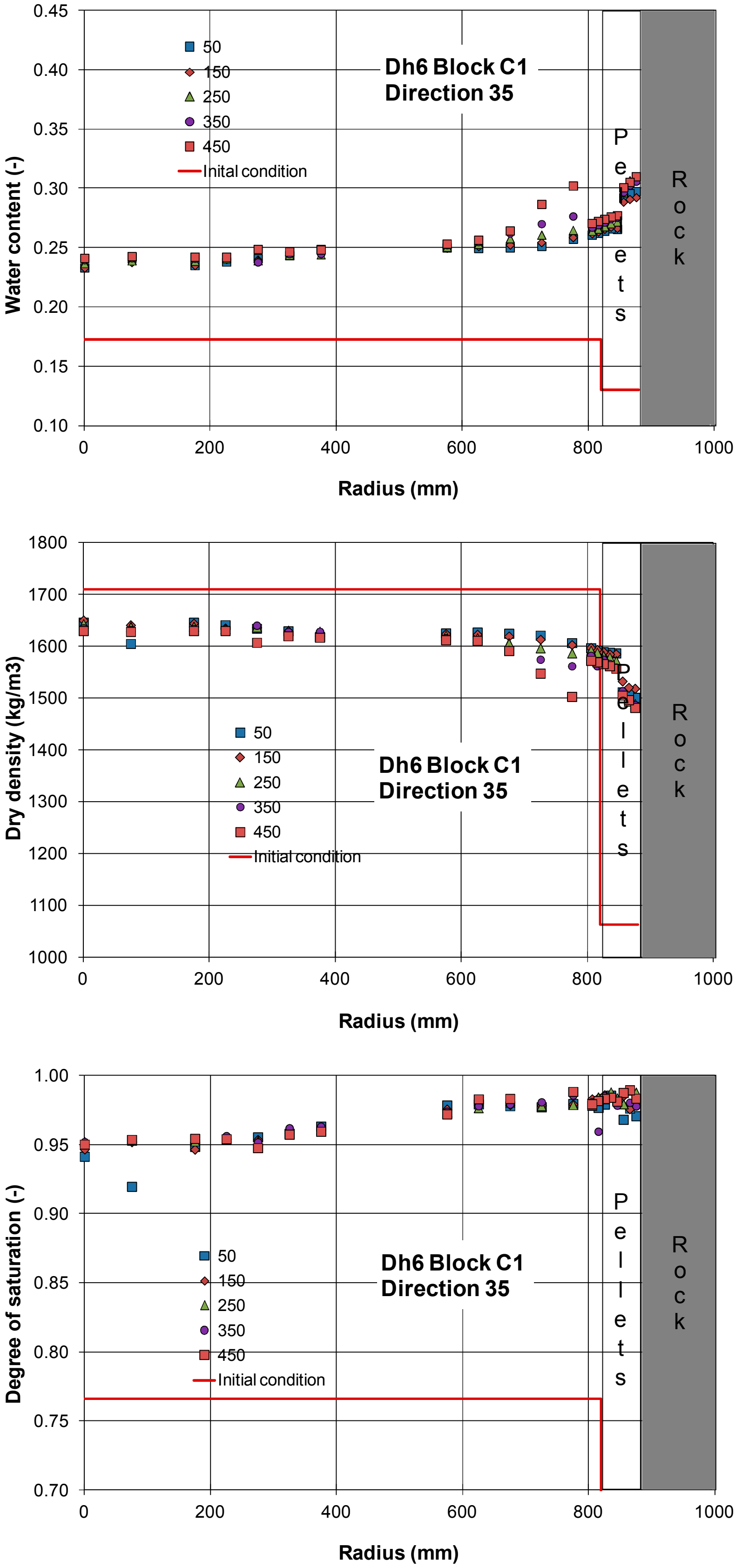

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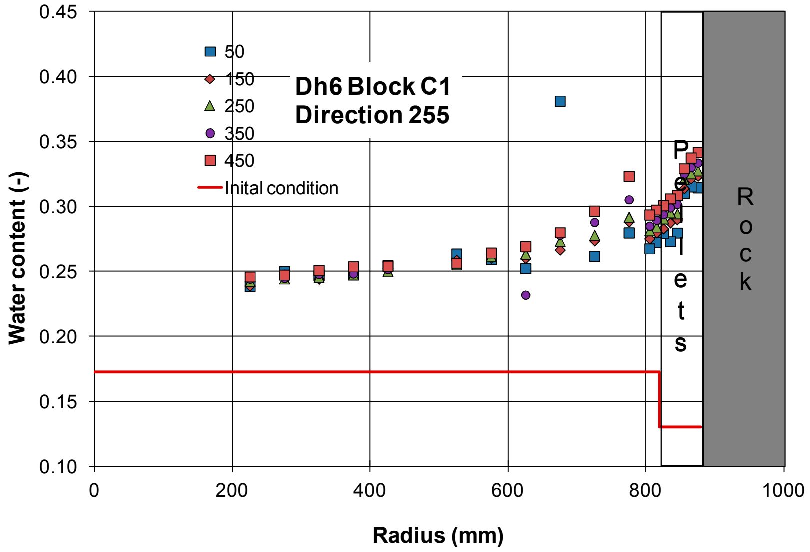
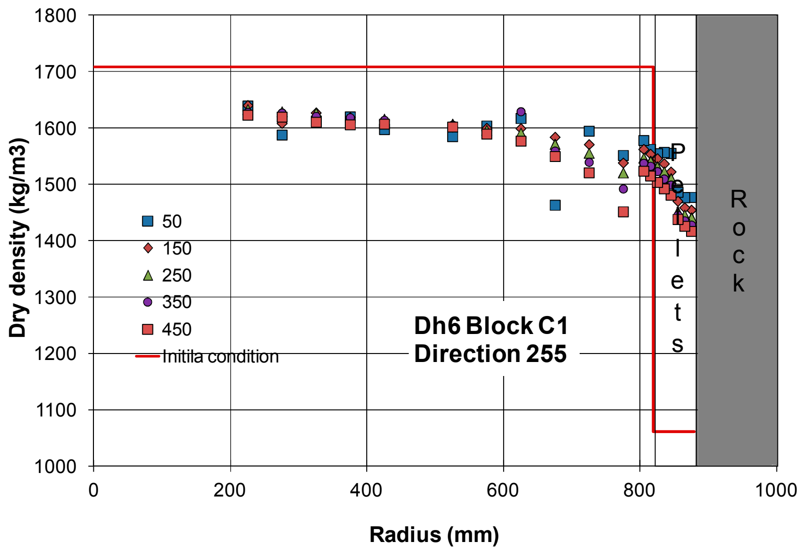
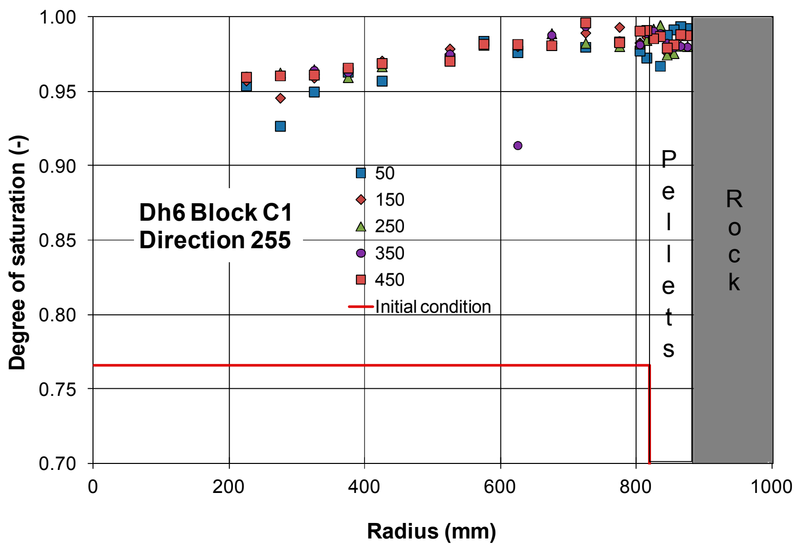
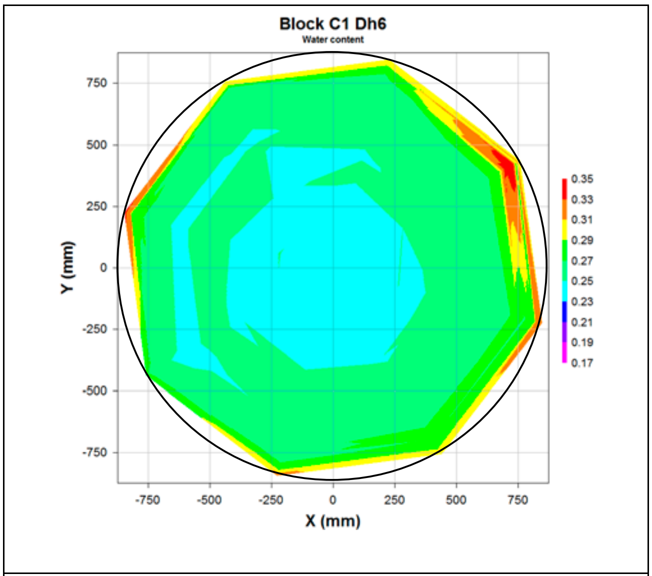
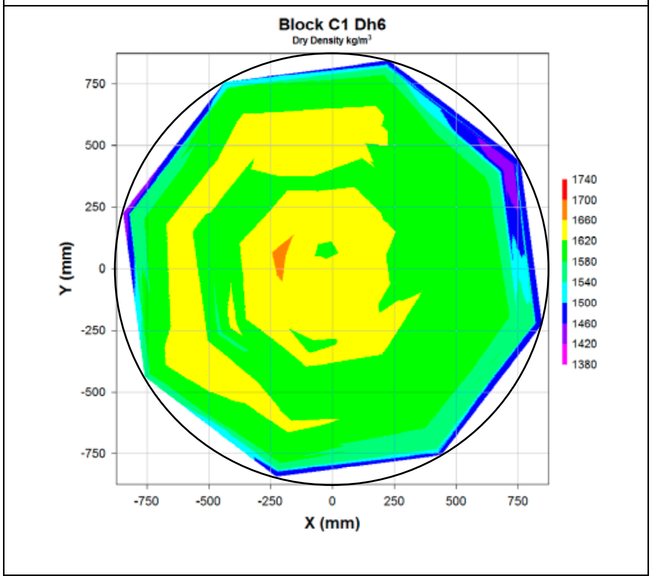


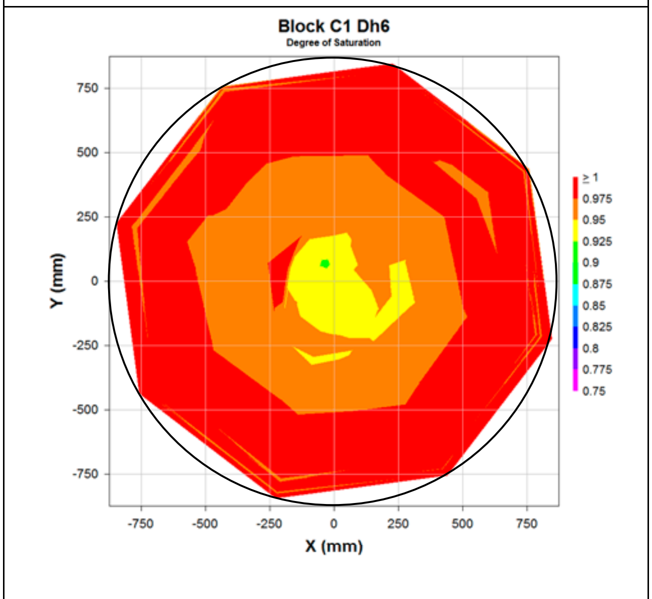



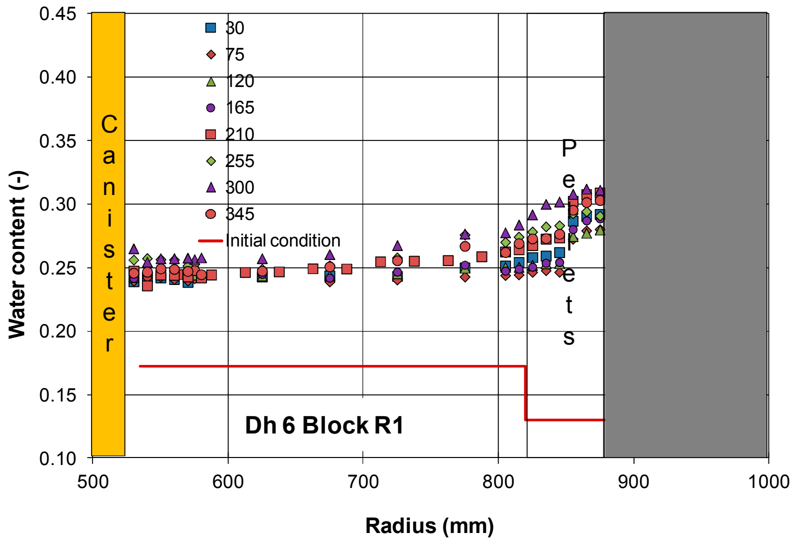
## Contour plots of water content, dry density and degree of saturation block C1, Dh 6

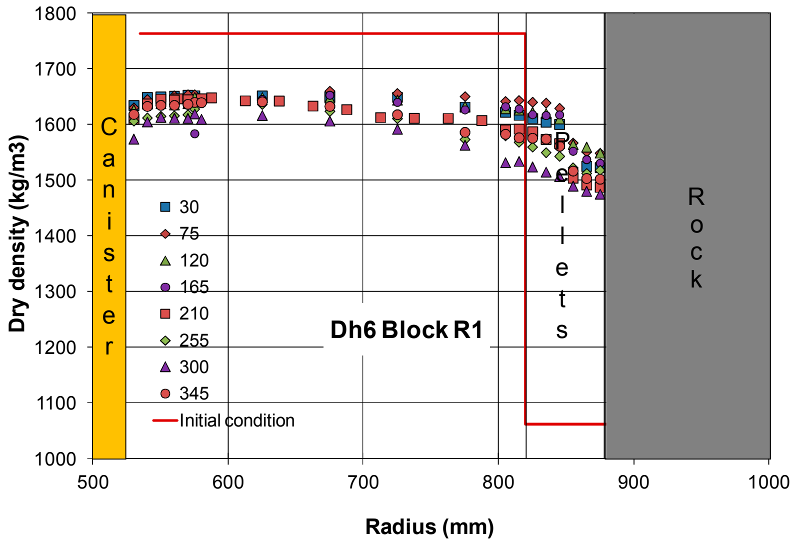


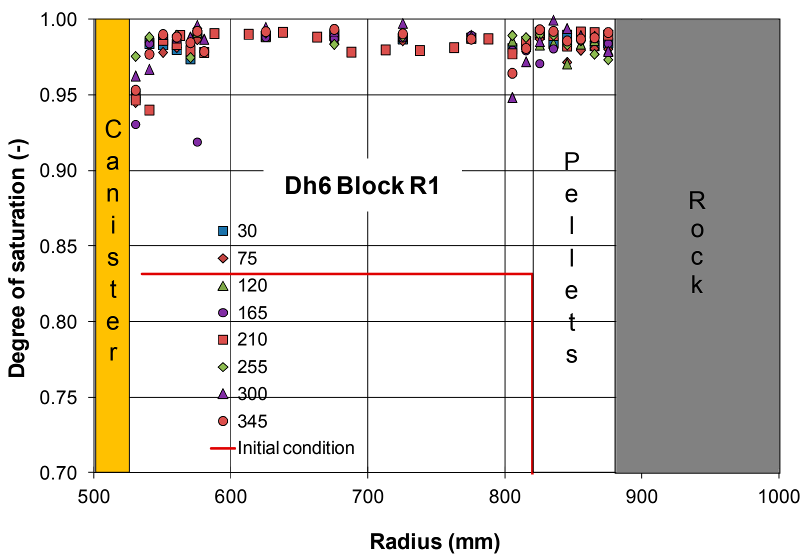



## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block R1, Dh 6



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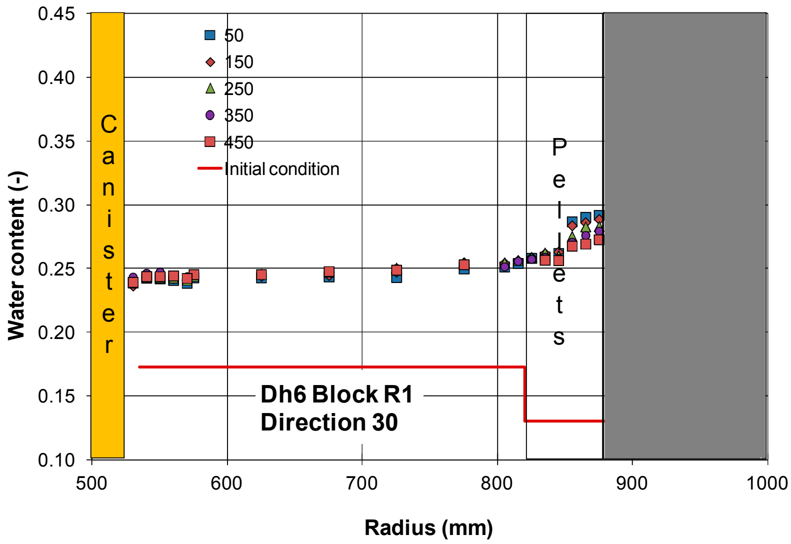
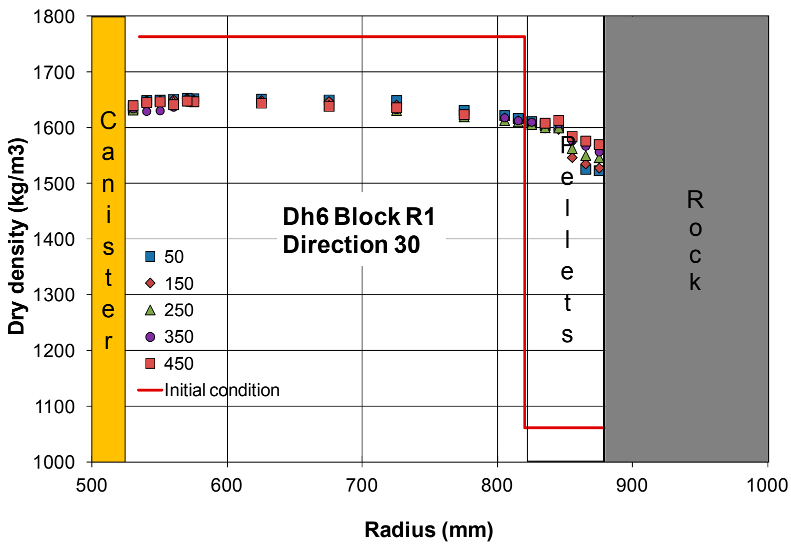
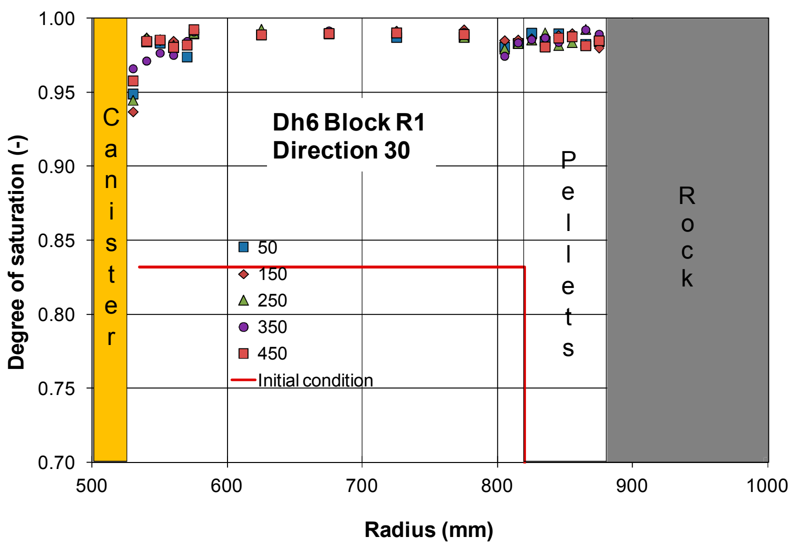
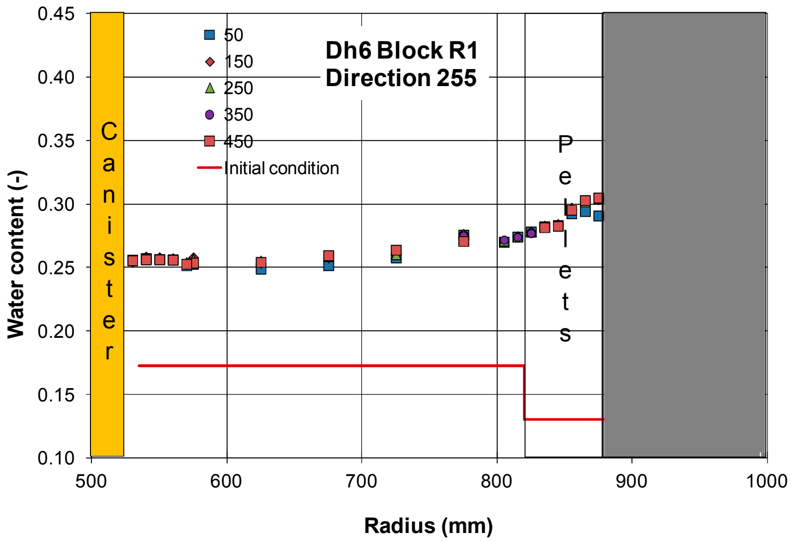
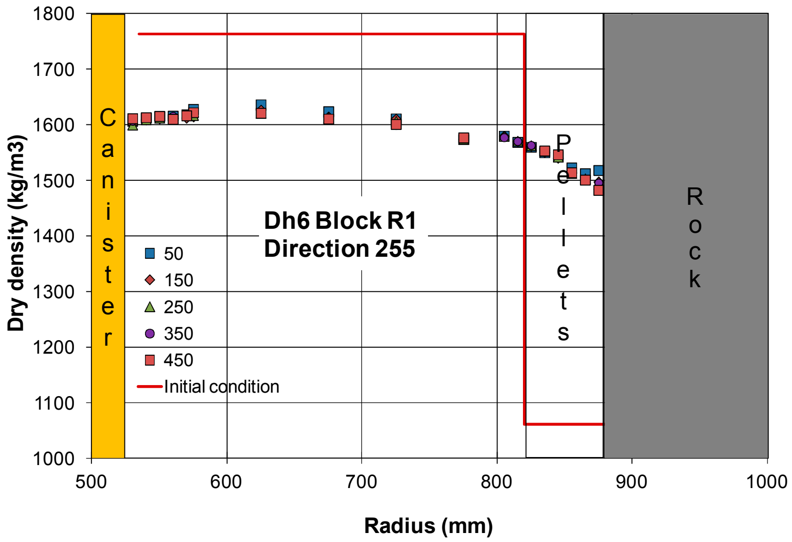


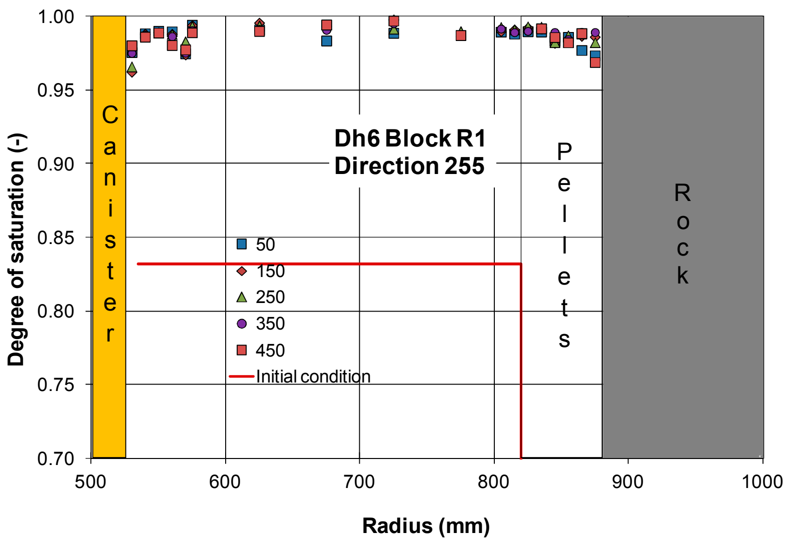



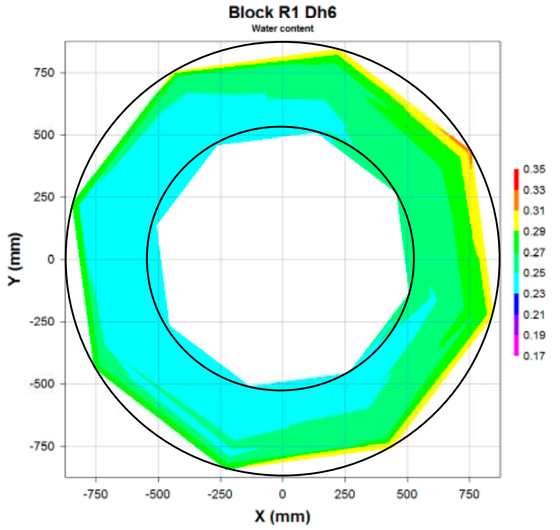
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 255° block R1, Dh 6

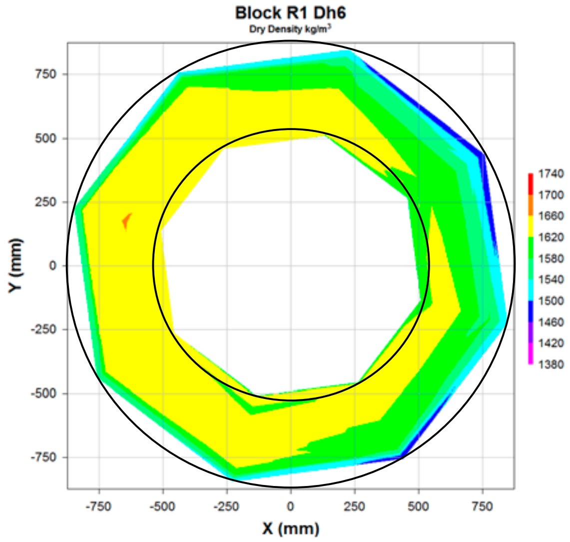


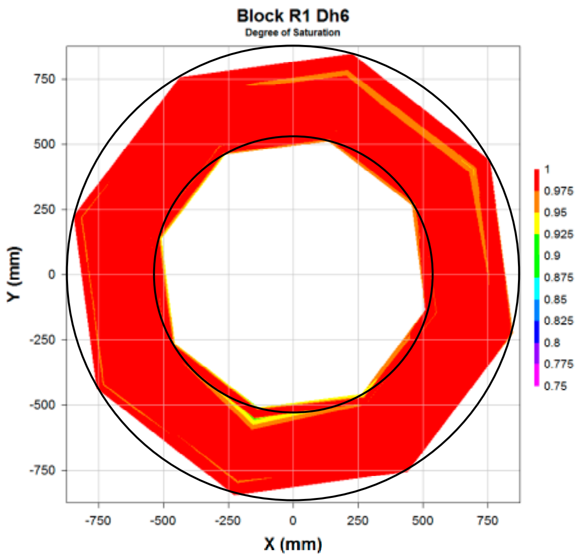



# Contour plots of water content, dry density and degree of saturation block R1, Dh 6

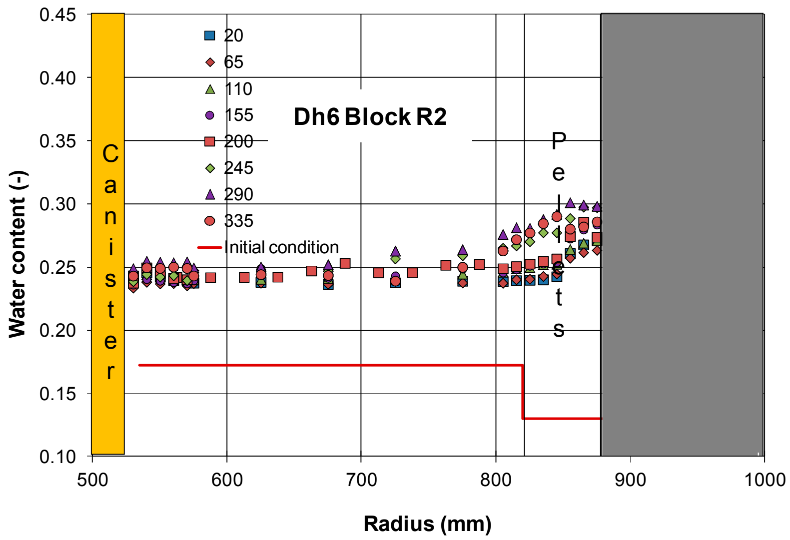


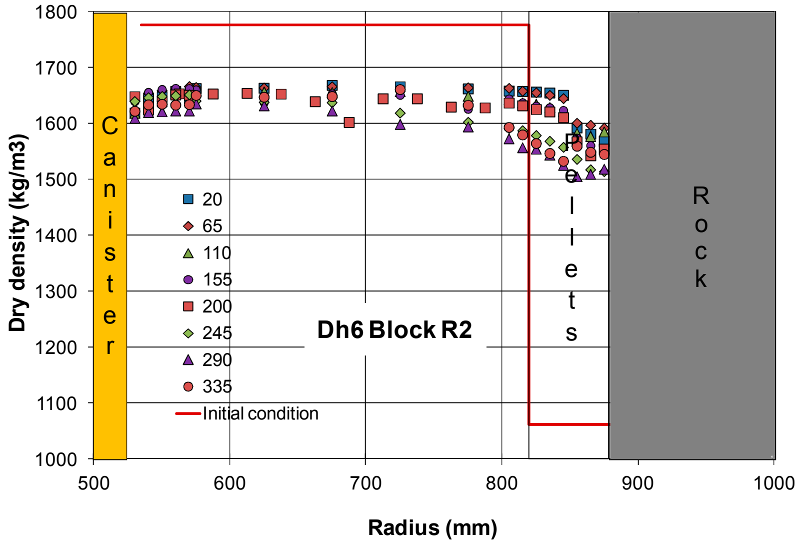



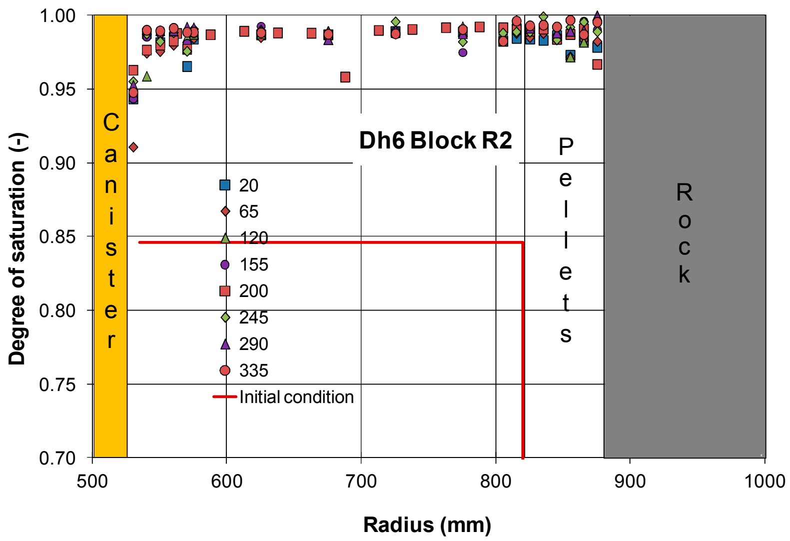



## Appendix 6

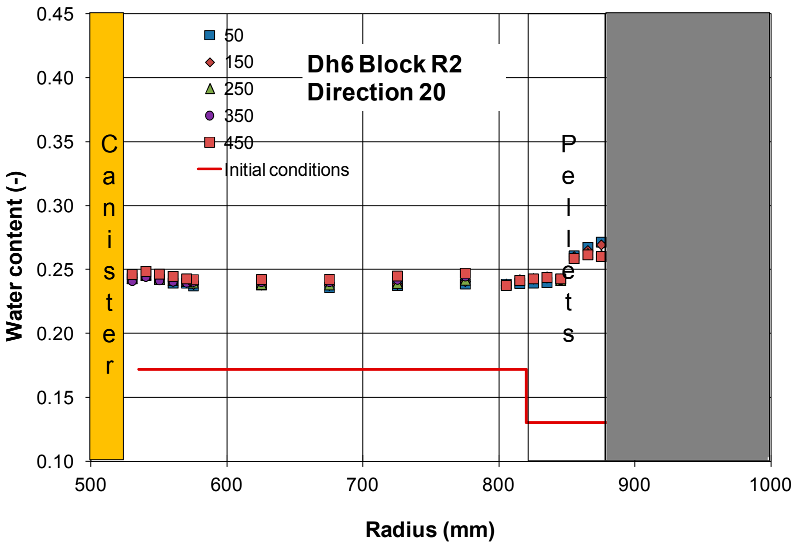
## Water content, dry density and degree of saturation measured in eight directions (20, 65, 110, 155, 200, 245, 290 and 335°) in block R2, Dh 6

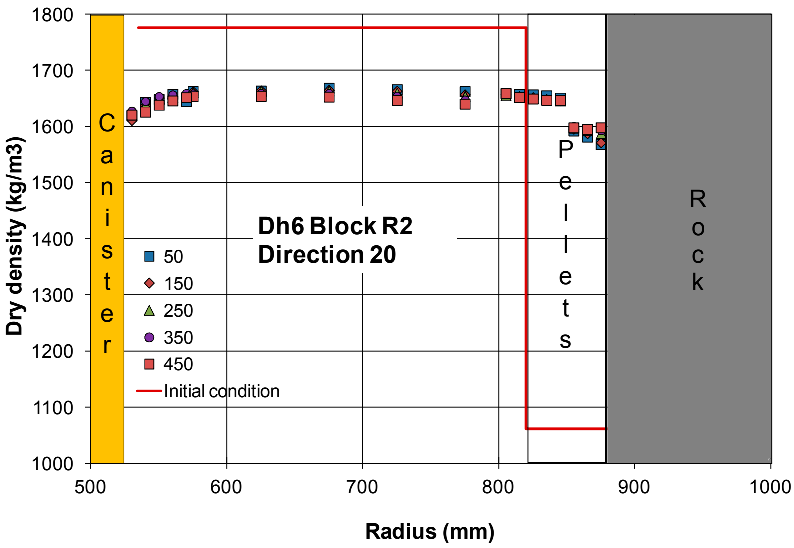


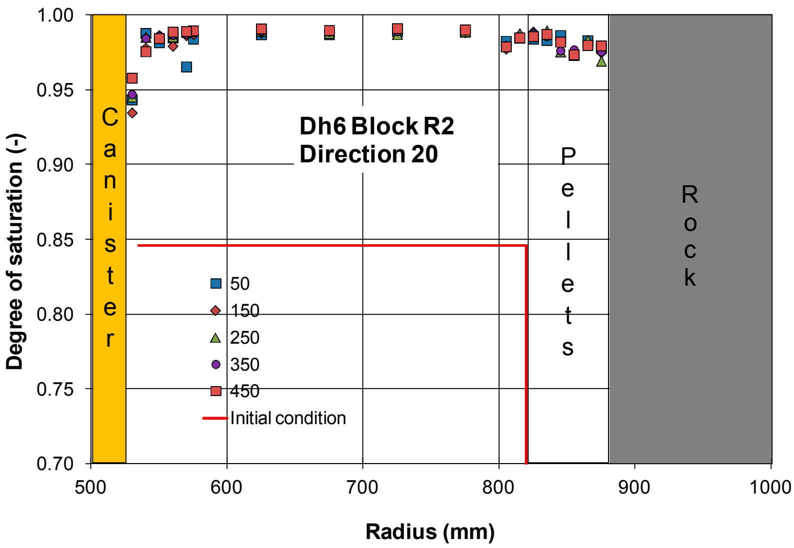



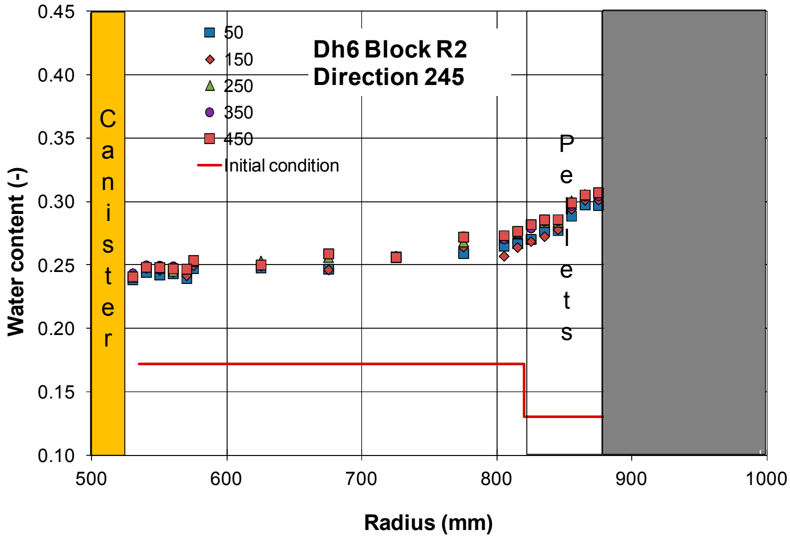
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 20° block R2, Dh 6**

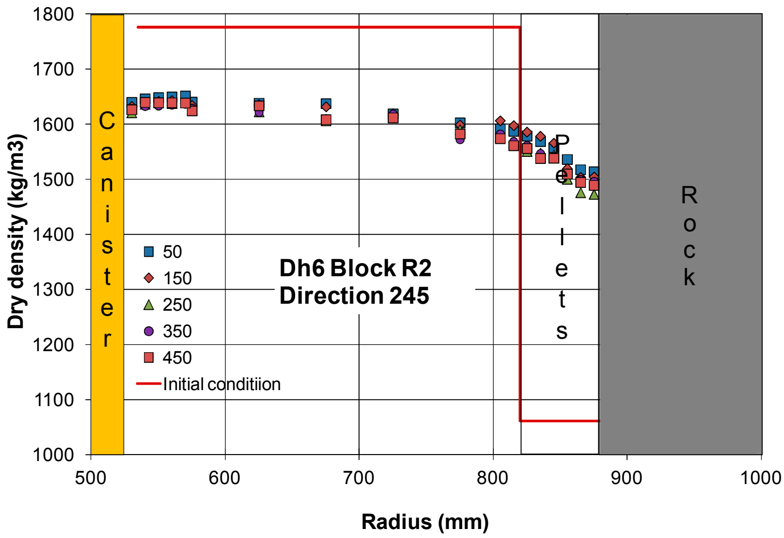


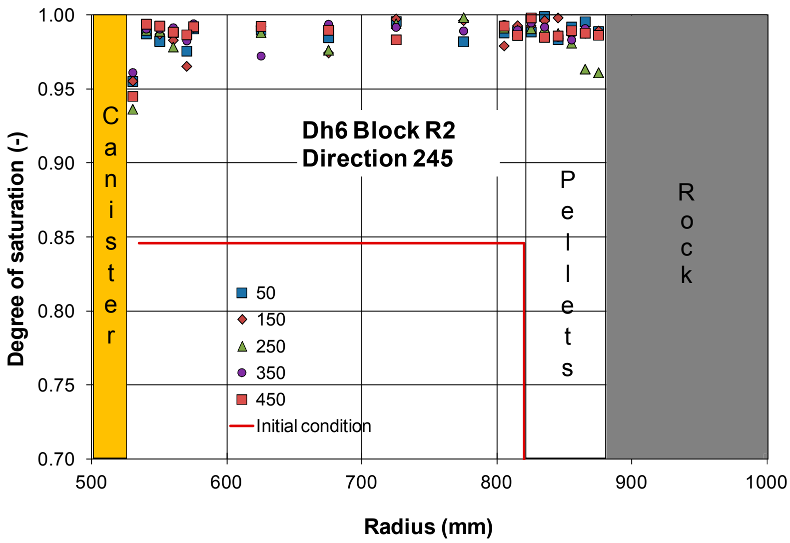



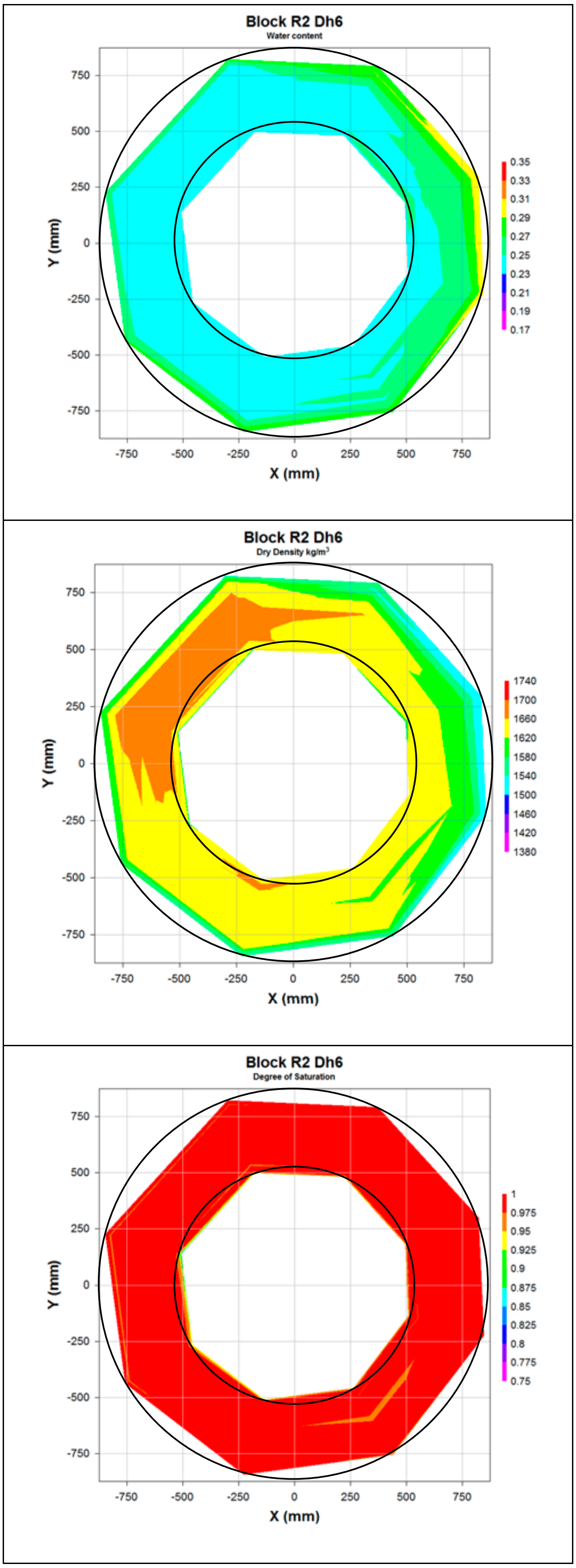
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 245° block R2, Dh 6



## Contour plots of water content, dry density and degree of saturation block R2, Dh 6



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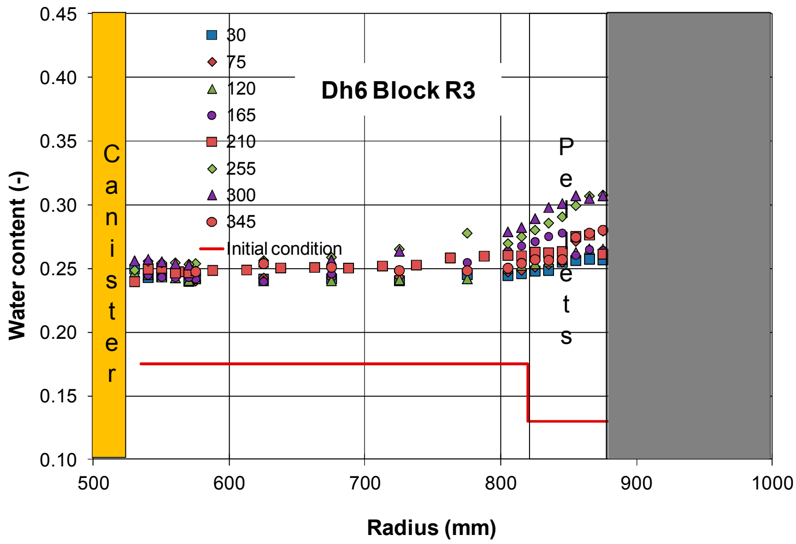
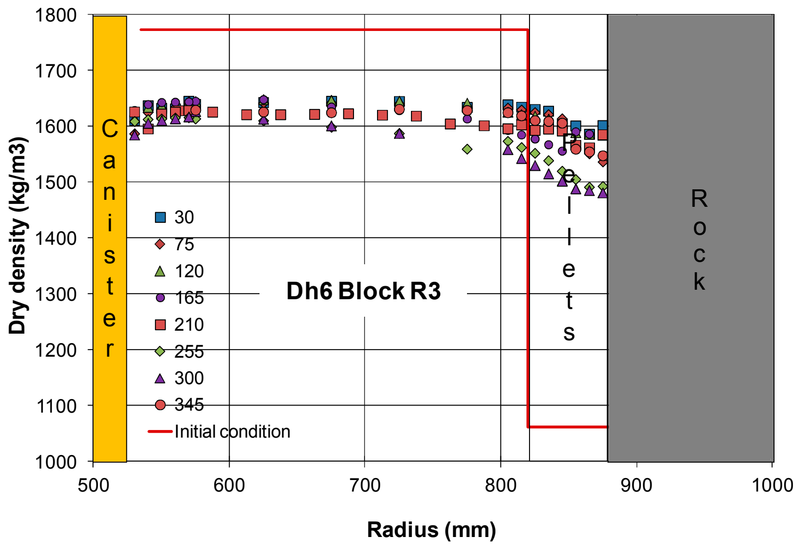
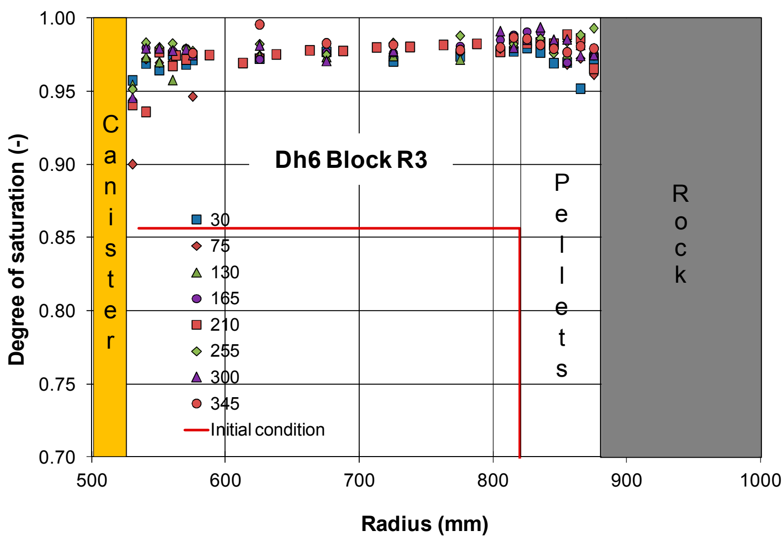
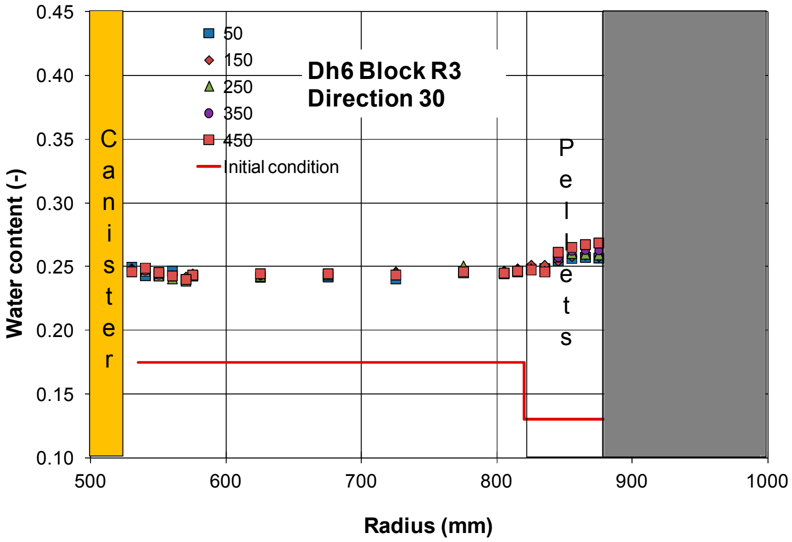
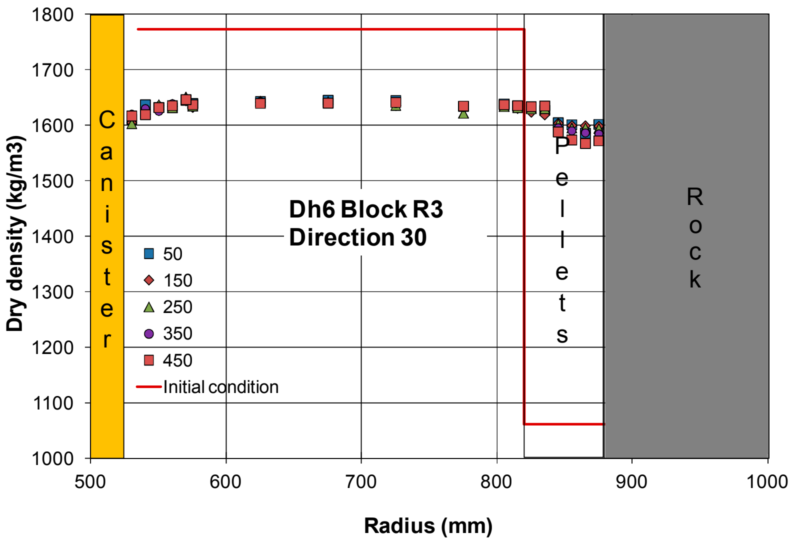


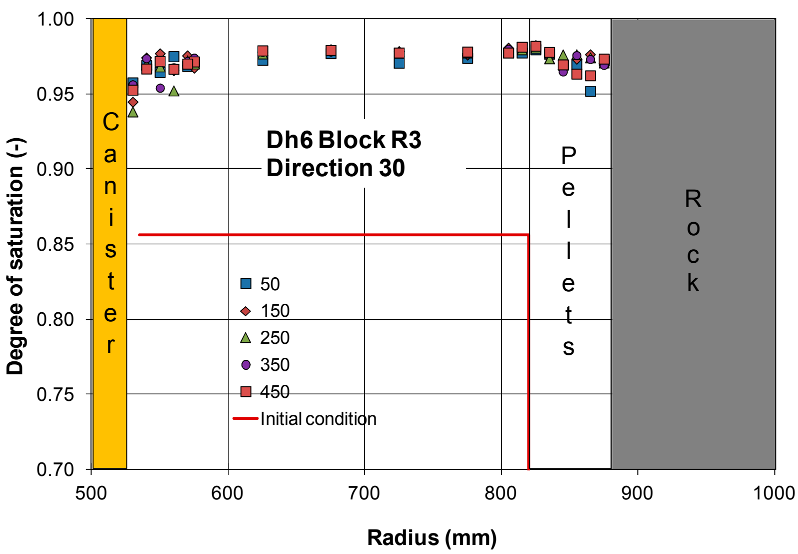



## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block R3, Dh 6



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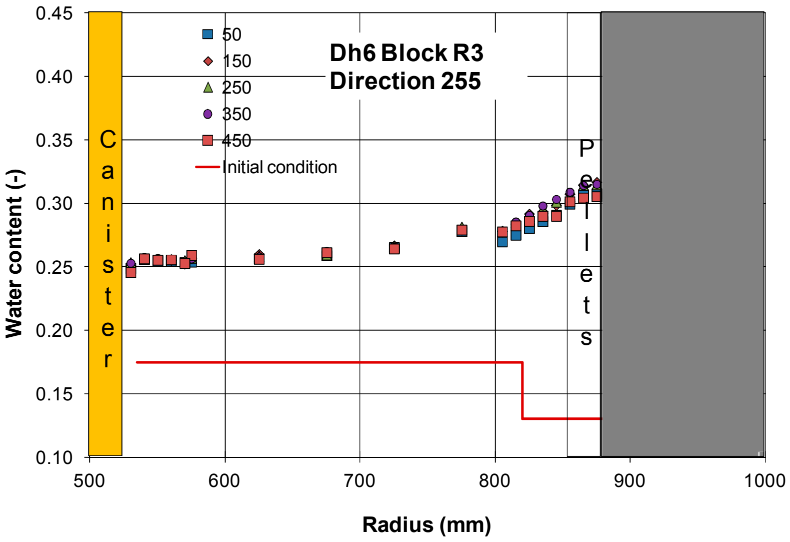
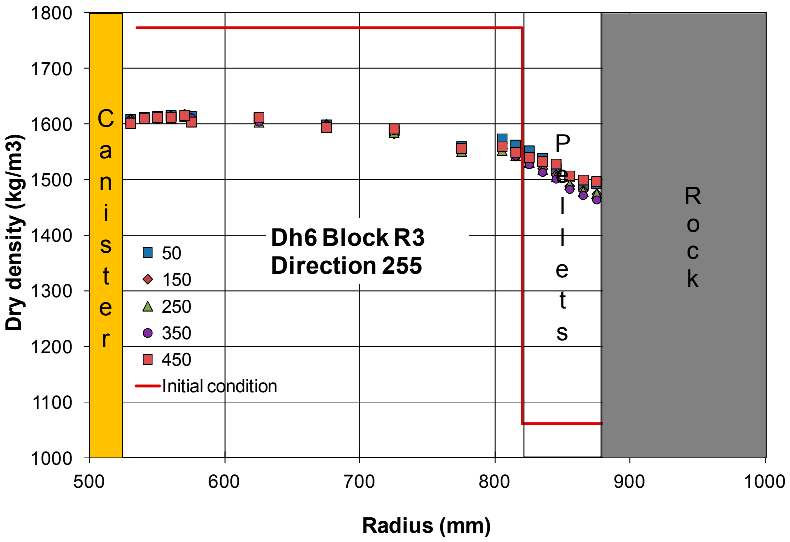
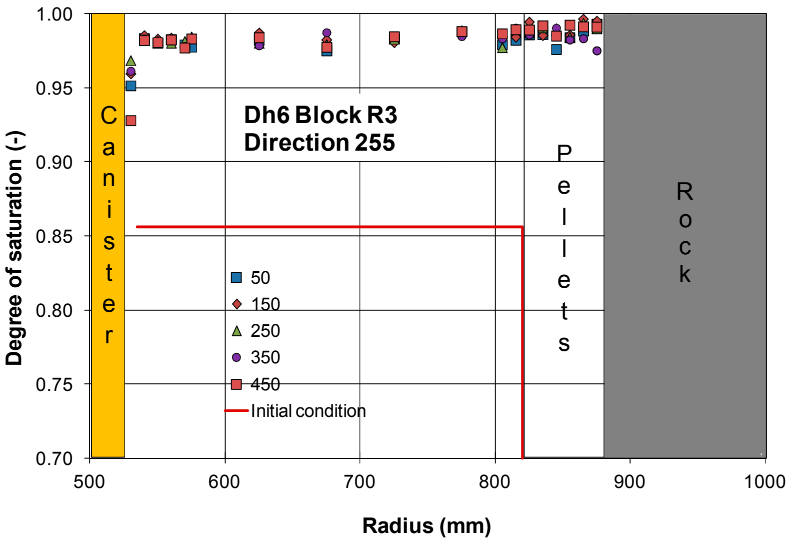
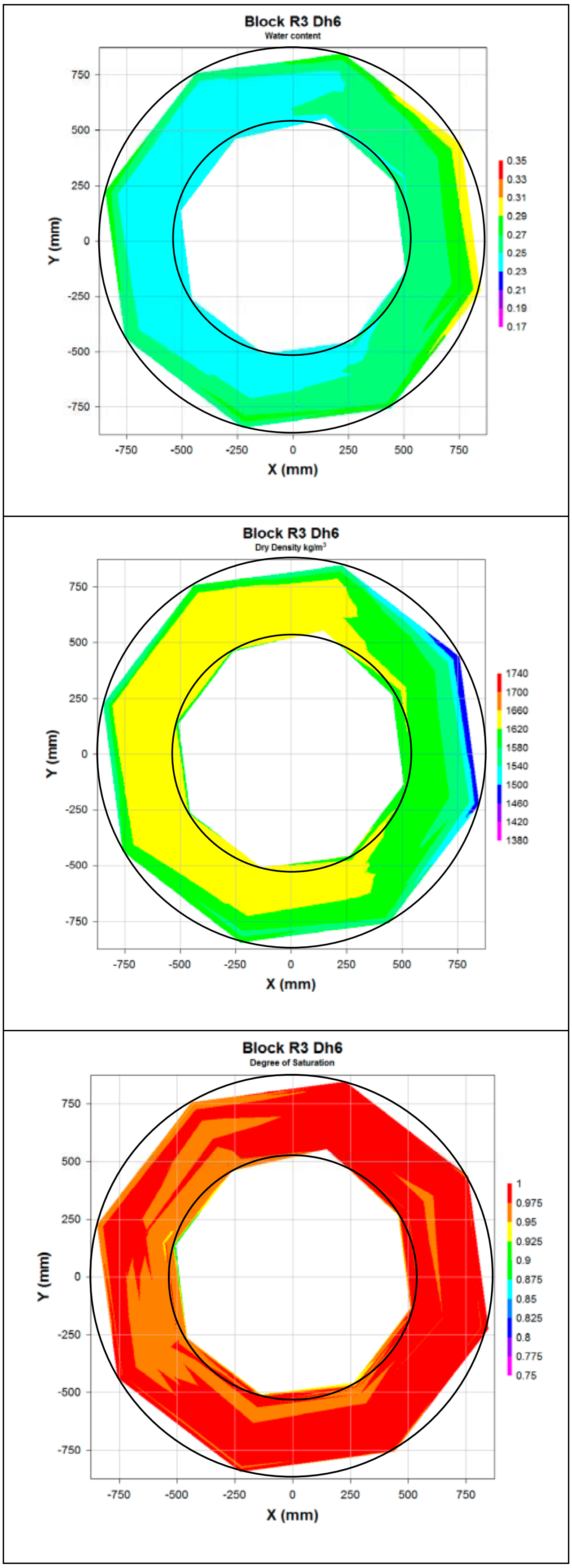


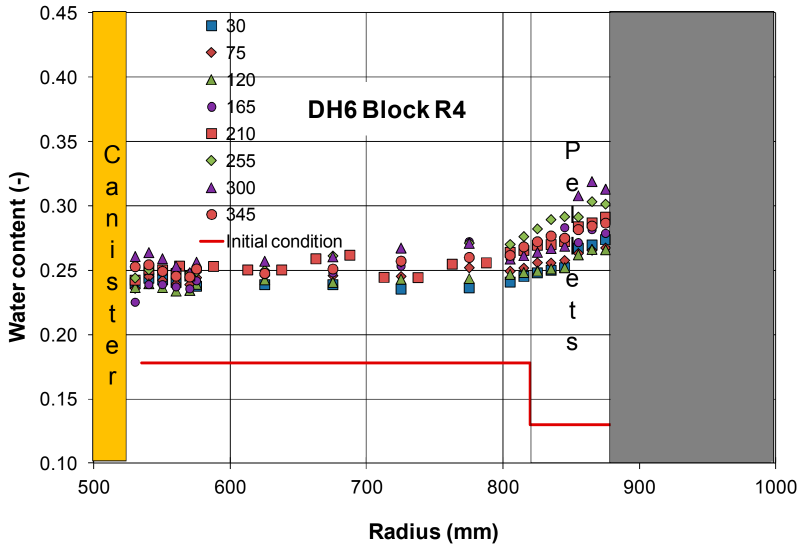



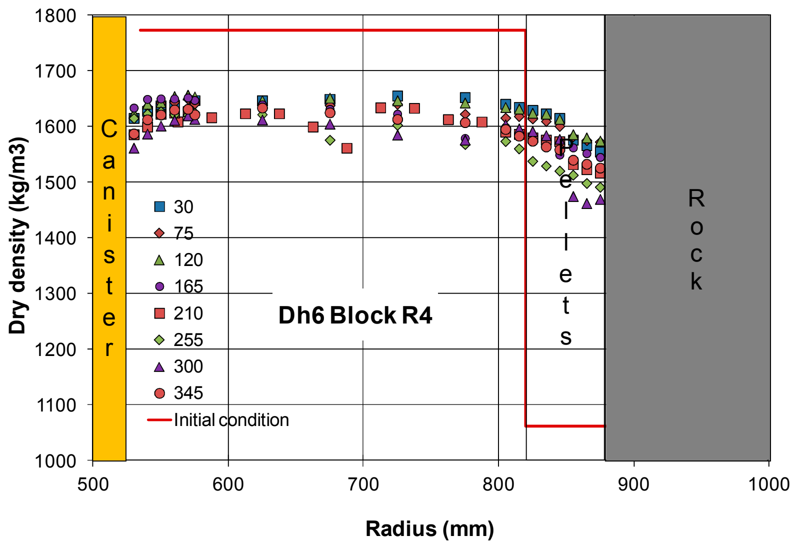



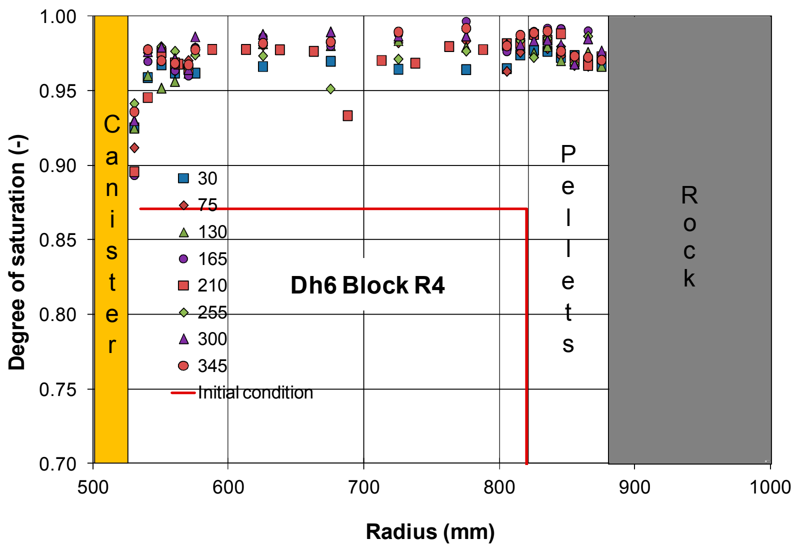
## Contour plots of water content, dry density and degree of saturation block R3, Dh 6



## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block R4, Dh 6



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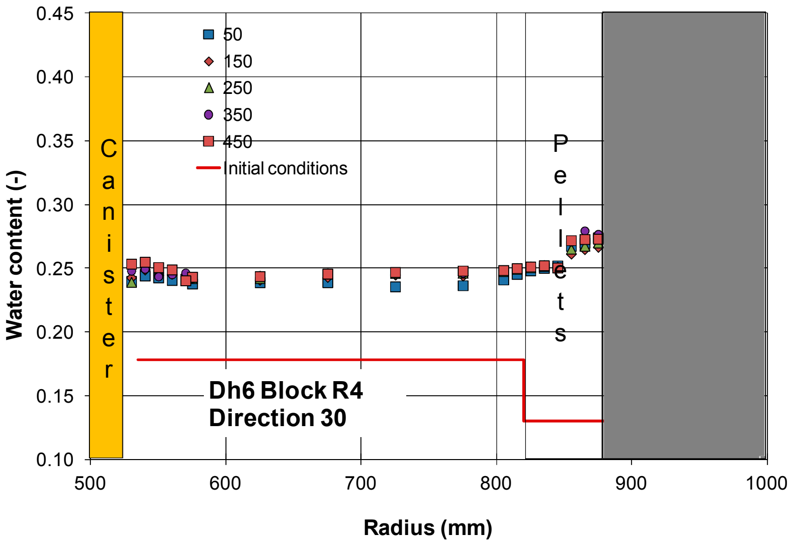


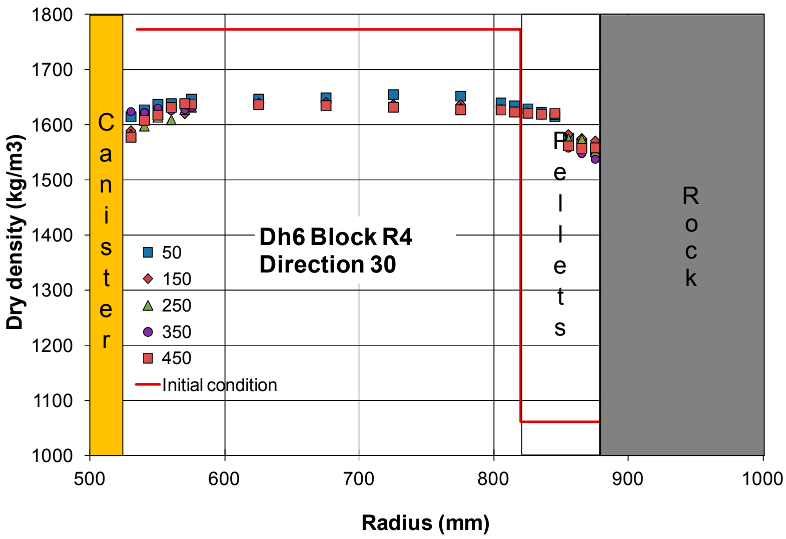


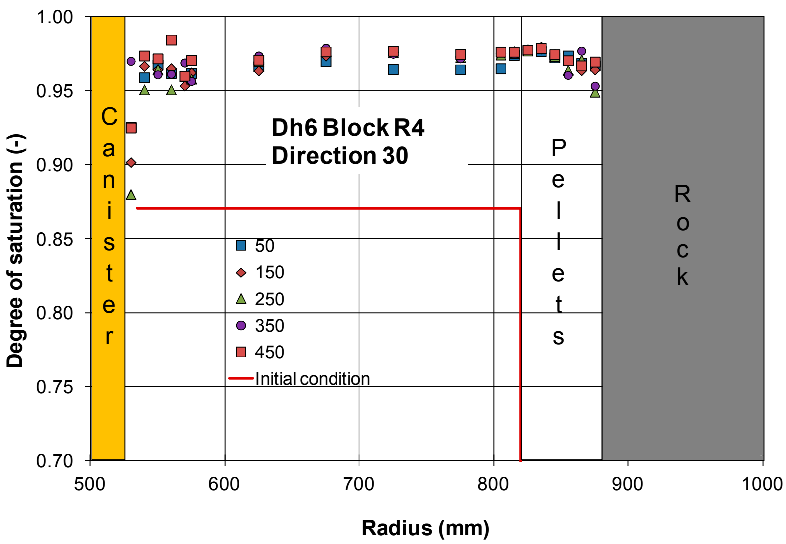

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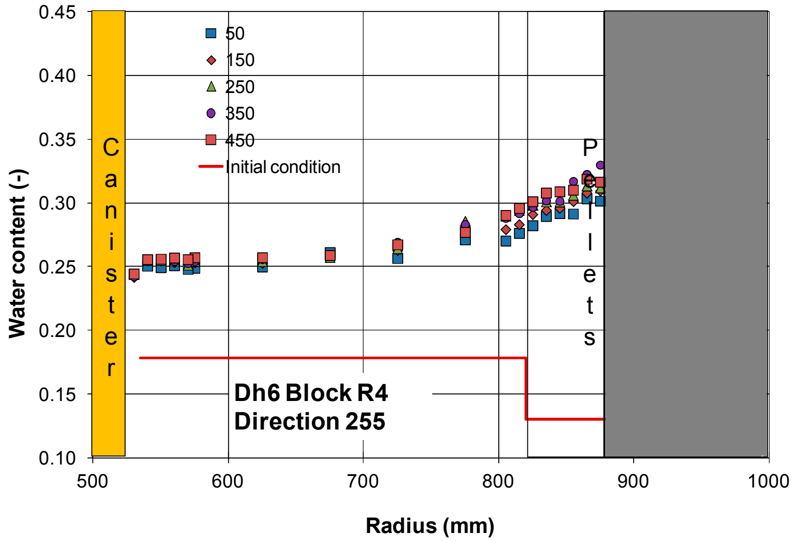
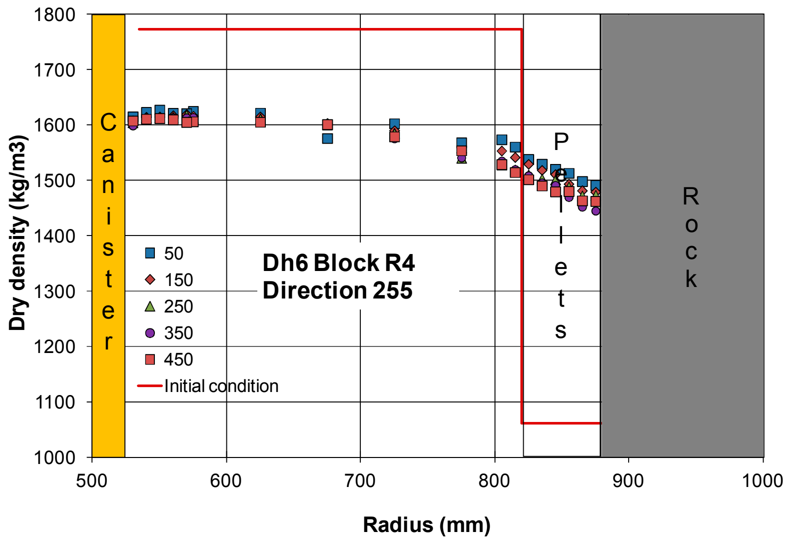
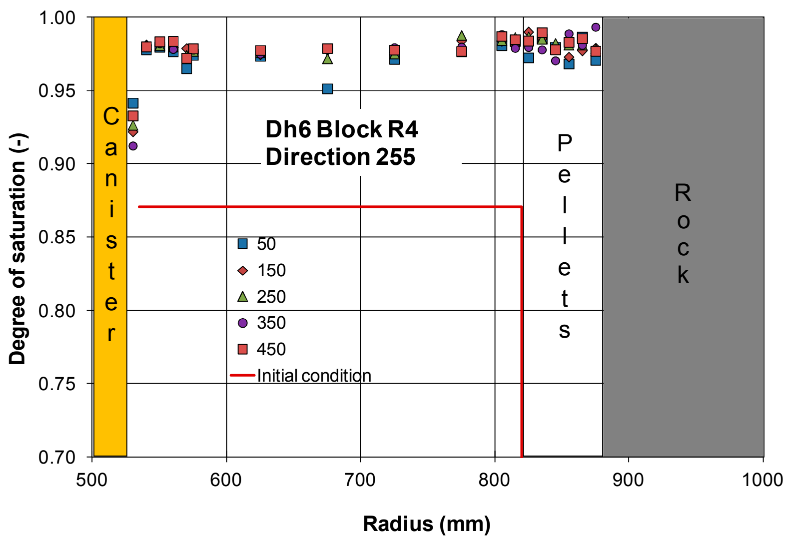
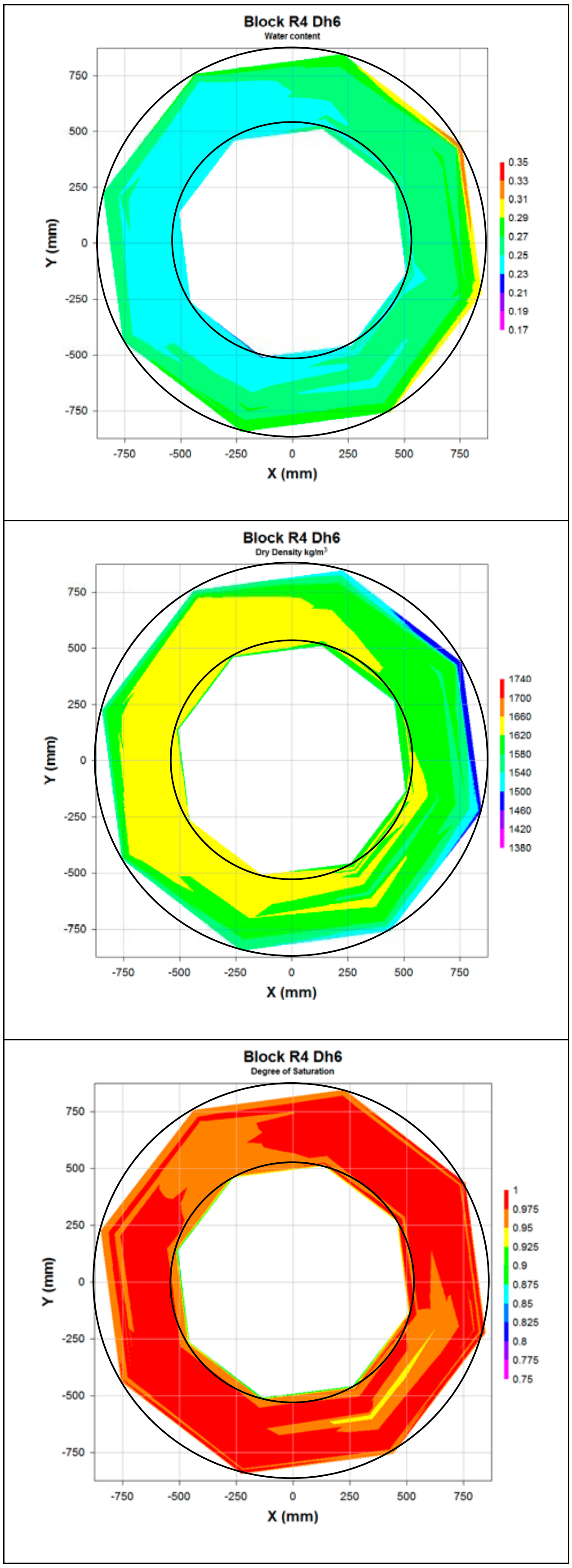


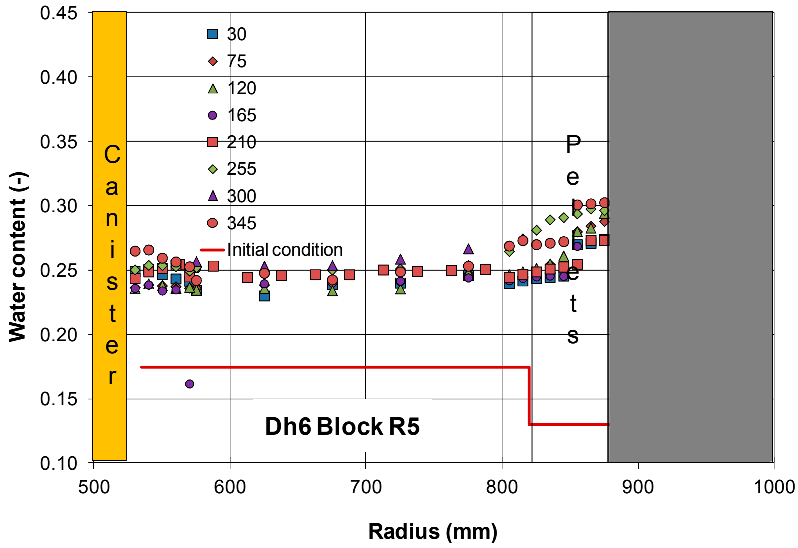



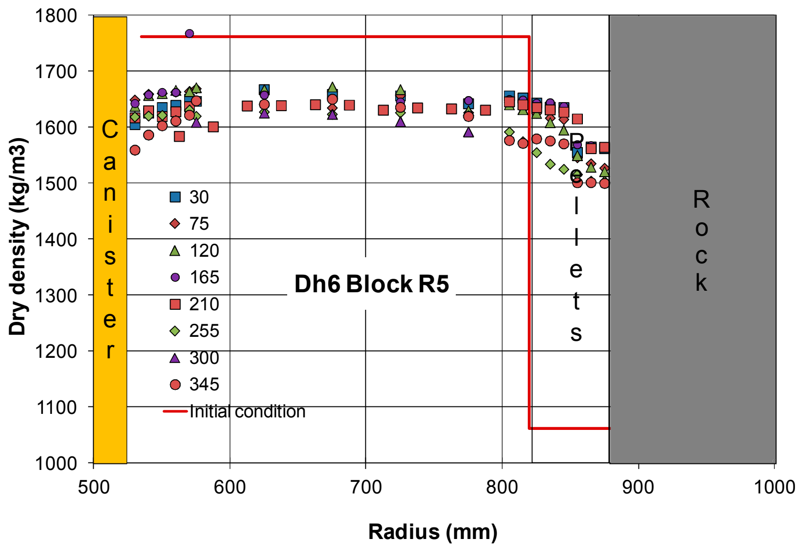



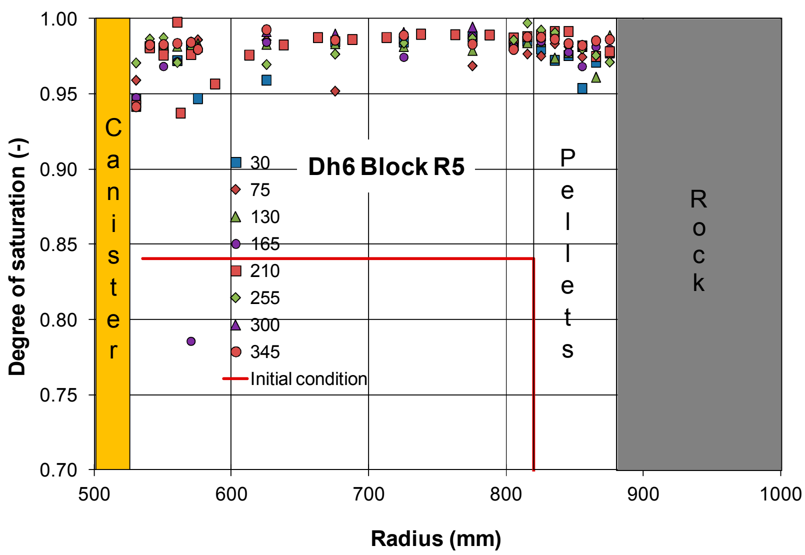
## Contour plots of water content, dry density and degree of saturation block R4, Dh 6



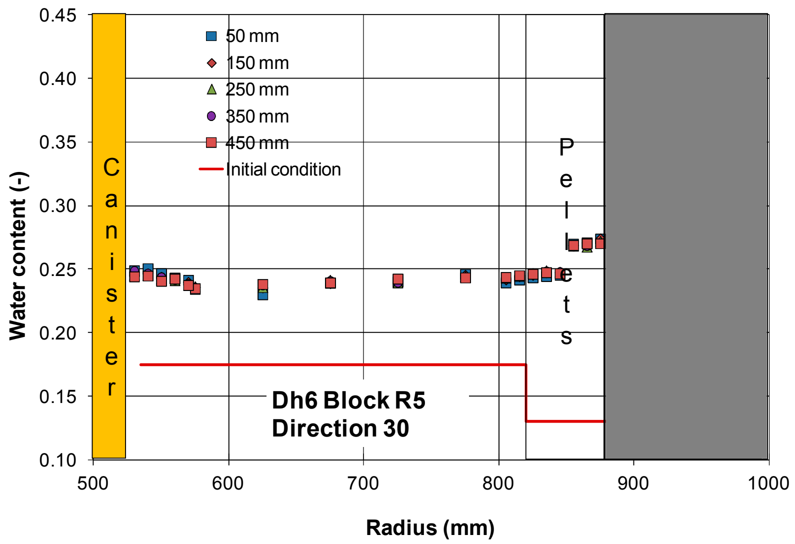
## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block R5, Dh 6

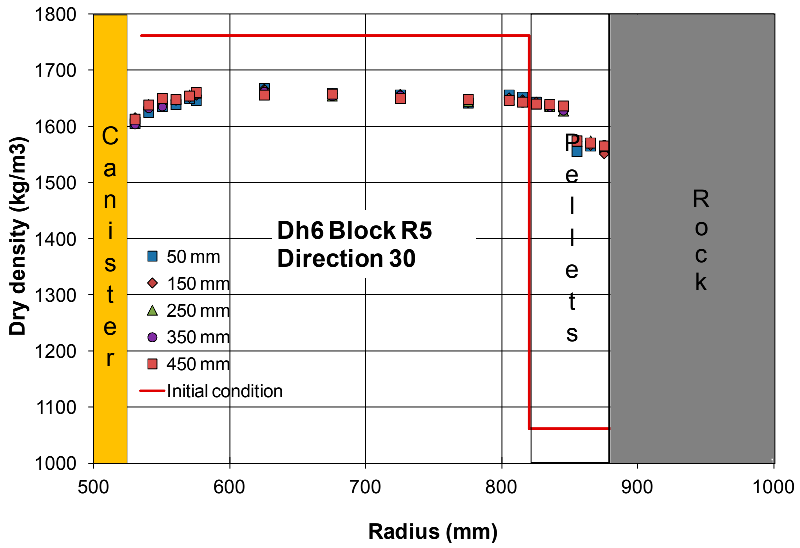


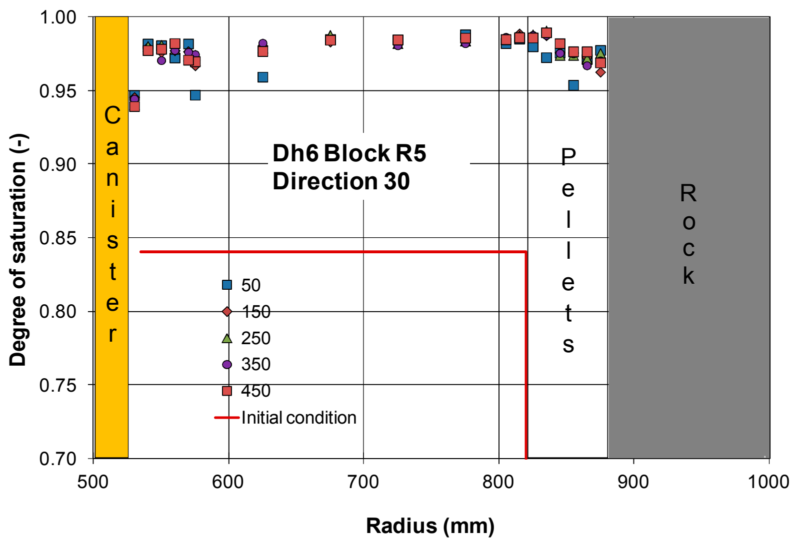



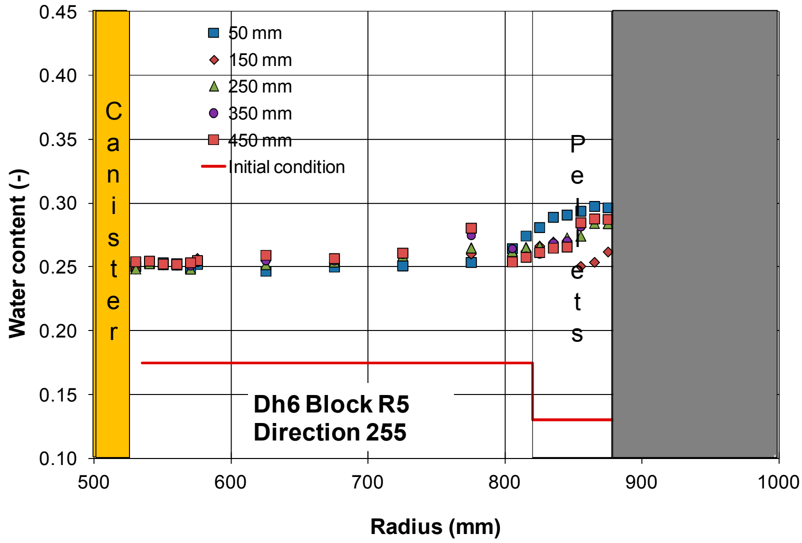
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block R5, Dh 6**

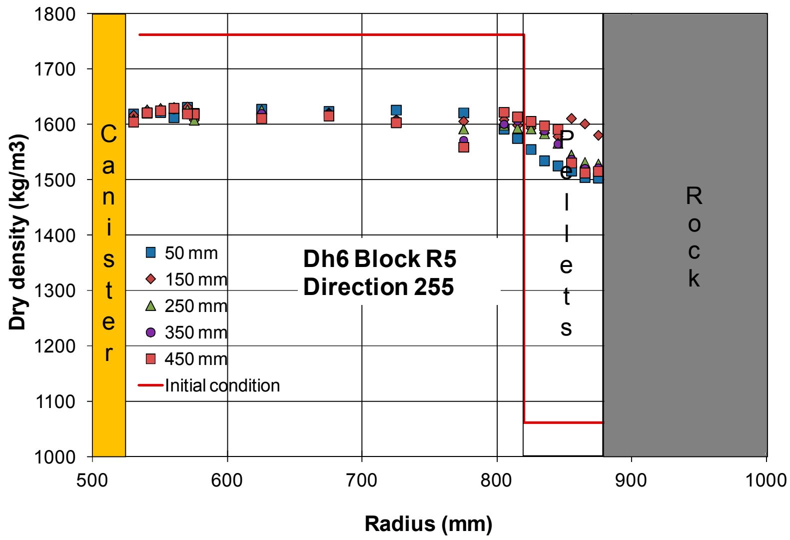


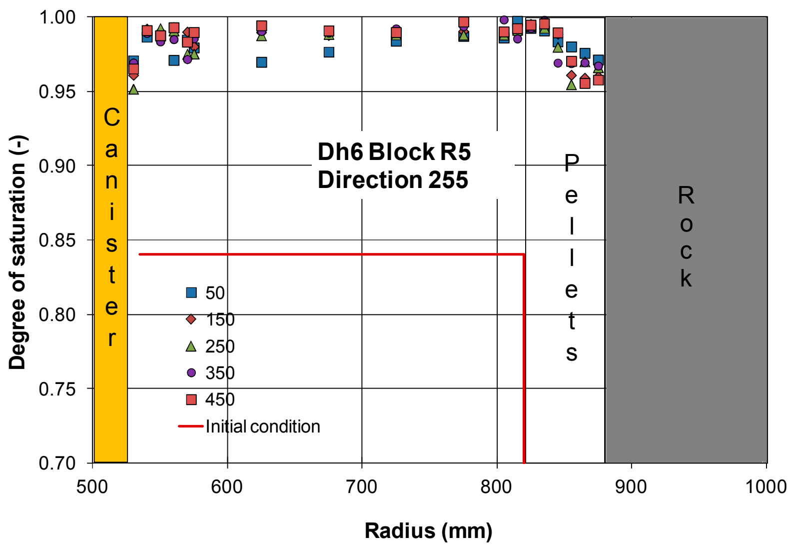



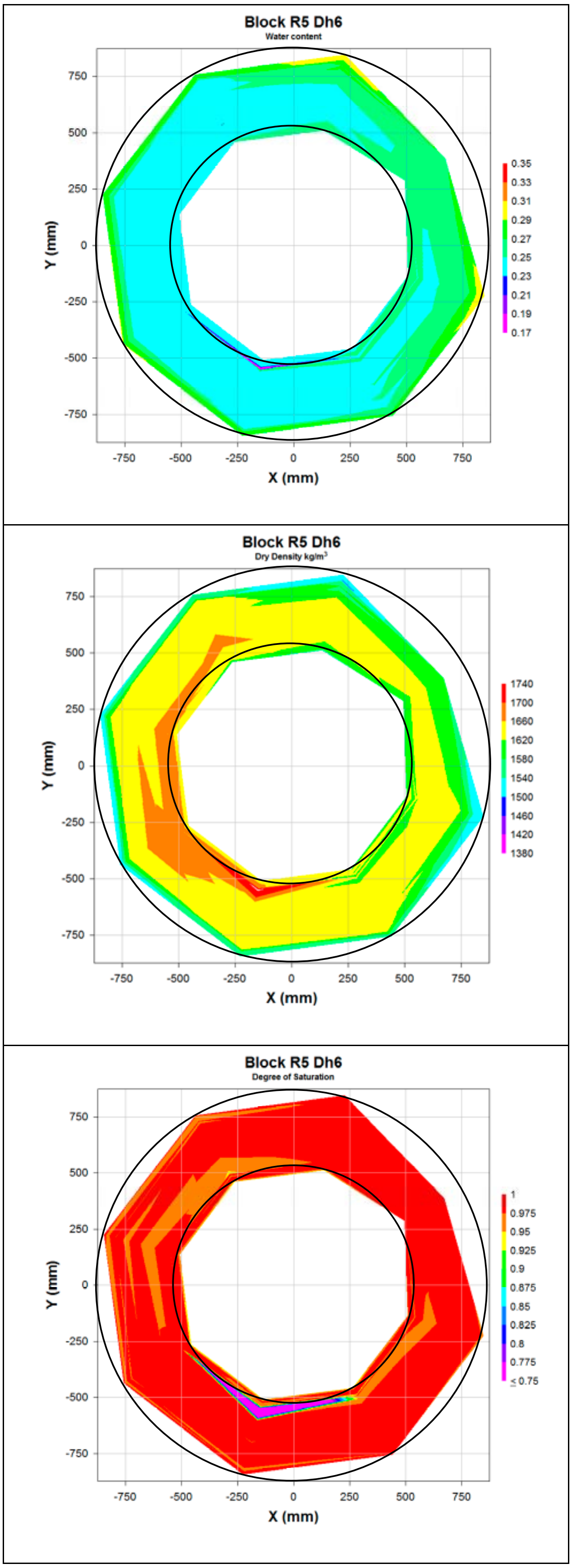
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 255° block R5, Dh 6



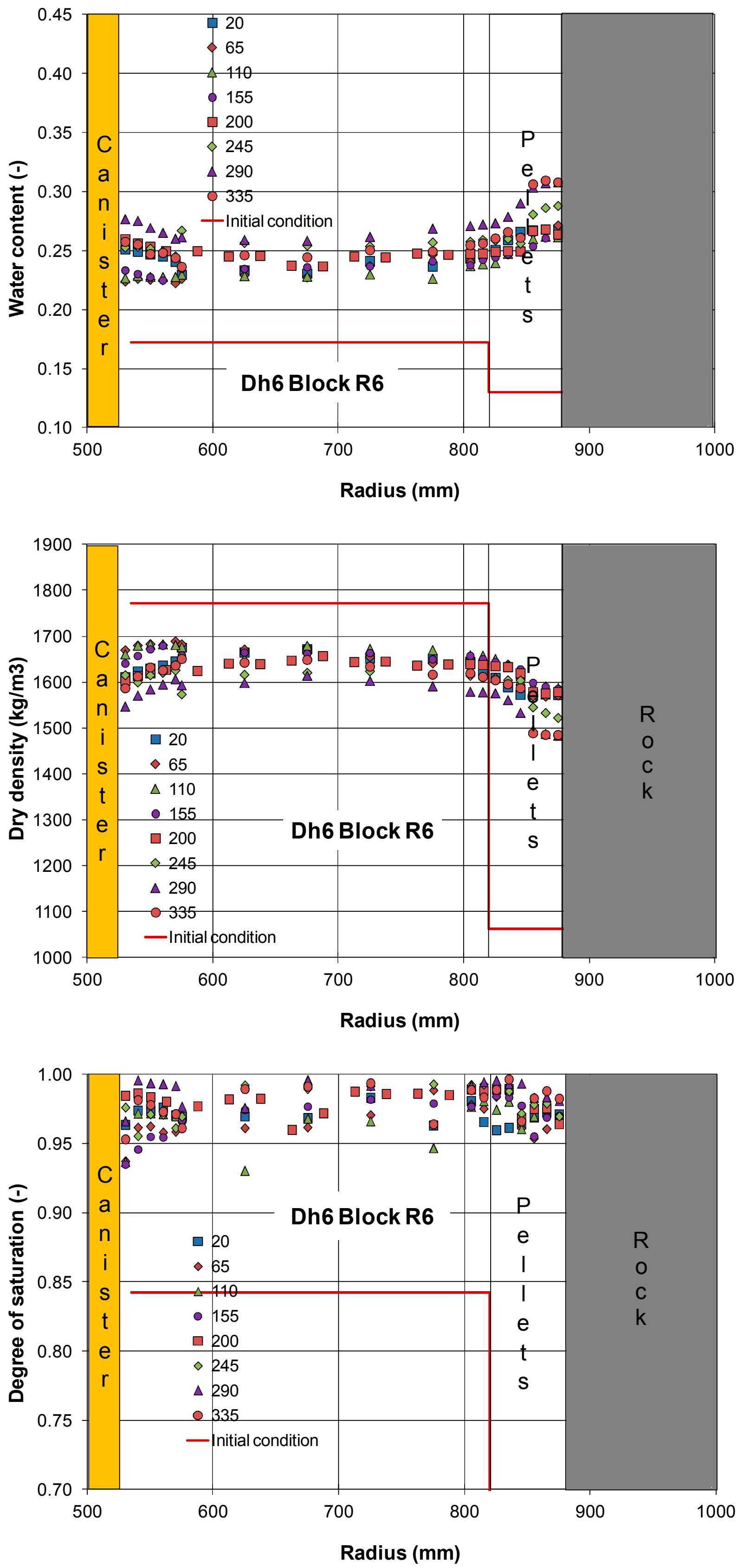



## Contour plots of water content, dry density and degree of saturation block R5, Dh 6

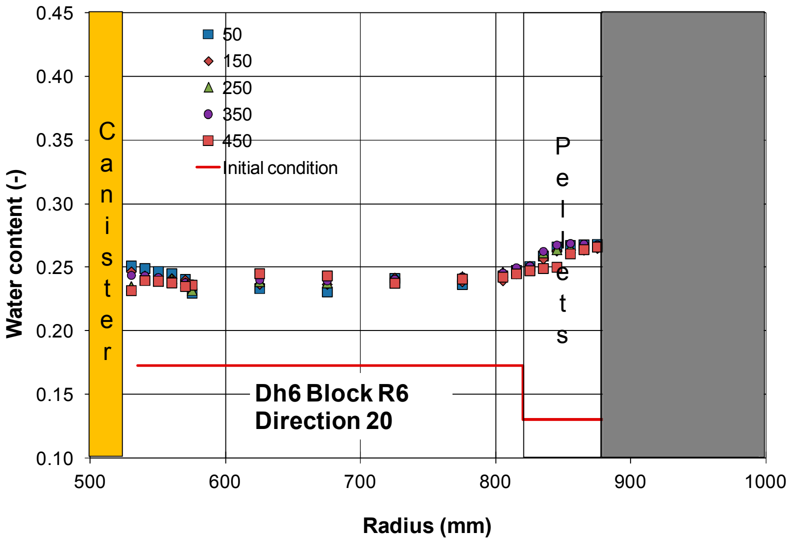


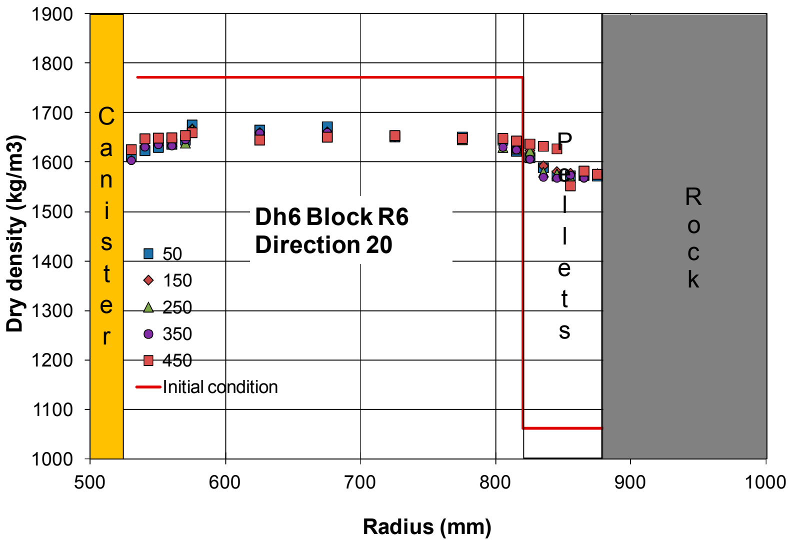
# Appendix 10

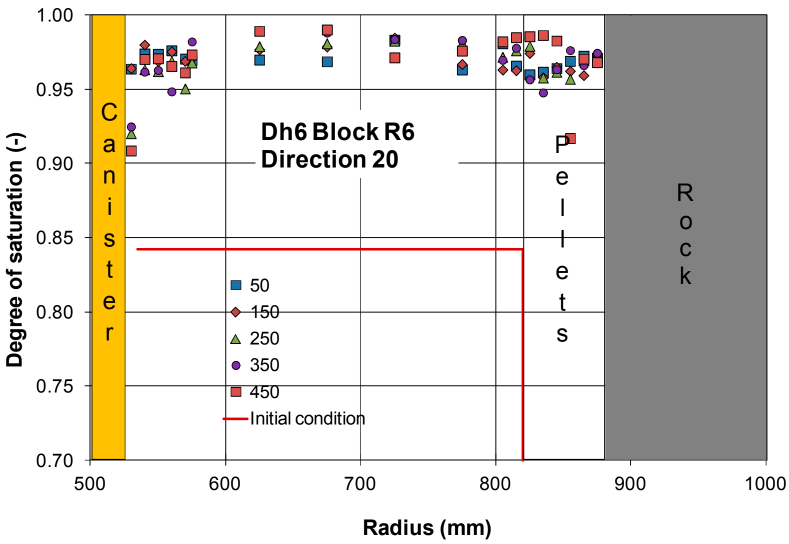
## Water content, dry density and degree of saturation measured in eight directions (20, 65, 110, 155, 200, 245, 290 and 335°) in block R6, Dh 6



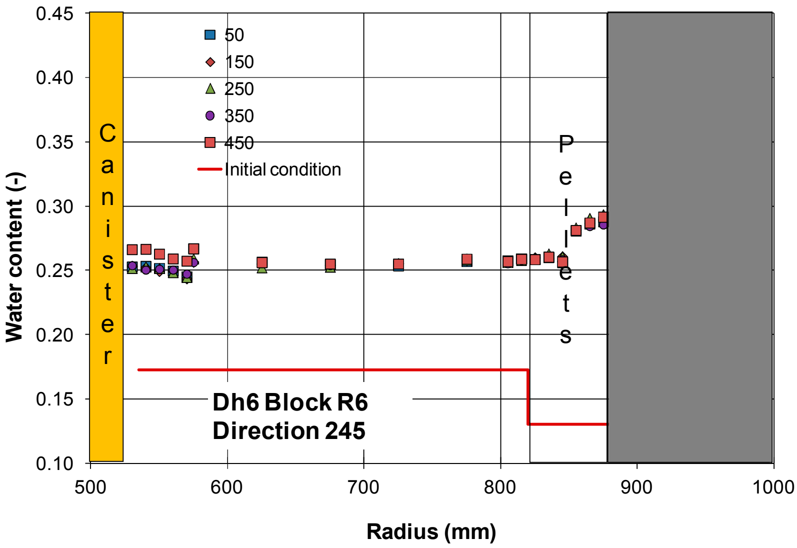
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 20° block R6, Dh 6

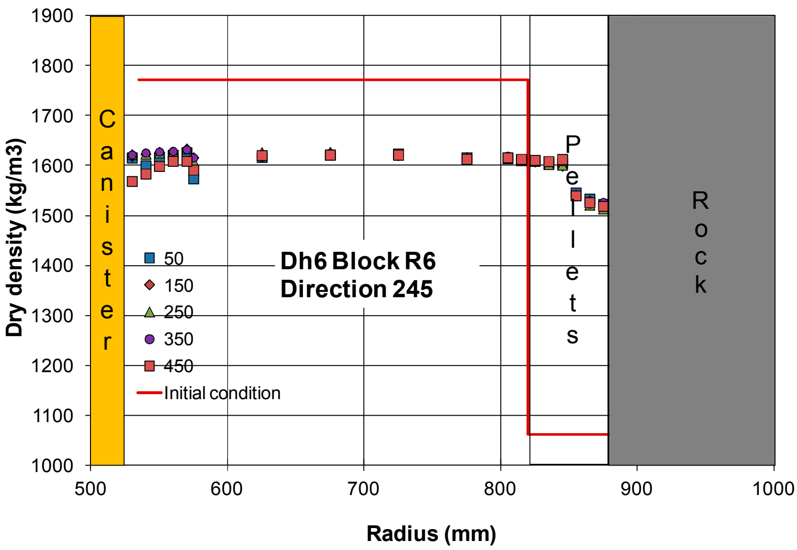


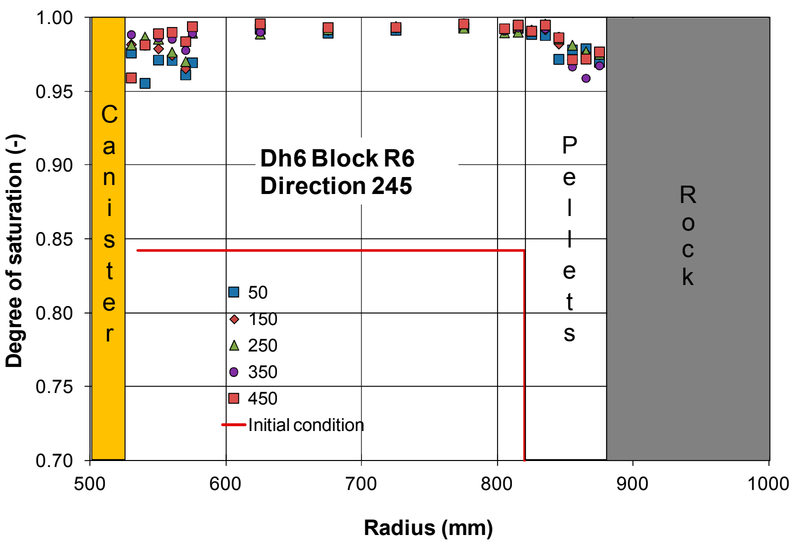



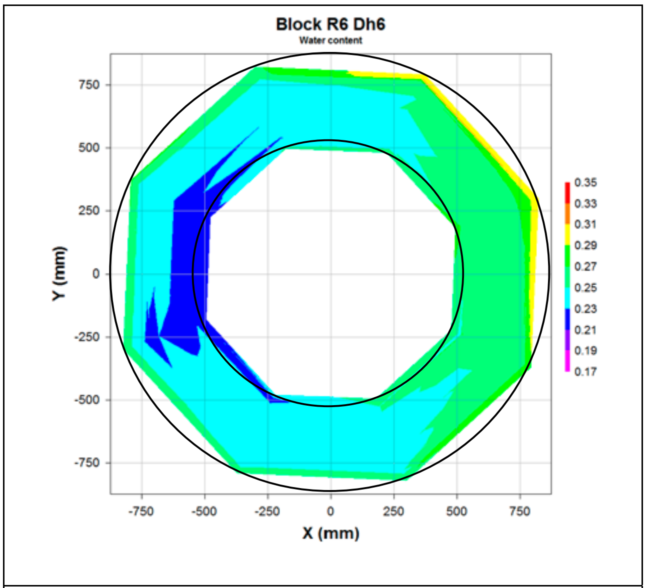
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 245° block R6, Dh 6**

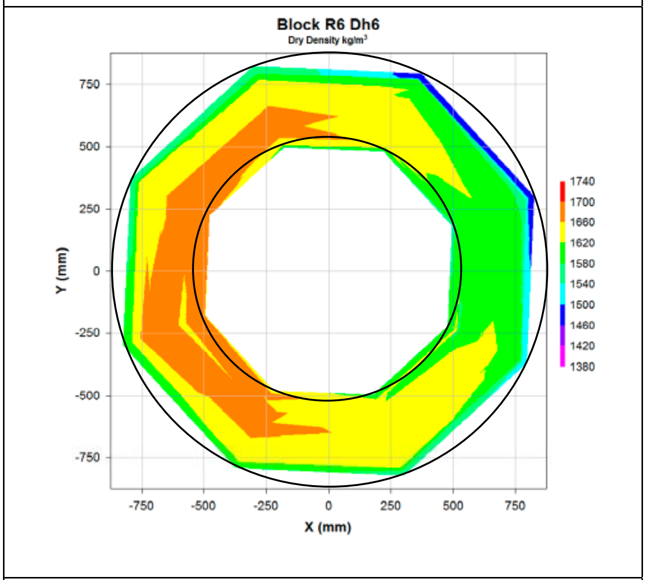


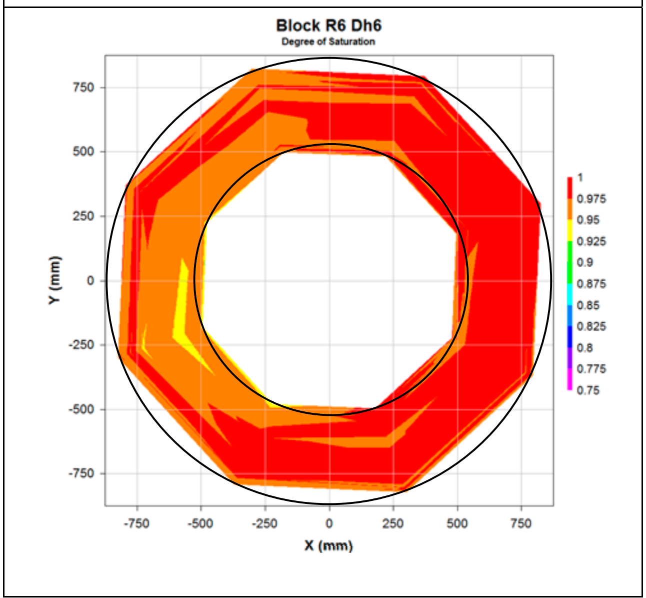



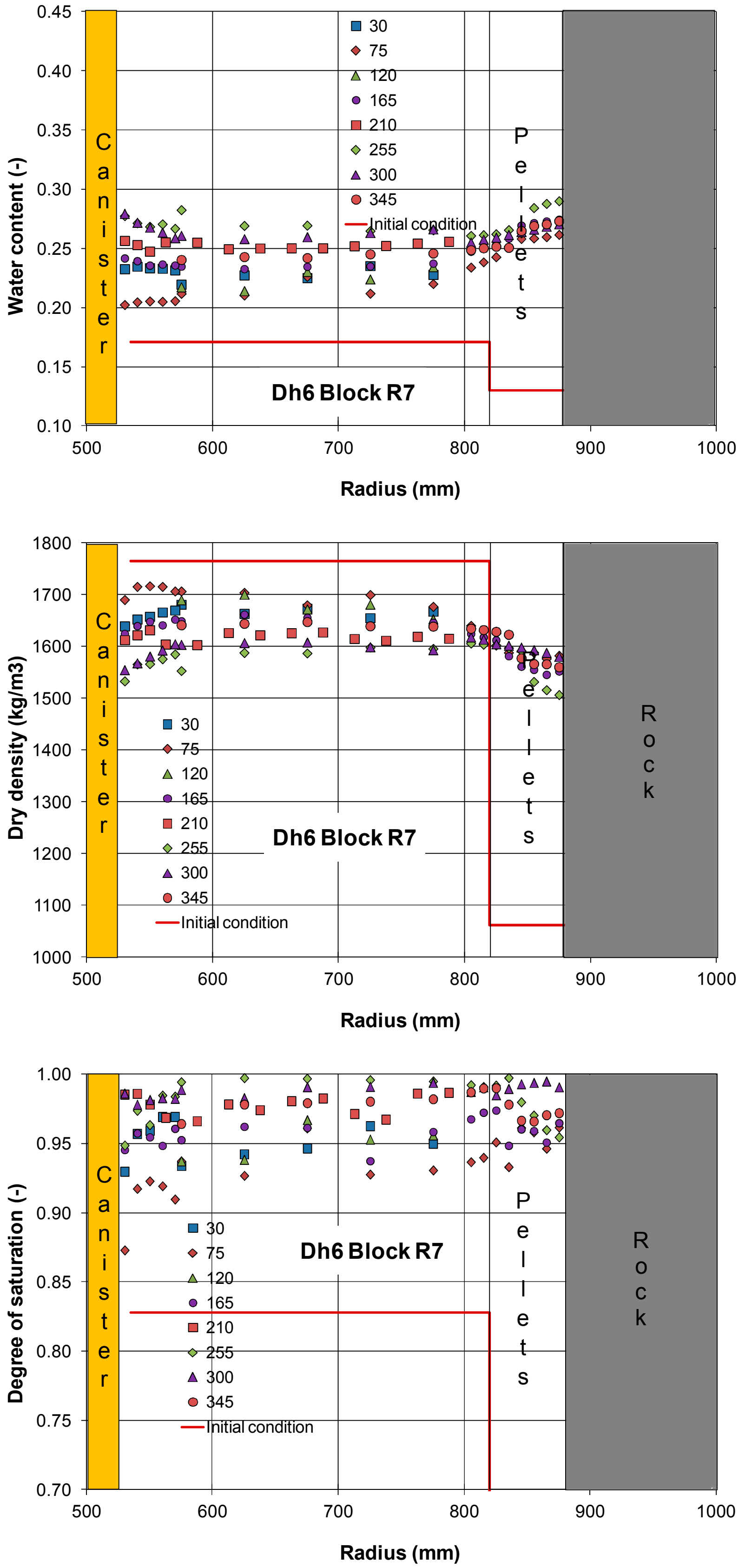
## Contour plots of water content, dry density and degree of saturation block R6, Dh 6



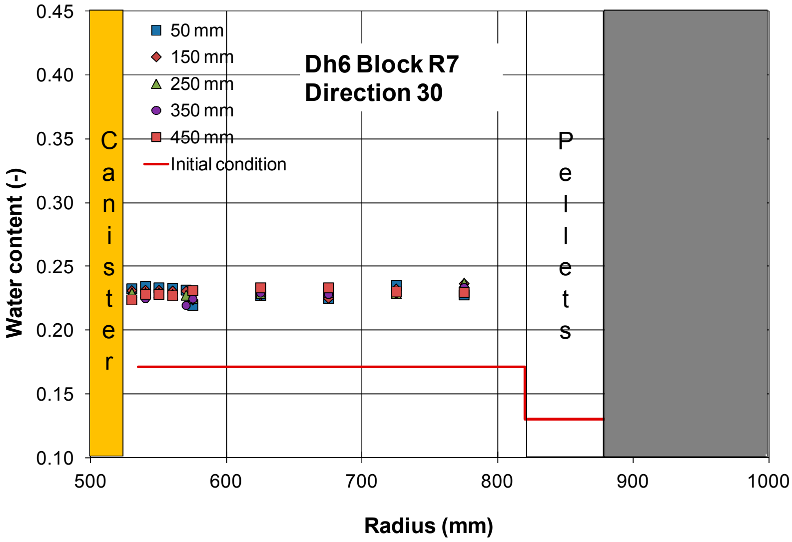



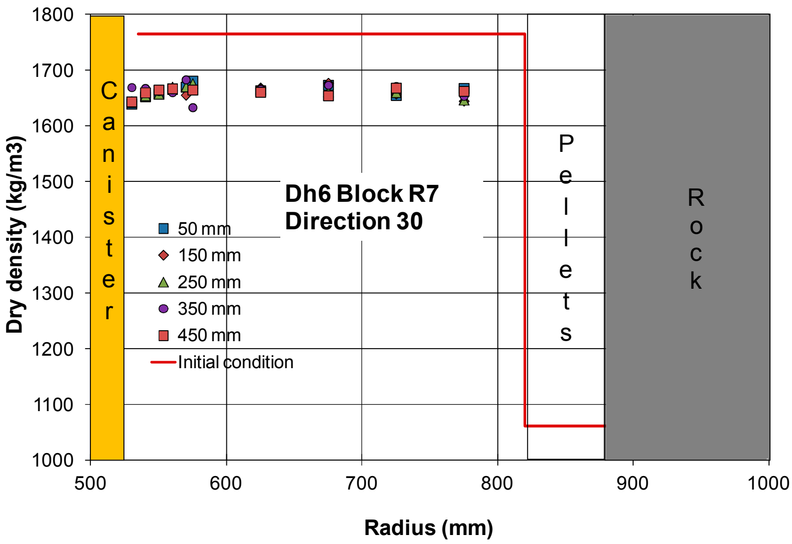



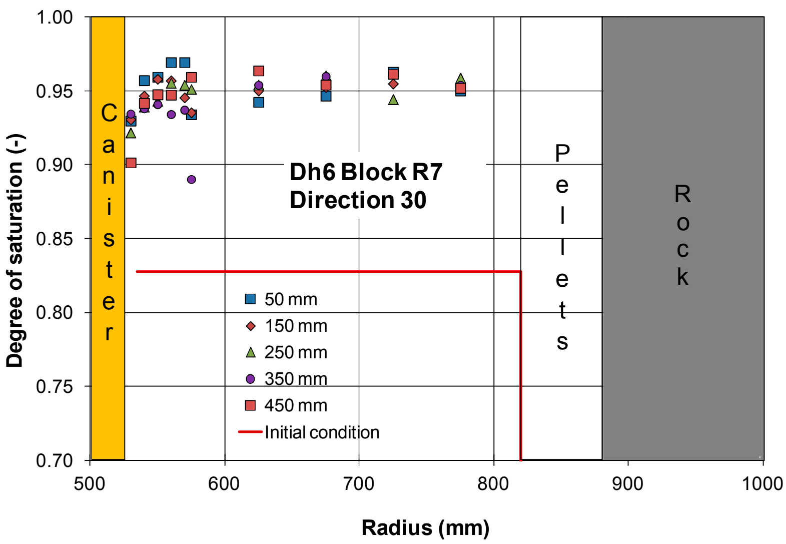
# Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block R7, Dh 6



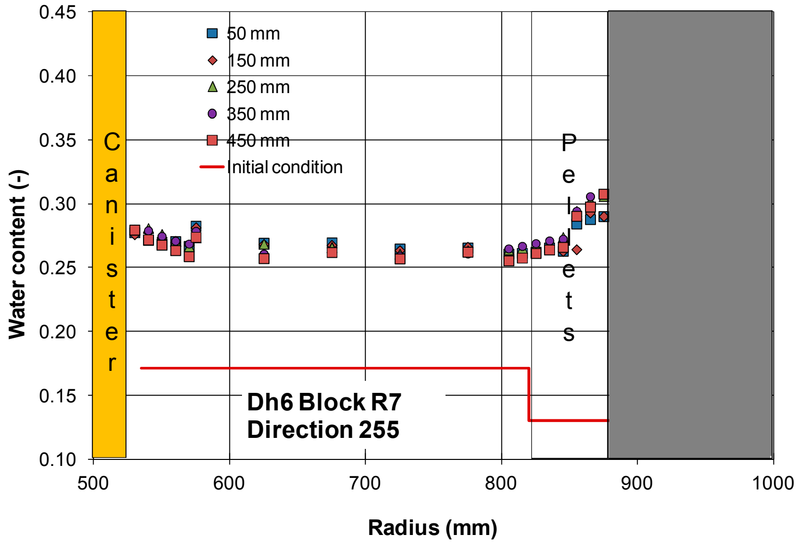
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block R7, Dh 6

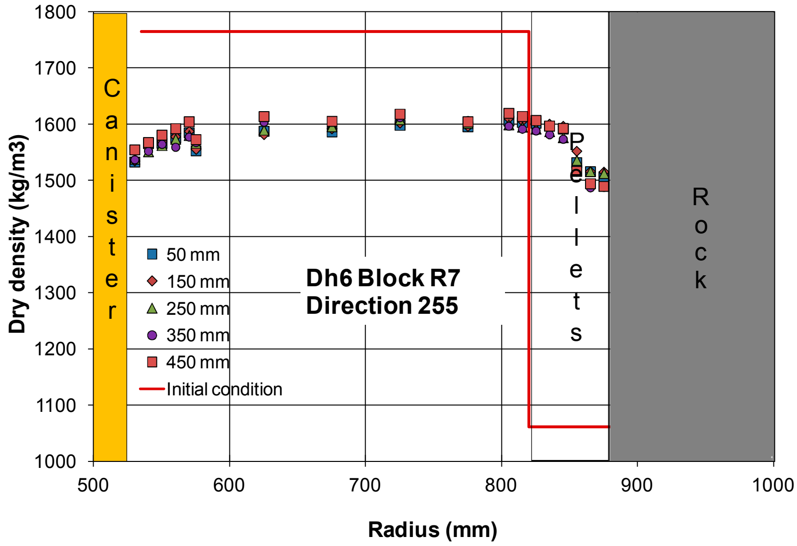


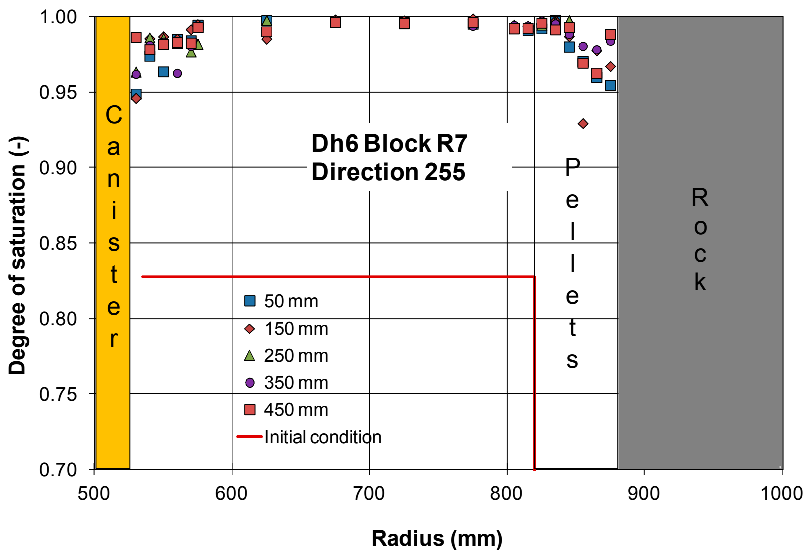



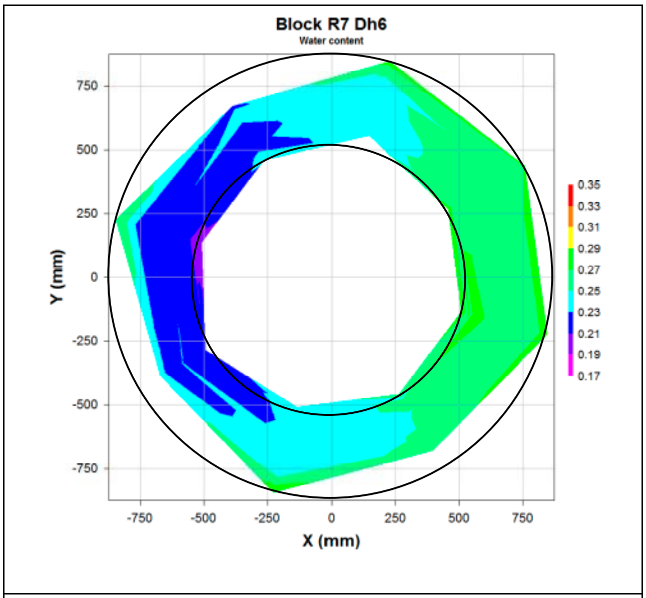
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 255° block R7, Dh 6

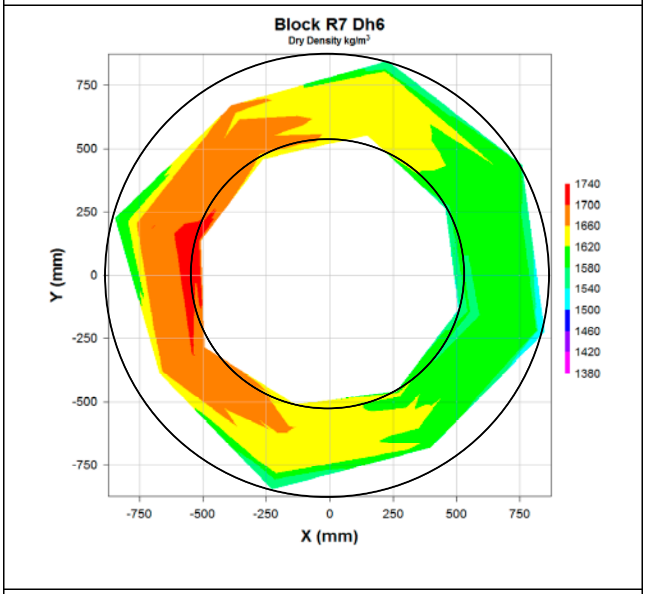


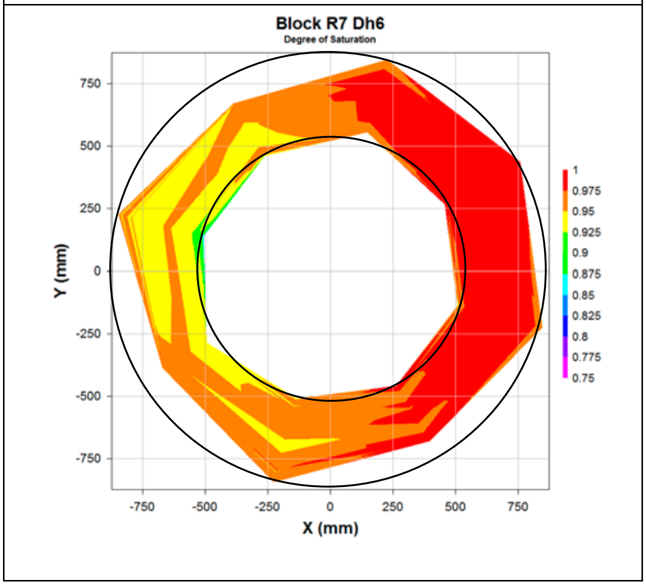



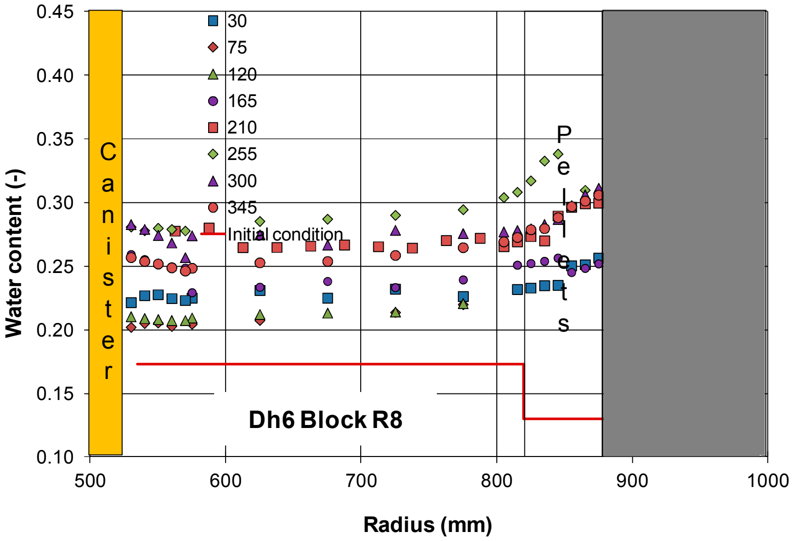
## Contour plots of water content, dry density and degree of saturation block R7, Dh 6

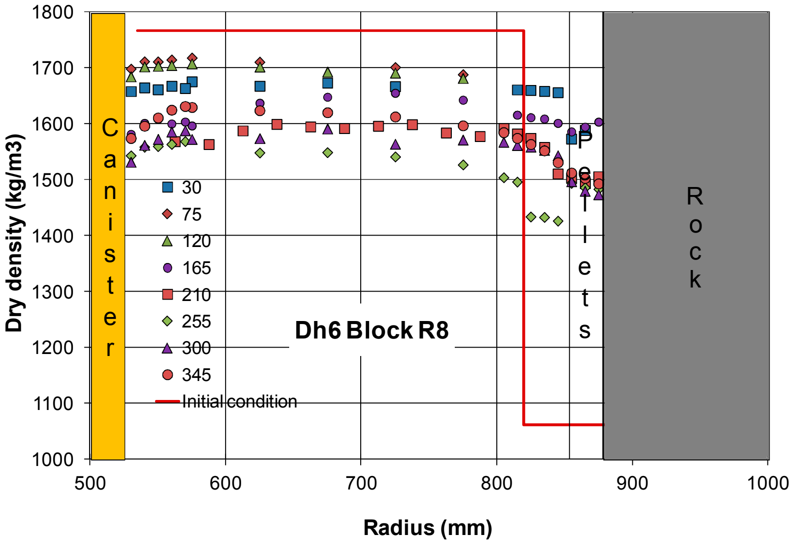


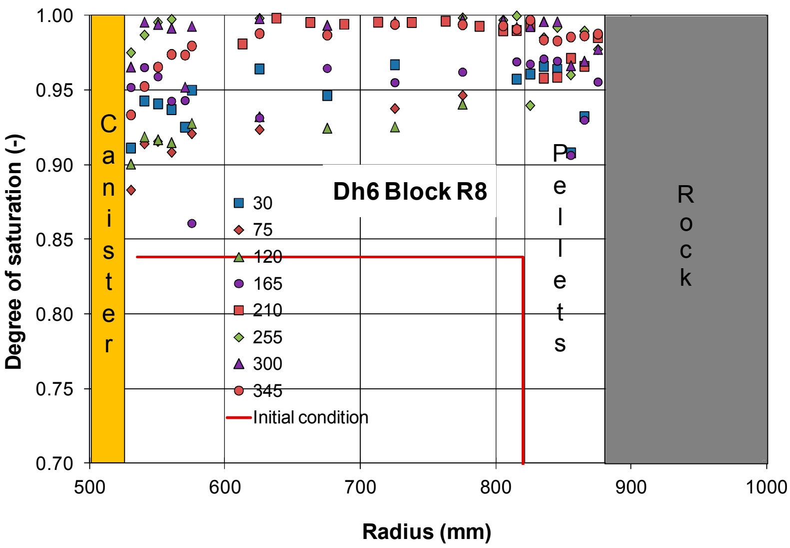



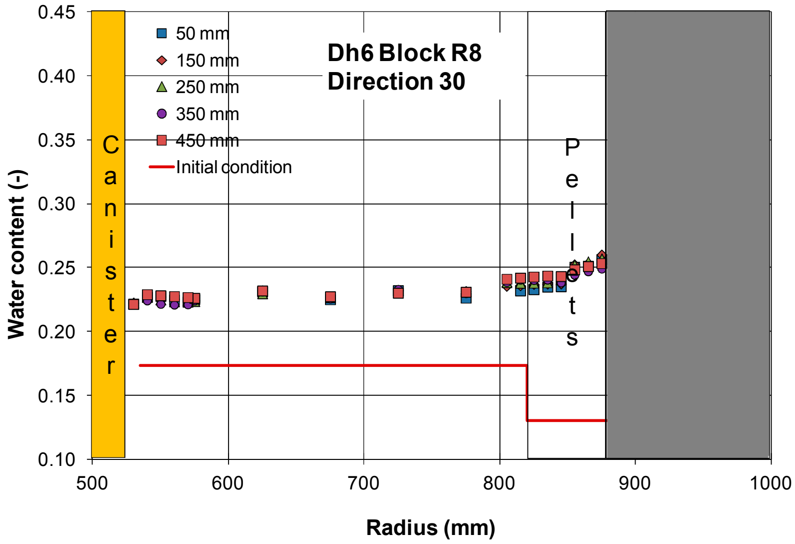
## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 345°) in block R8, Dh 6

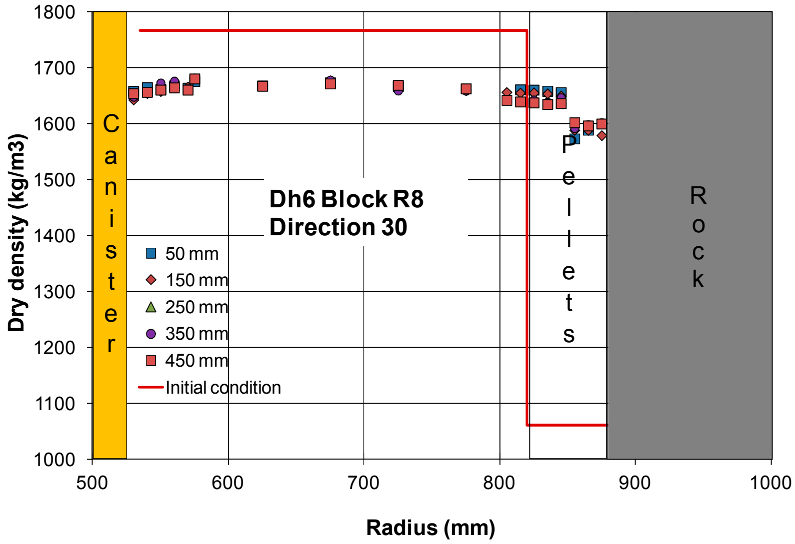


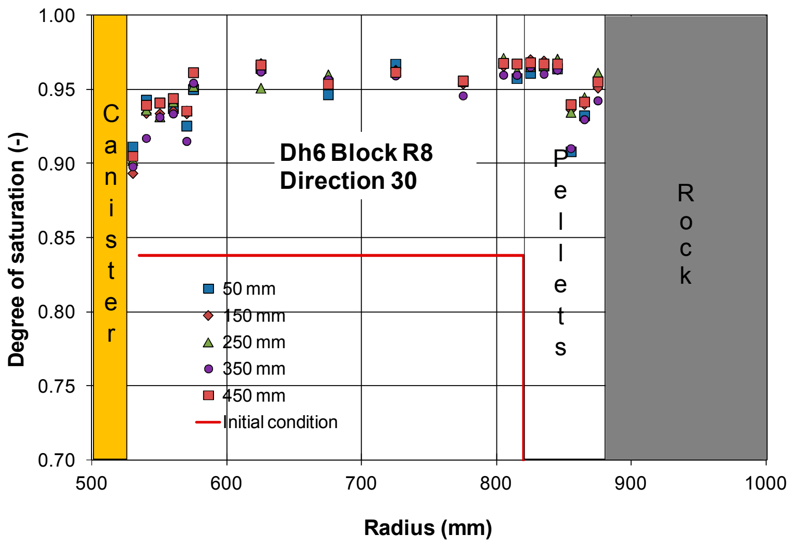



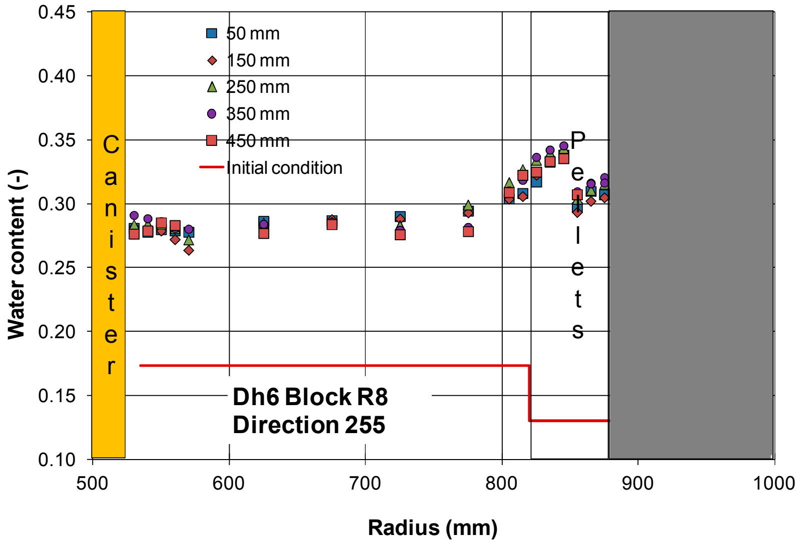
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block R8, Dh 6

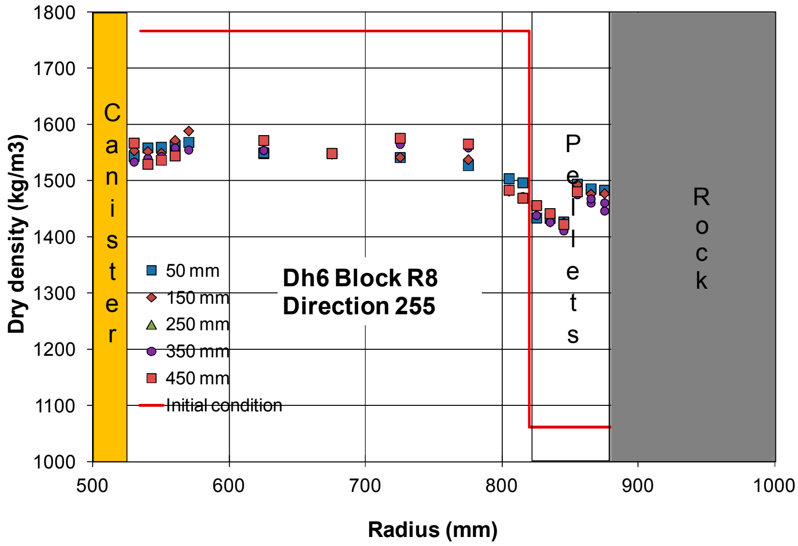


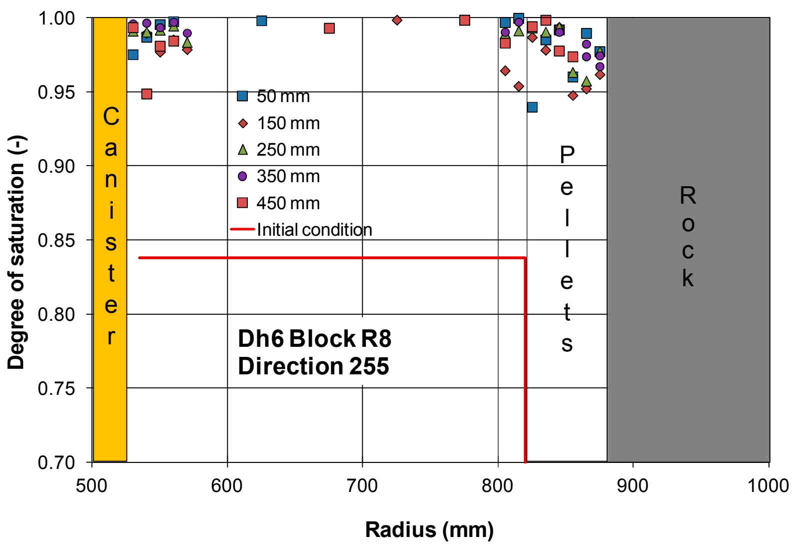



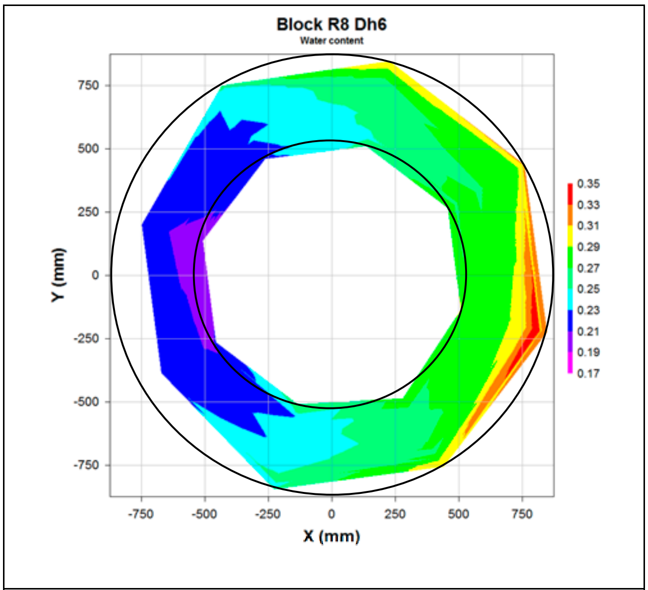
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 255° block R8, Dh 6

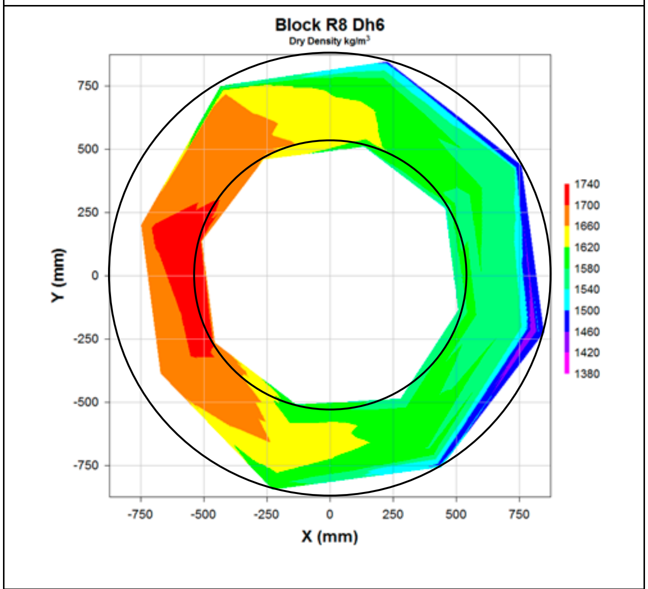


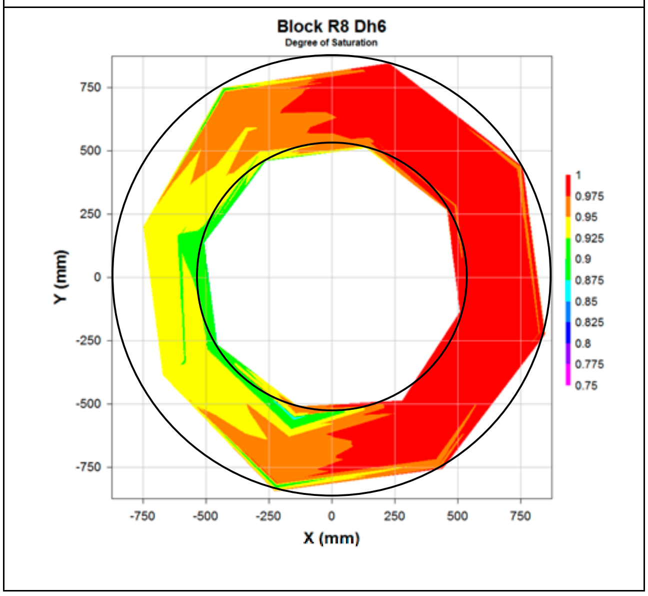



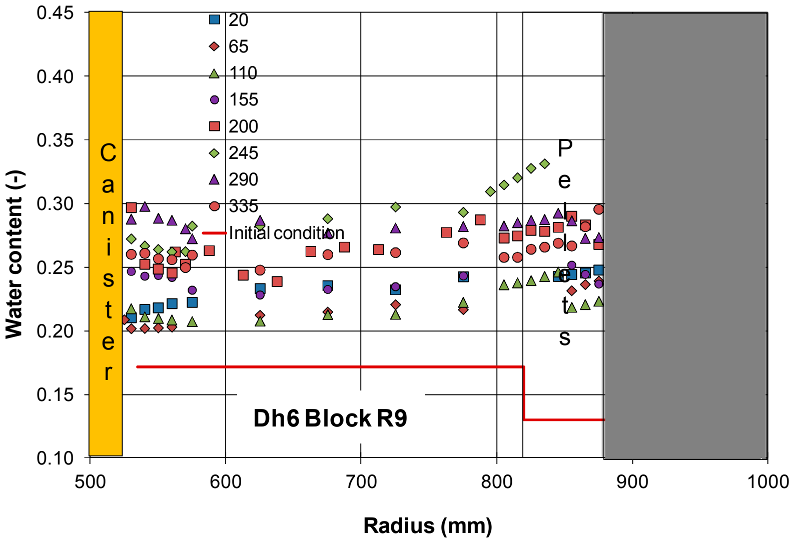
## Contour plots of water content, dry density and degree of saturation block R8, Dh 6

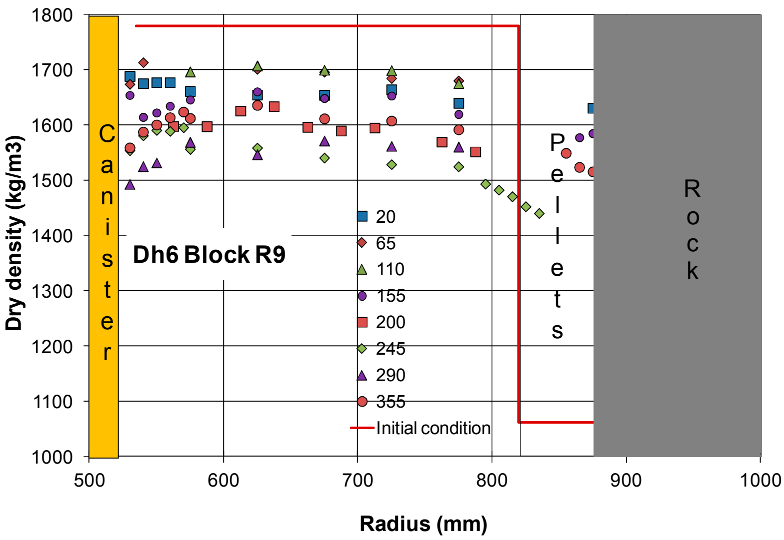


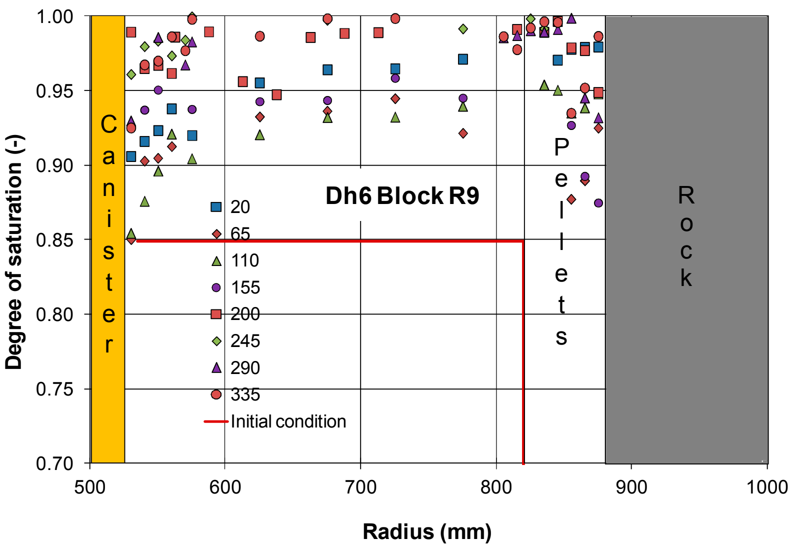



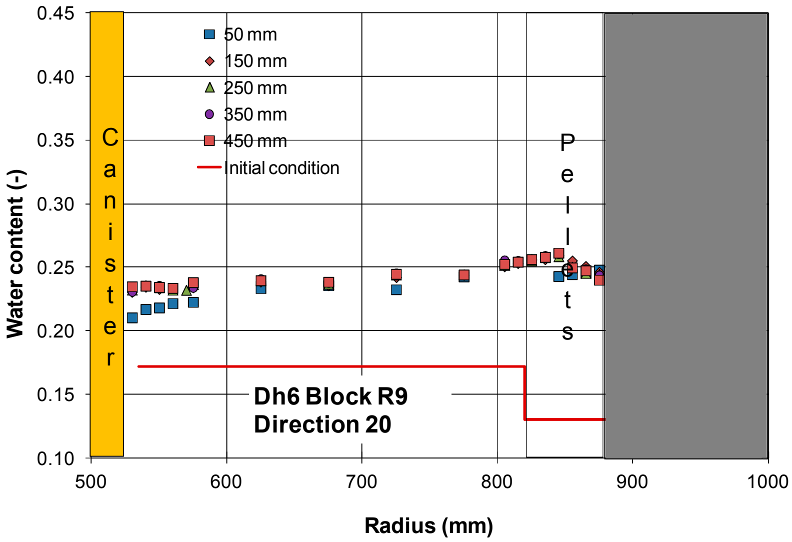
## Water content, dry density and degree of saturation measured in eight directions (20, 65, 110, 155, 210, 245, 290 and 335°) in block R9, Dh 6

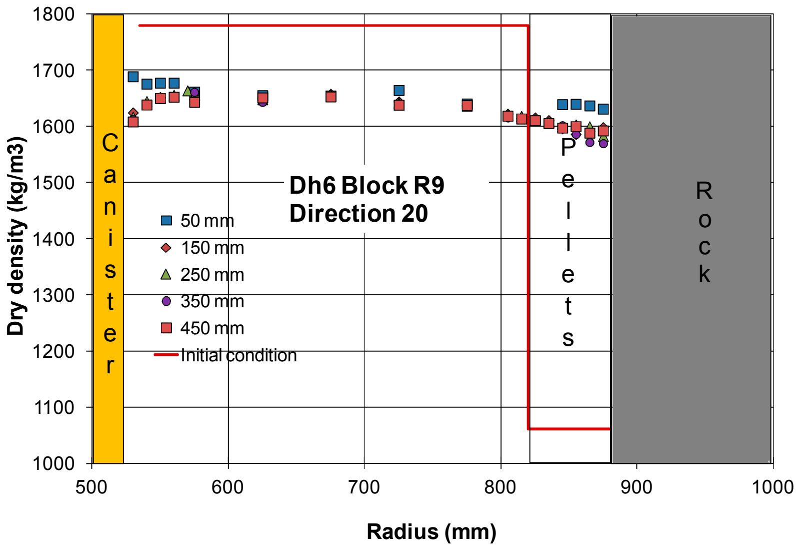


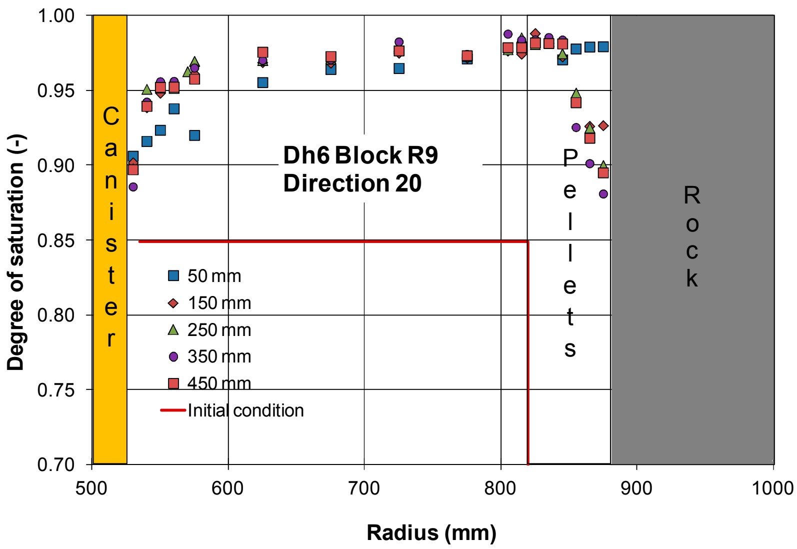



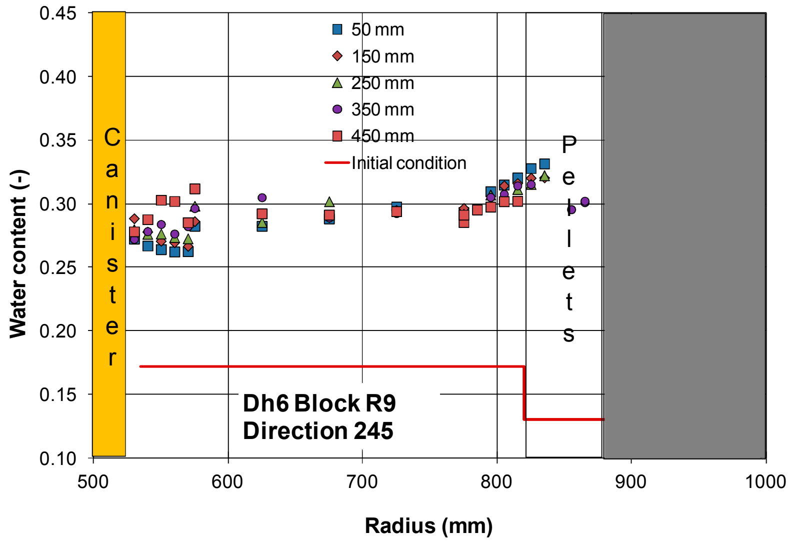
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 20° block R9, Dh 6

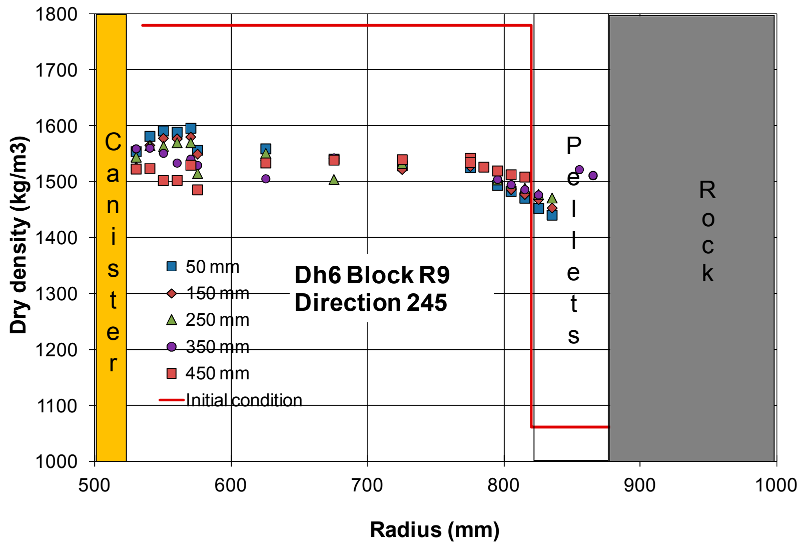


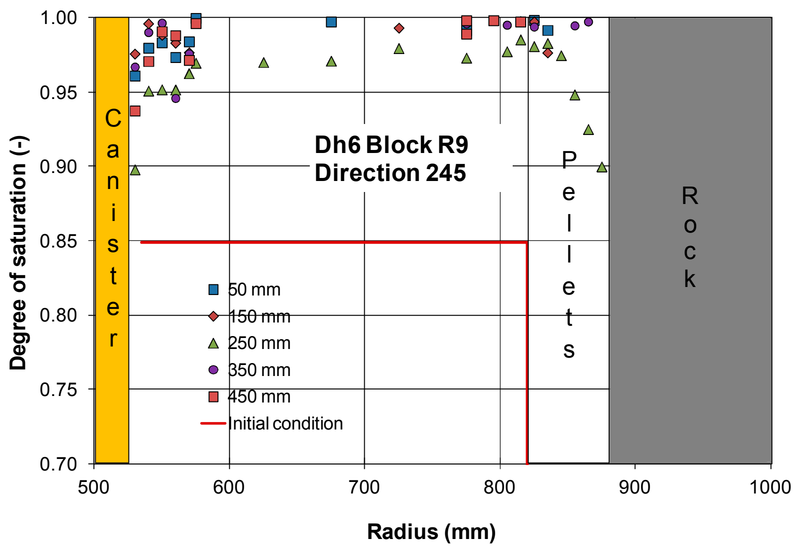



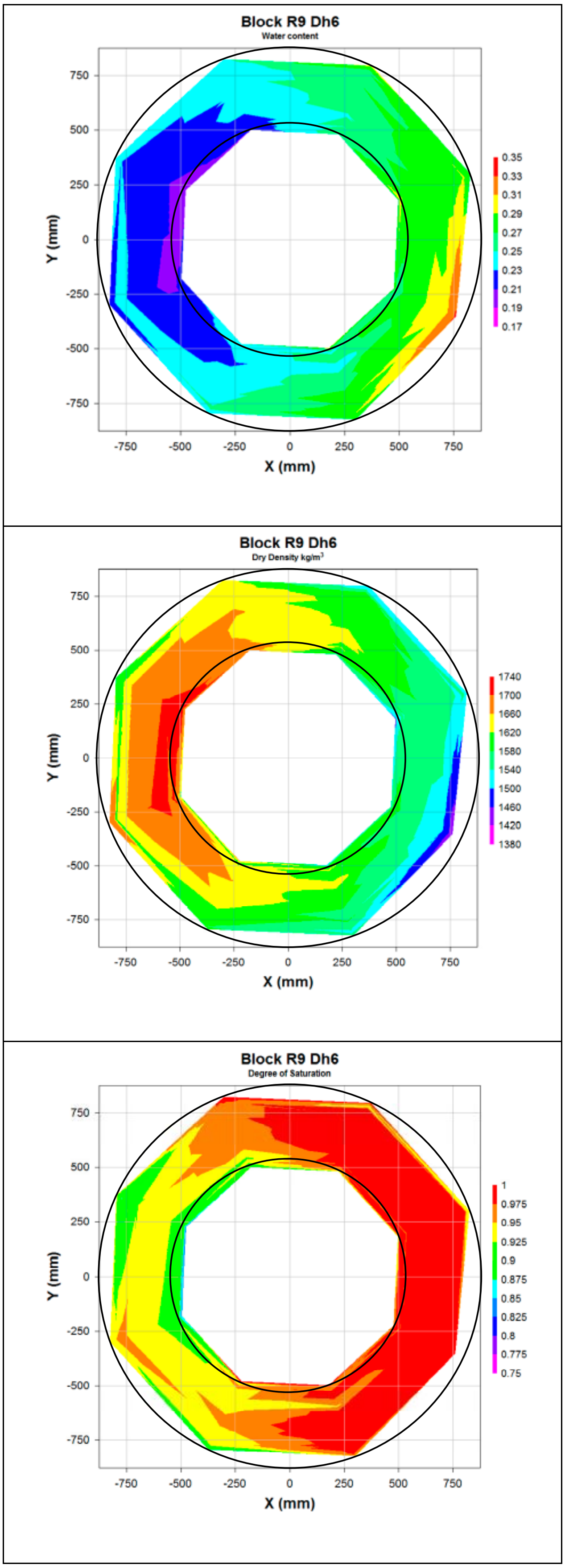
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 245° block R9, Dh 6



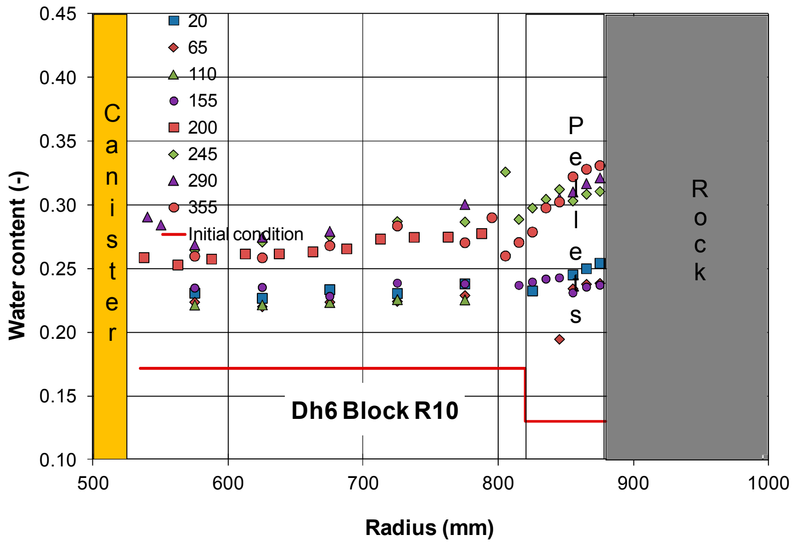



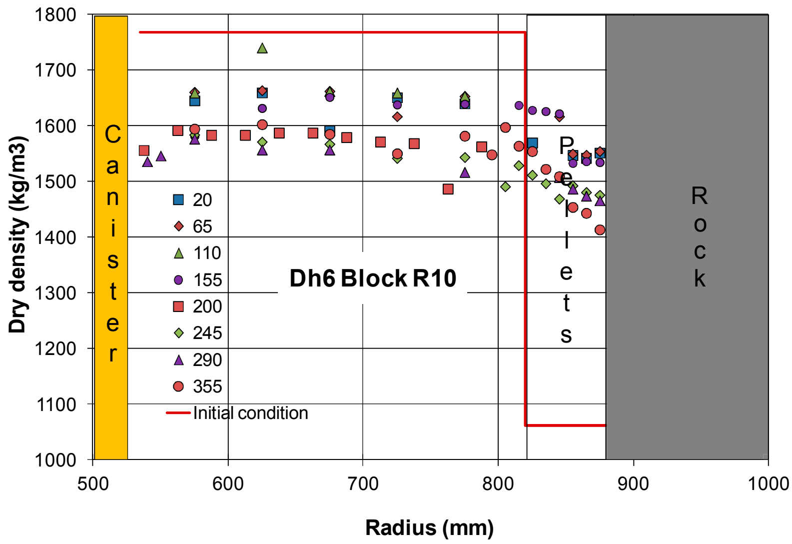



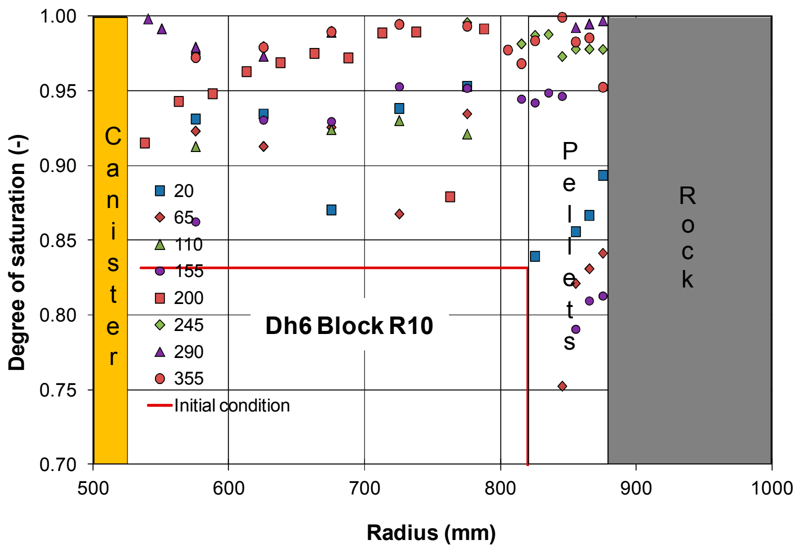
## Contour plots of water content, dry density and degree of saturation block R9, Dh 6



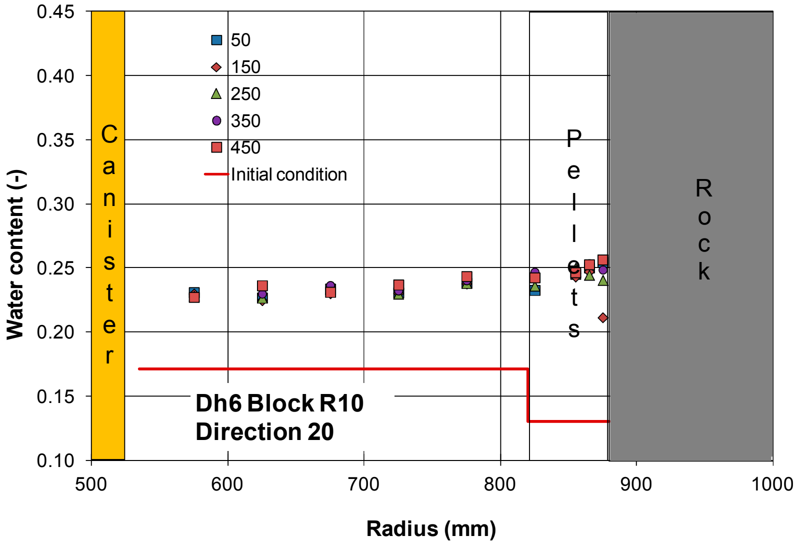
## Water content, dry density and degree of saturation measured in eight directions (20, 65, 110, 155, 210, 245, 290 and 335°) in block R10, Dh 6

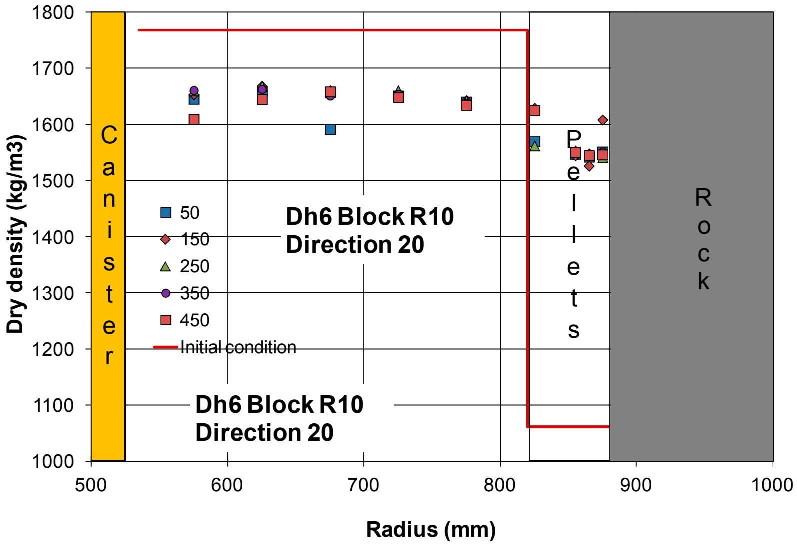


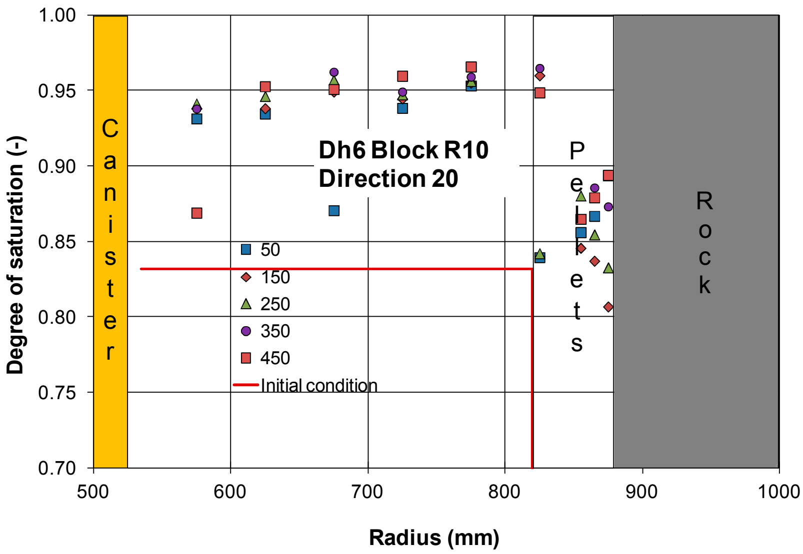



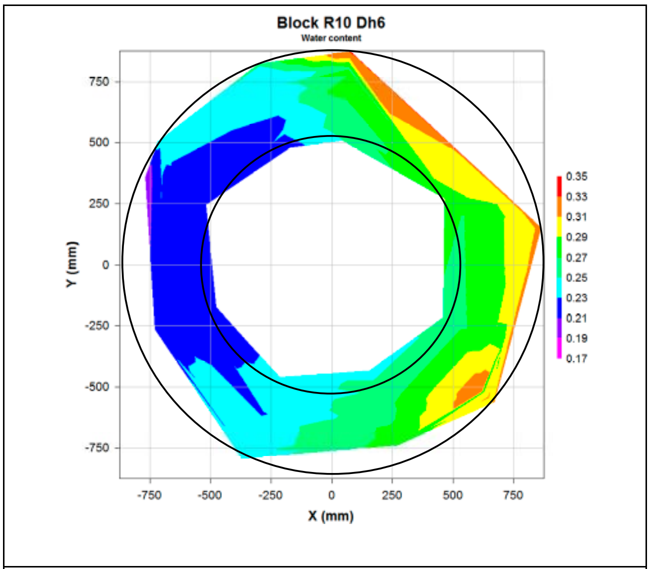
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 20° block R10, Dh 6**

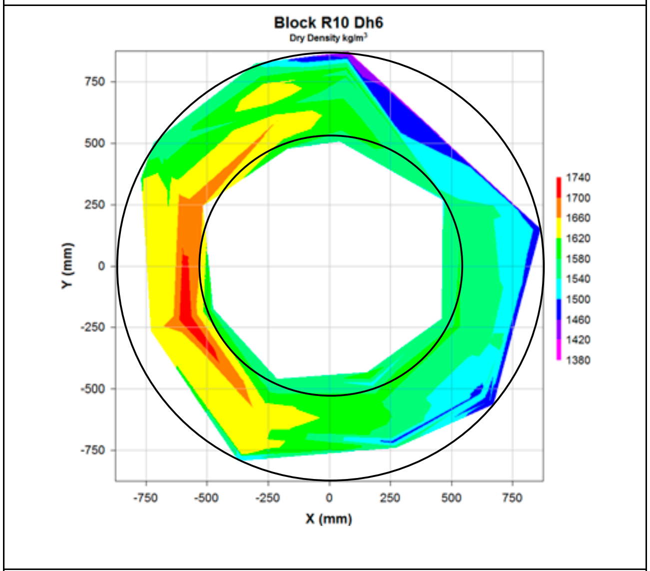


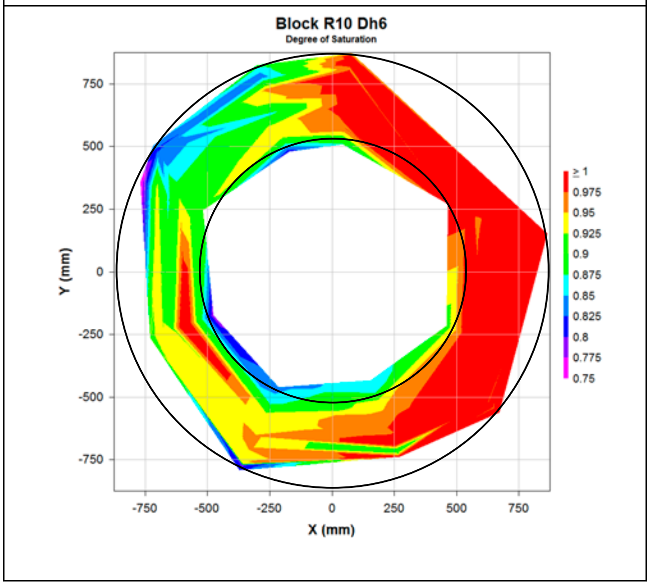



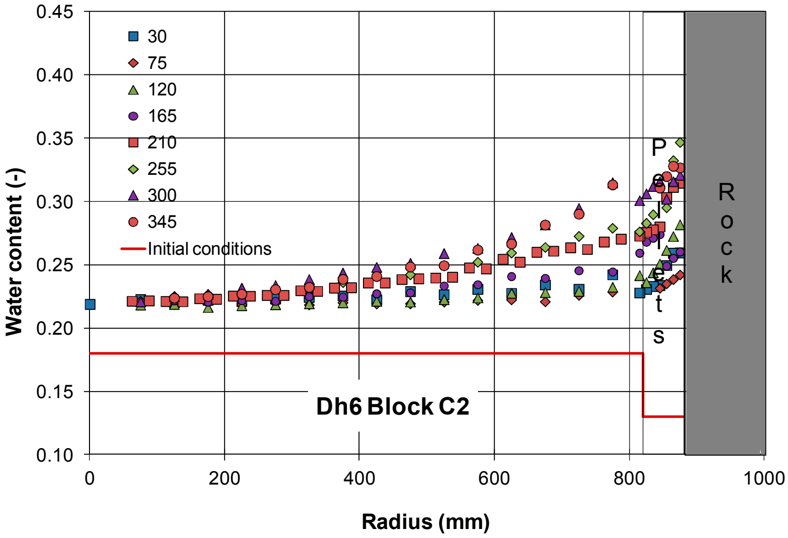
## Contour plots of water content, dry density and degree of saturation block R10, Dh 6

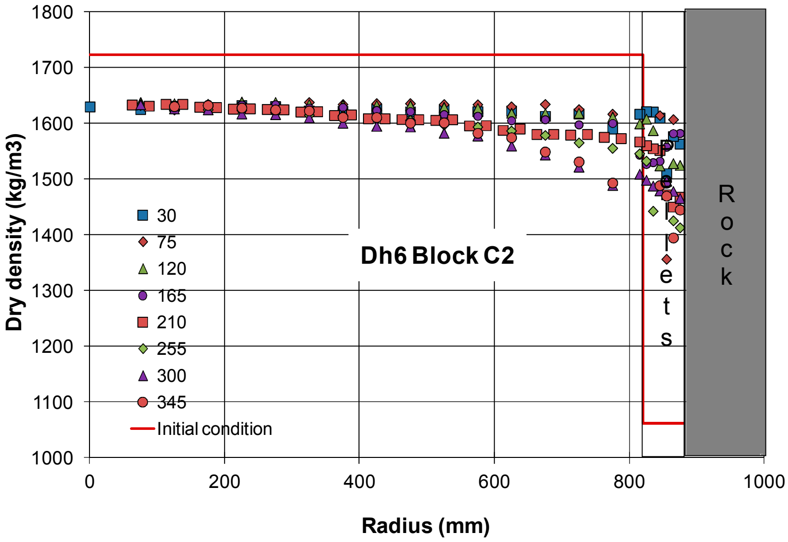


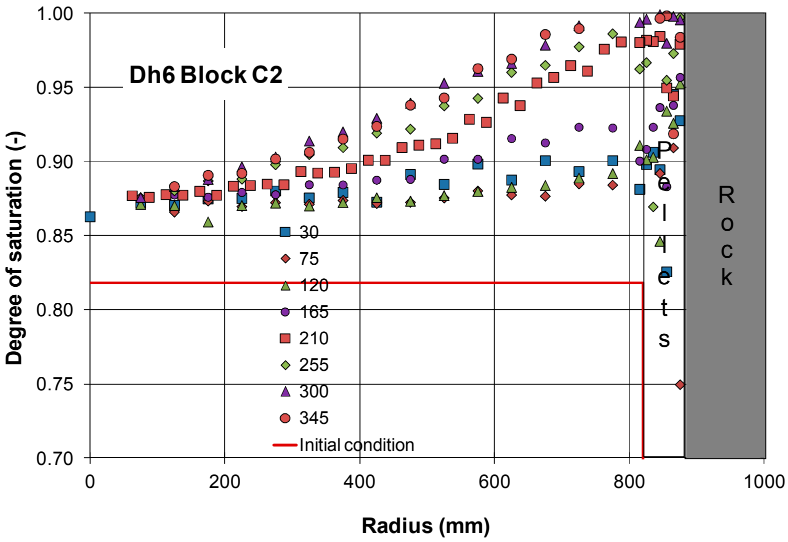



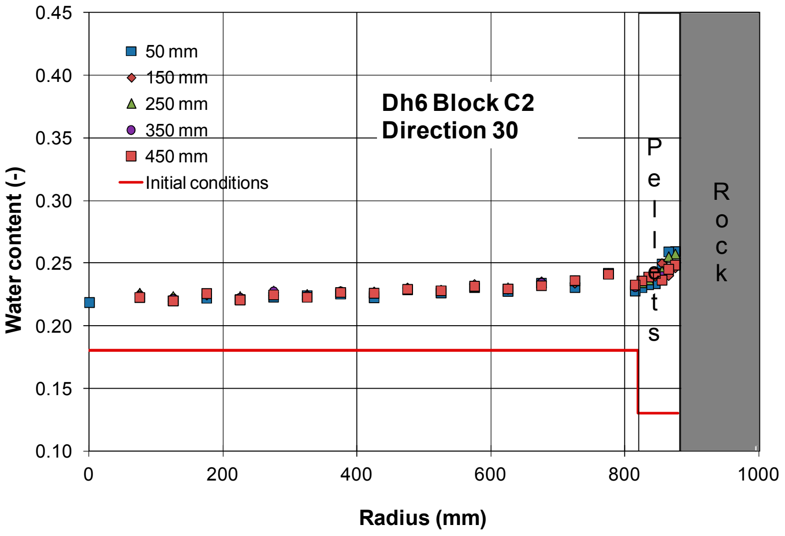
## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 355°) in block C2, Dh 6

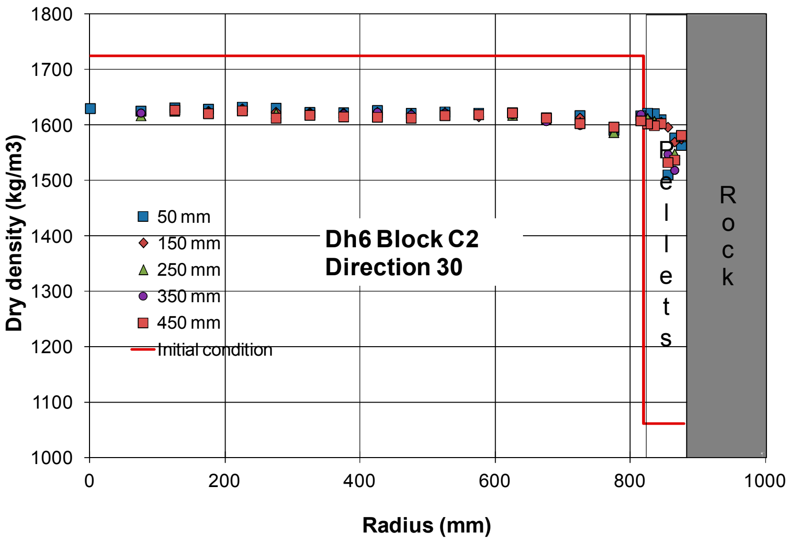


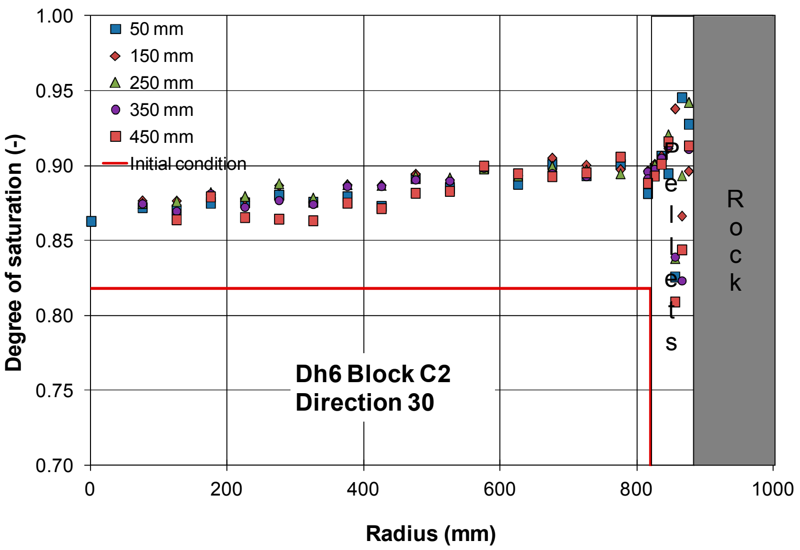



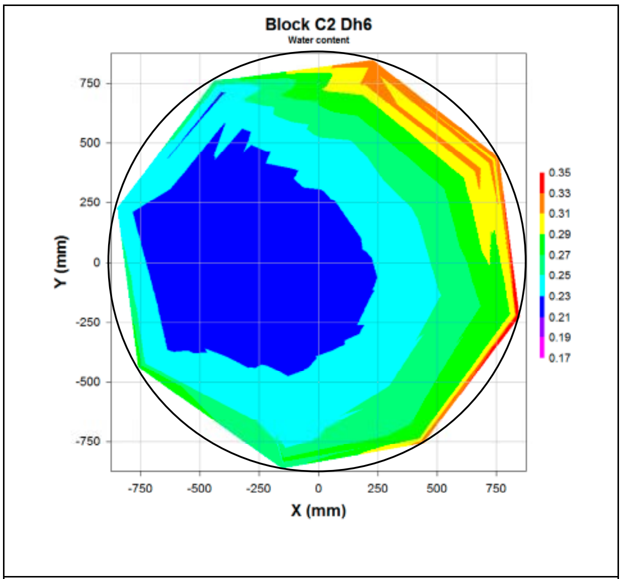
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block C2, Dh 6**

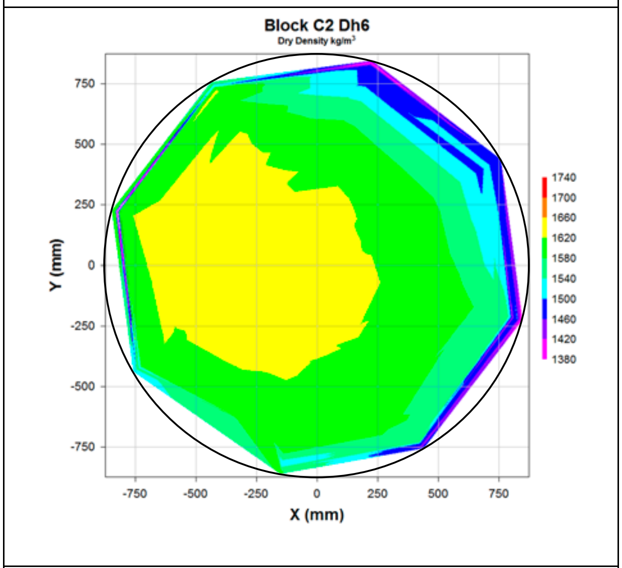


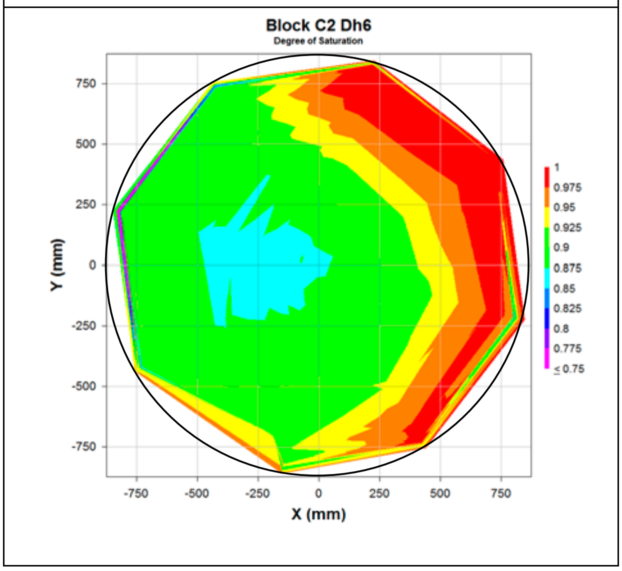



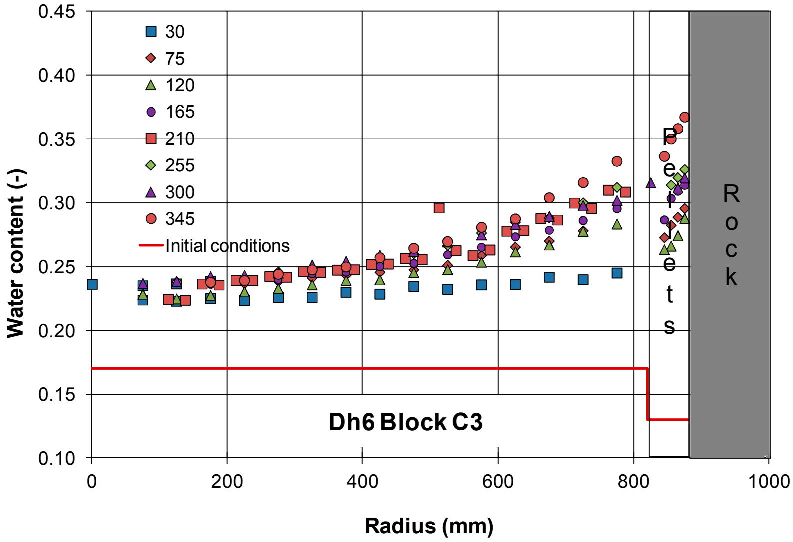
## Contour plots of water content, dry density and degree of saturation block C2, Dh 6

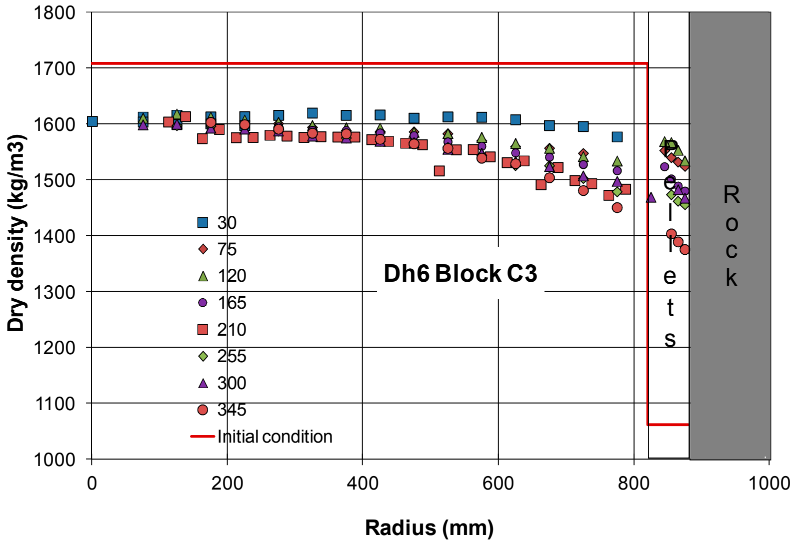


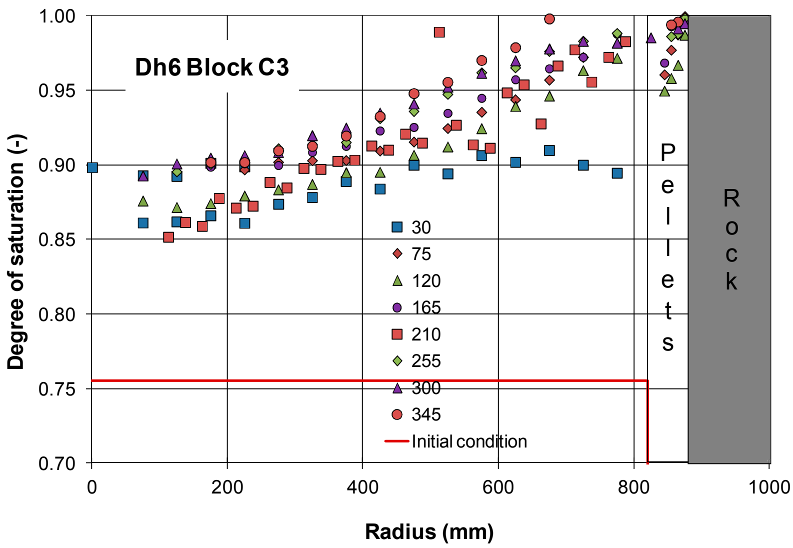



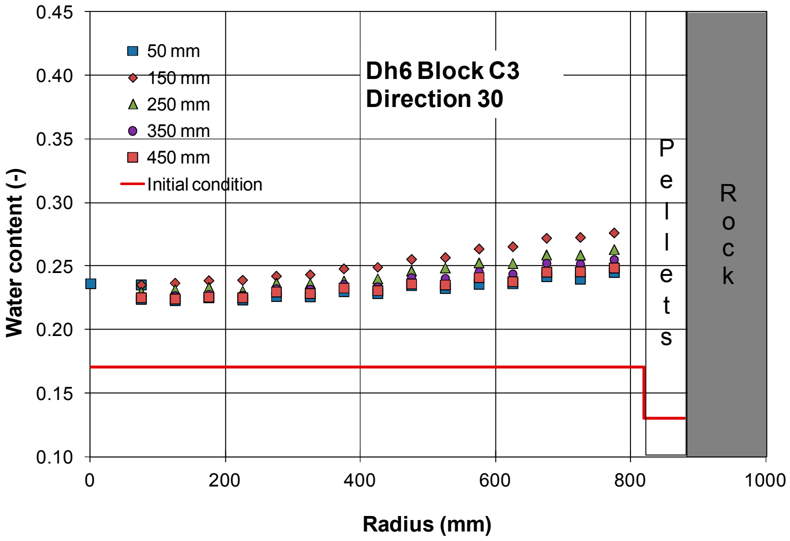
## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 355°) in block C3, Dh 6

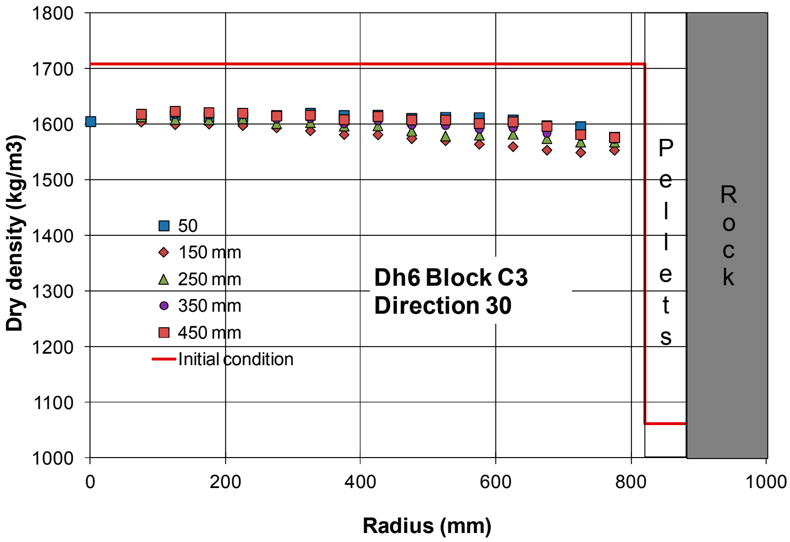


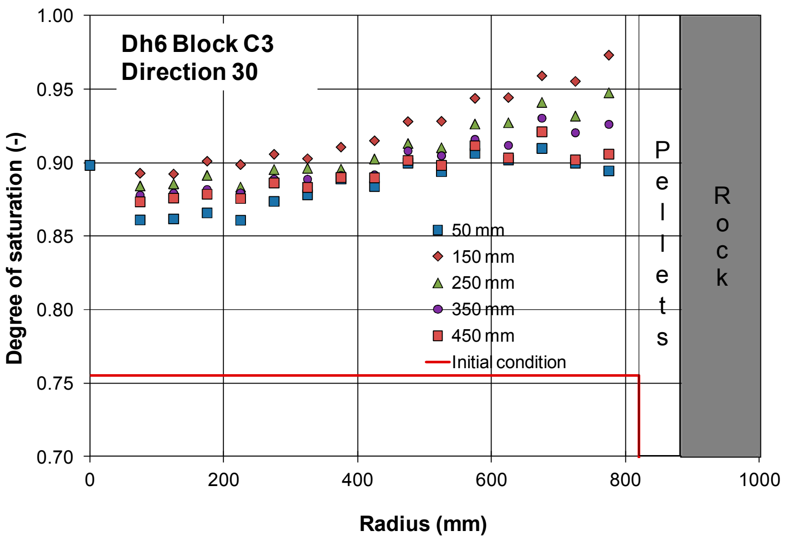



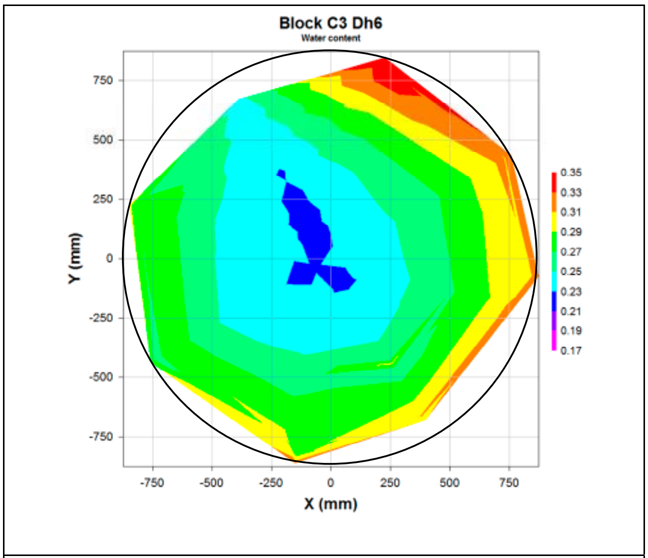
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block C3, Dh 6

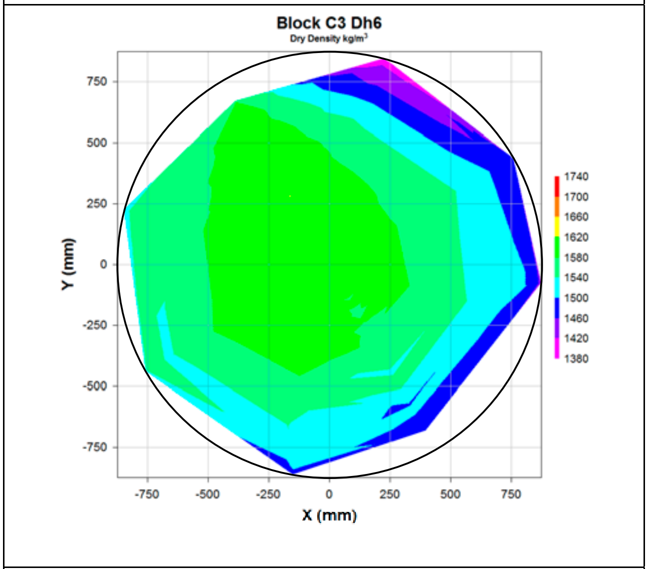


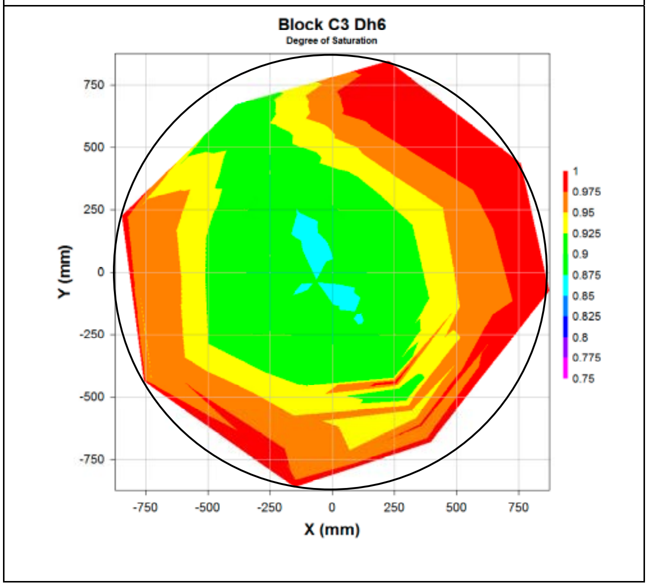



## Contour plots of water content, dry density and degree of saturation block C3, Dh 6

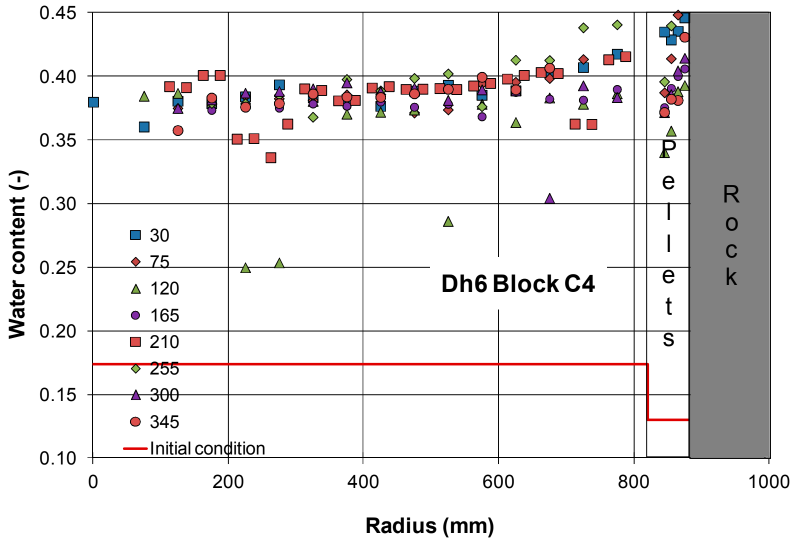


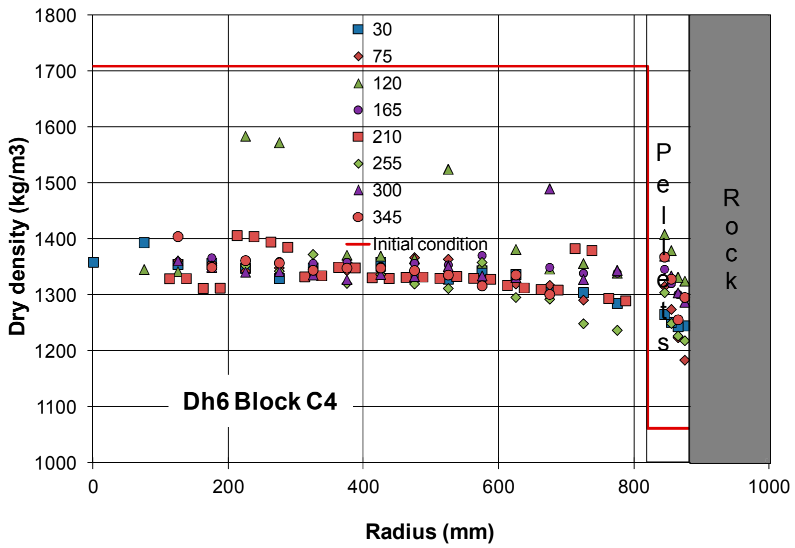



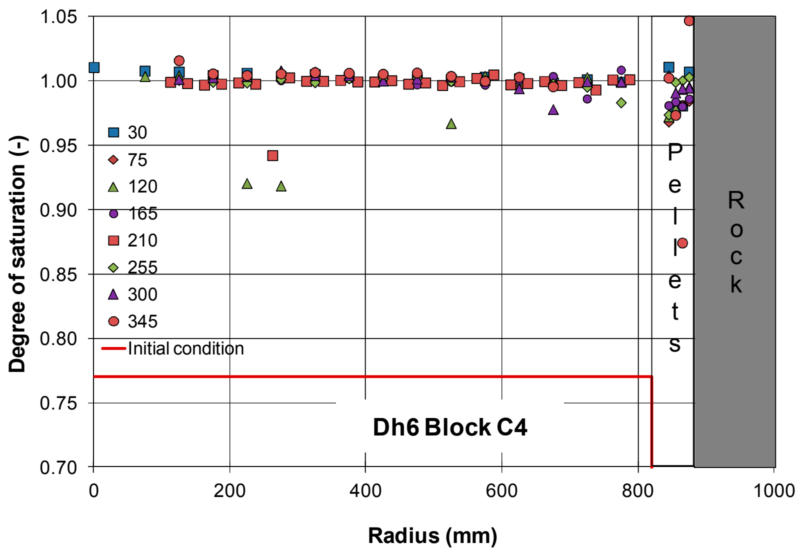



**Appendix 17**

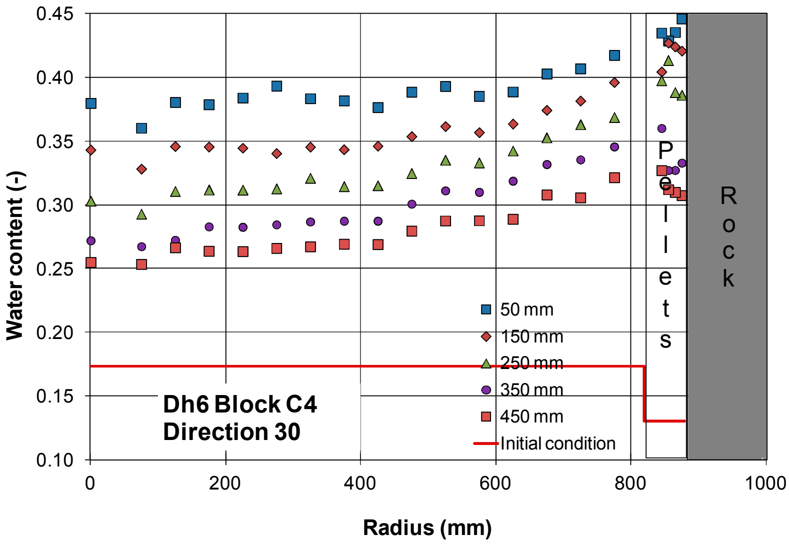
## Water content, dry density and degree of saturation measured in eight directions (30, 75, 120, 165, 210, 255, 300 and 355°) in block C4, Dh 6

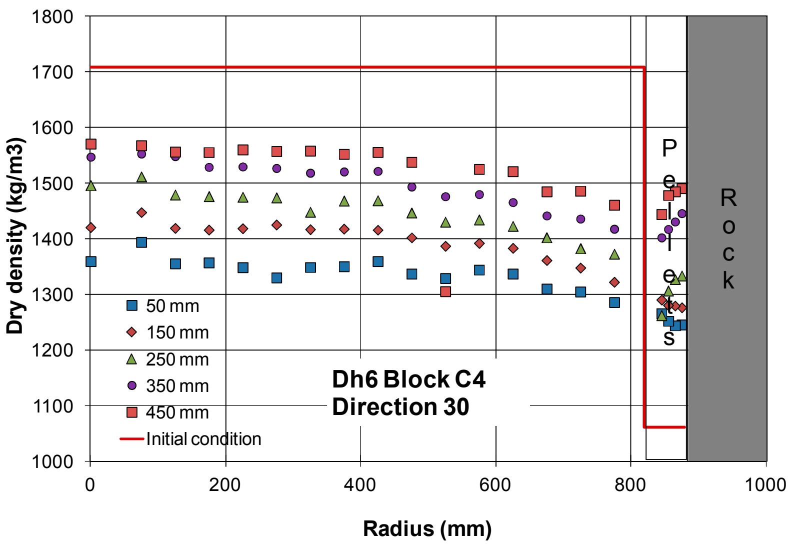


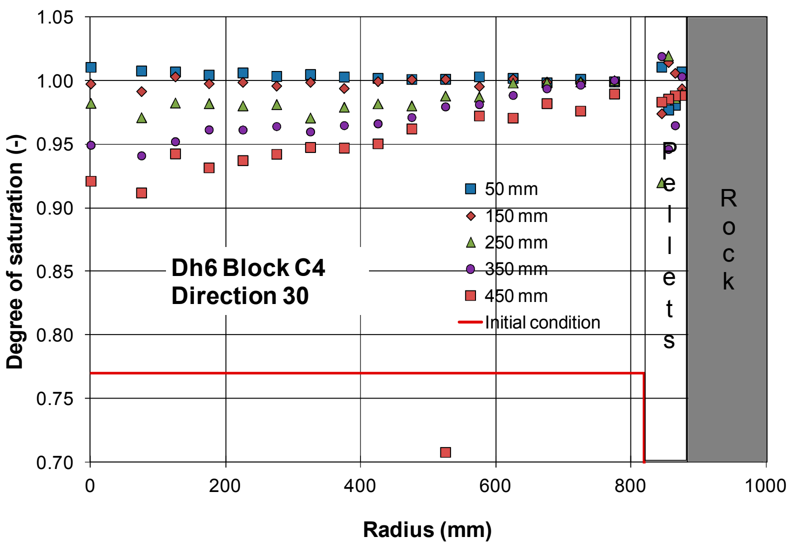



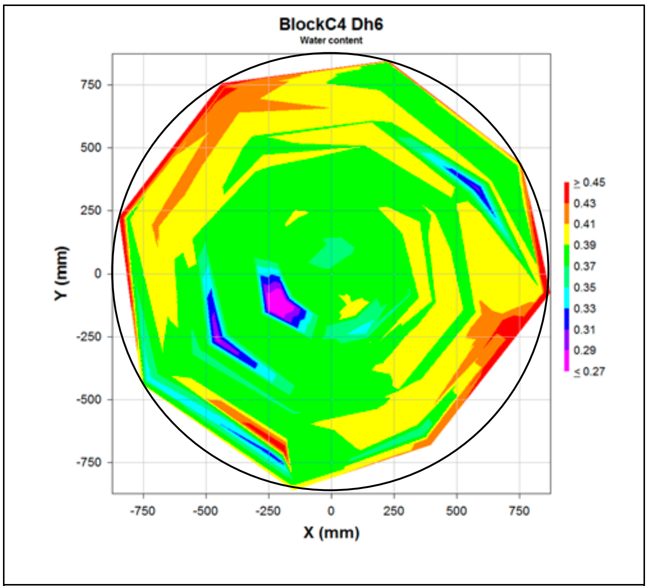
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 30° block C4, Dh 6

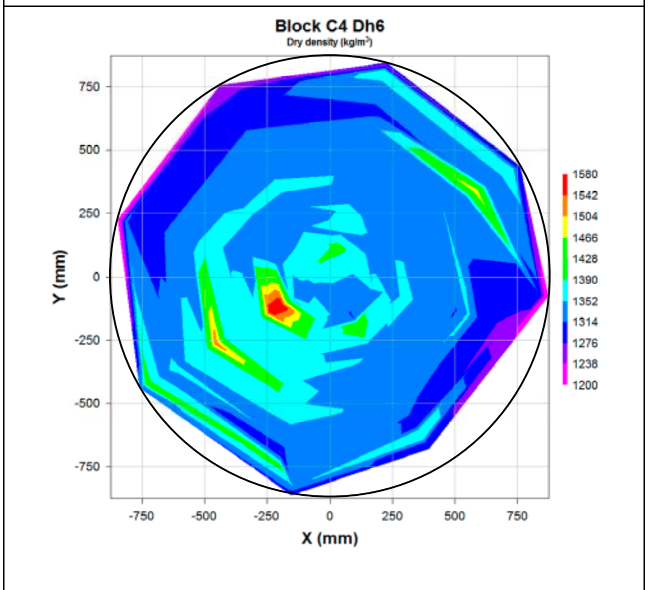


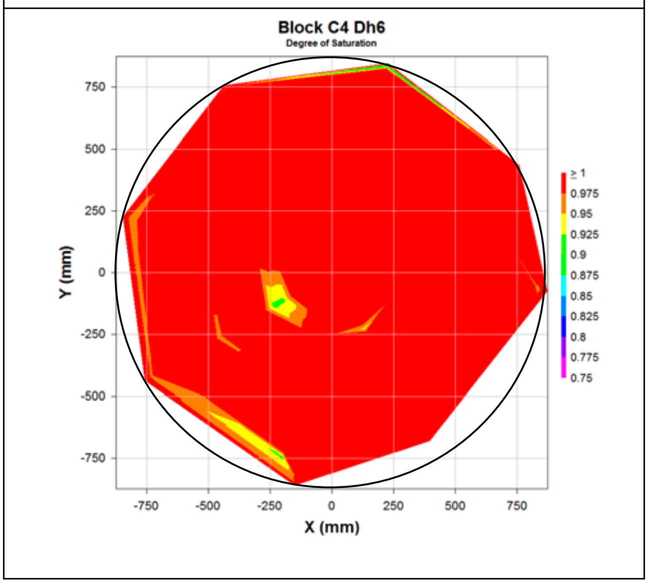



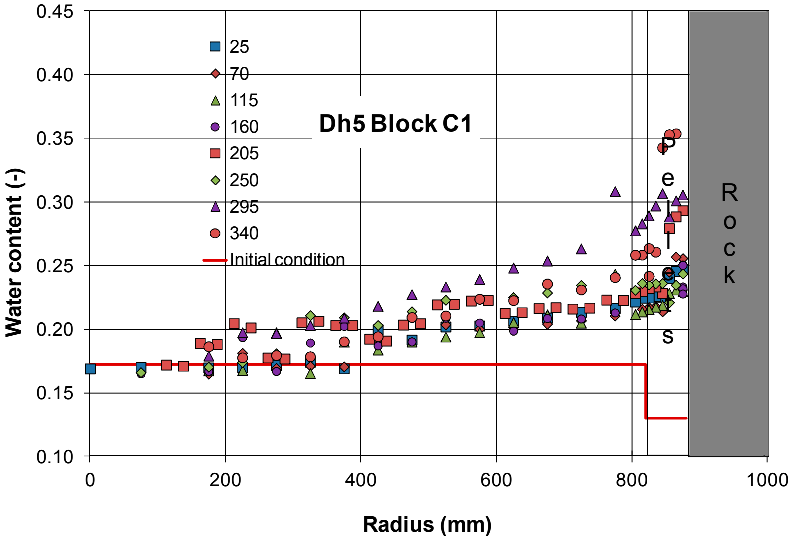
## Contour plots of water content, dry density and degree of saturation block C4, Dh 6

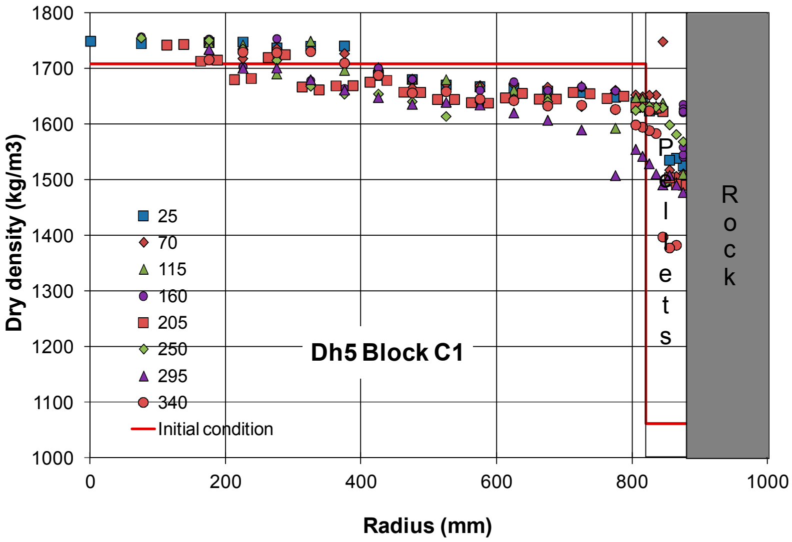


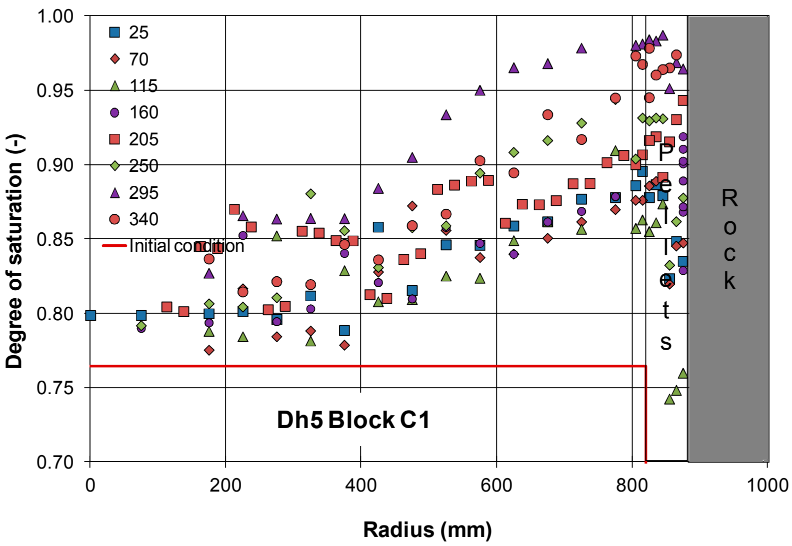



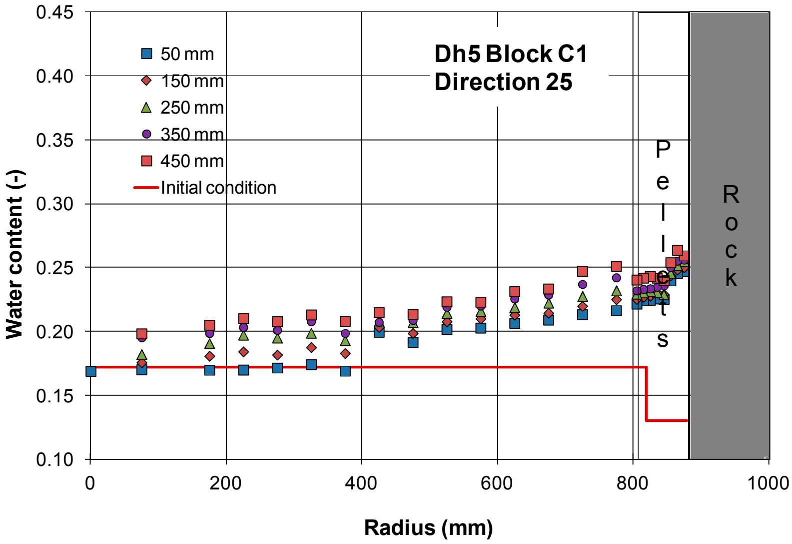
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block C1, Dh 5

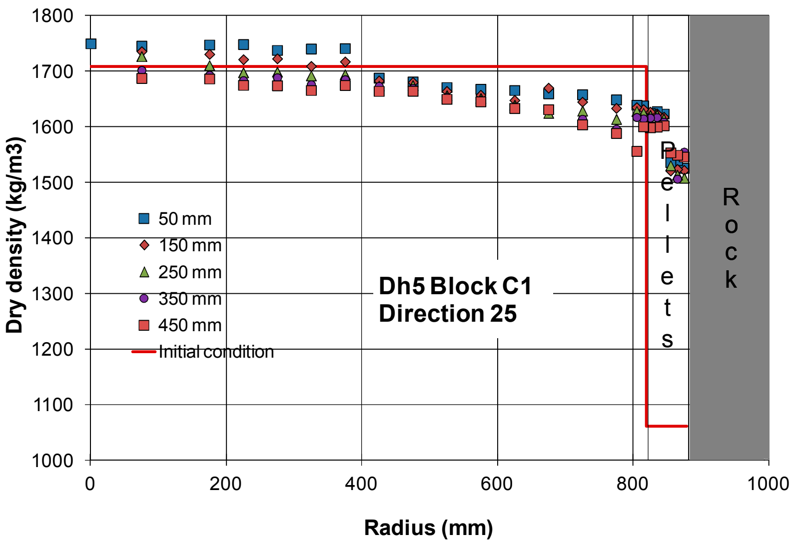


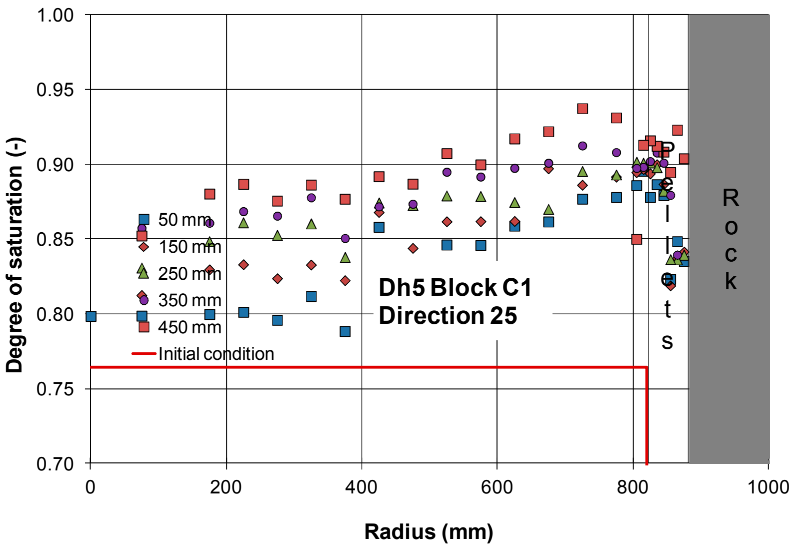



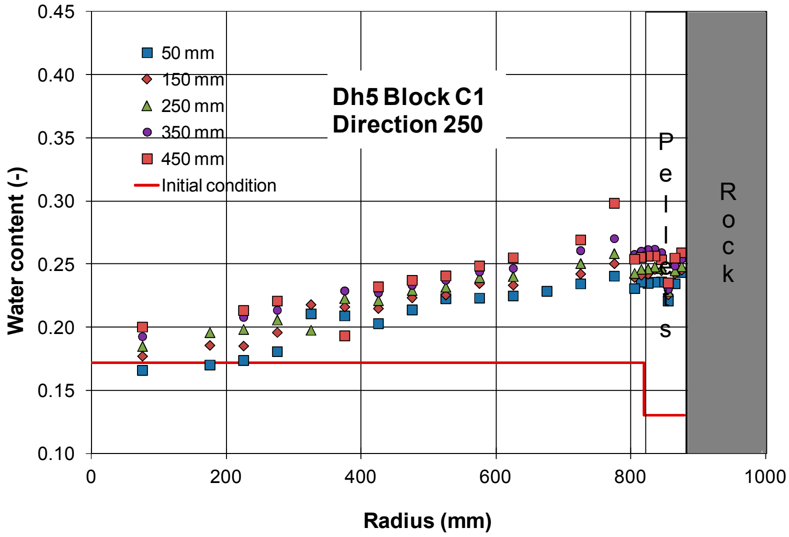
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block C1, Dh 5

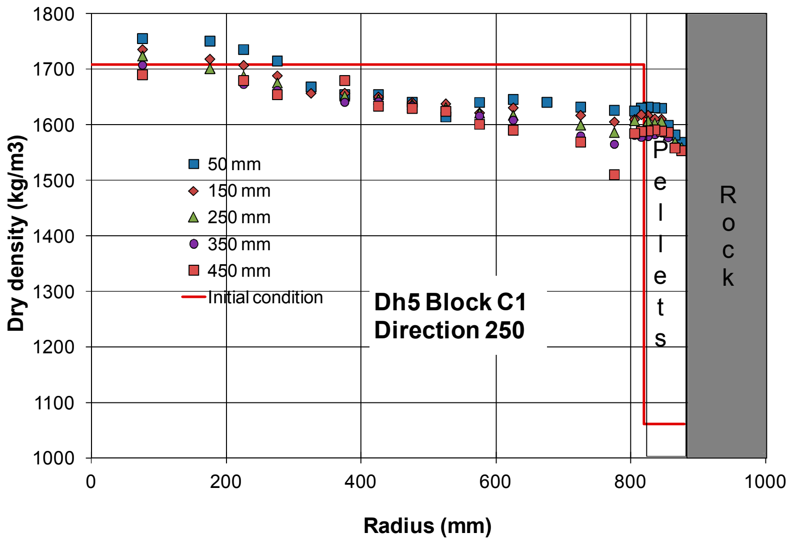


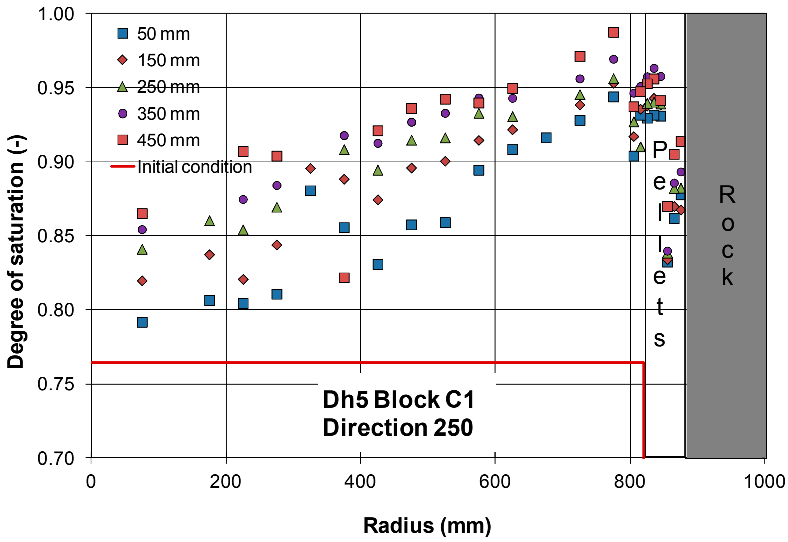



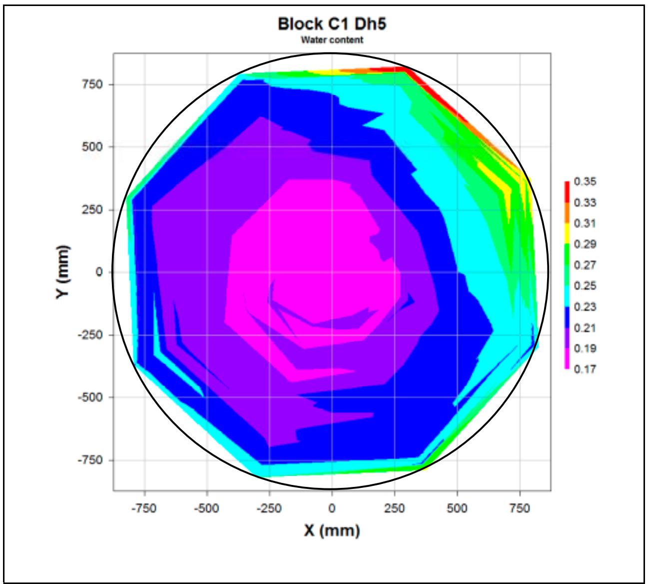
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block C1, Dh 5**

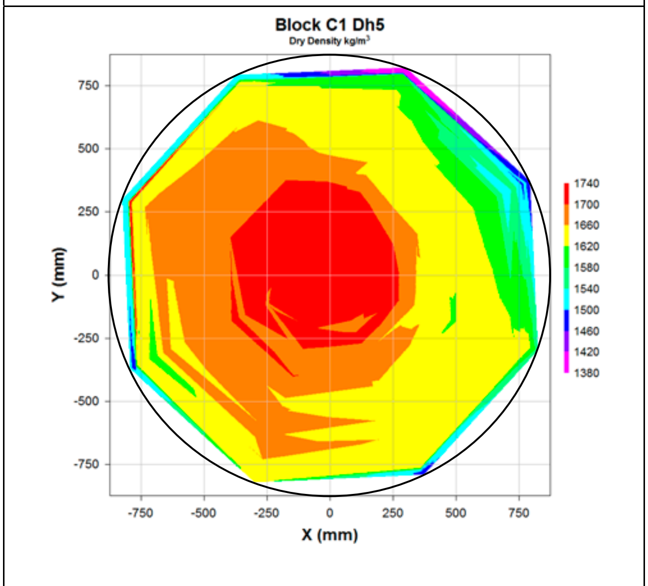


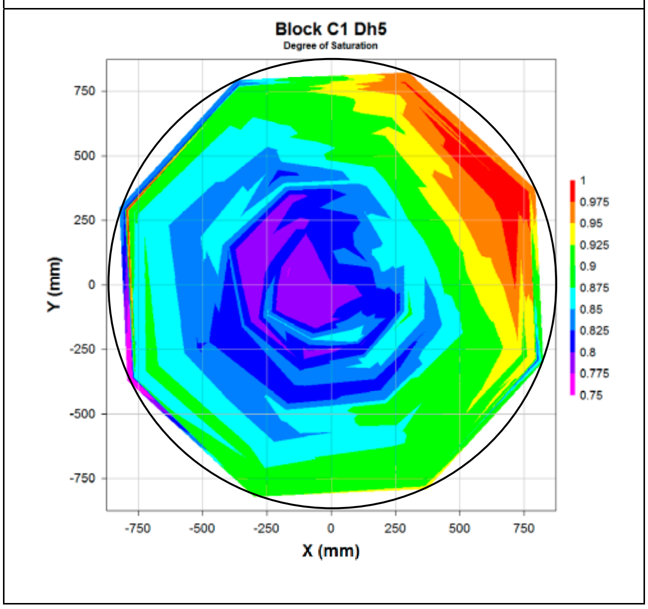



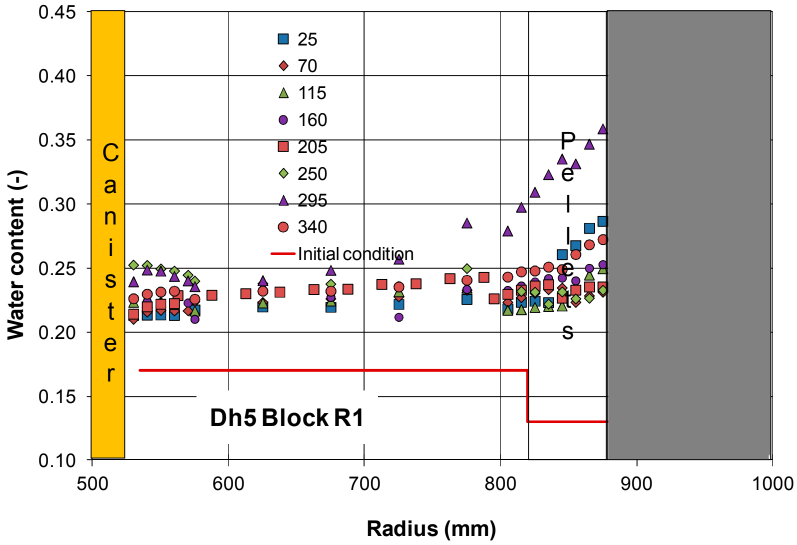
## Contour plots of water content, dry density and degree of saturation block C1, Dh 5

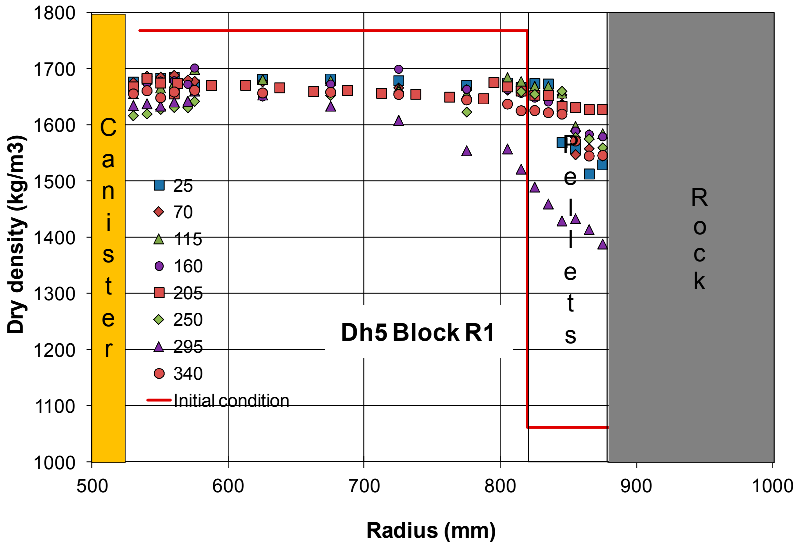


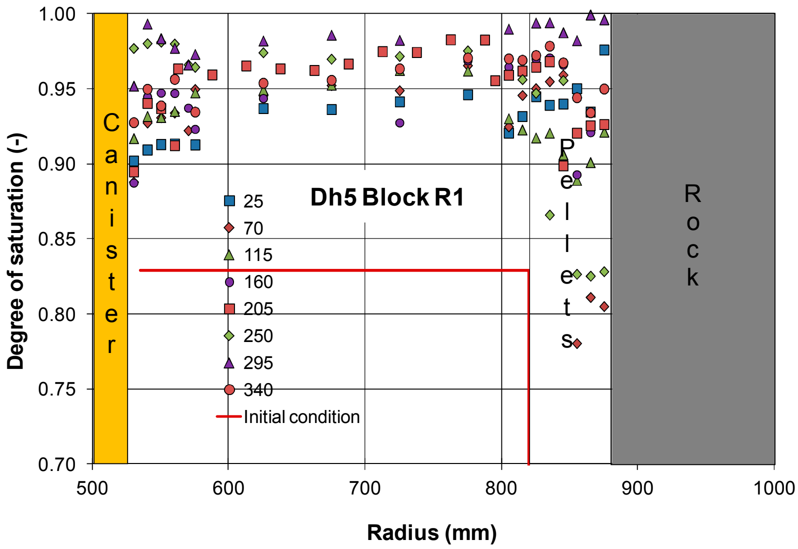



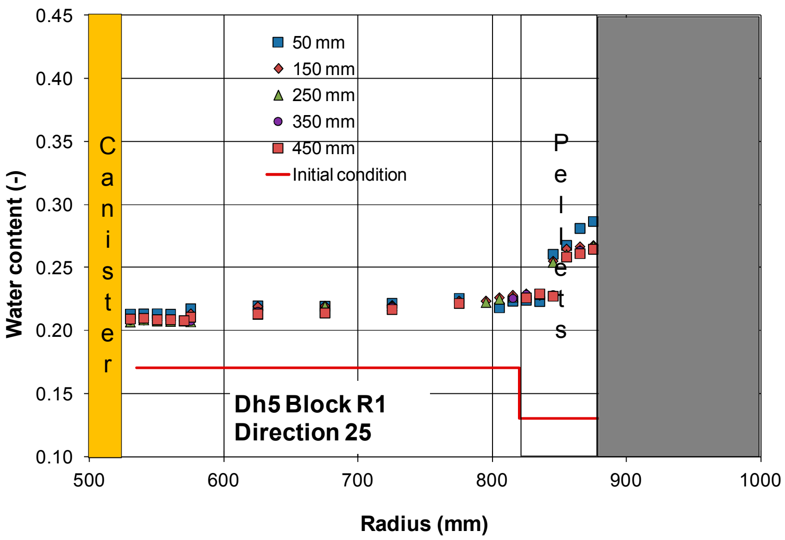
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R1, Dh 5

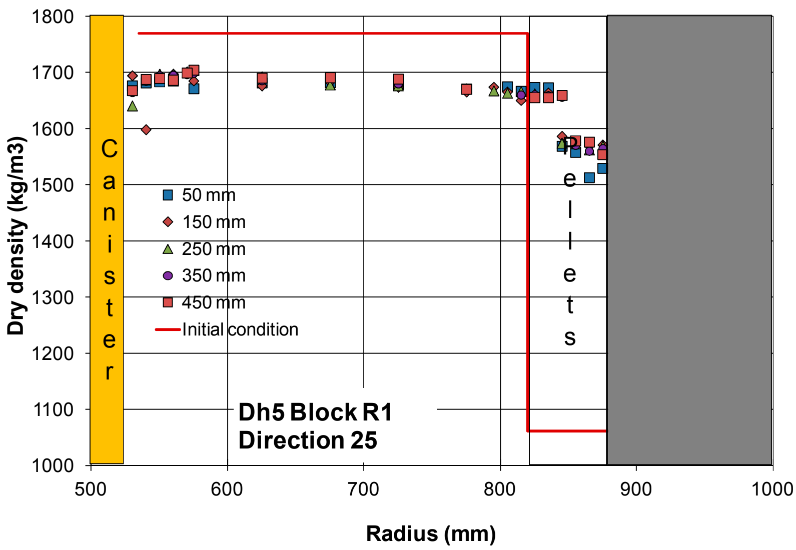


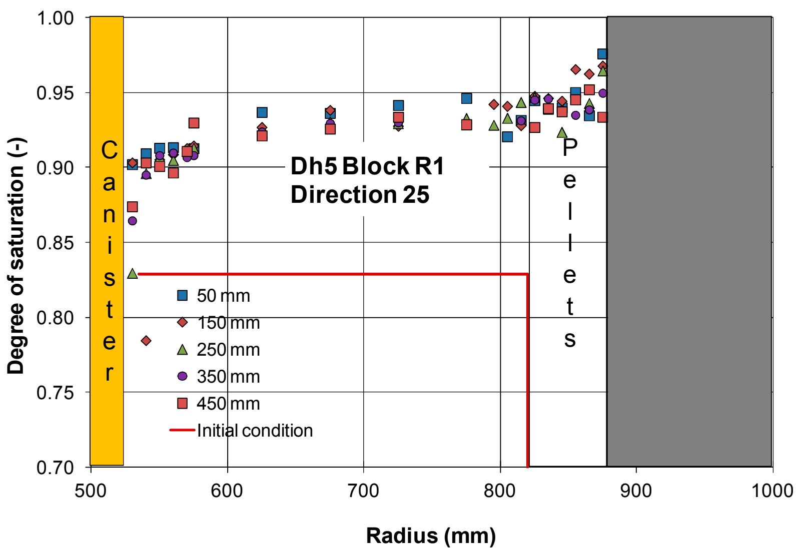



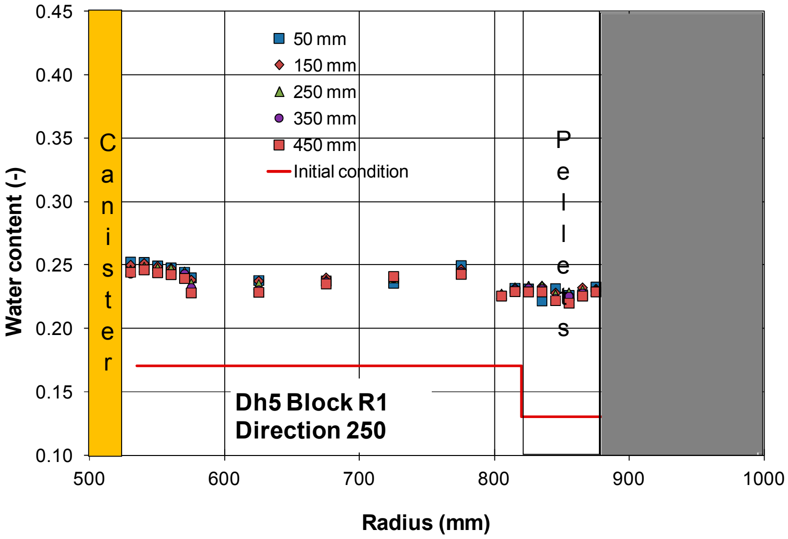
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R1, Dh 5**

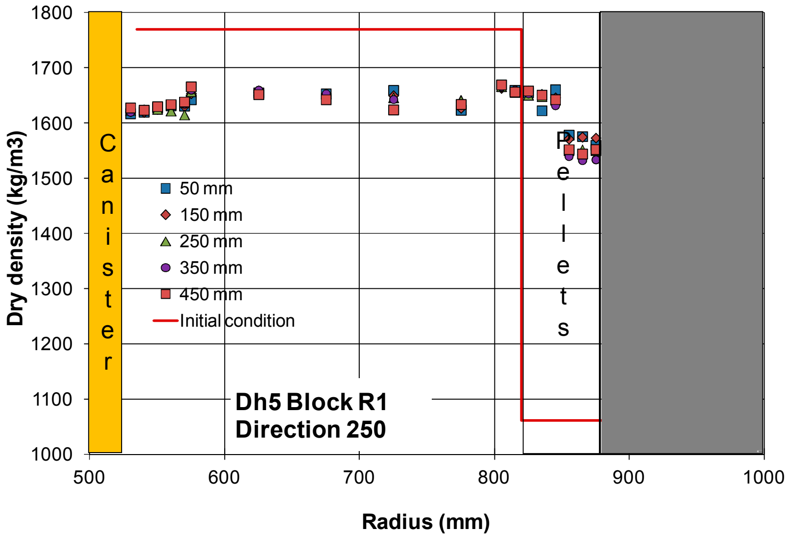


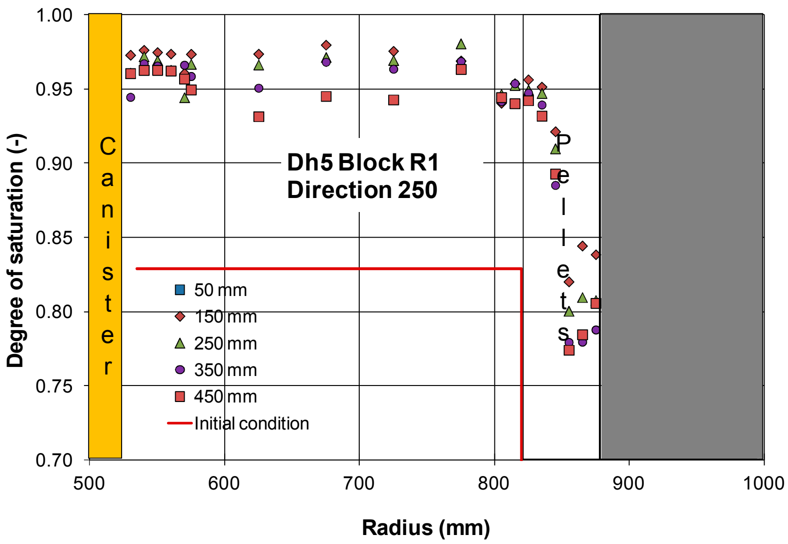



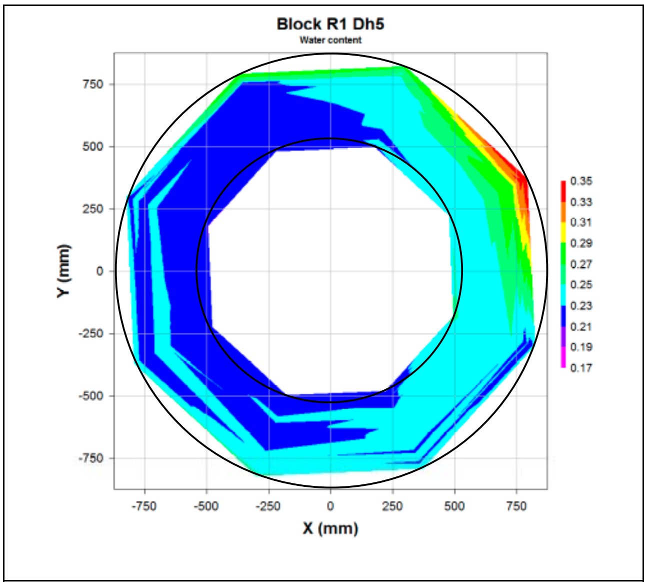
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R1, Dh 5

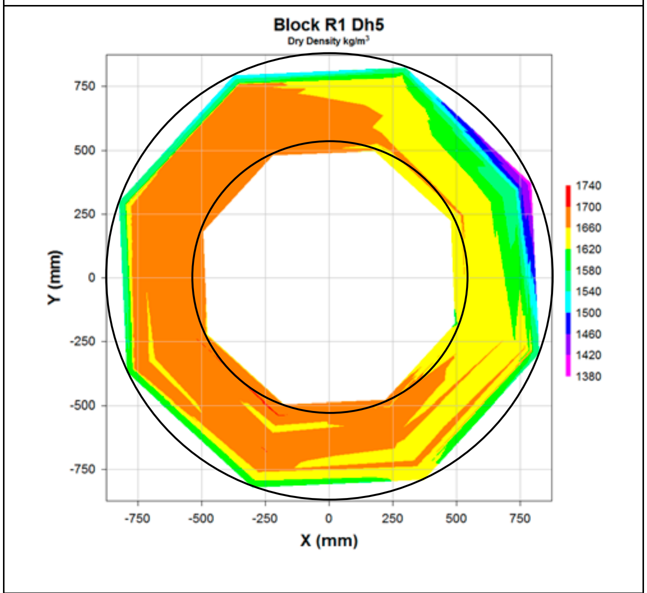


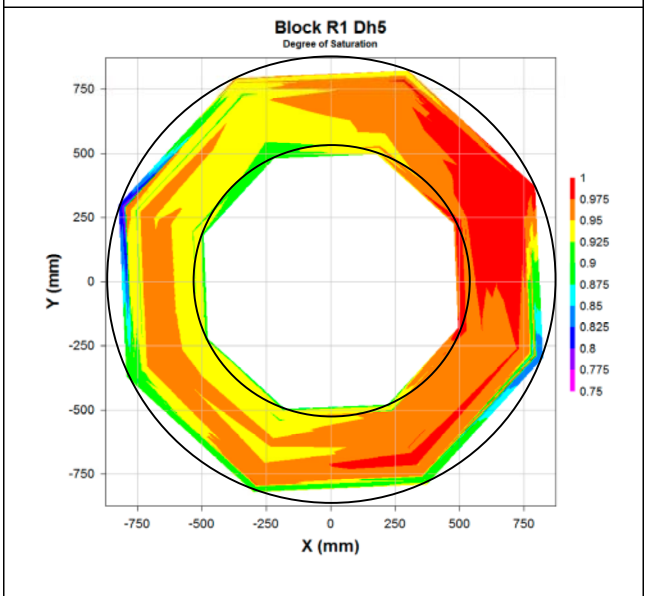



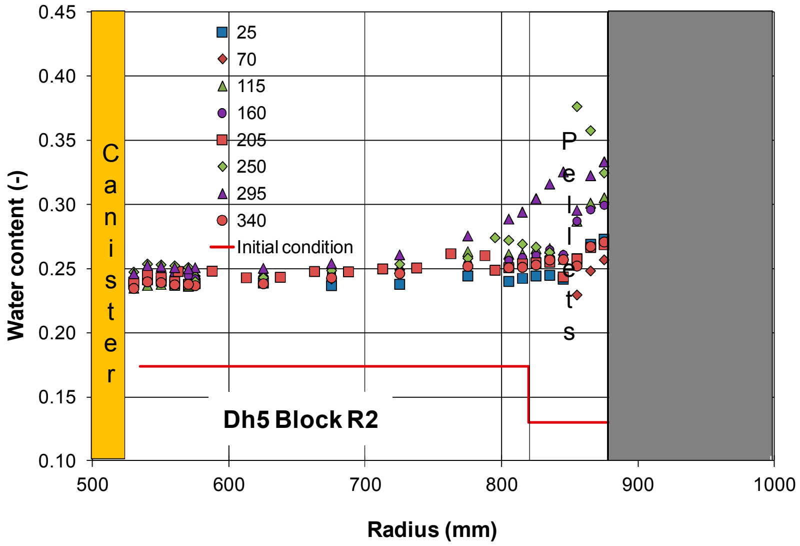
## Contour plots of water content, dry density and degree of saturation block R1, Dh 5.

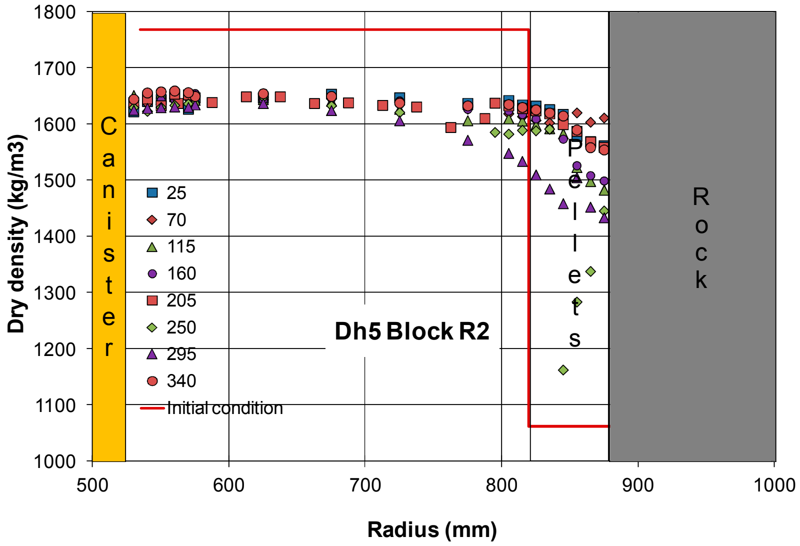


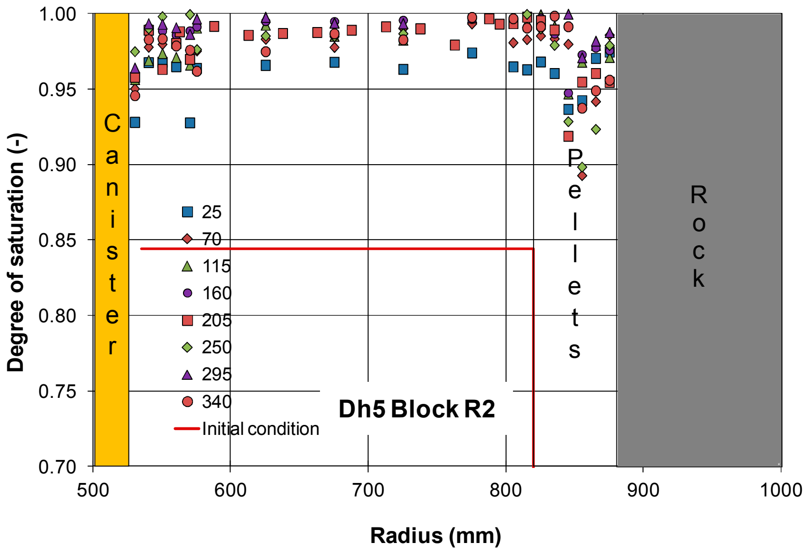



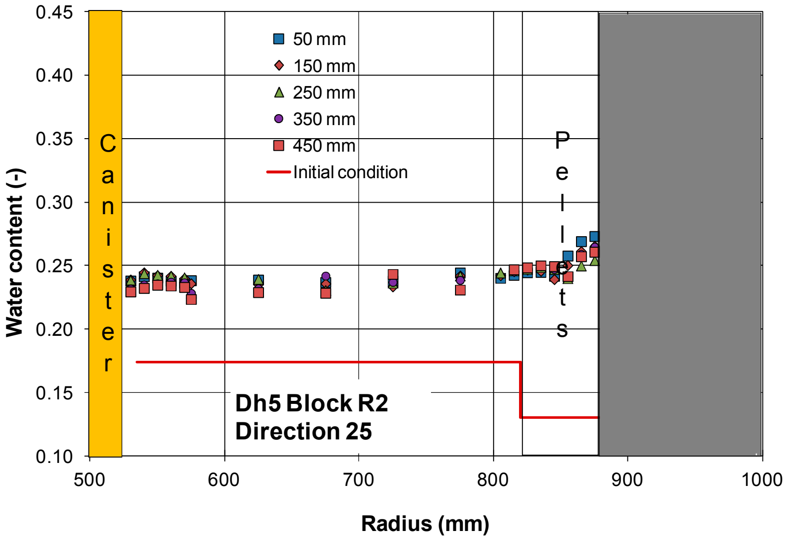
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R2, Dh 5

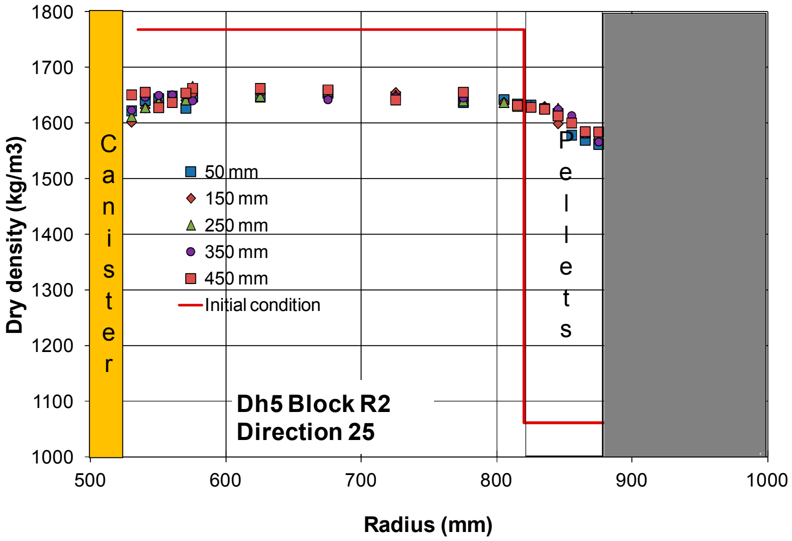


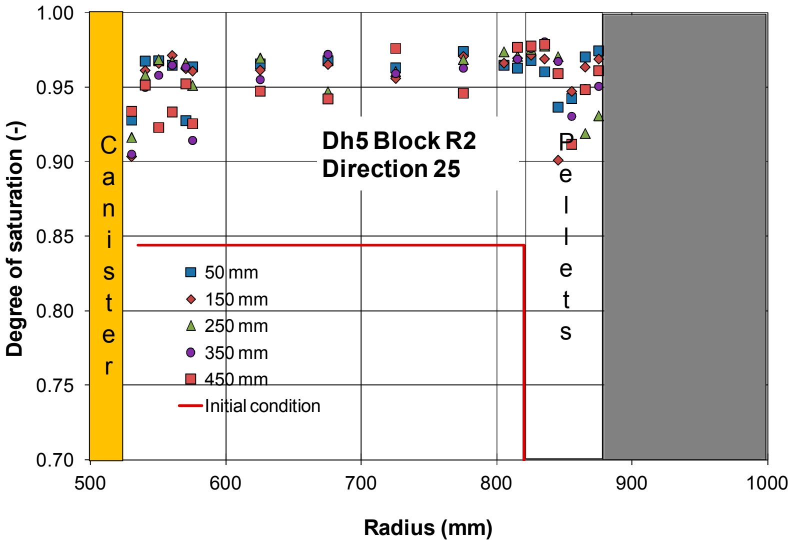



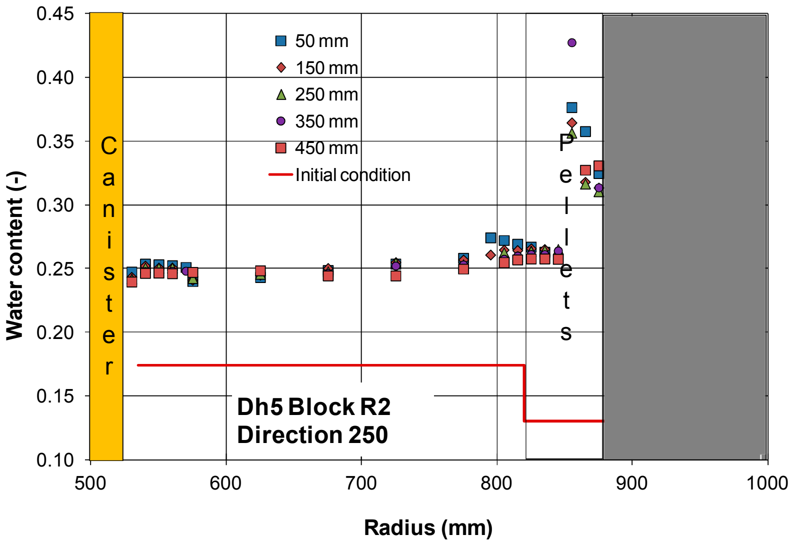
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R2, Dh 5

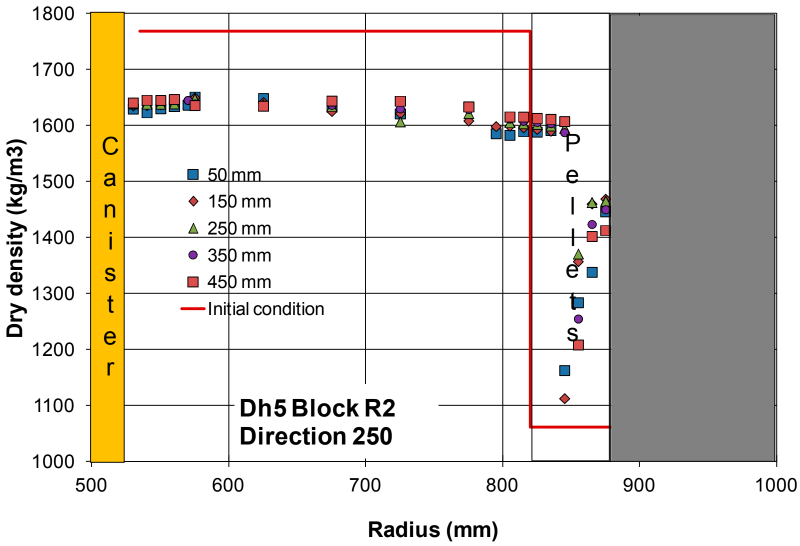


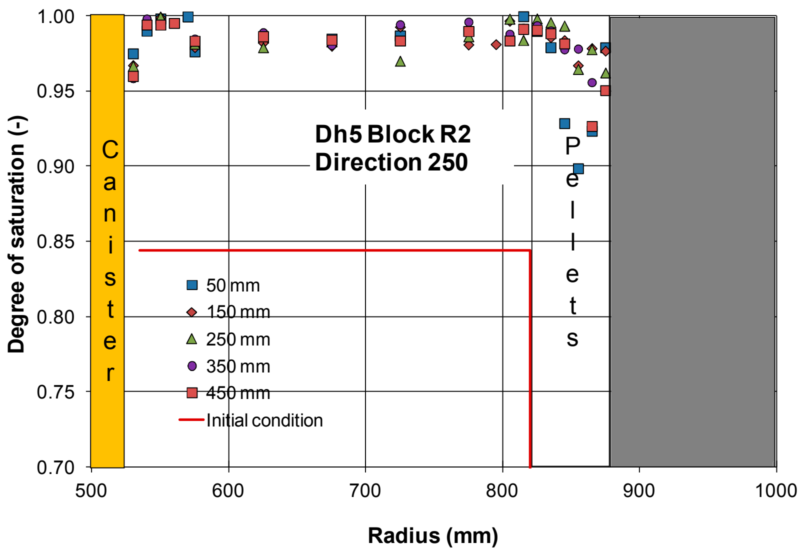



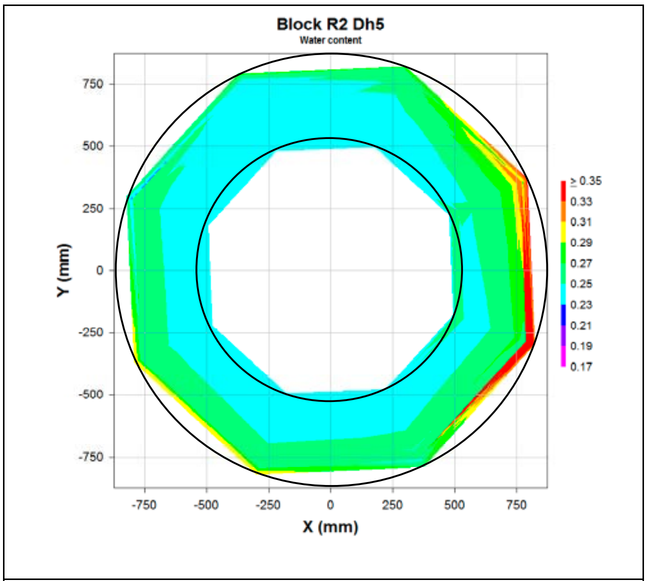
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R2, Dh 5

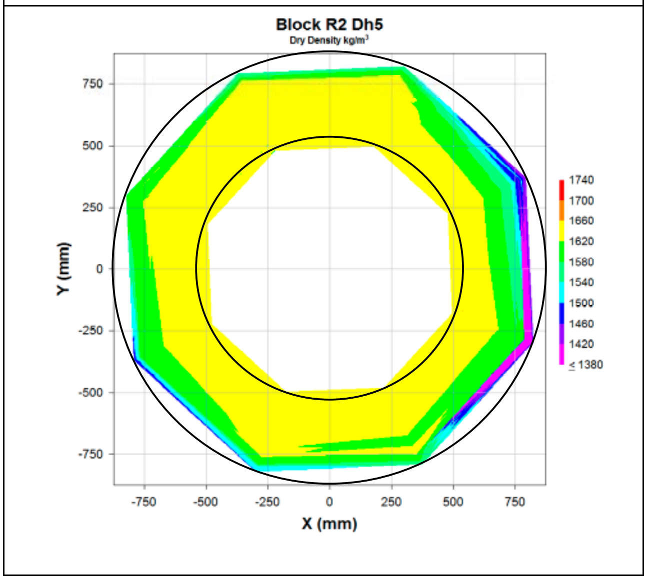


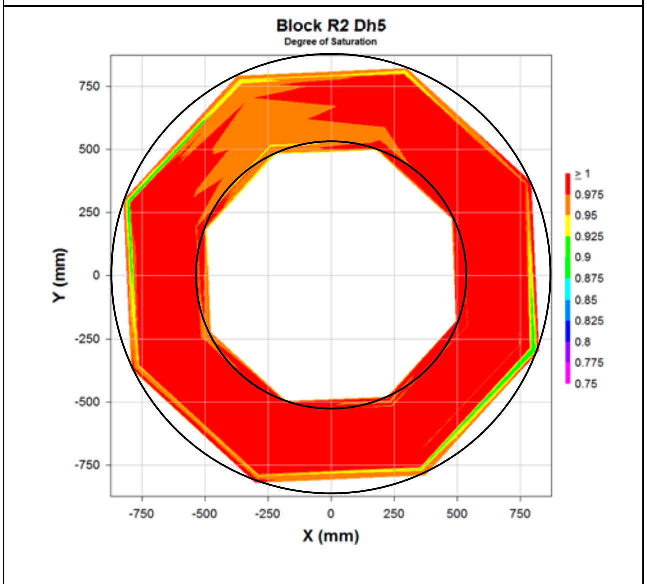



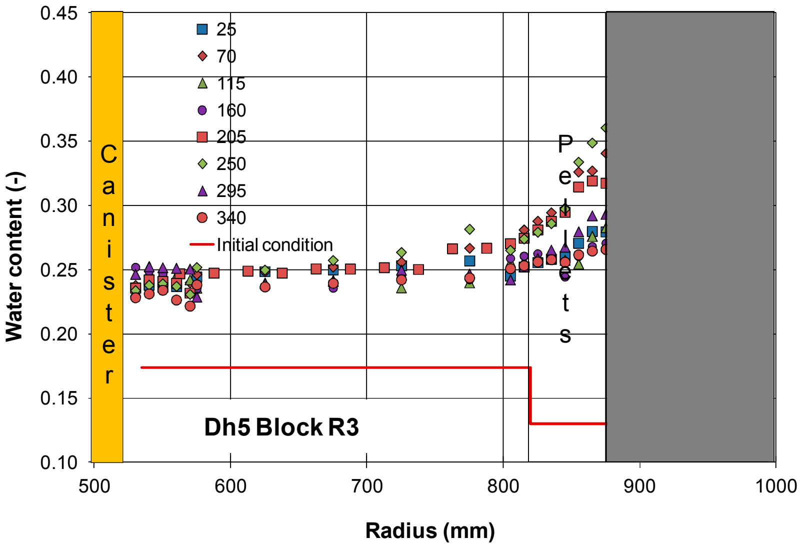
## Contour plots of water content, dry density and degree of saturation block R2, Dh 5

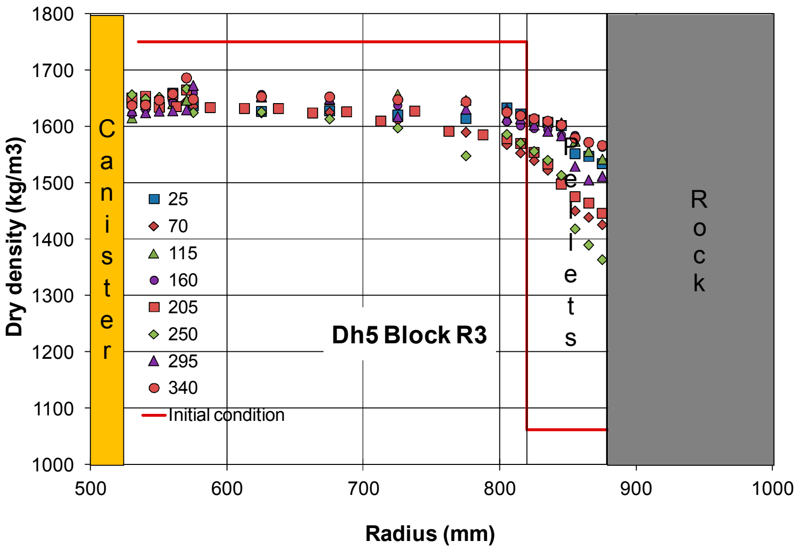


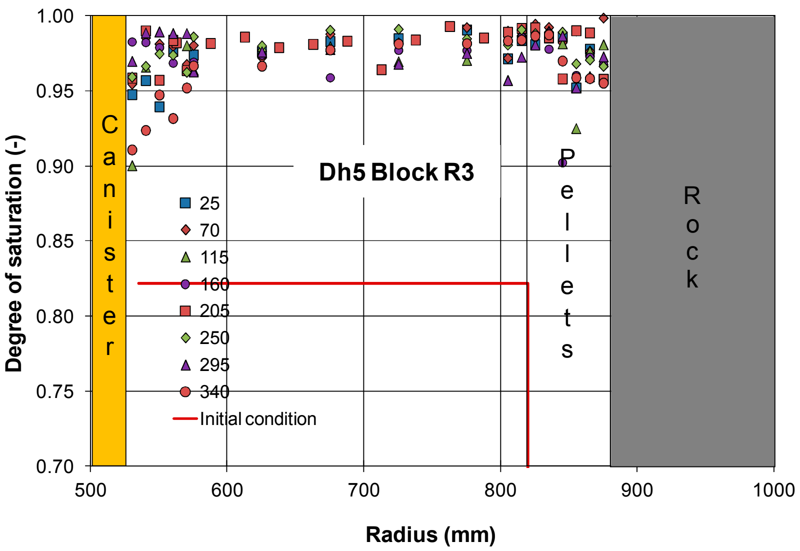



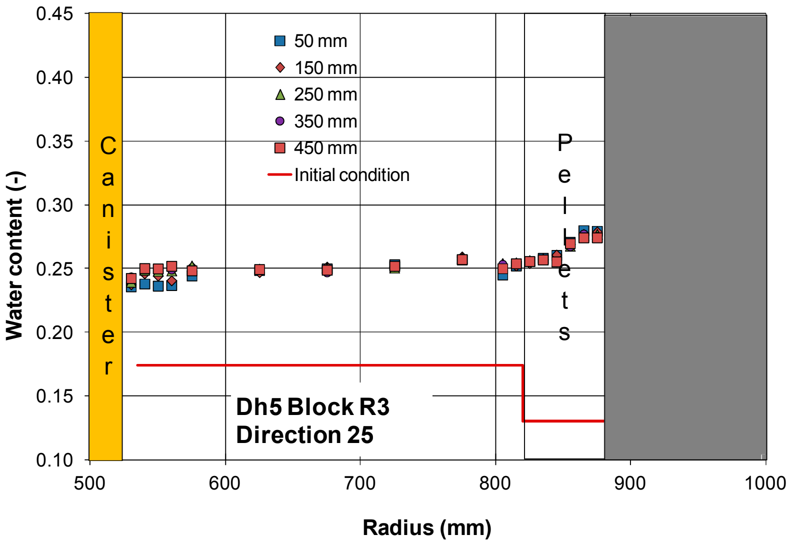
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R3, Dh 5

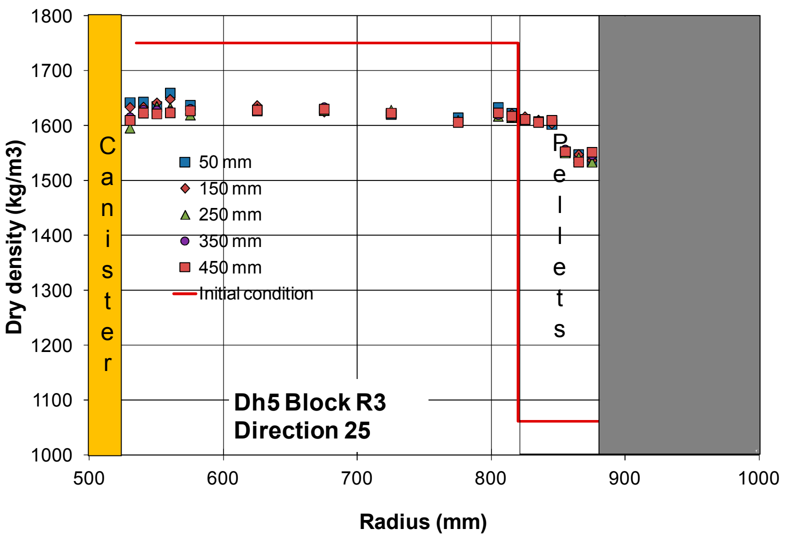


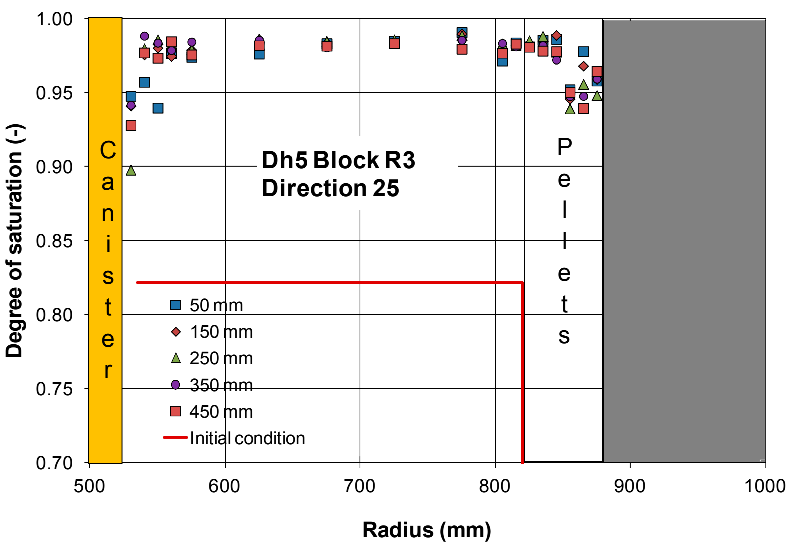



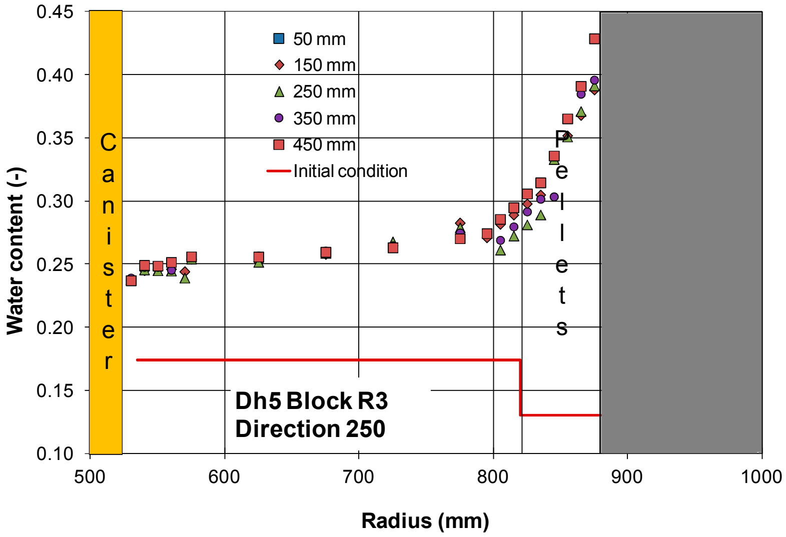
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R3, Dh 5

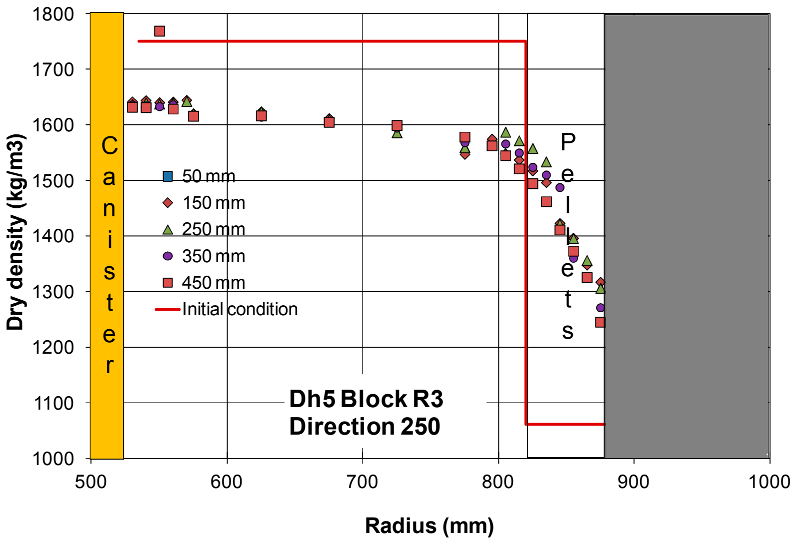


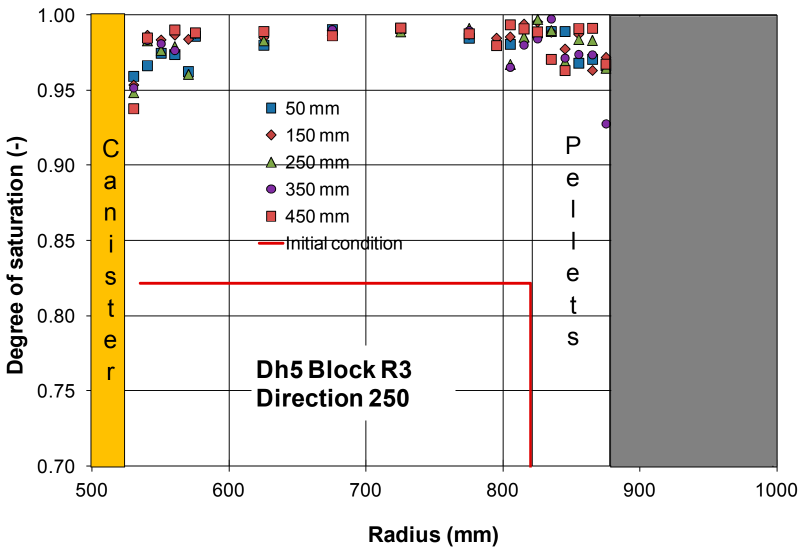



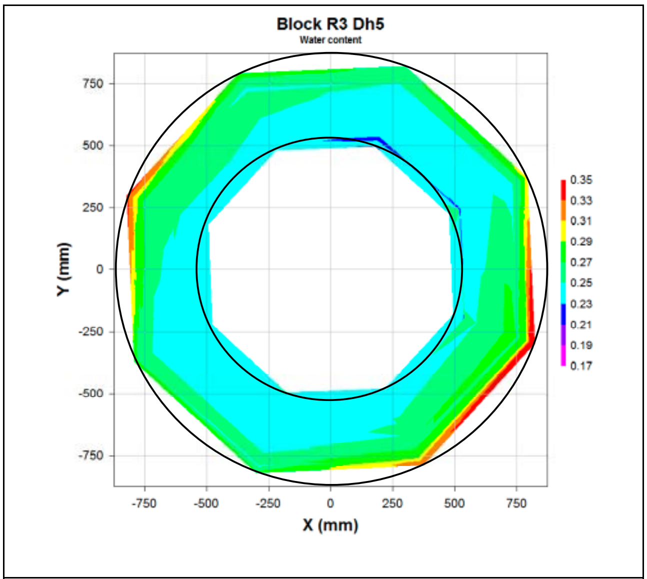
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R3, Dh 5

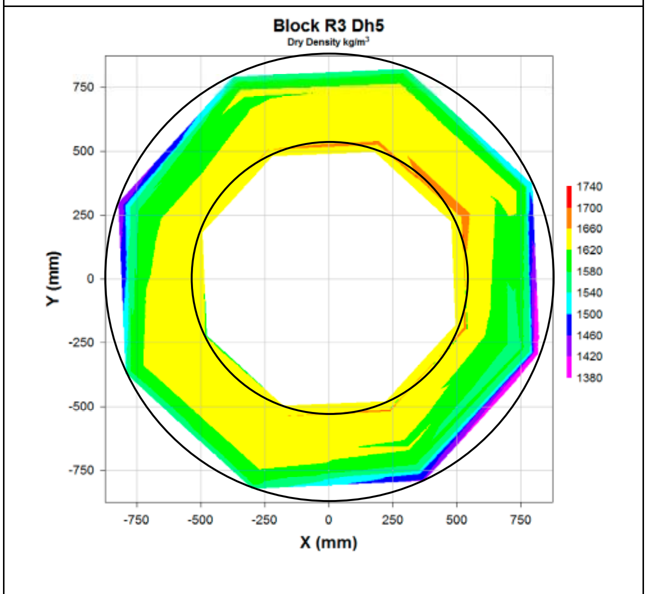


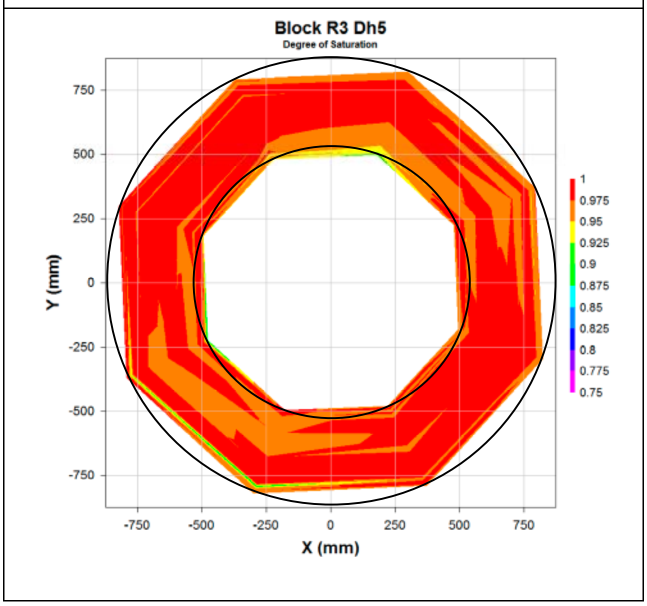



## Contour plots of water content, dry density and degree of saturation block R3, Dh 5

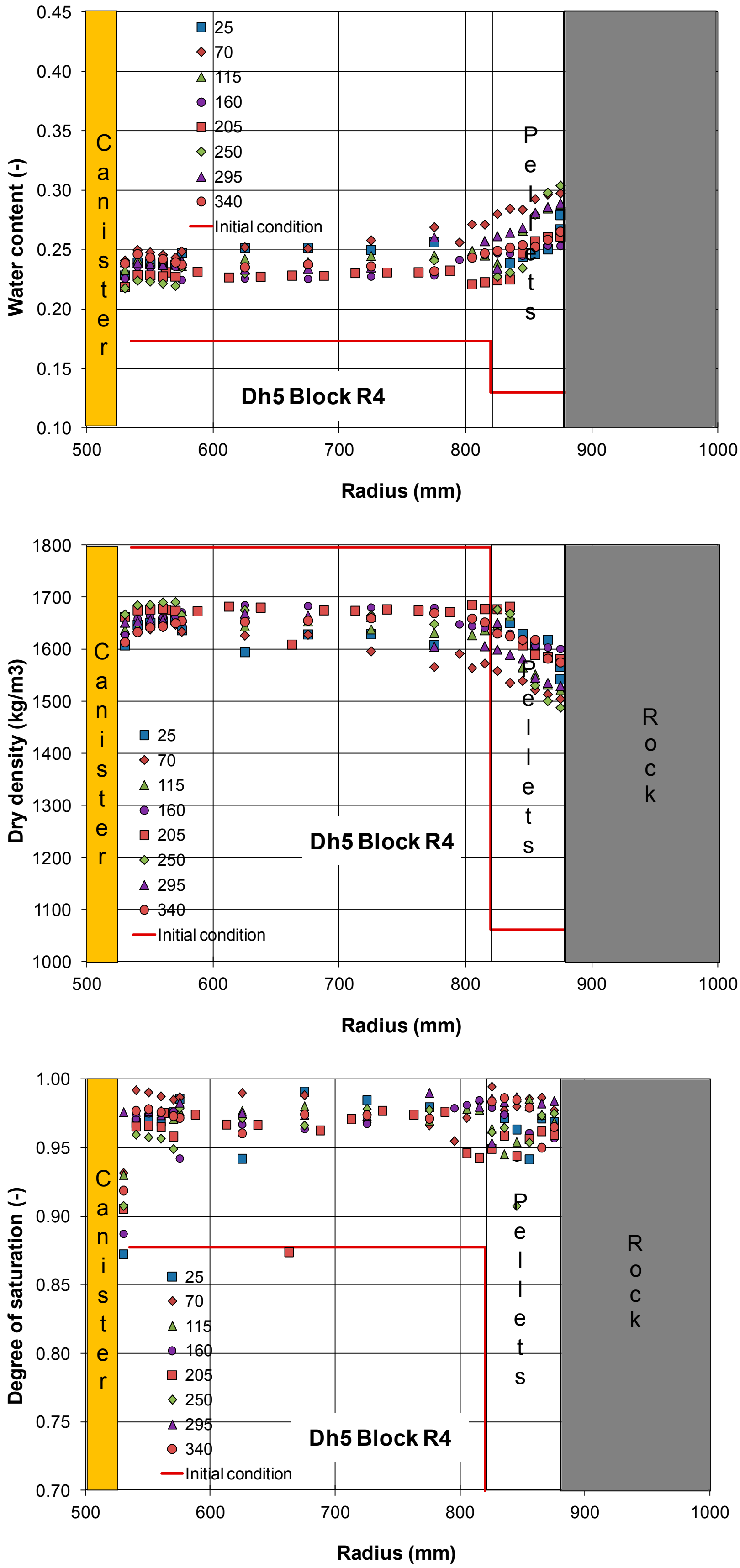


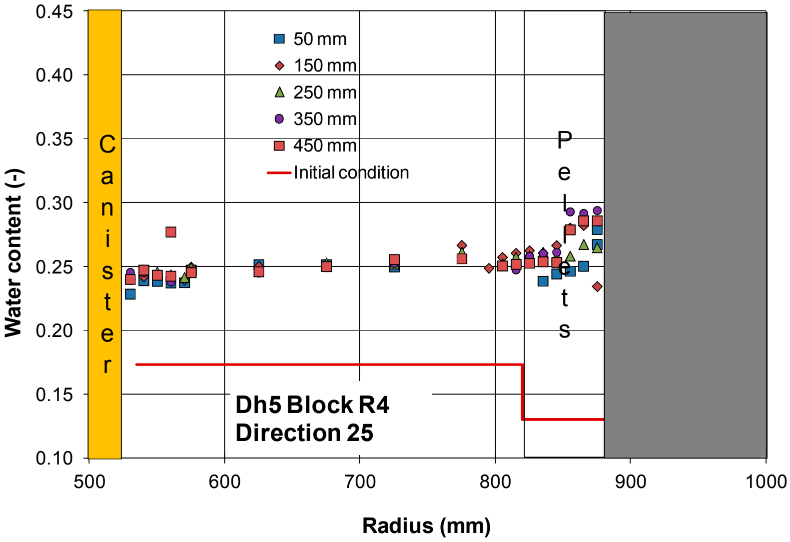



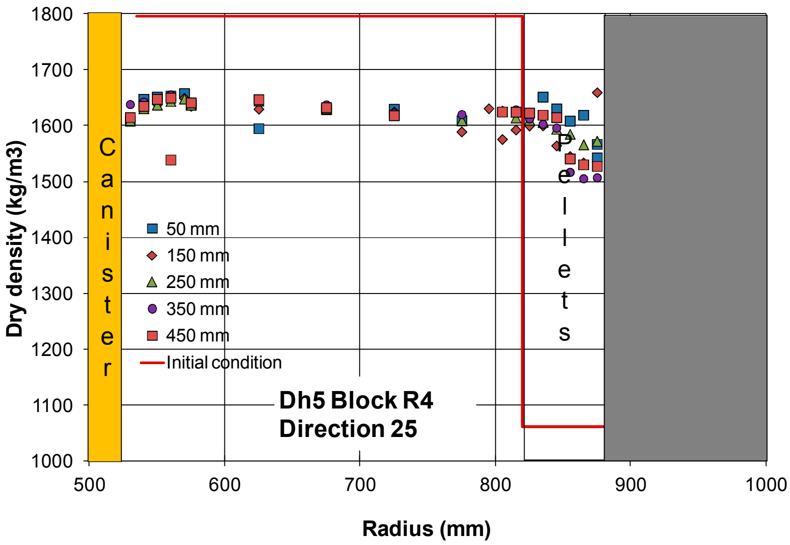
# Appendix 22

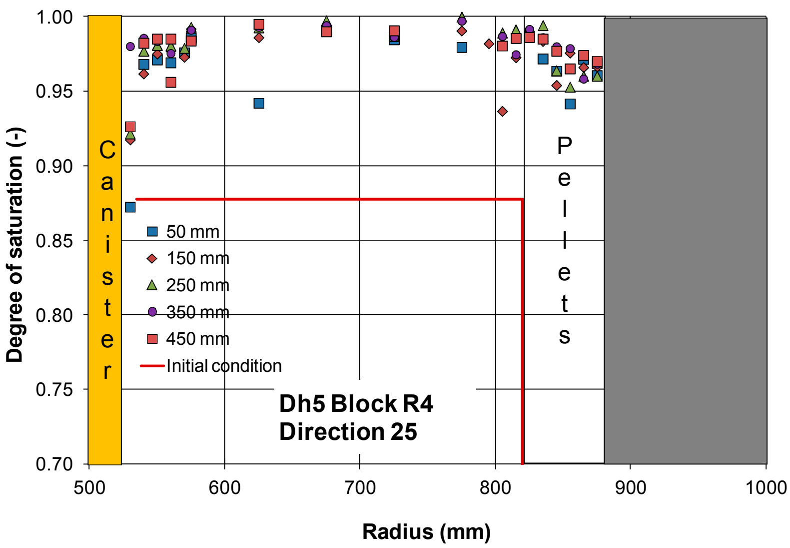
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R4, Dh 5



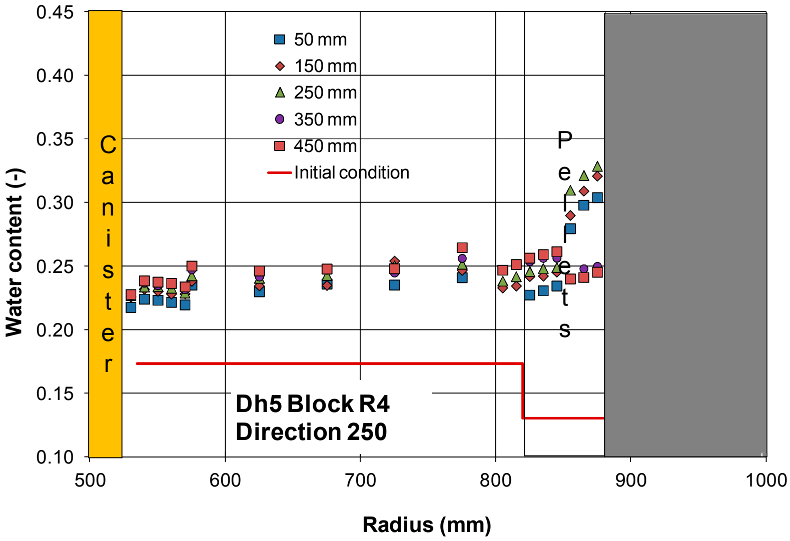
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R4, Dh 5

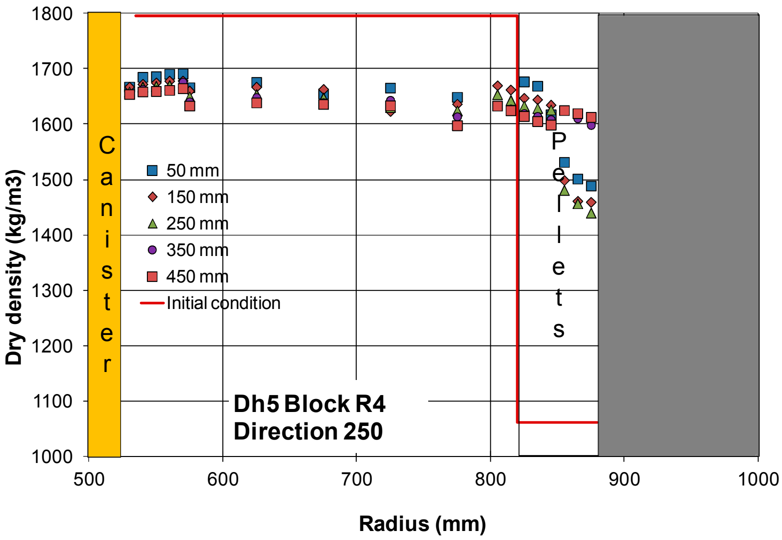


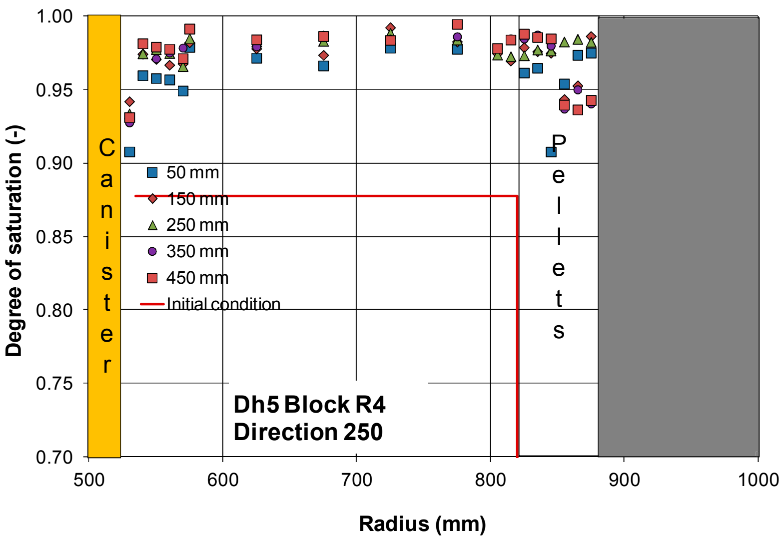



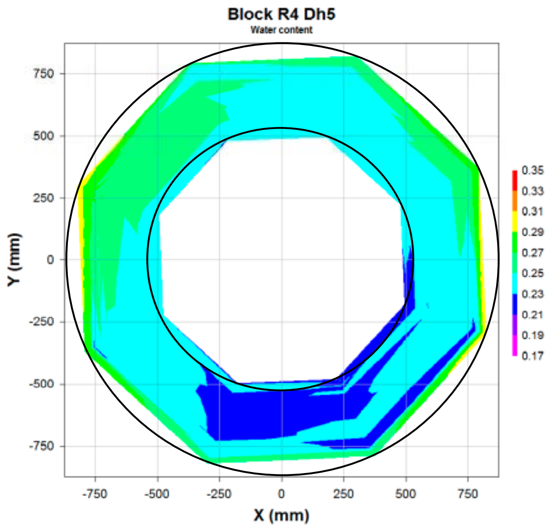
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R4, Dh 5**

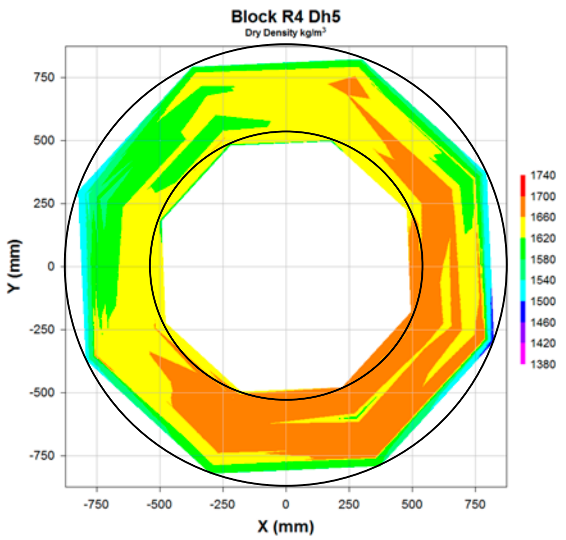


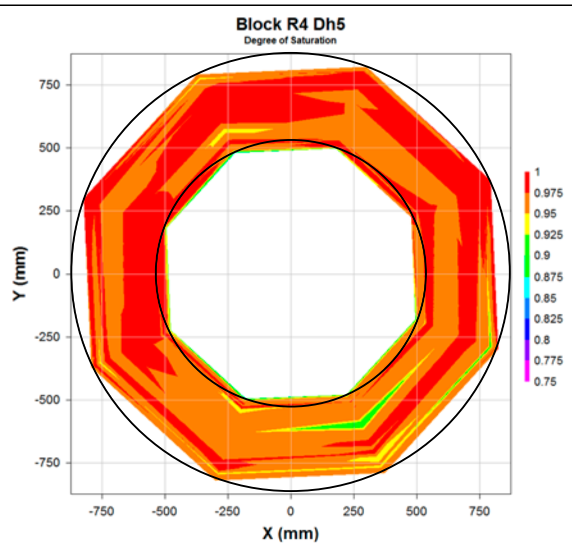



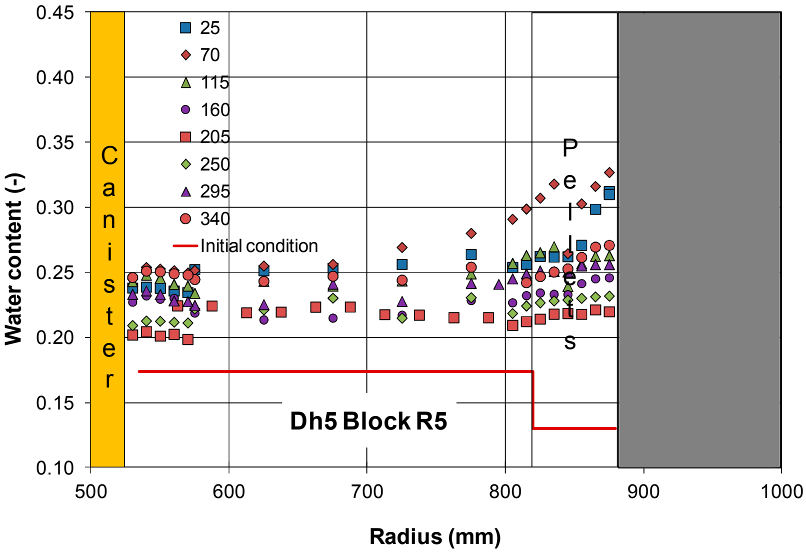
## Contour plots of water content, dry density and degree of saturation block R4, Dh 5

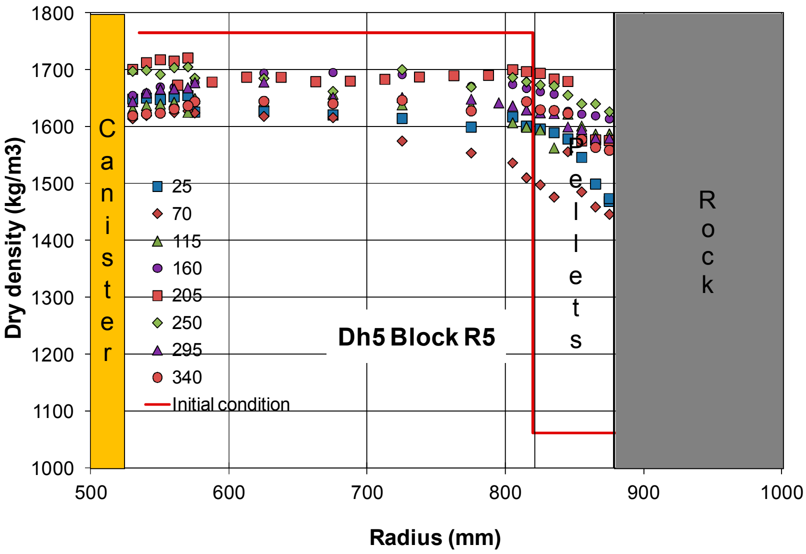


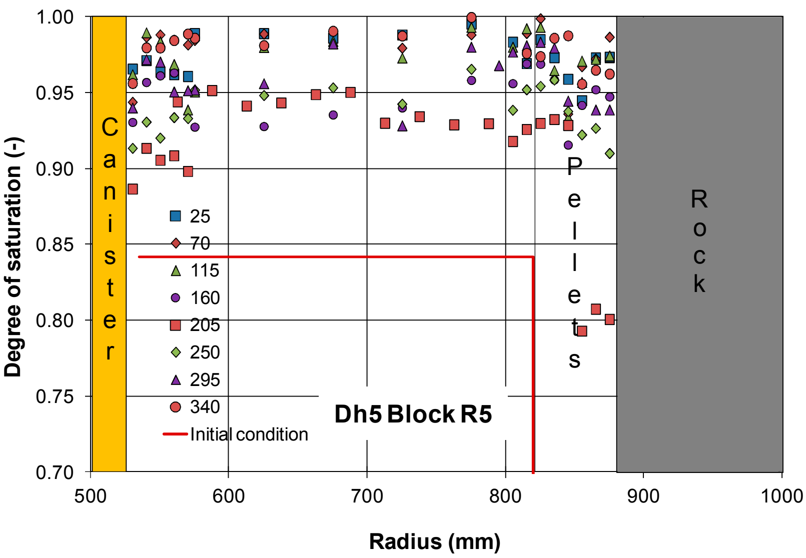



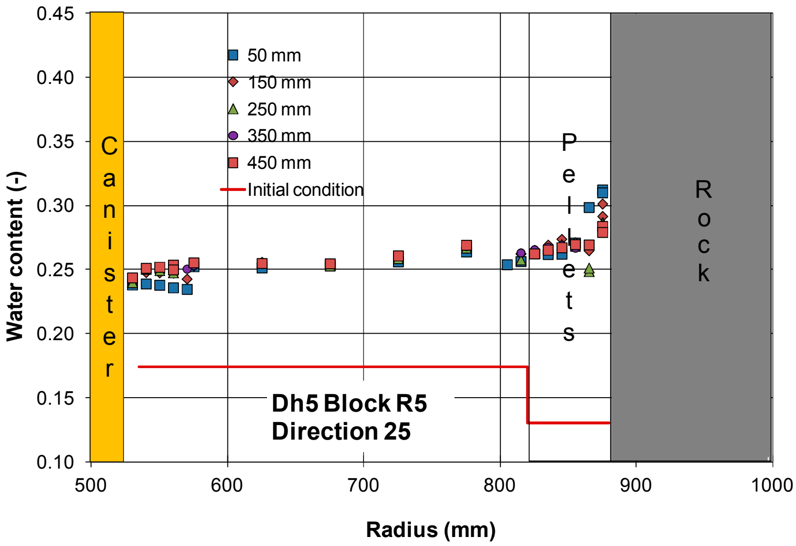
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R5, Dh 5

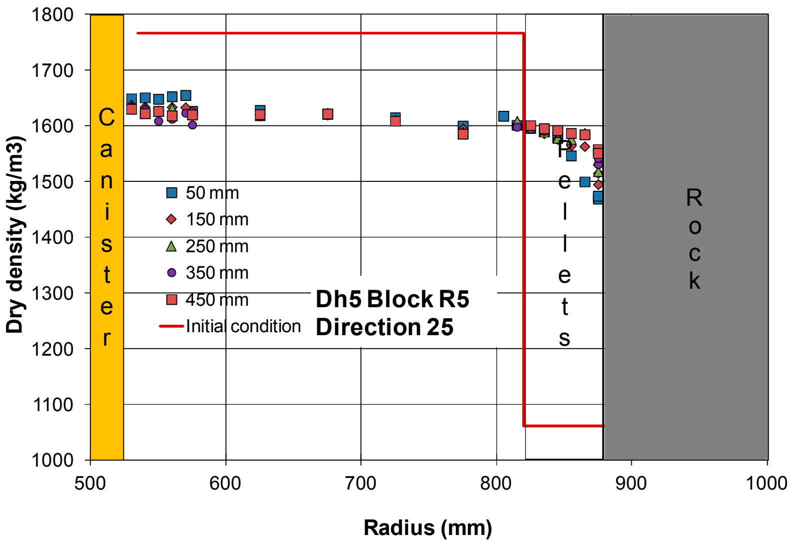


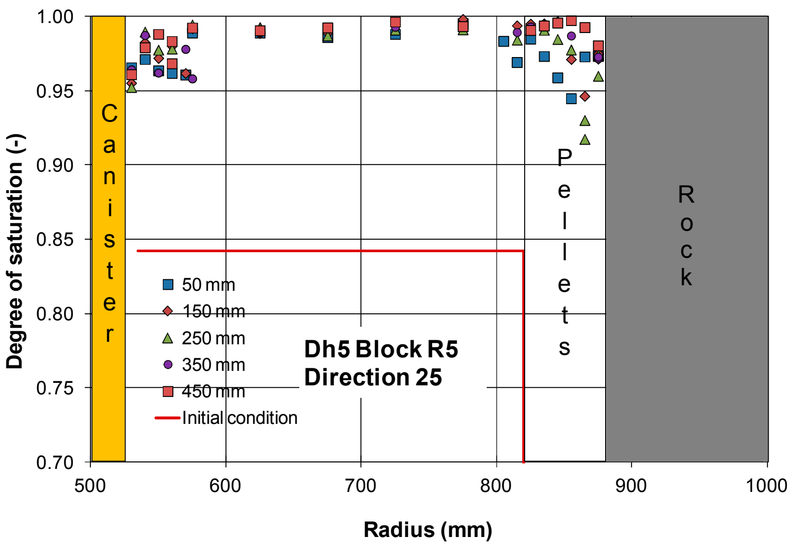



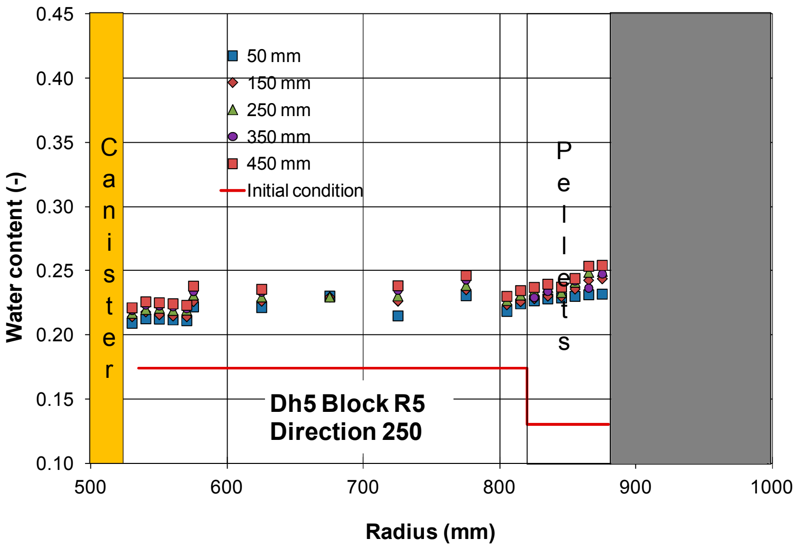
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R5, Dh 5

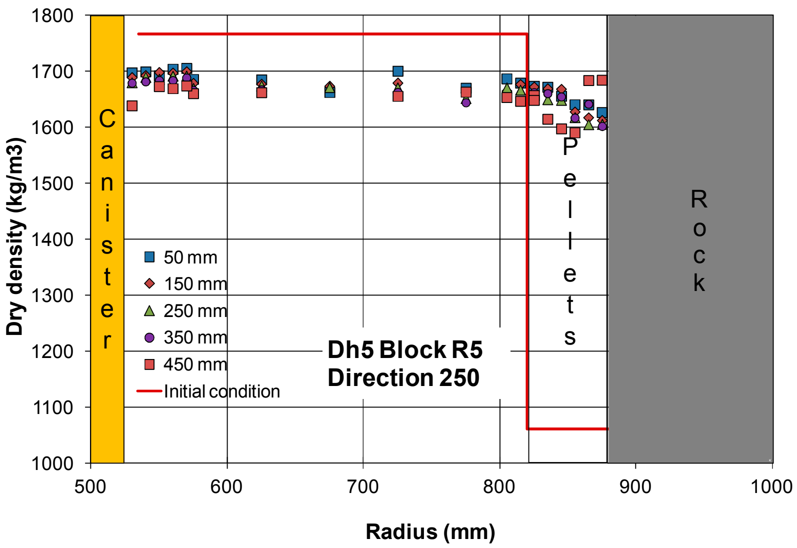


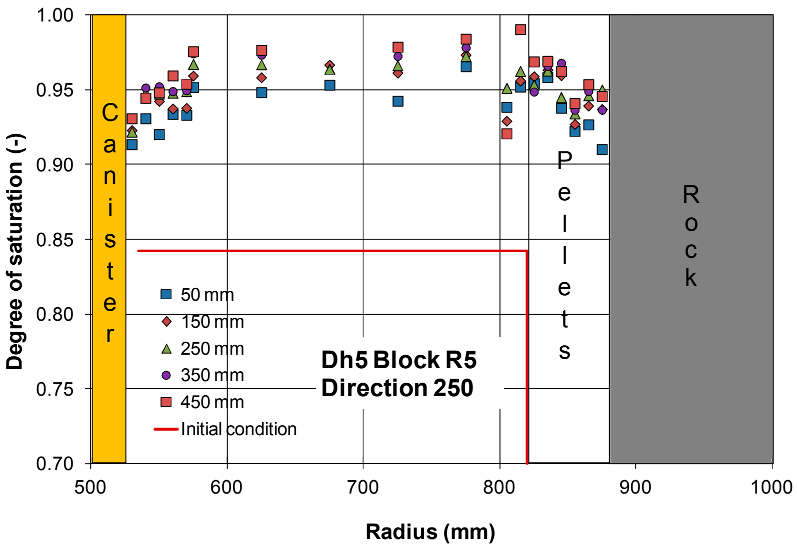



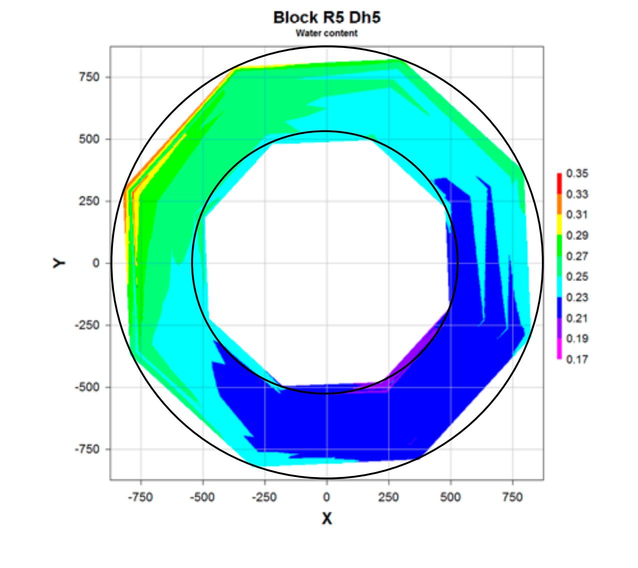
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R5, Dh 5.**

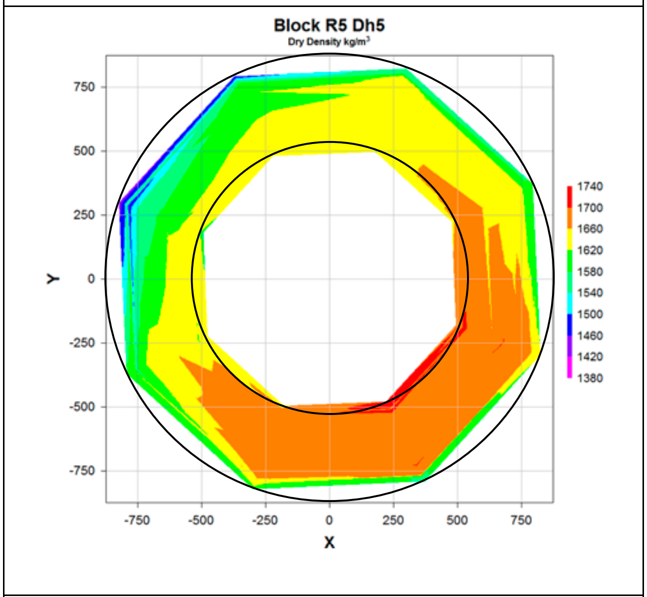


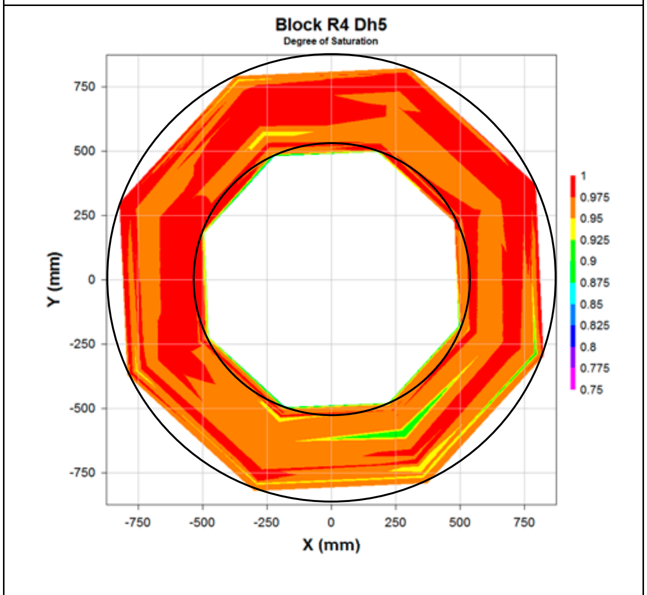



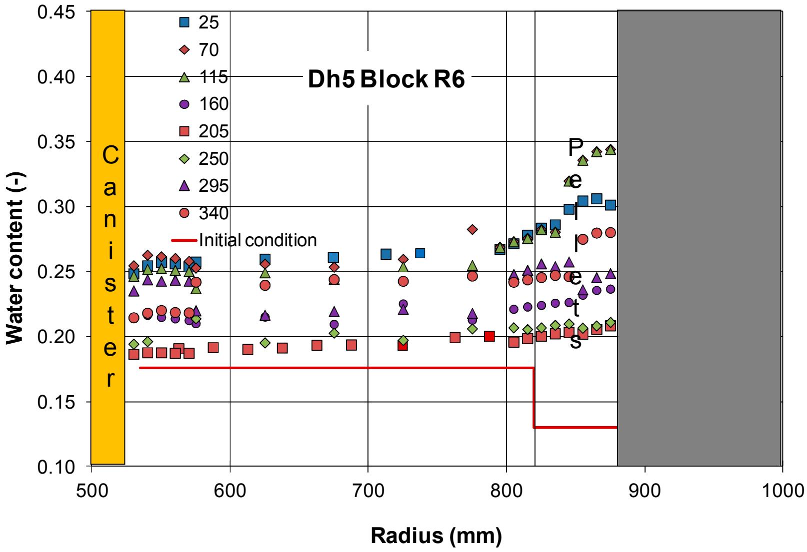
## Contour plots of water content, dry density and degree of saturation block R5, Dh 5

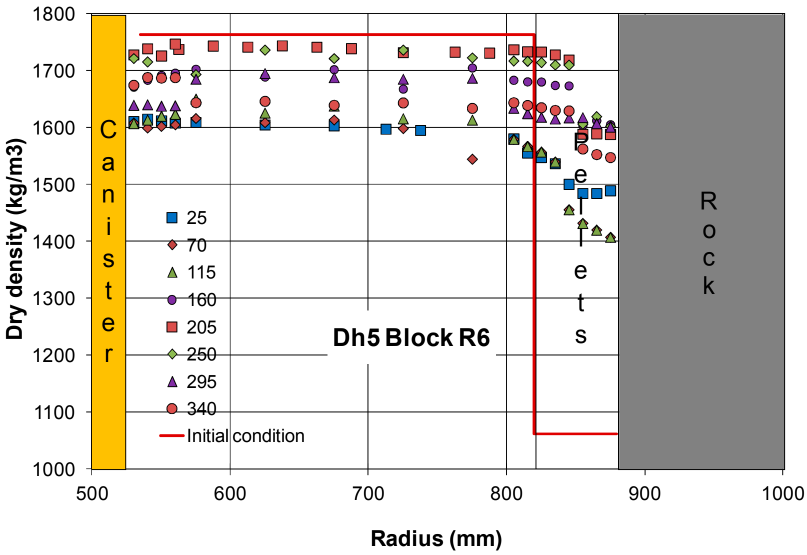


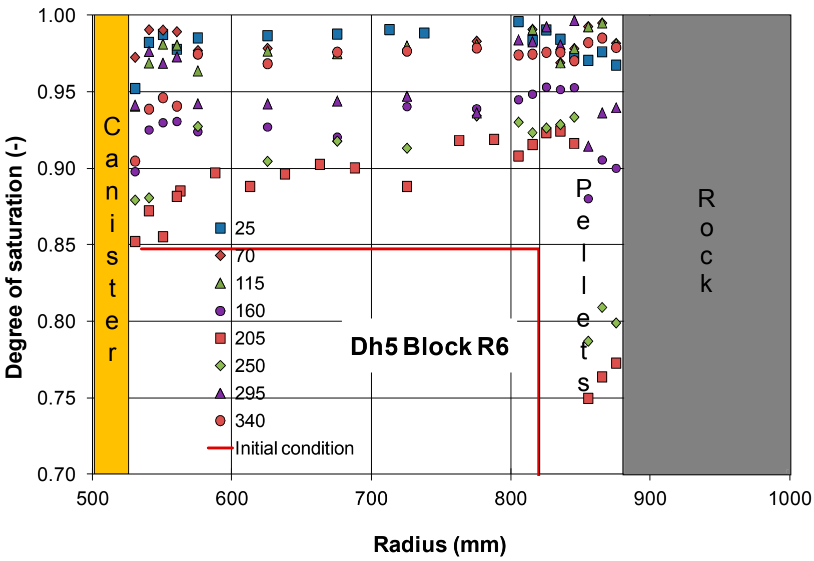



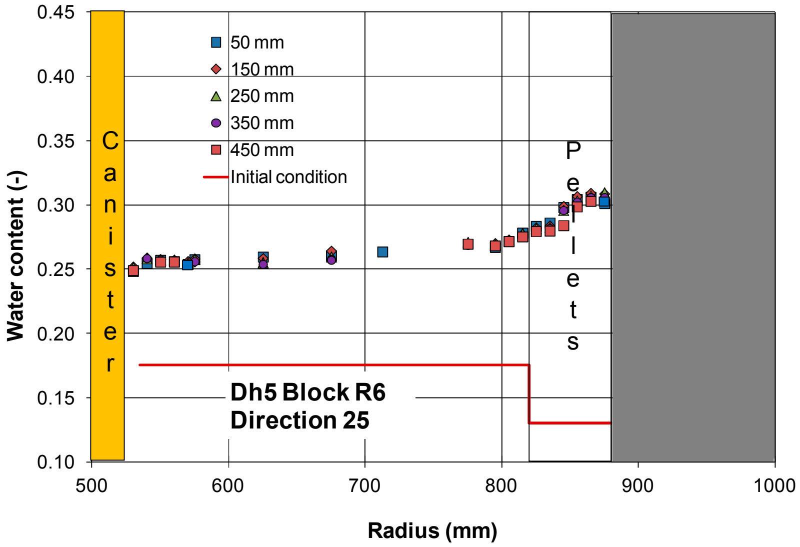
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R6, Dh 5

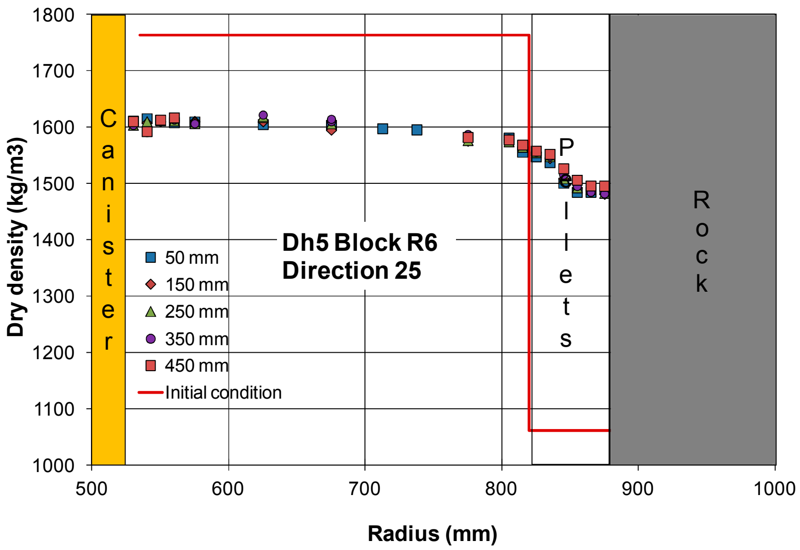


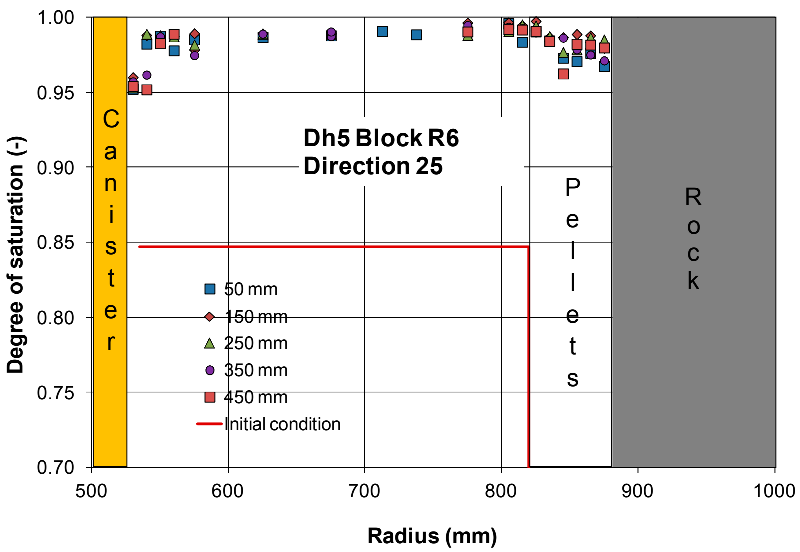



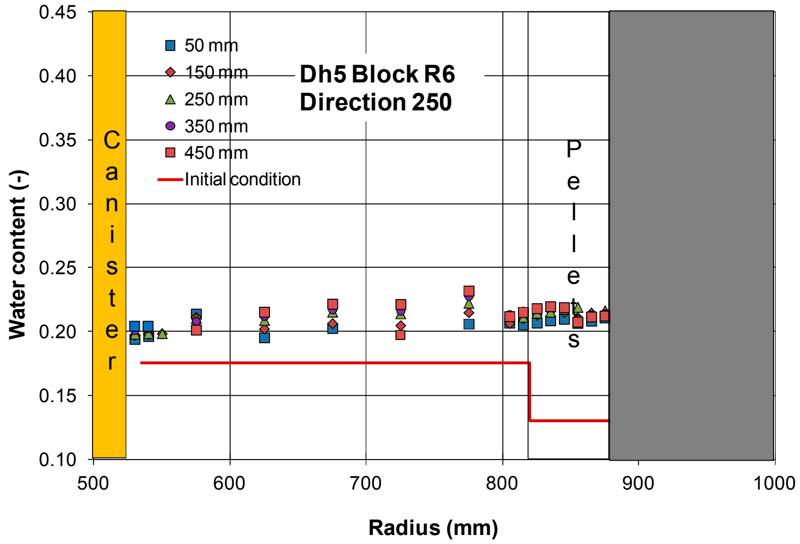
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R6, Dh 5

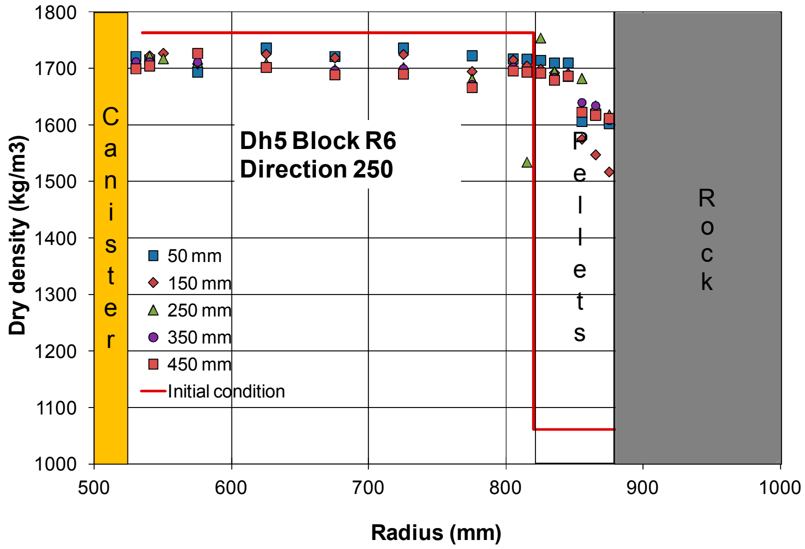


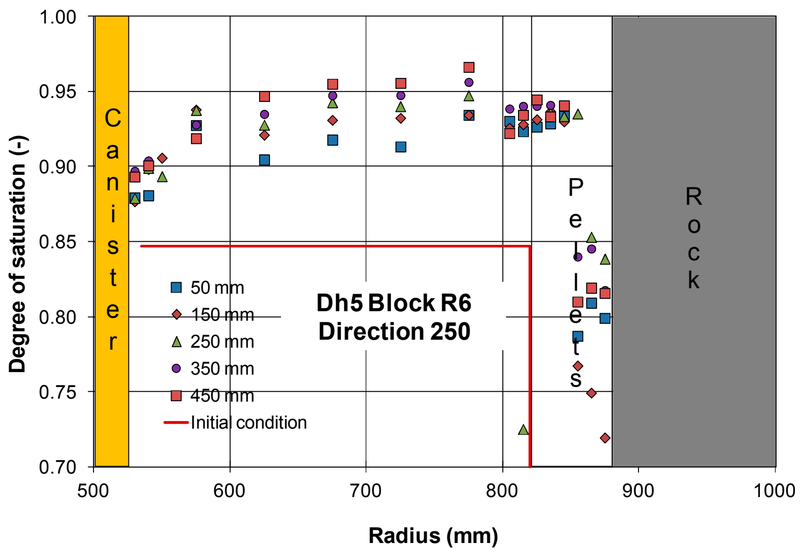



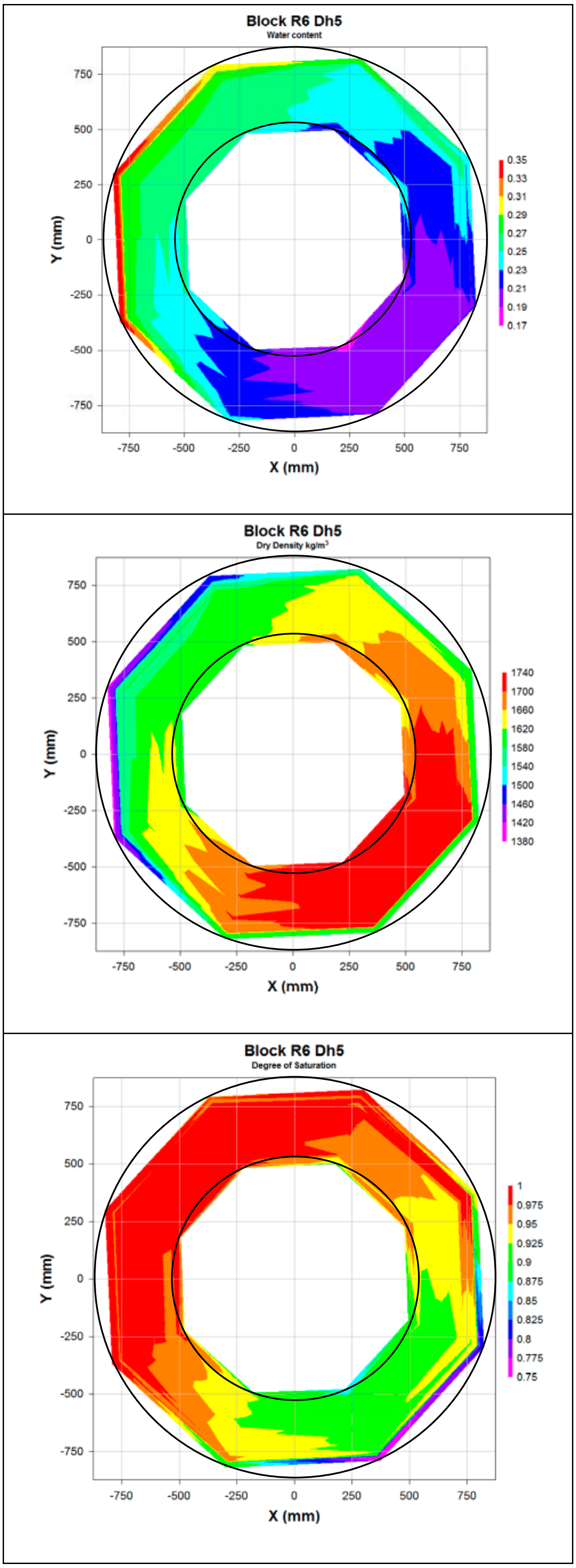
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R6, Dh 5



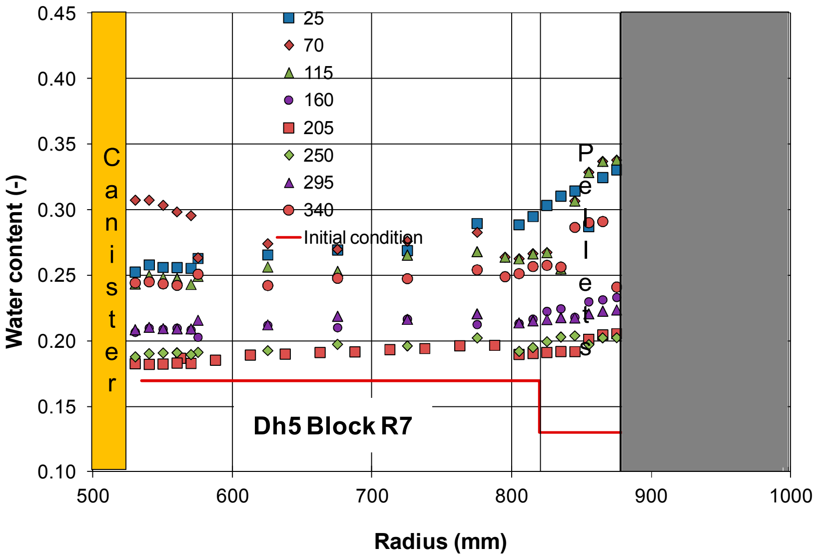



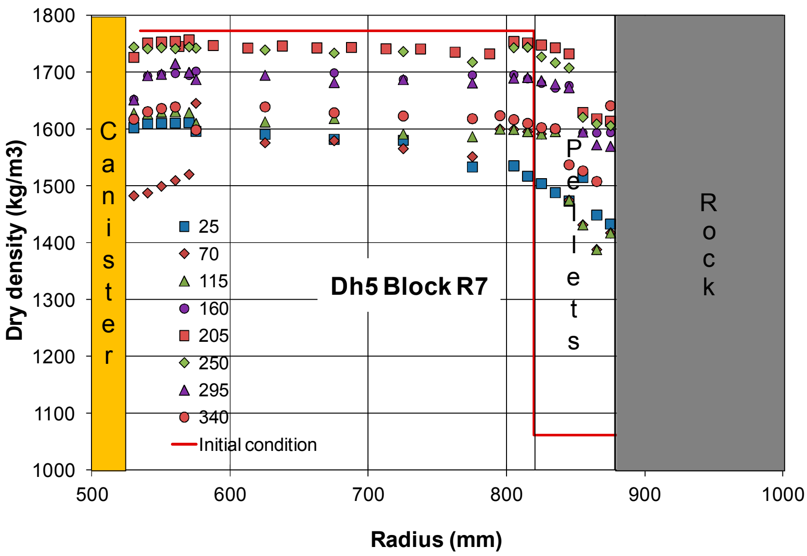
## Contour plots of water content, dry density and degree of saturation block R6, Dh 5

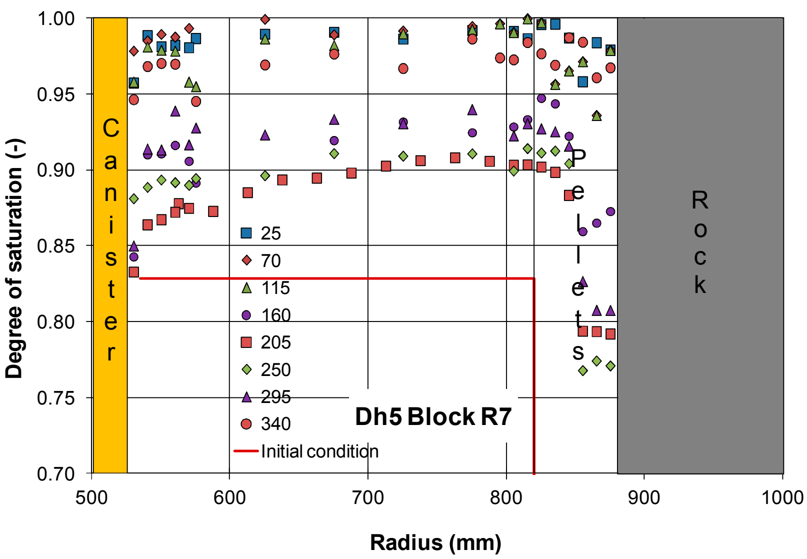


# Appendix 25

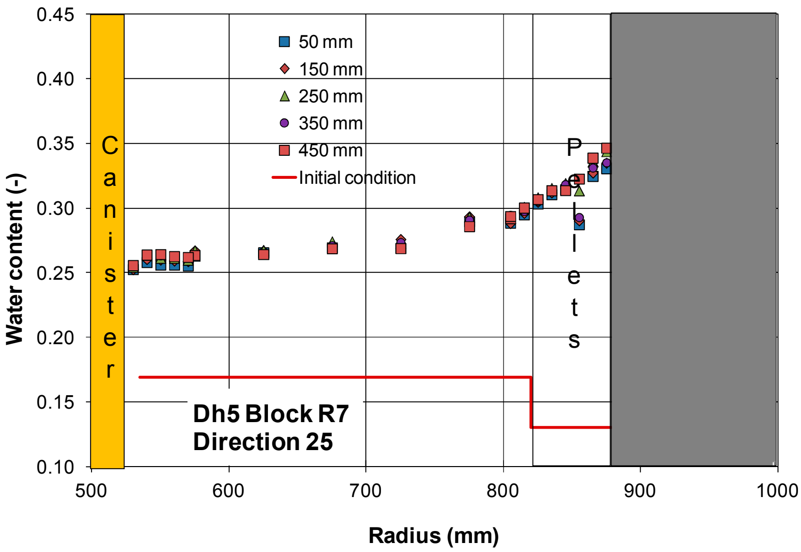
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R7, Dh 5

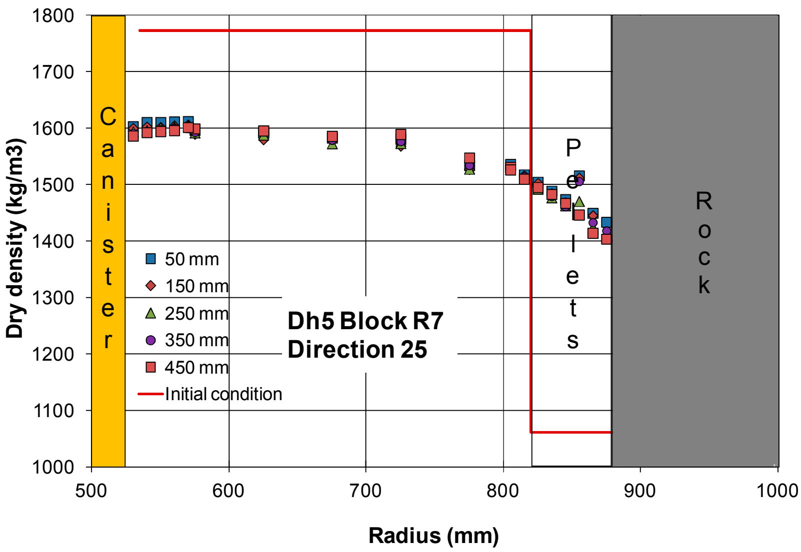


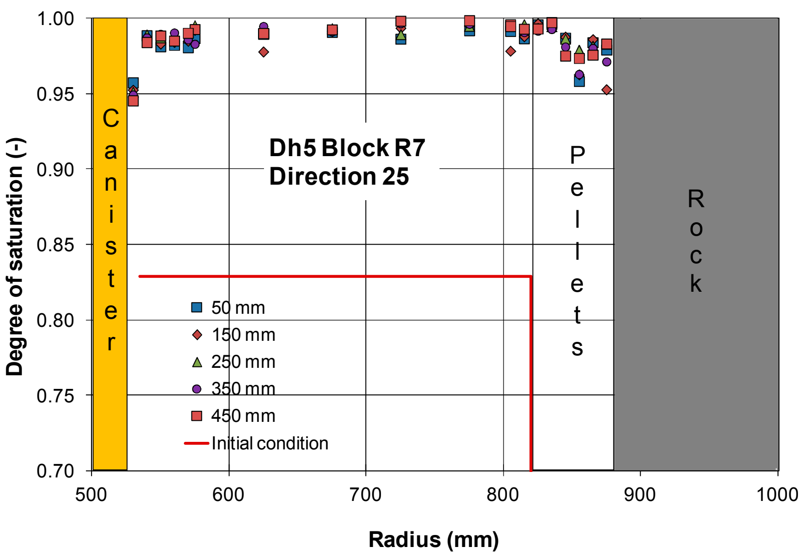



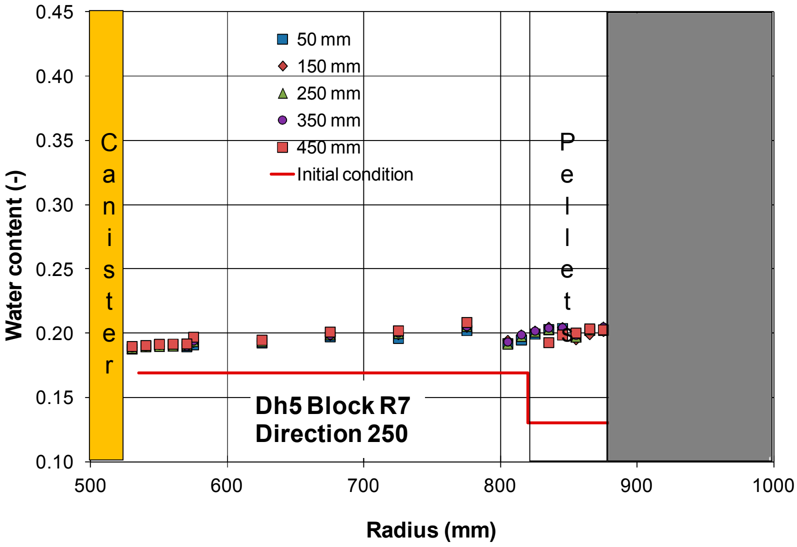
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R7, Dh 5

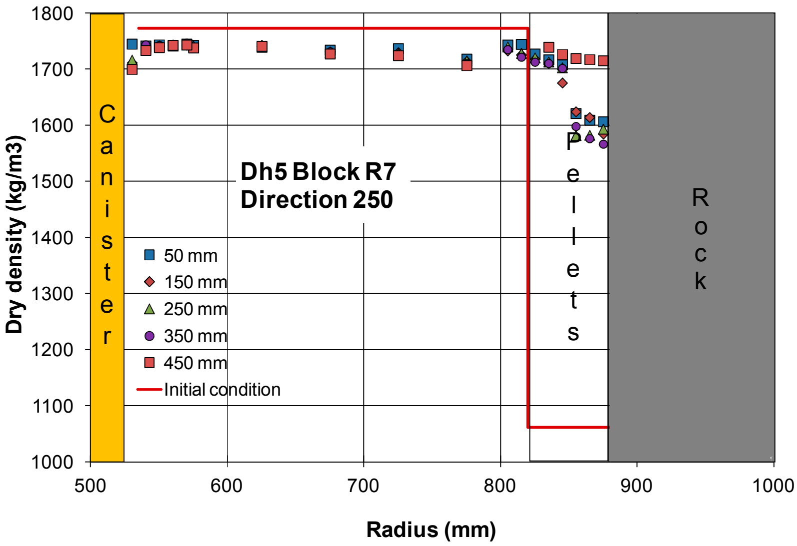


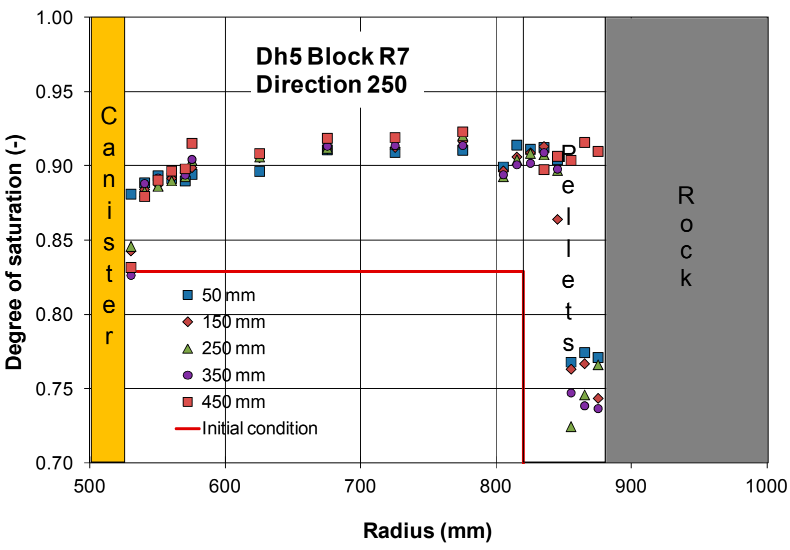



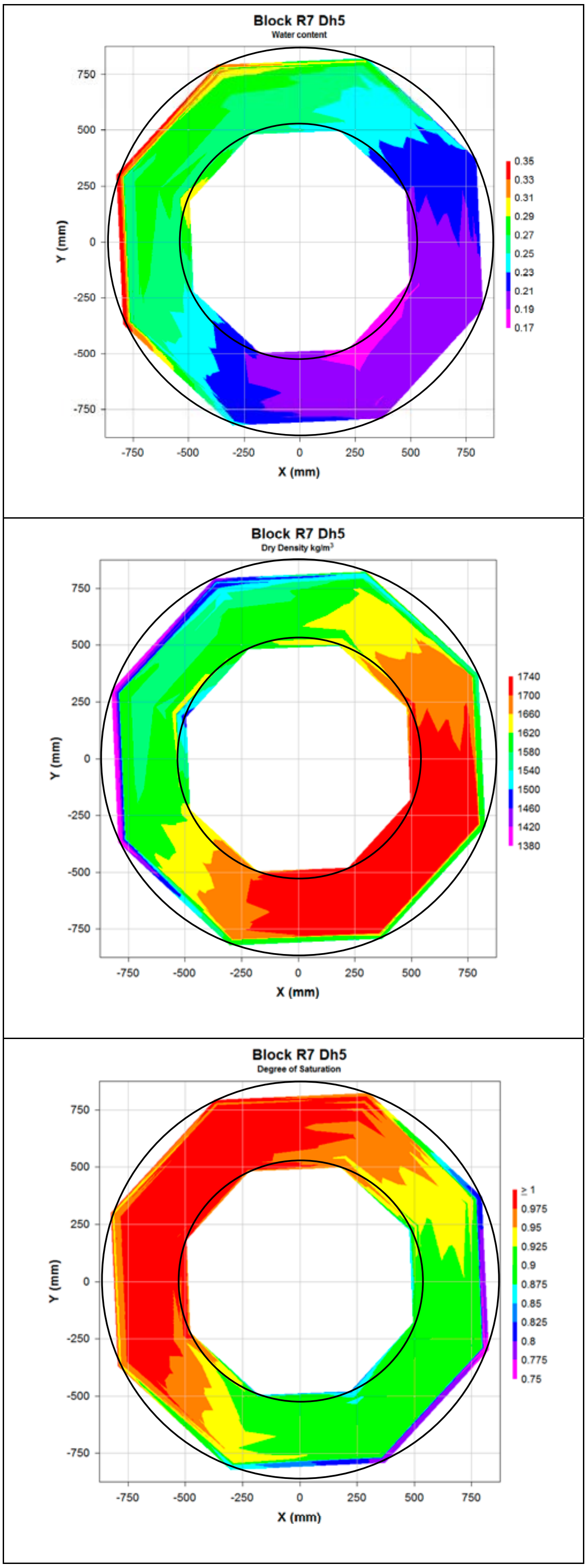
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R7, Dh 5



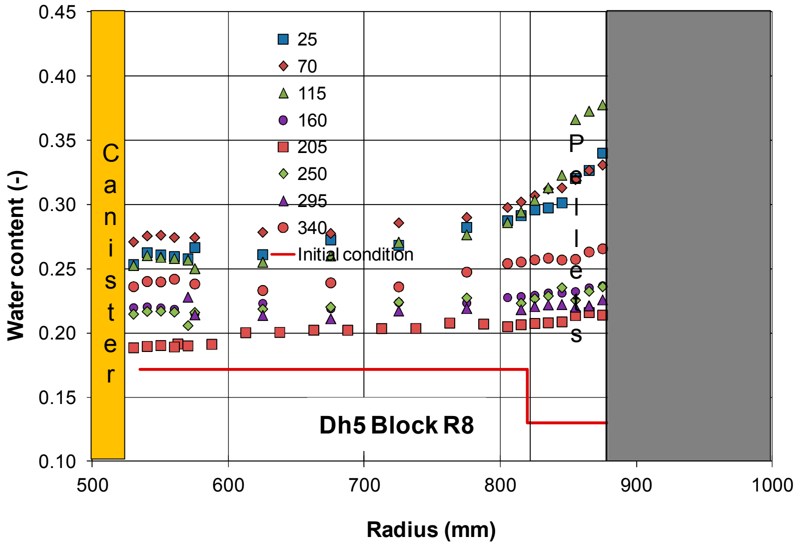



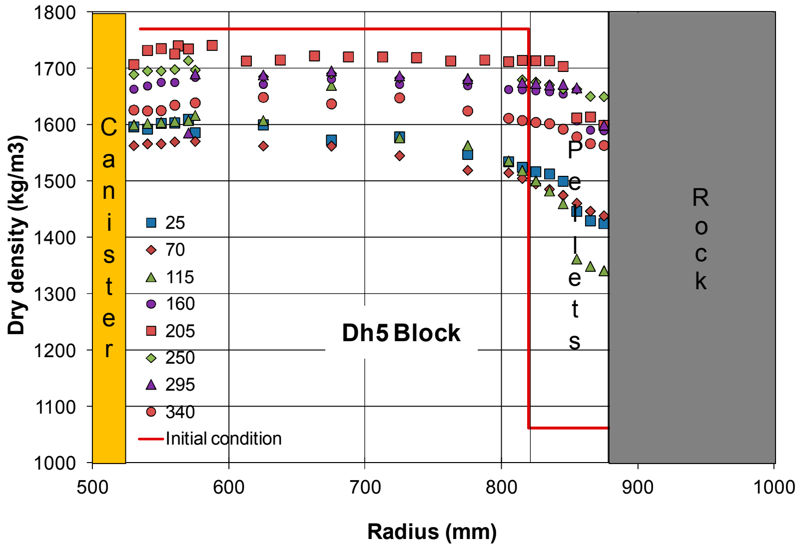



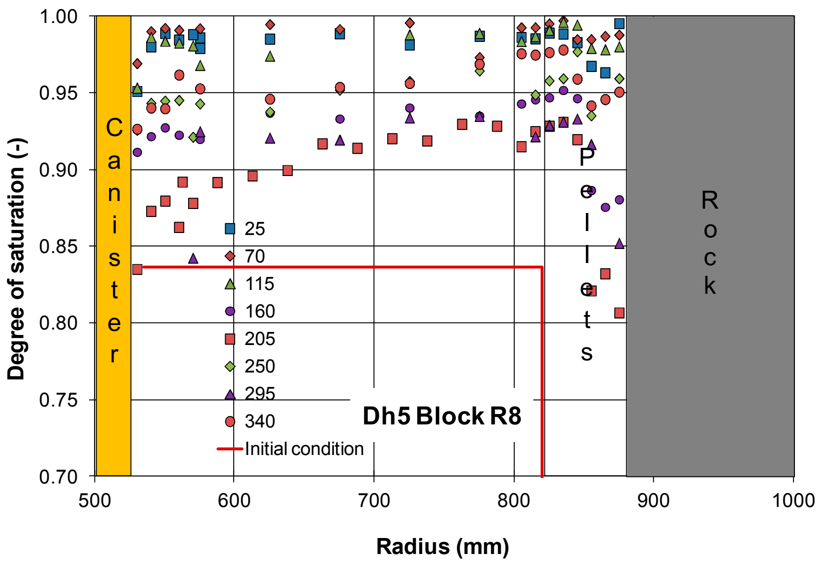
## Contour plots of water content, dry density and degree of saturation block R7, Dh 5



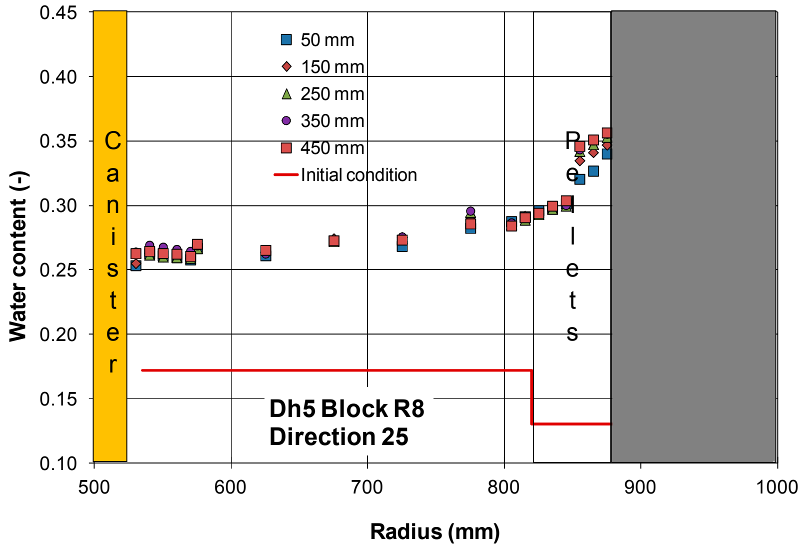
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R8, Dh 5

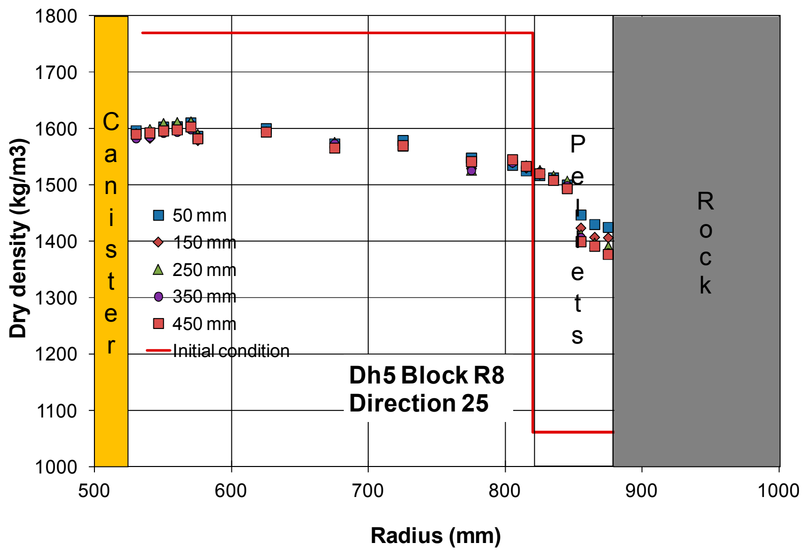


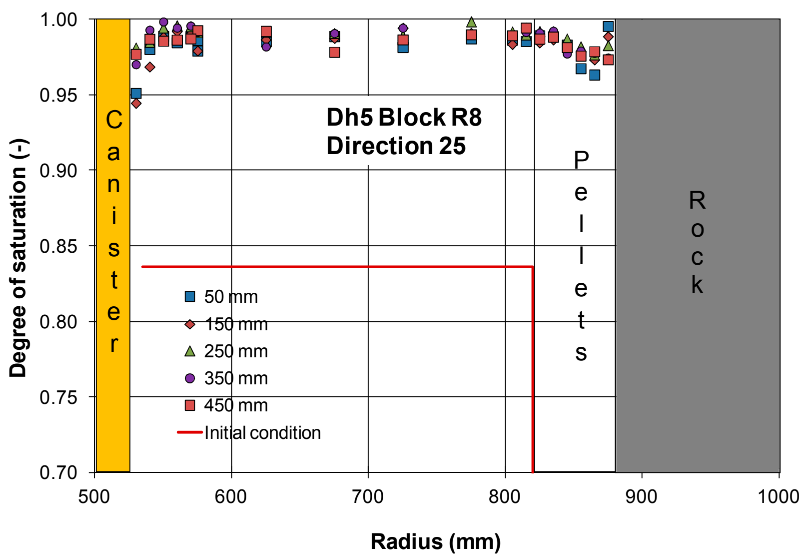



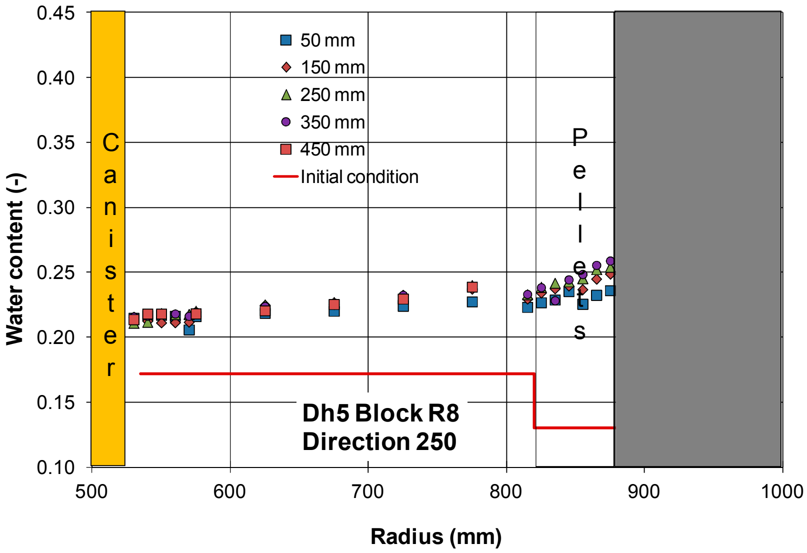
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R8, Dh 5

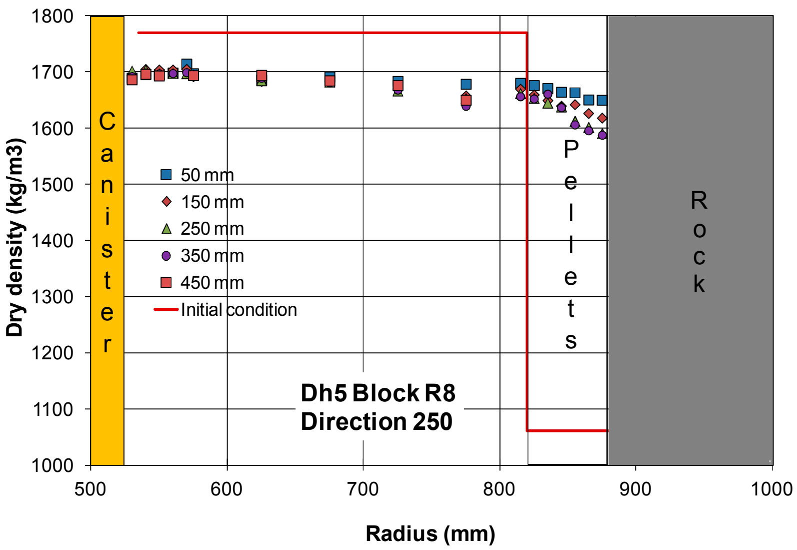


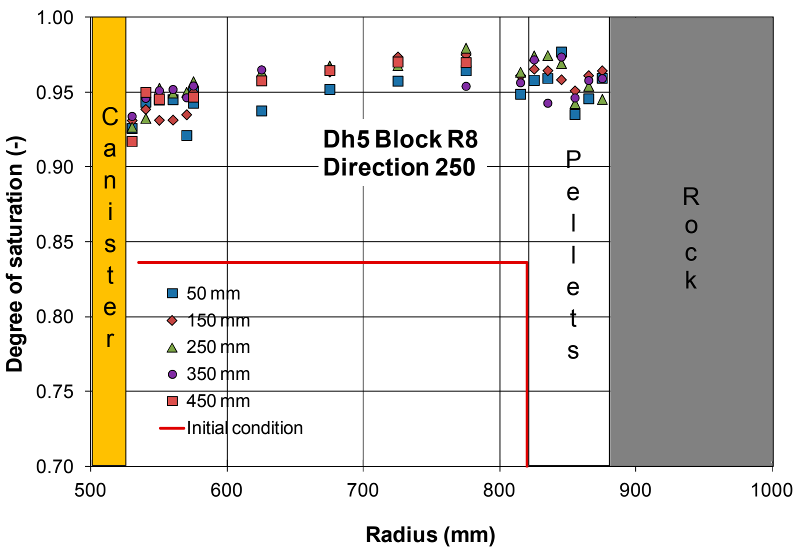



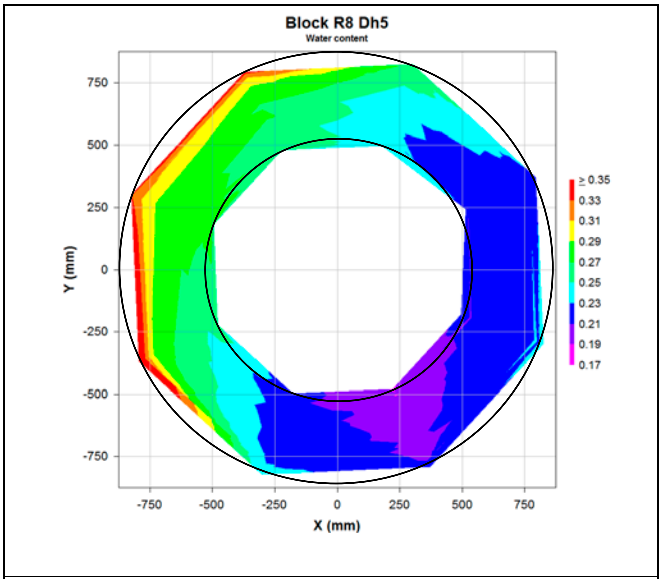
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R8, Dh 5**

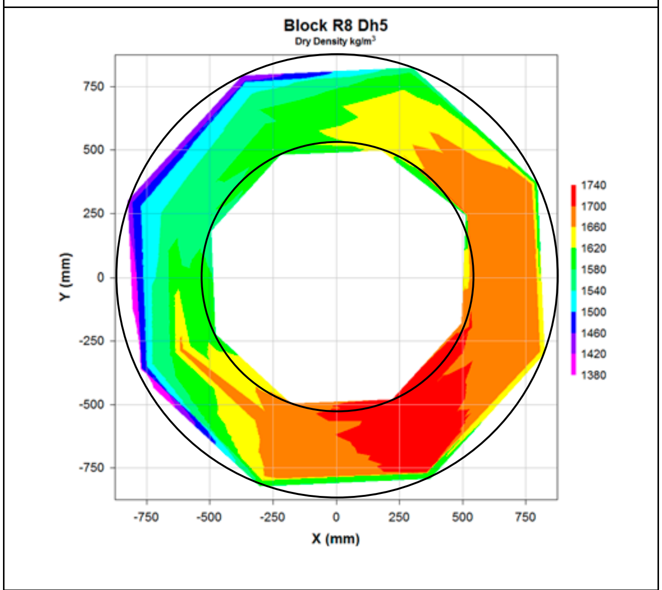


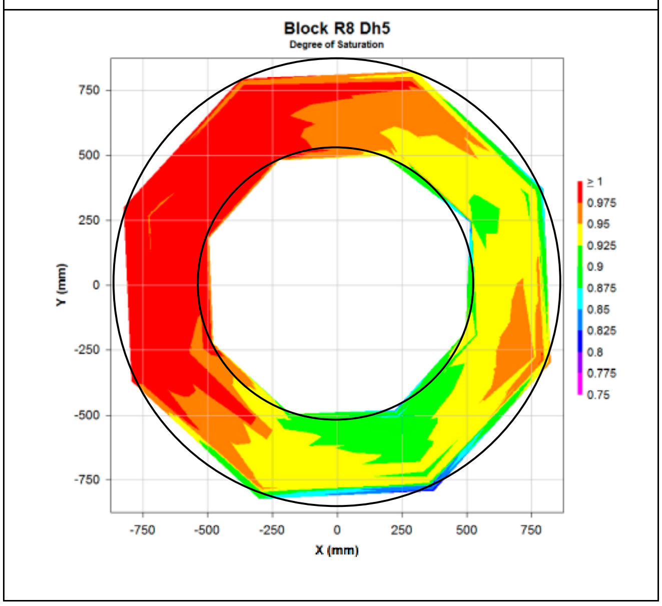



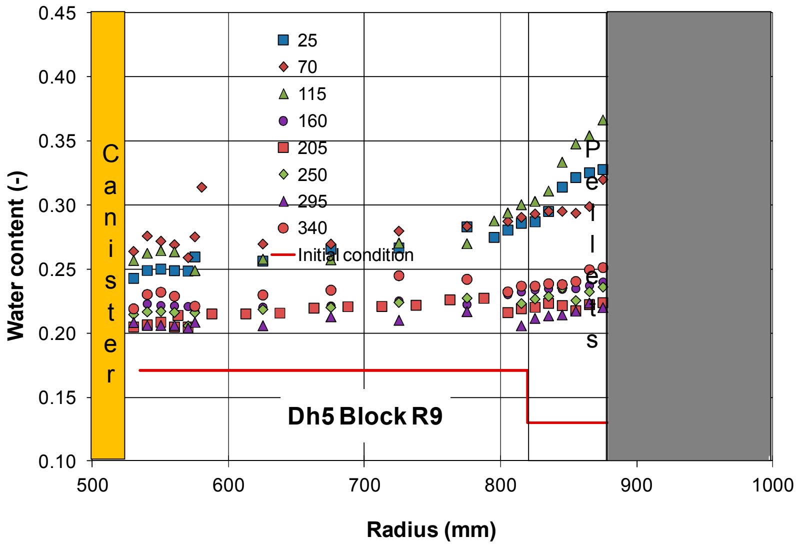
## Contour plots of water content, dry density and degree of saturation block R8, Dh 5

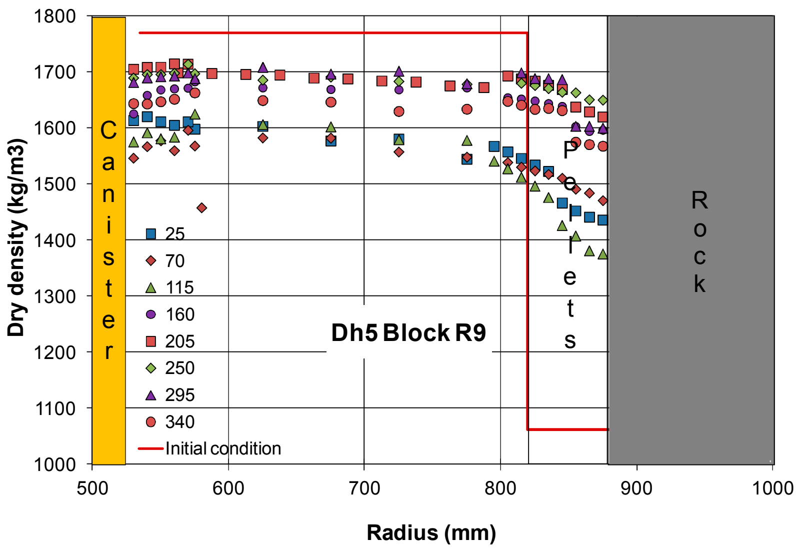


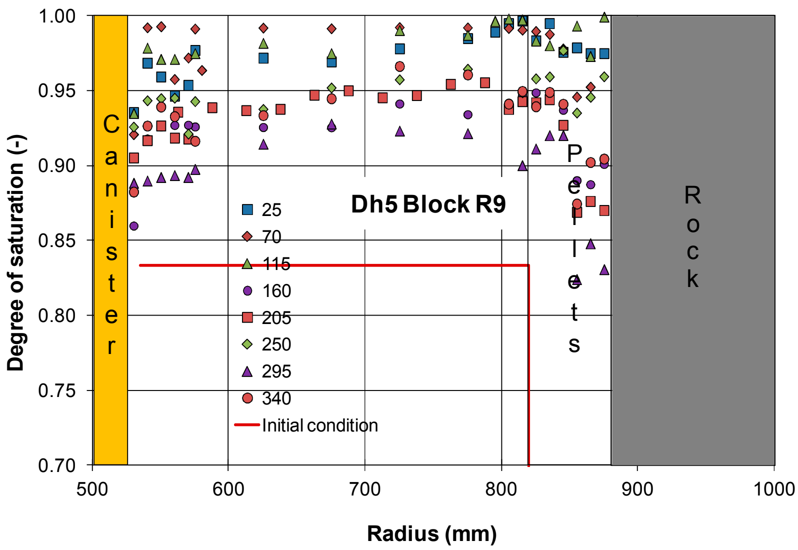



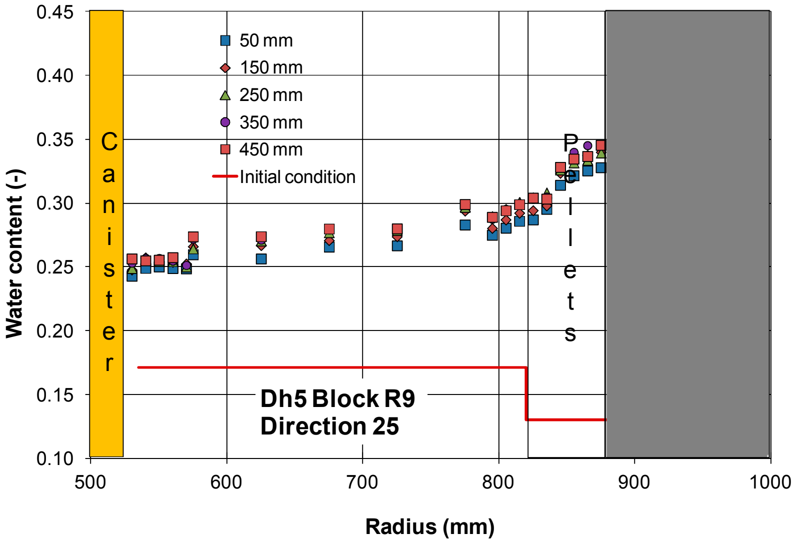
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R9, Dh 5

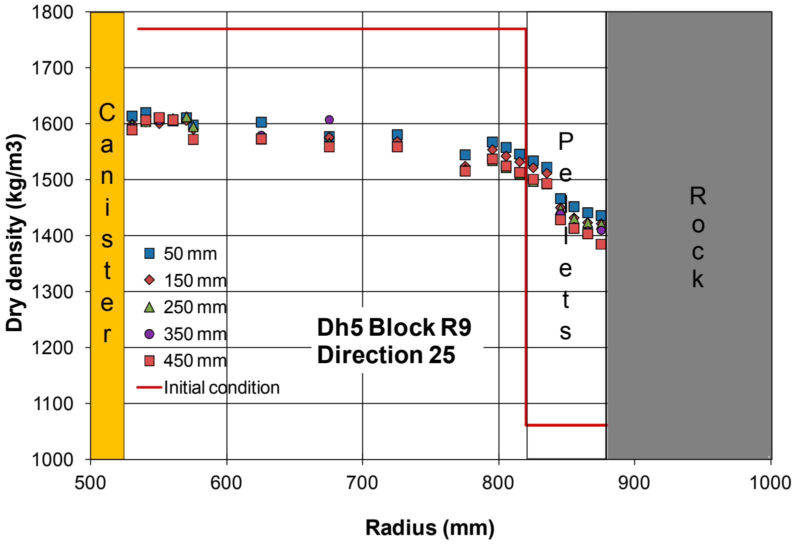


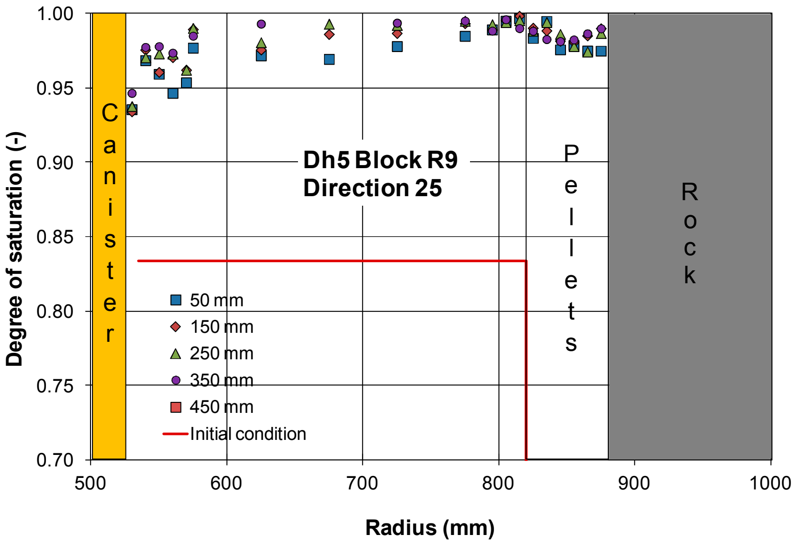



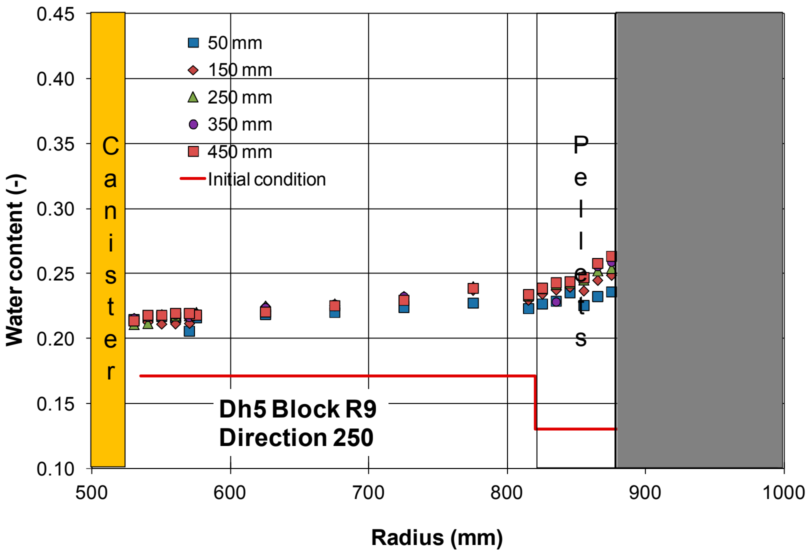
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R9, Dh 5**

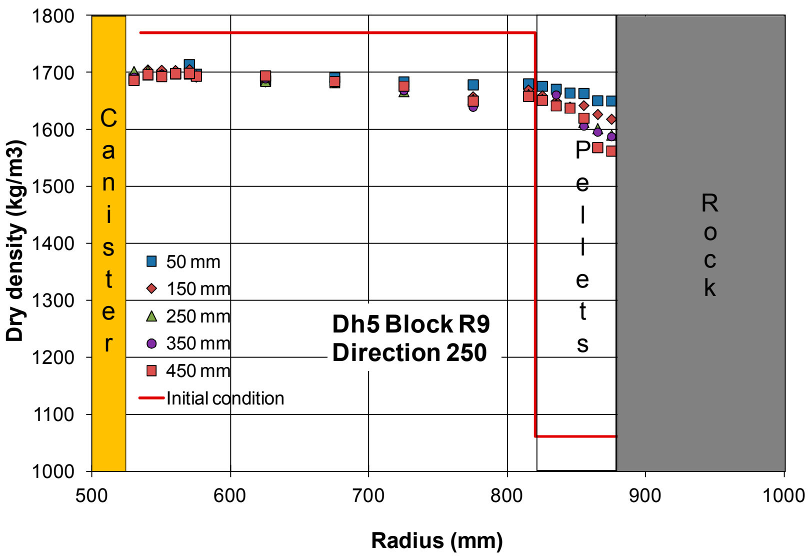


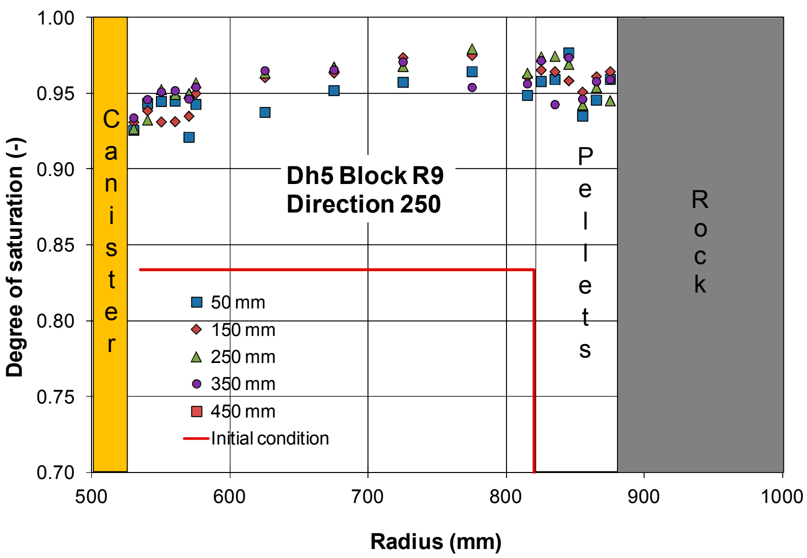



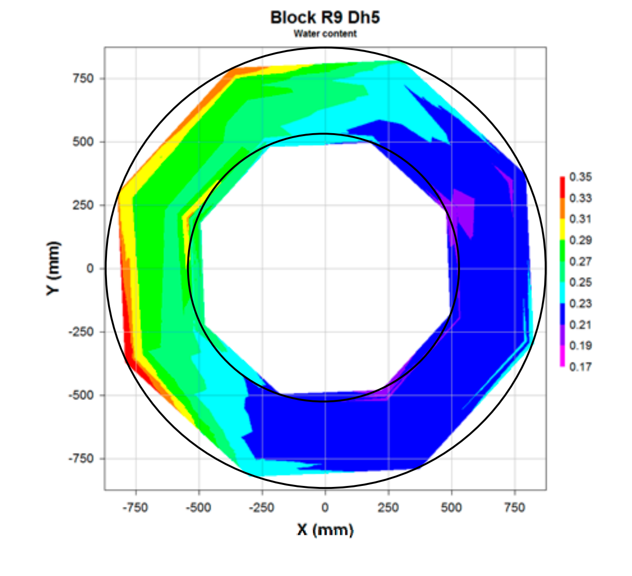
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R9, Dh 5**

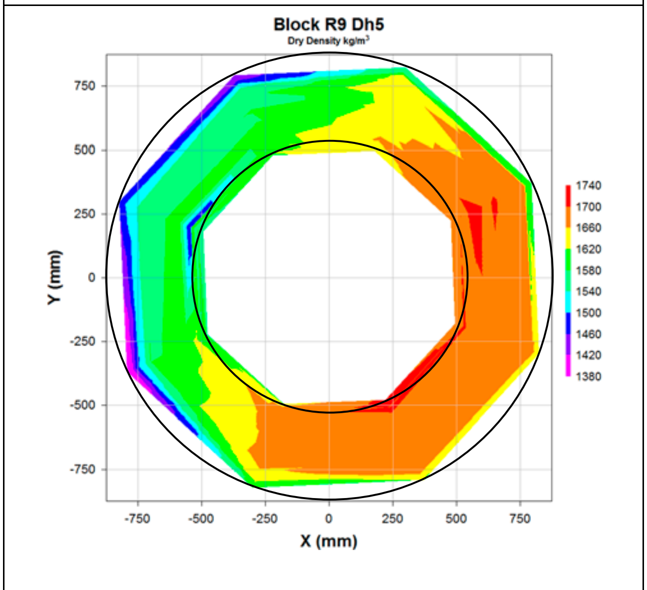


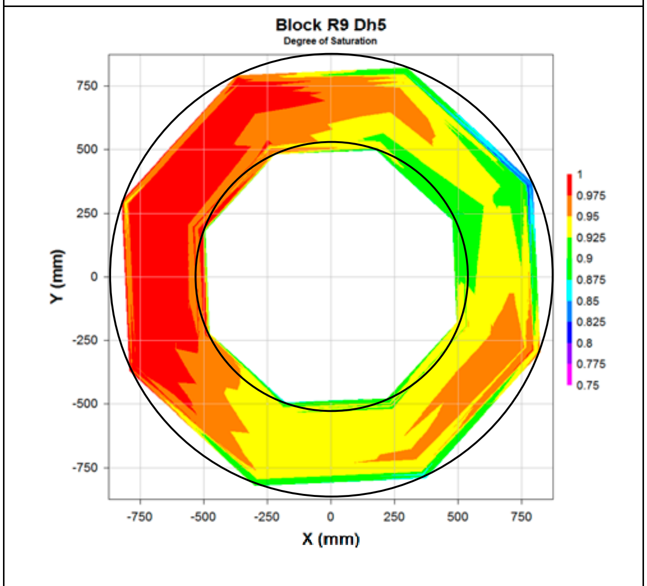



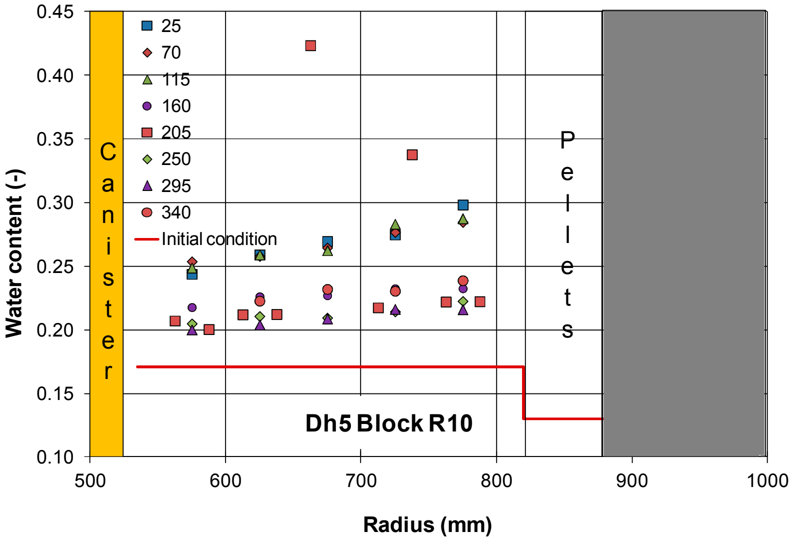
## Contour plots of water content, dry density and degree of saturation block R9, Dh 5

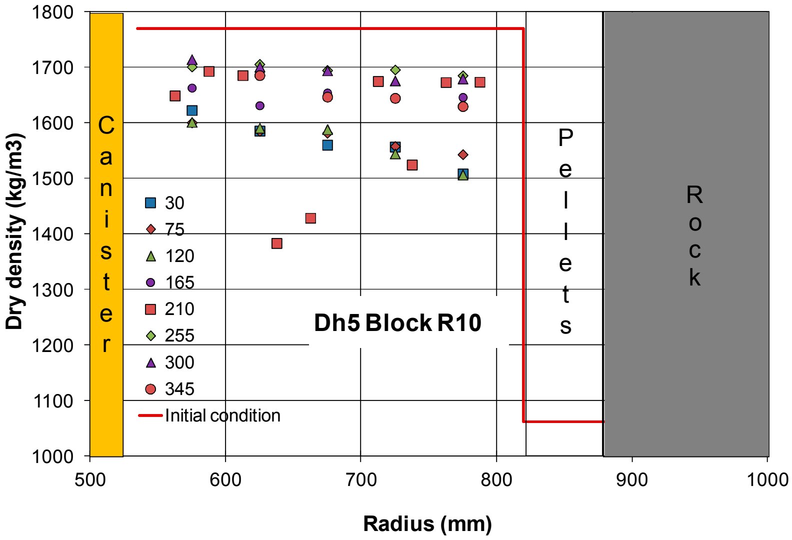


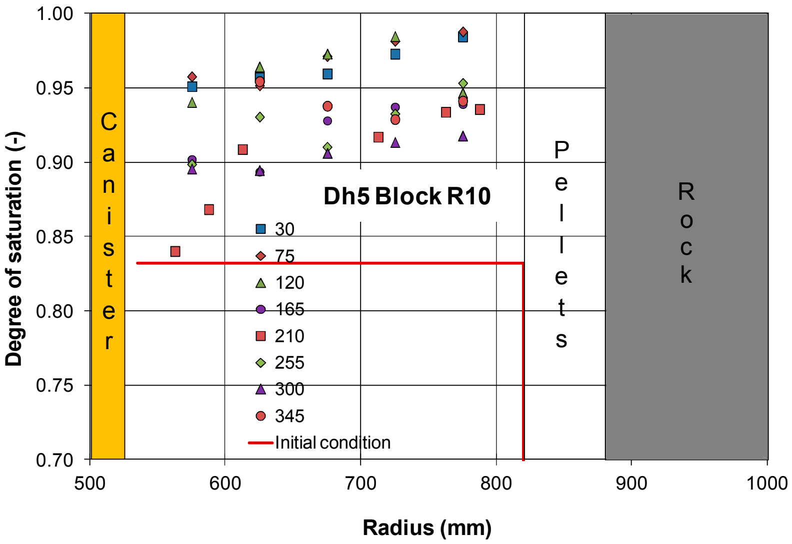



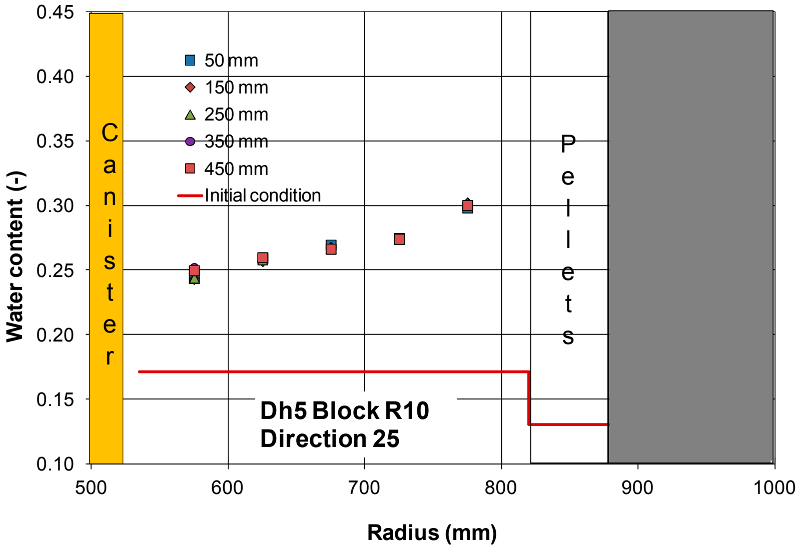
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block R10, Dh 5

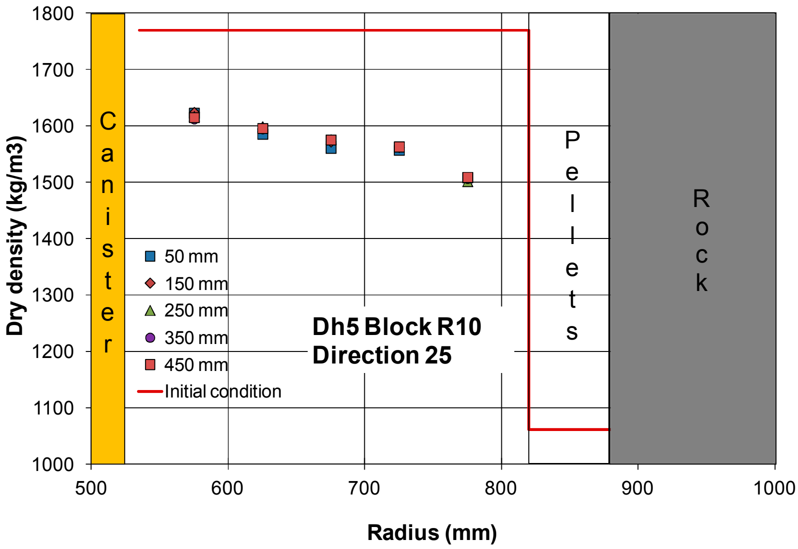


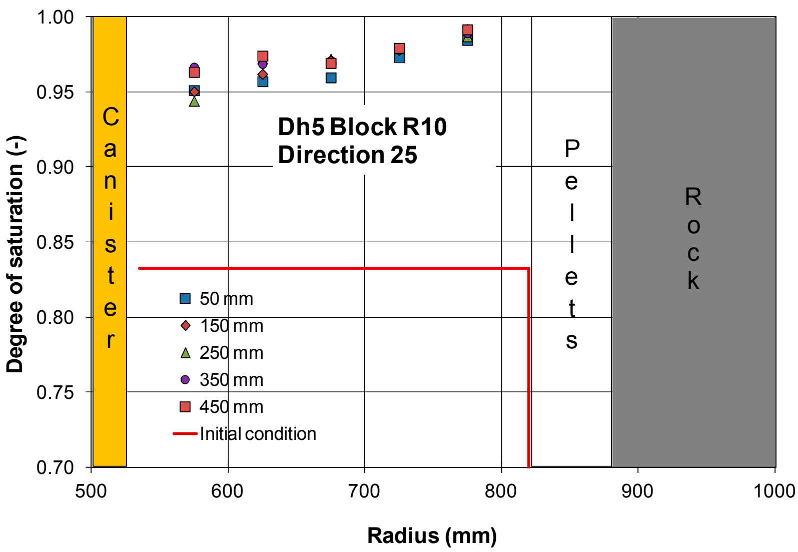



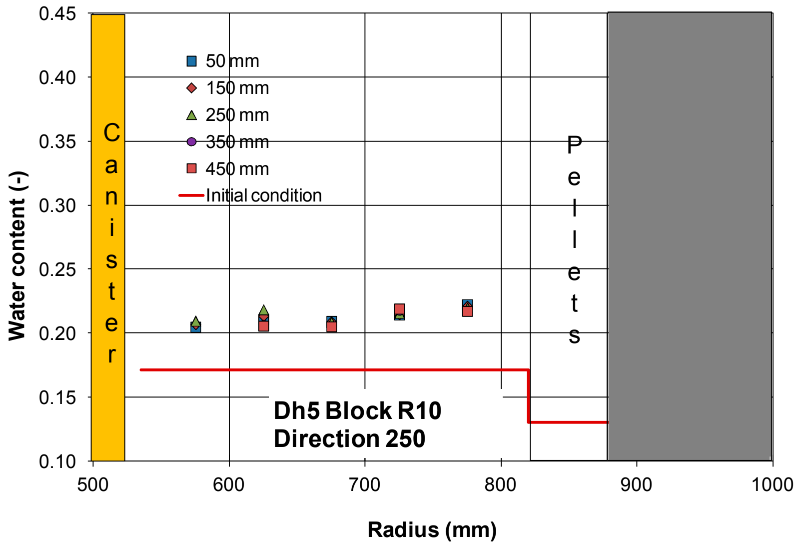
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block R10, Dh 5

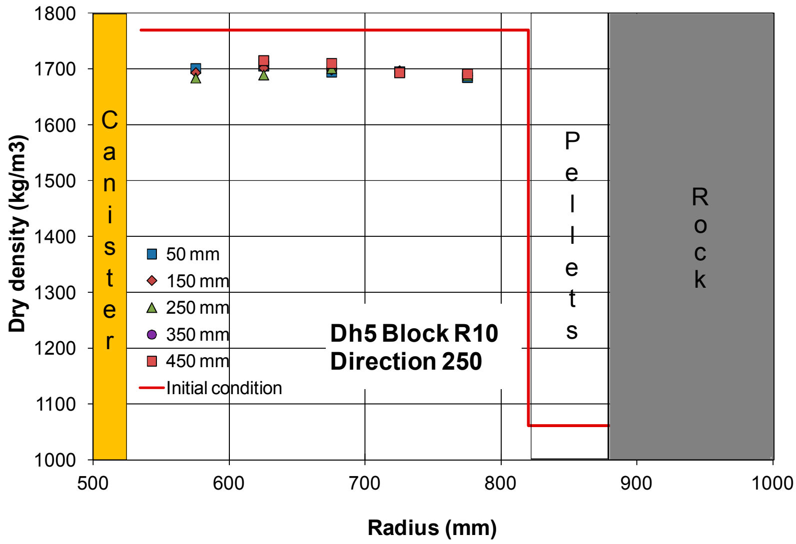


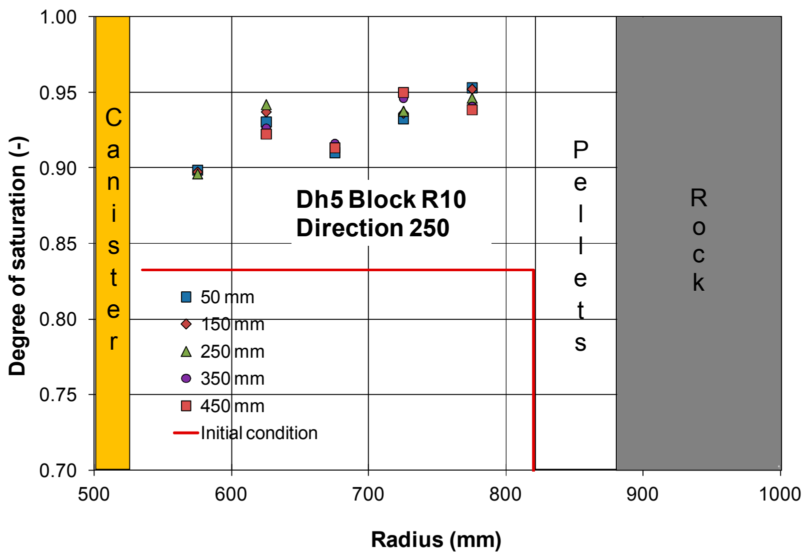



## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block R10, Dh 5

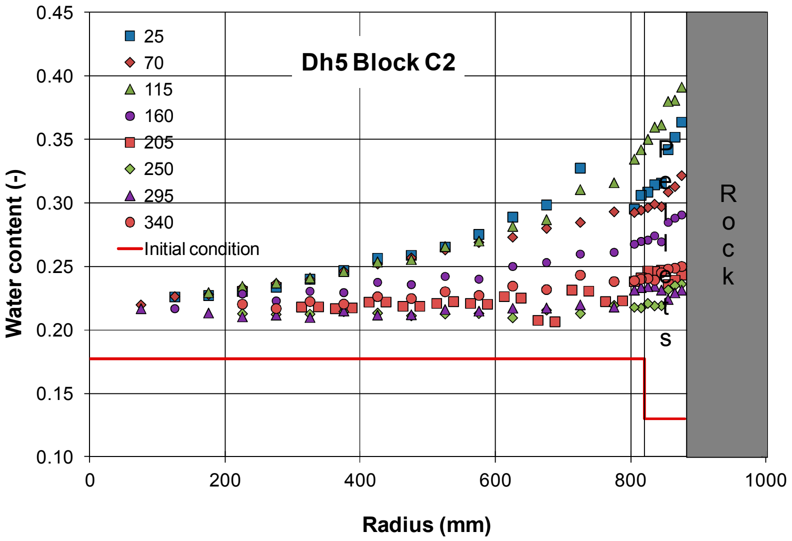


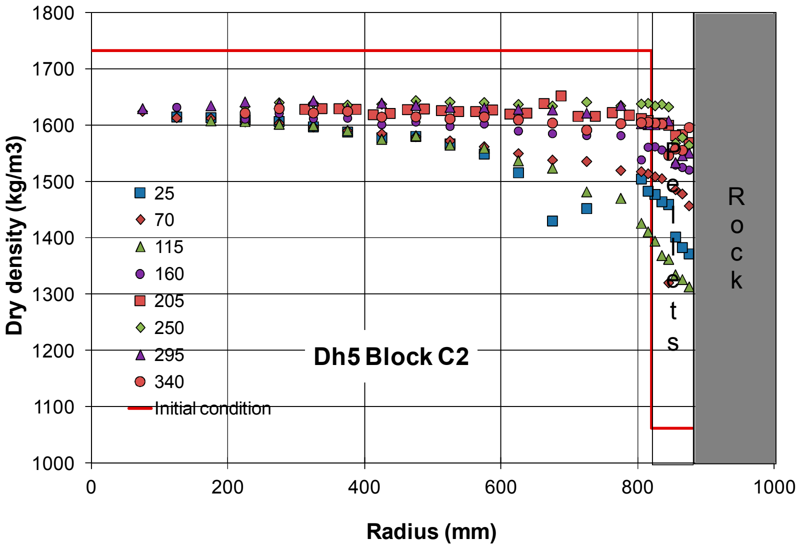



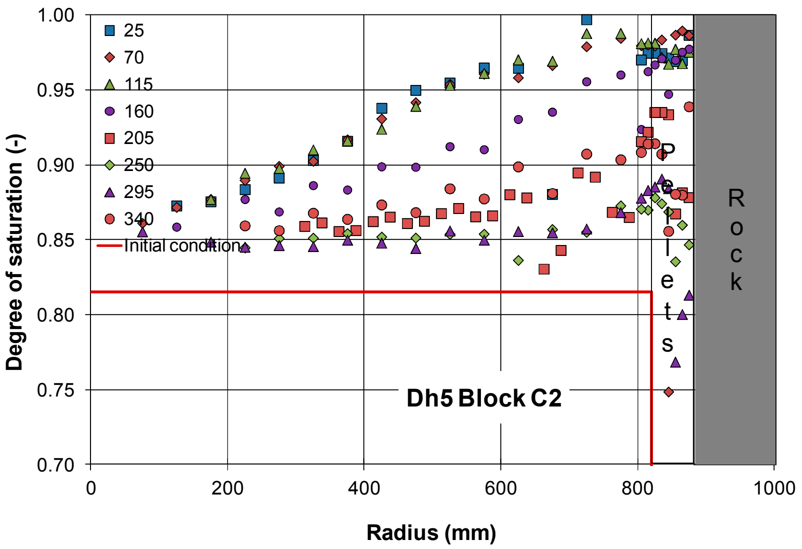



# Appendix 29

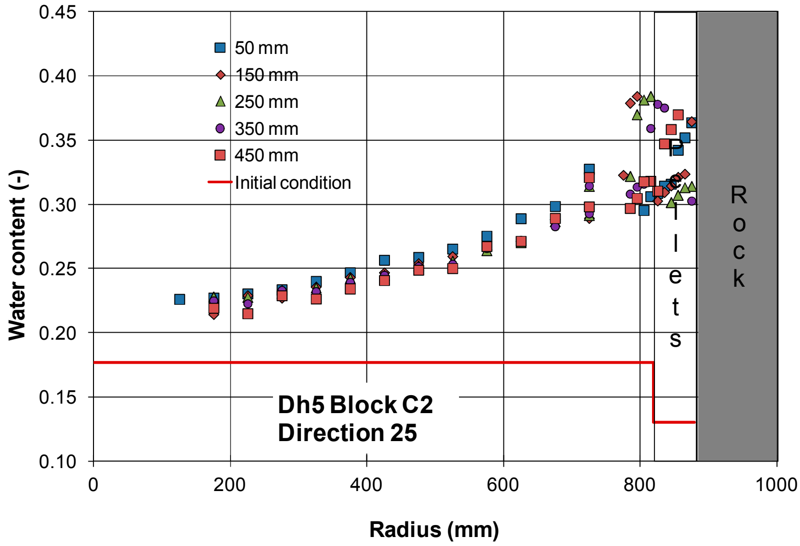
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block C2, Dh 5

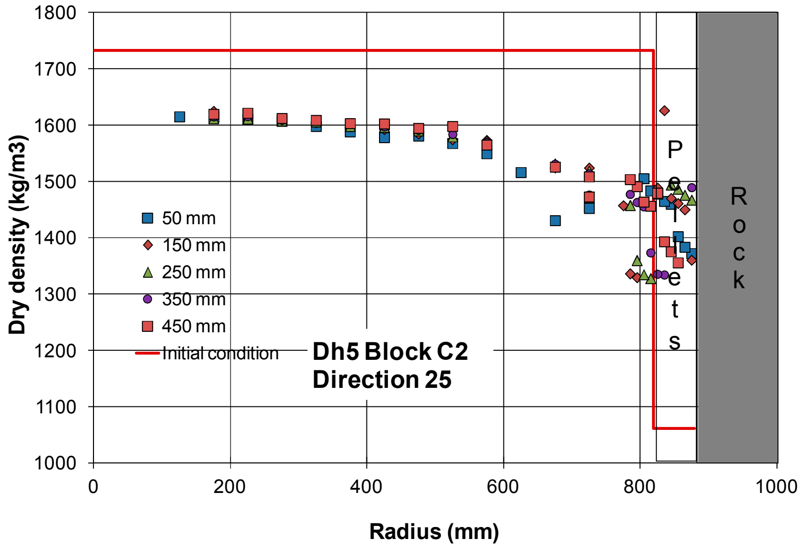


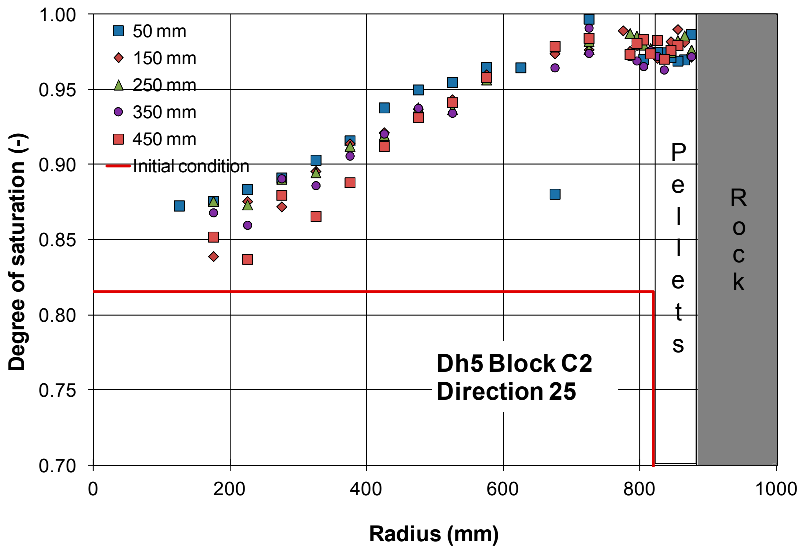



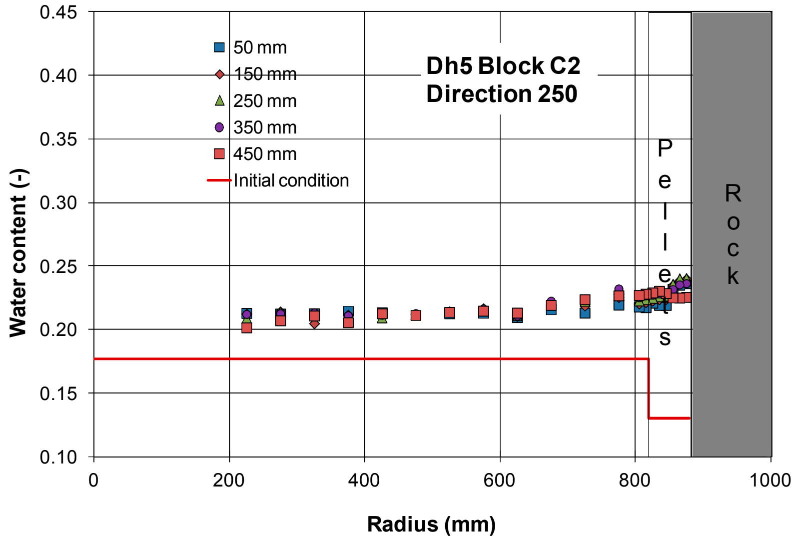
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block C2, Dh 5

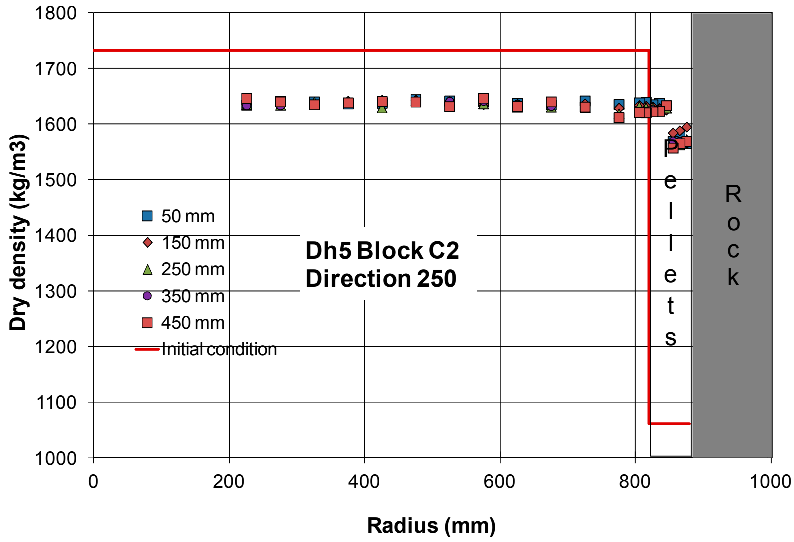


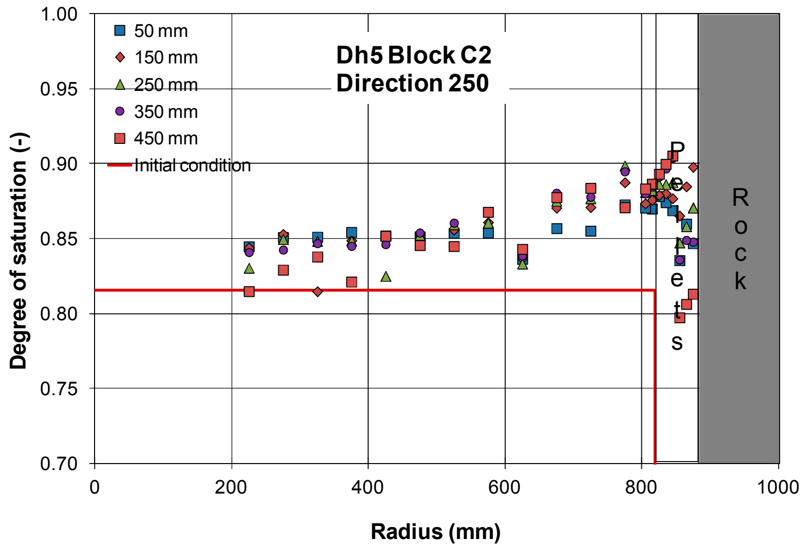



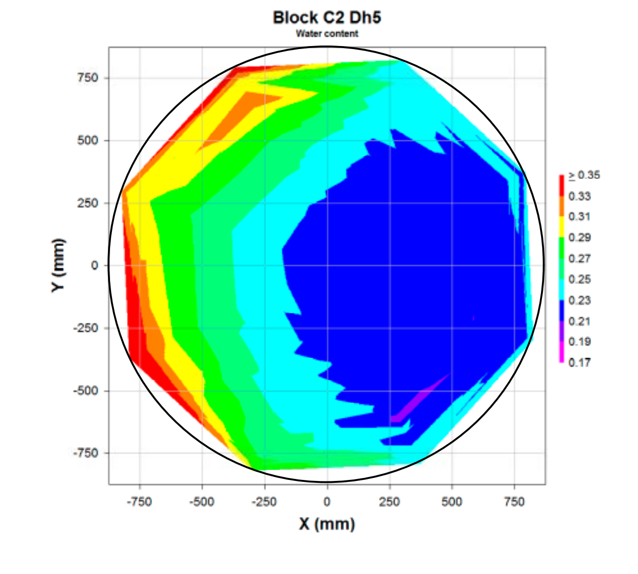
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block C2, Dh 5**

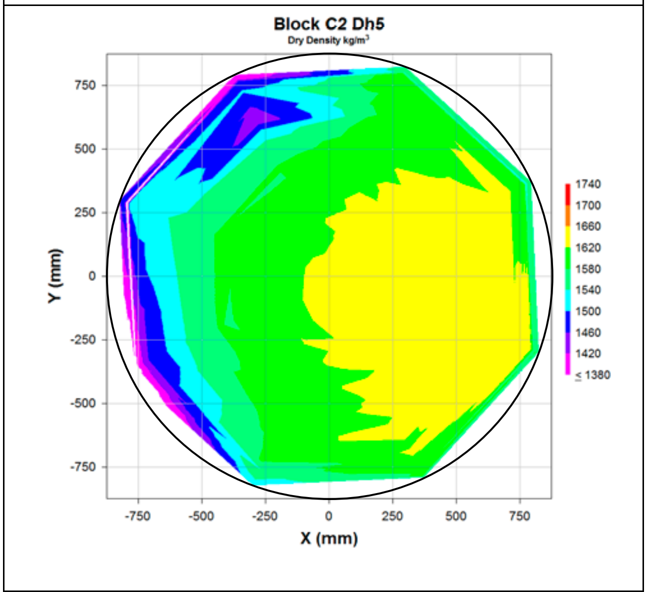


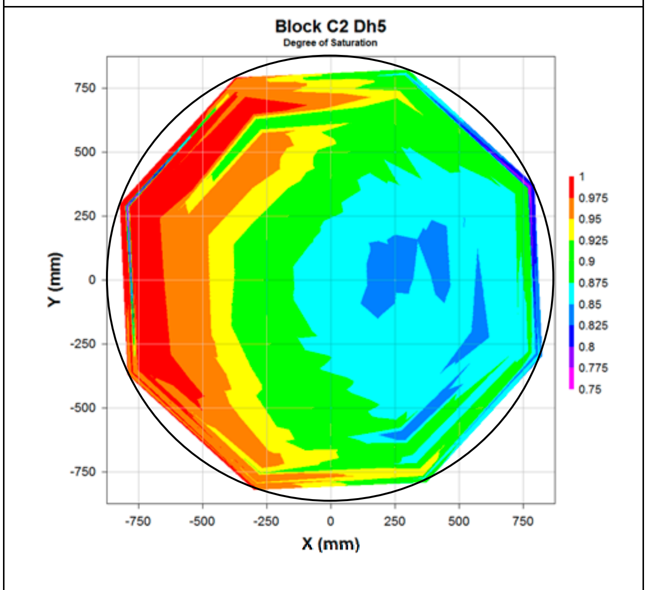



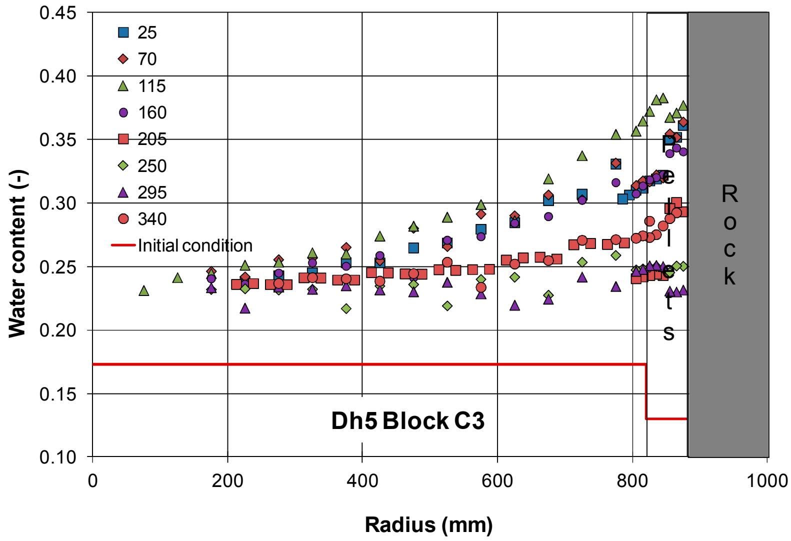
## Contour plots of water content, dry density and degree of saturation block C2, Dh 5

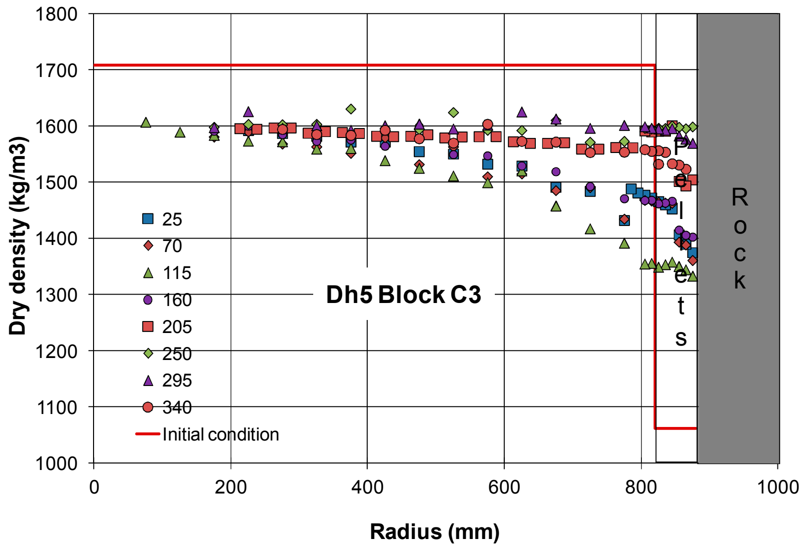


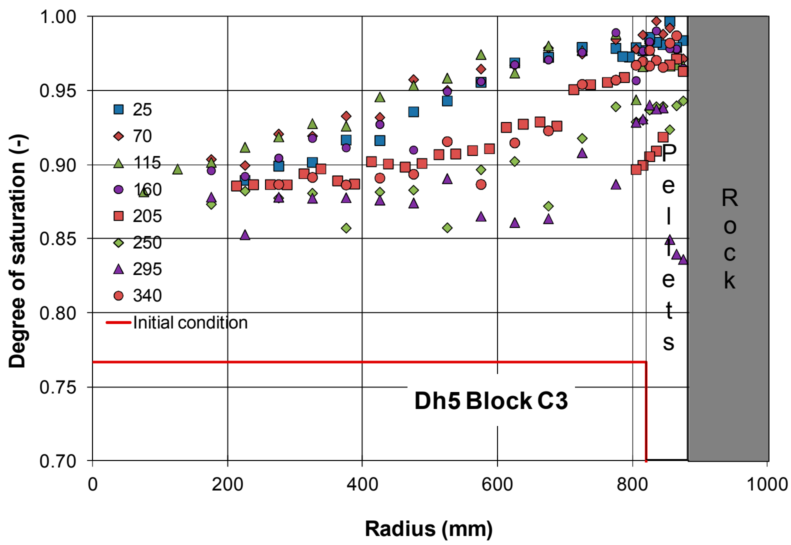



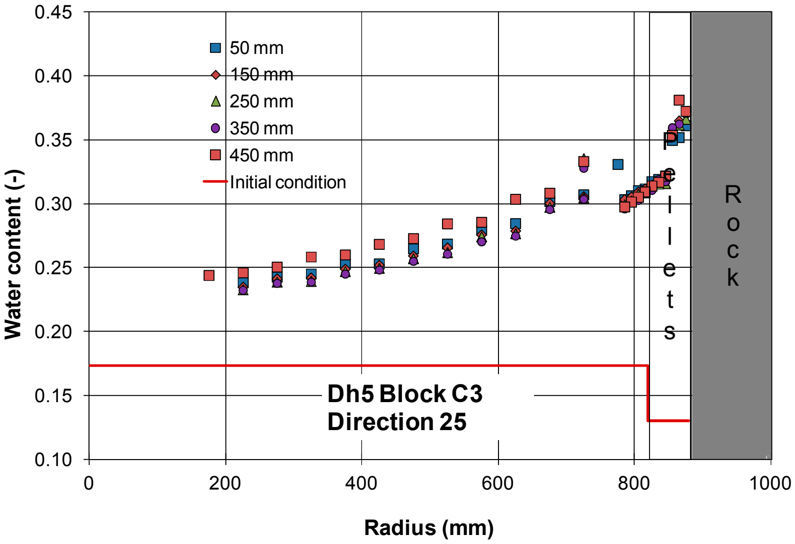
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block C3, Dh 5

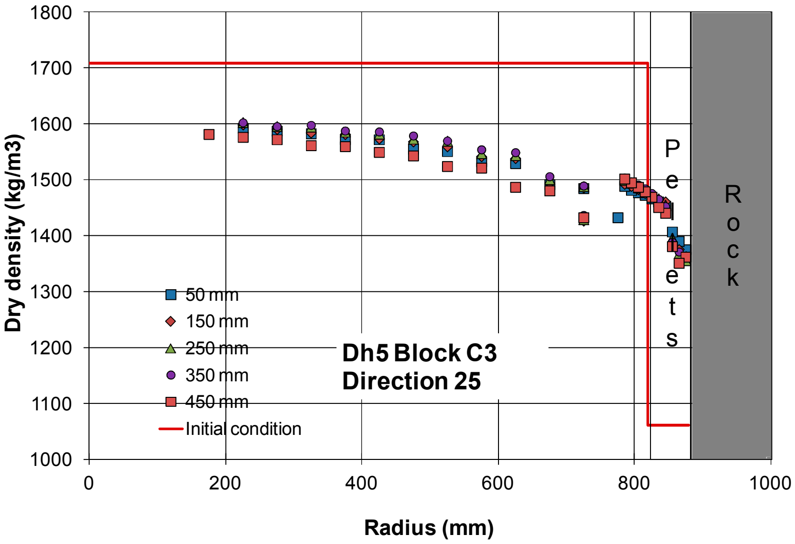


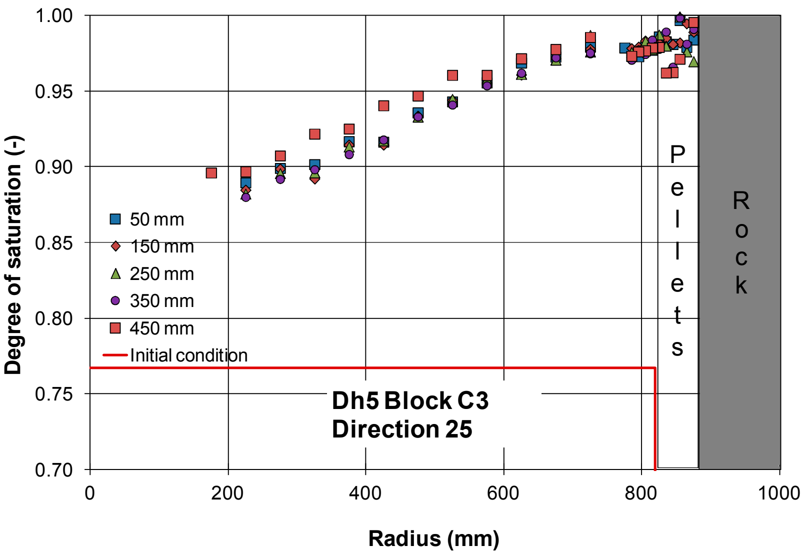



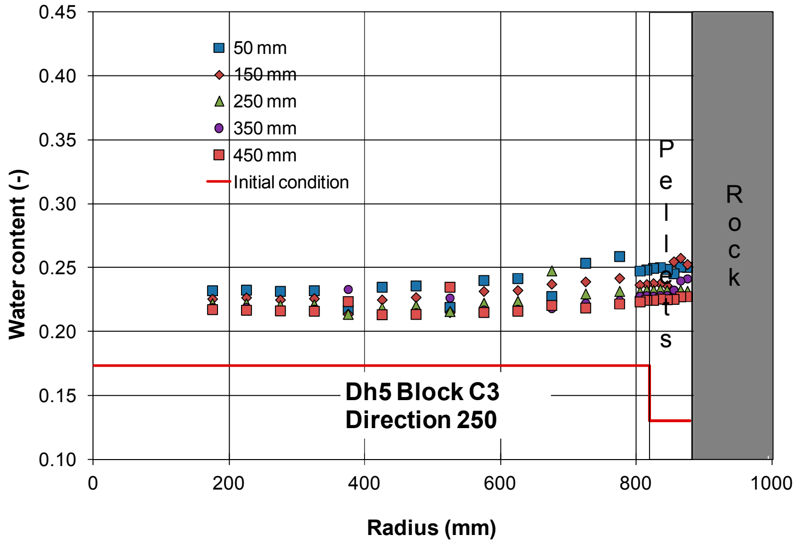
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block C3, Dh 5

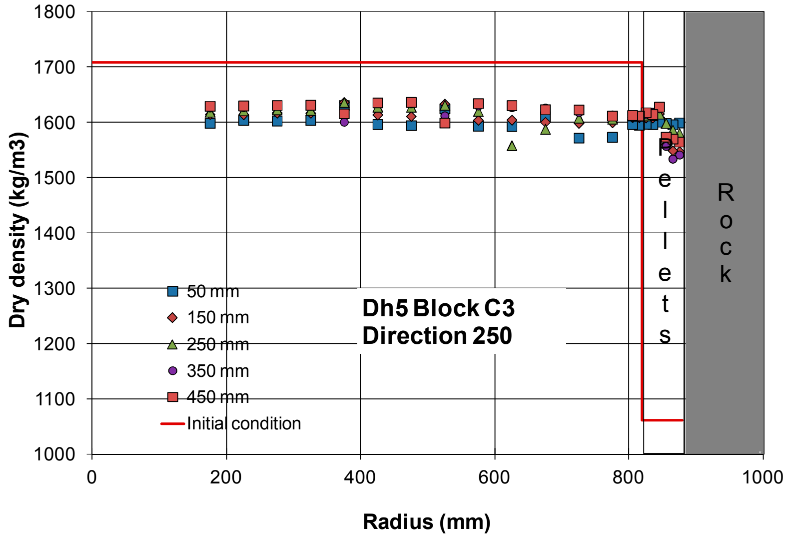


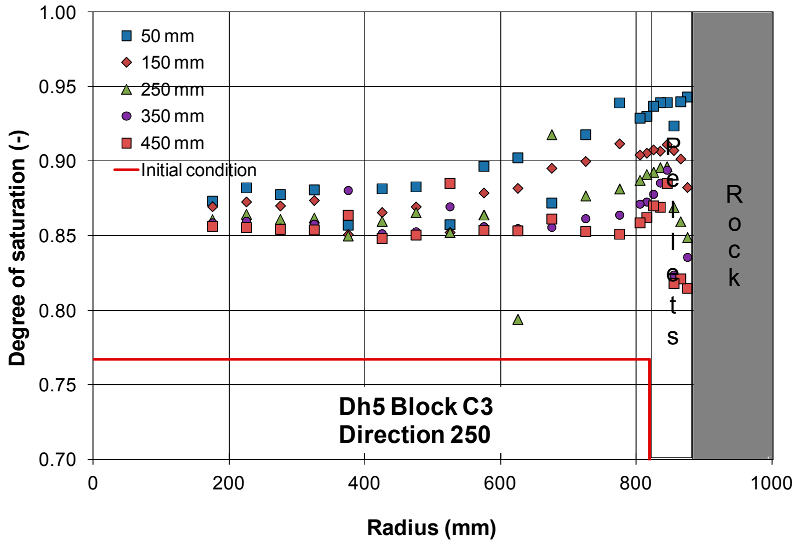



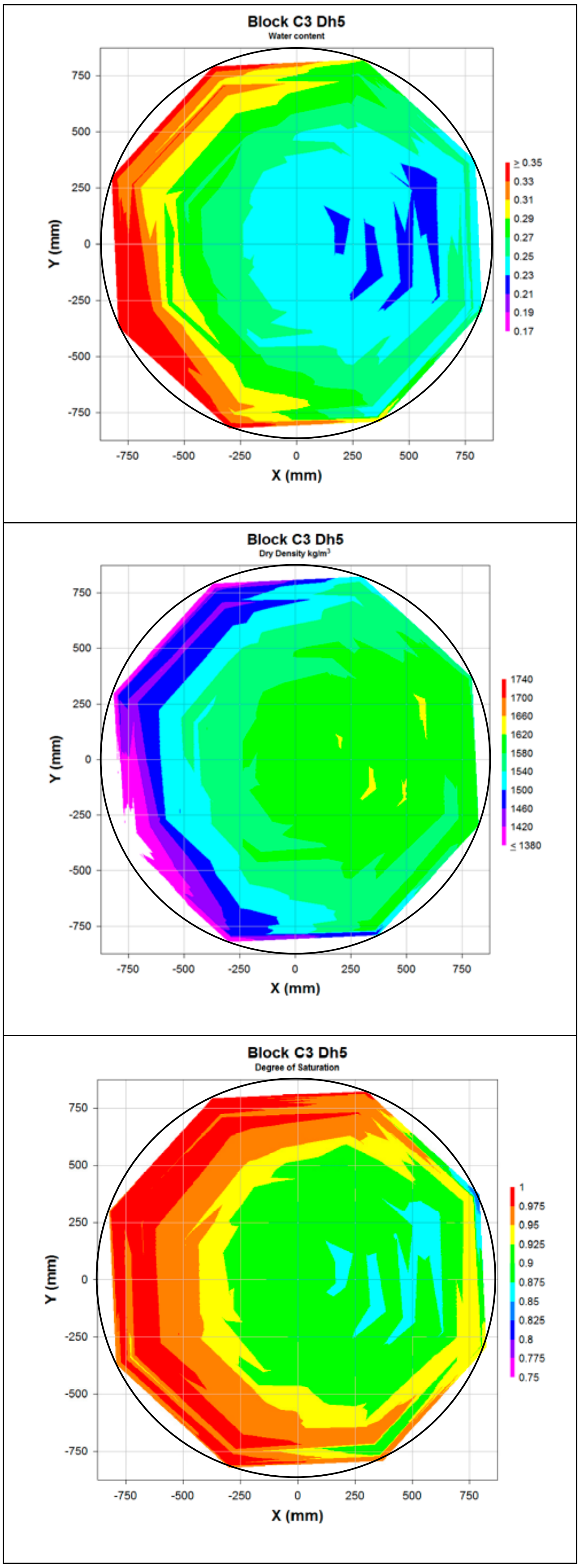
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block C3, Dh 5



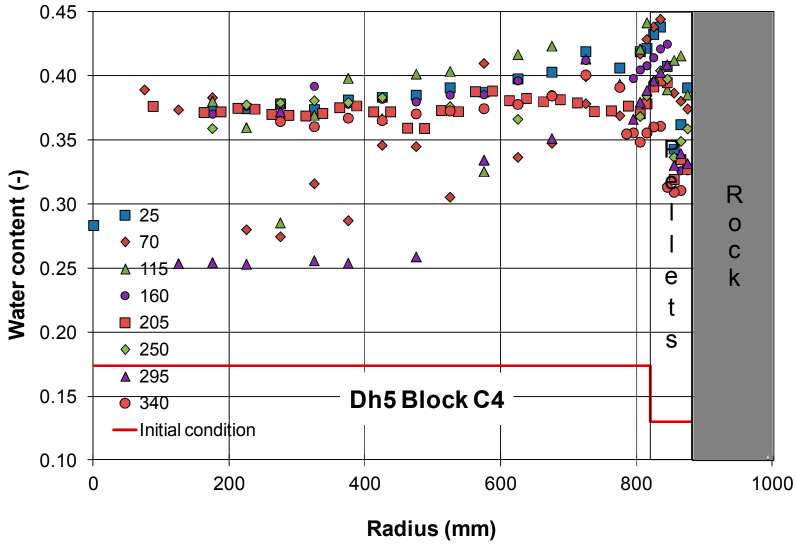



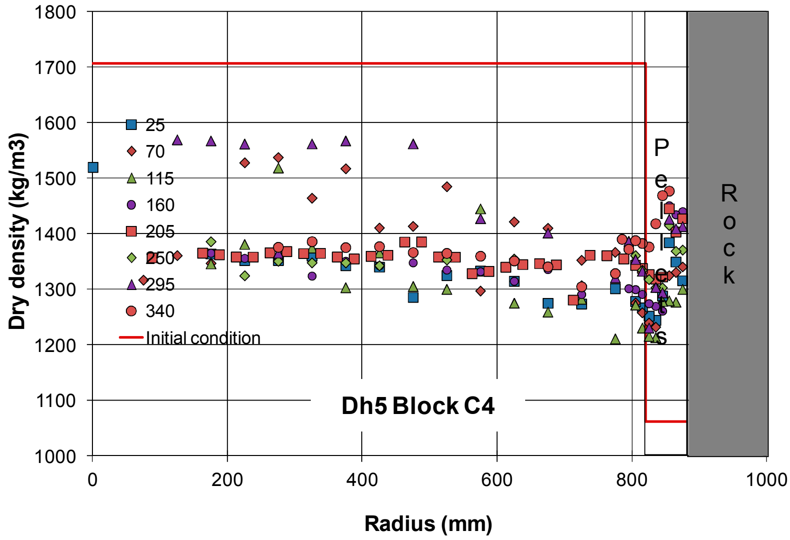



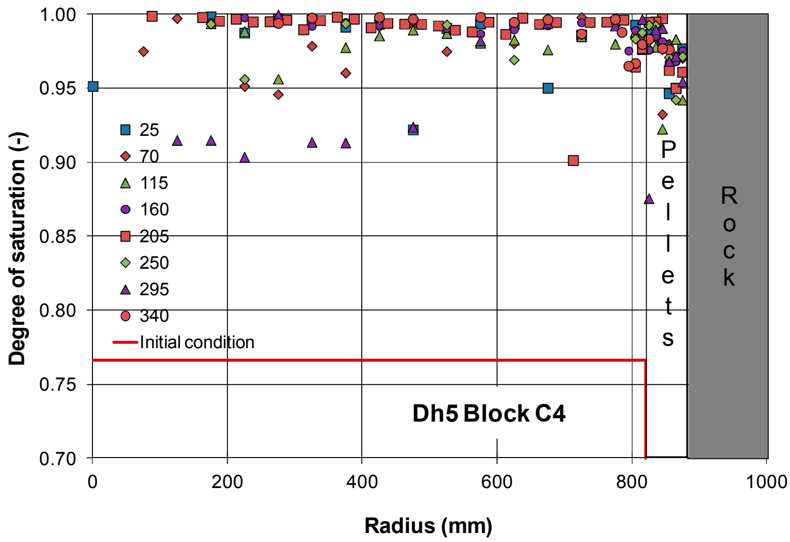
## Contour plots of water content, dry density and degree of saturation block C3, Dh 5



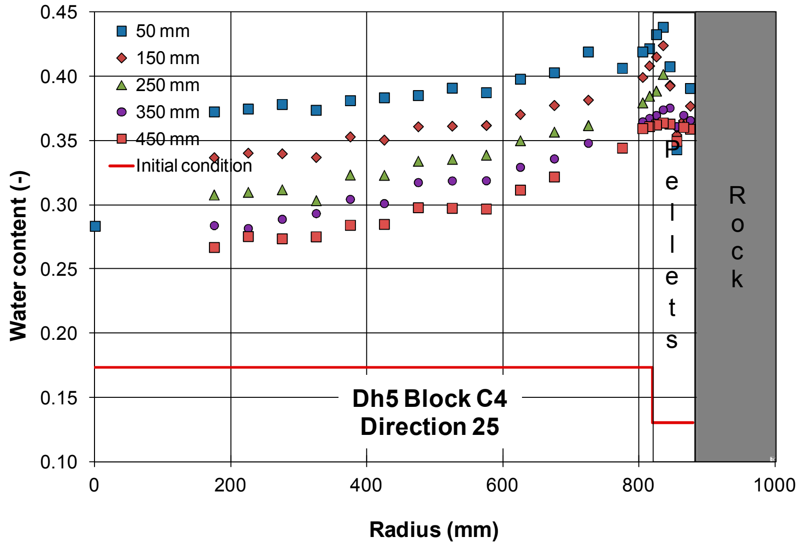
## Water content, dry density and degree of saturation measured in eight directions (25, 70, 115, 160, 205, 250, 295 and 340°) in block C4, Dh 5

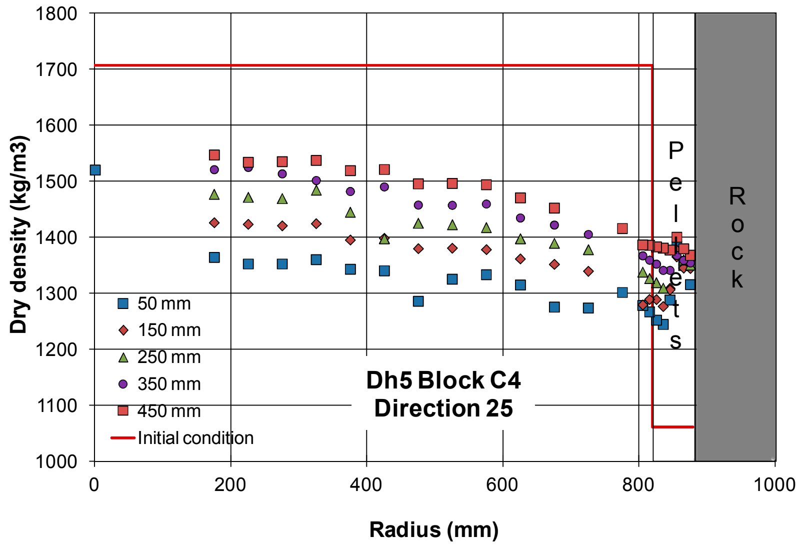


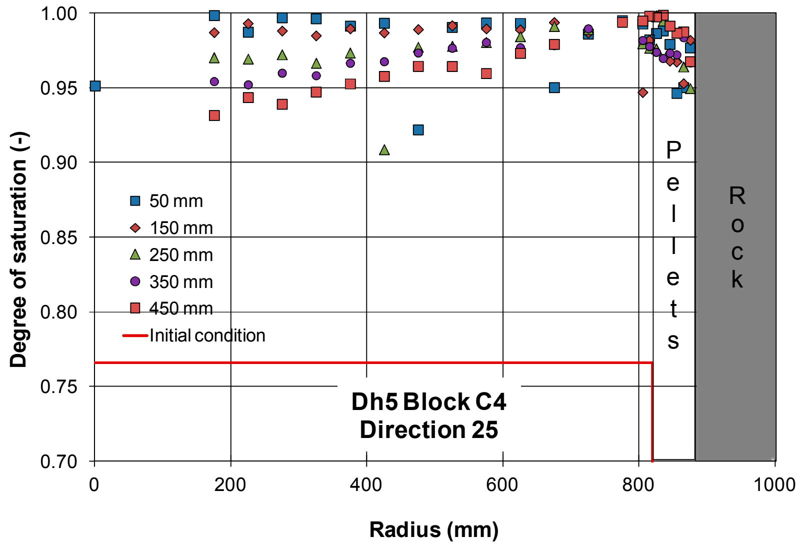



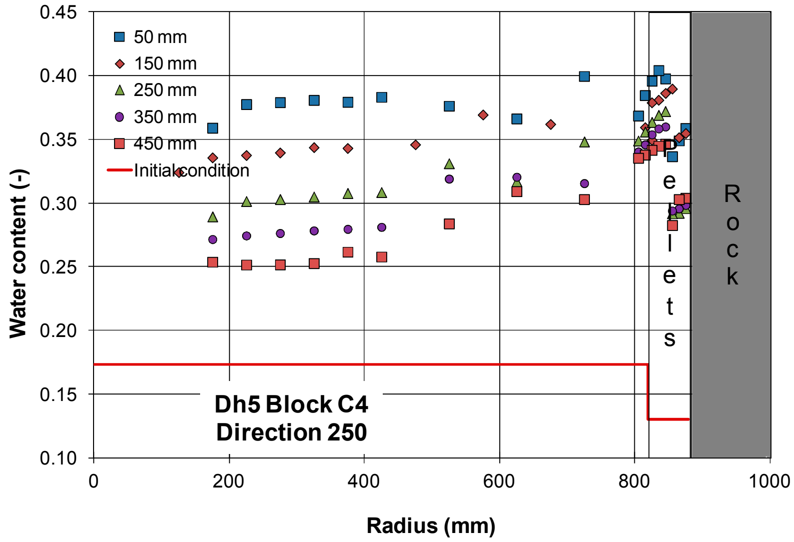
**Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 25° block C4, Dh 5**

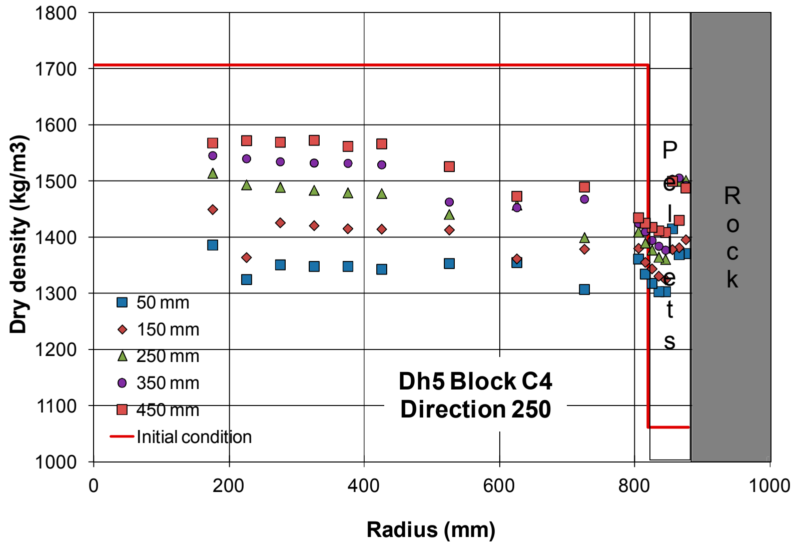


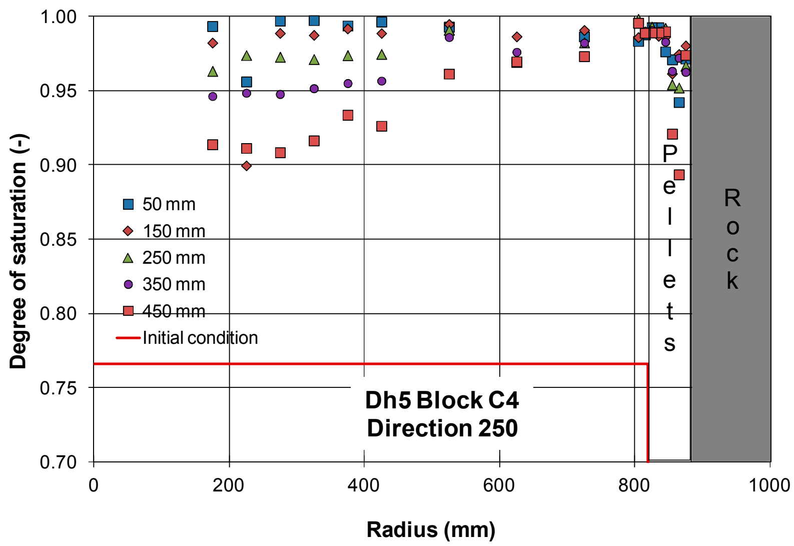



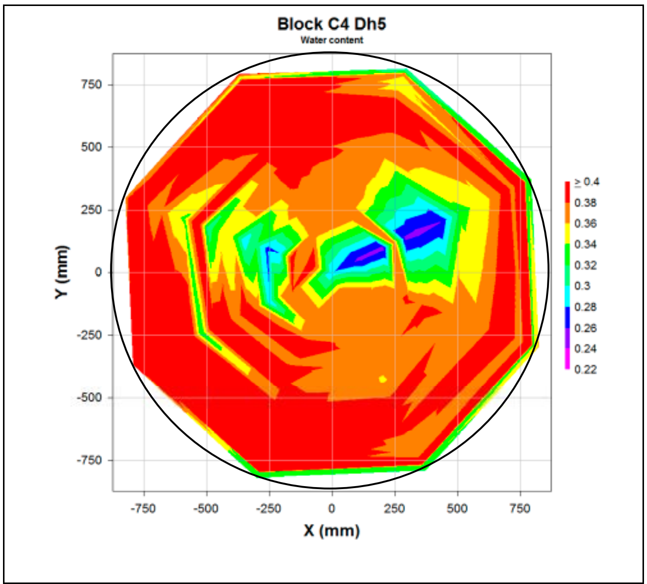
## Water content, dry density and degree of saturation measured at four depths (50, 150, 250, 350, and 450 mm from the upper surface) direction 250° block C4, Dh 5

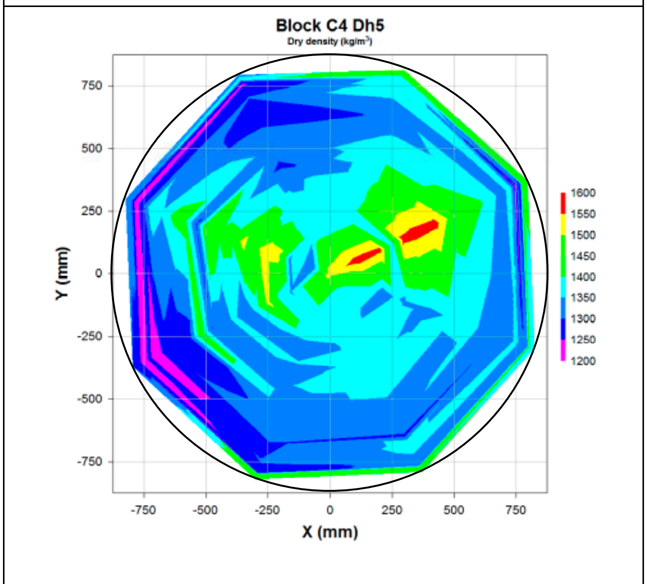


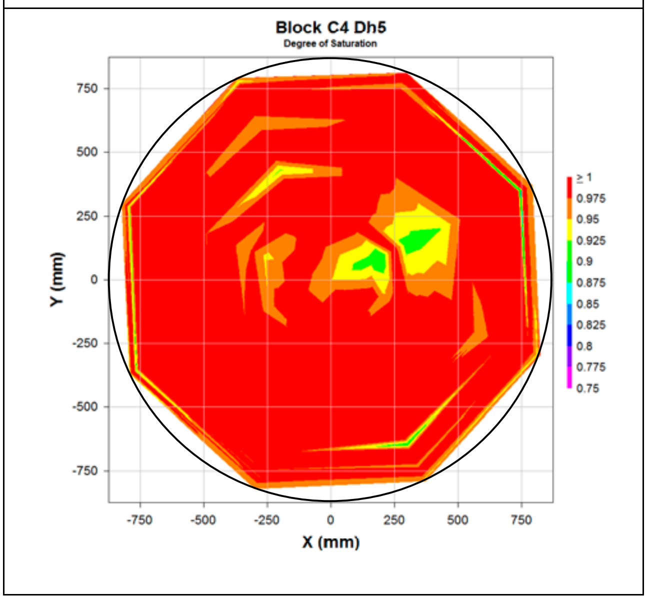



## Contour plots of water content, dry density and degree of saturation block C4, Dh 5

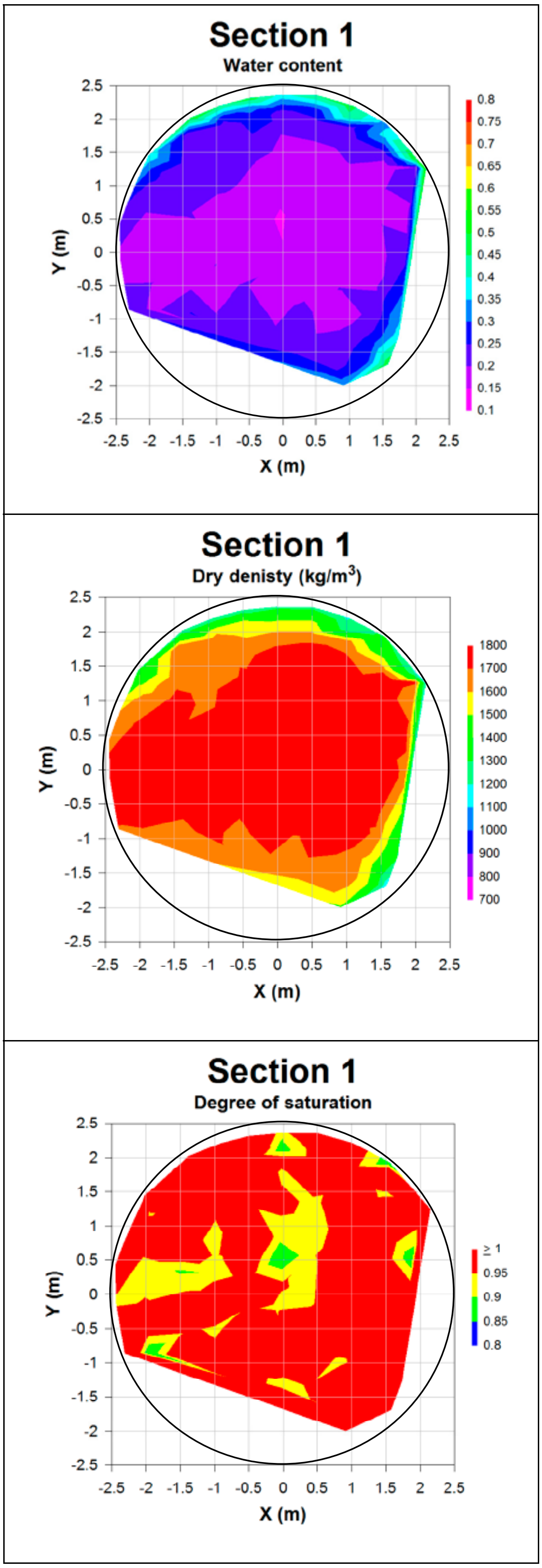


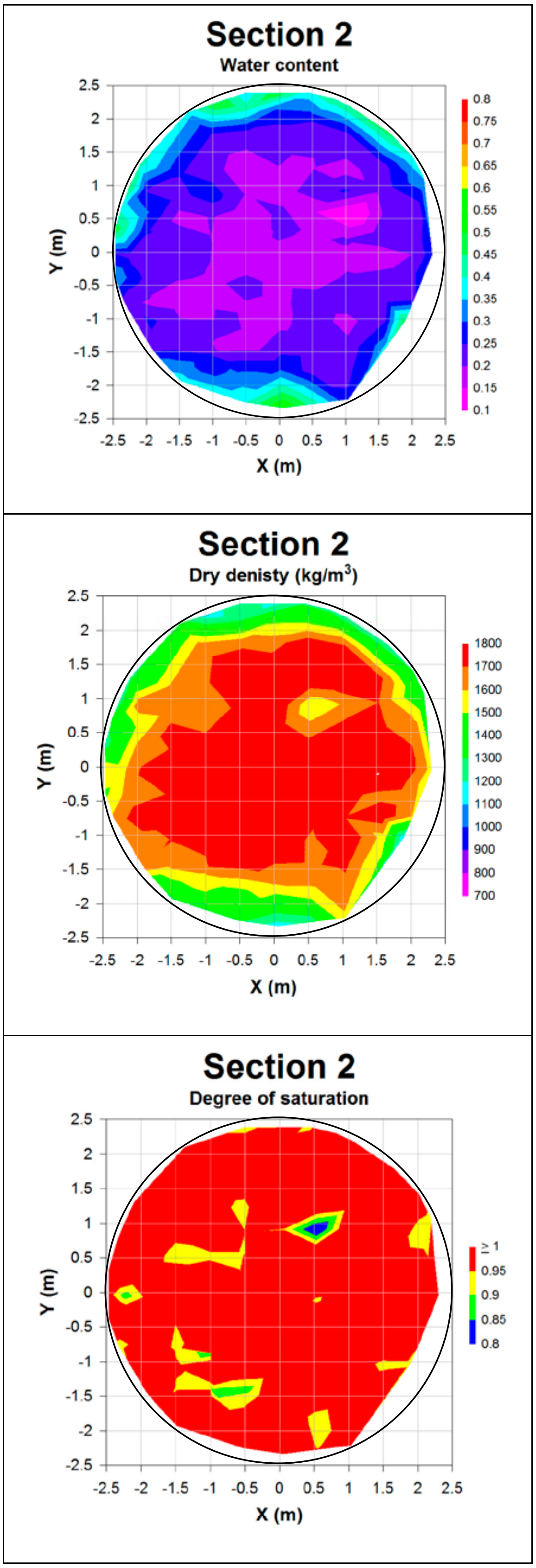



## Appendix 32

## Contour plots of water content, dry density and degree of saturation, Section 1

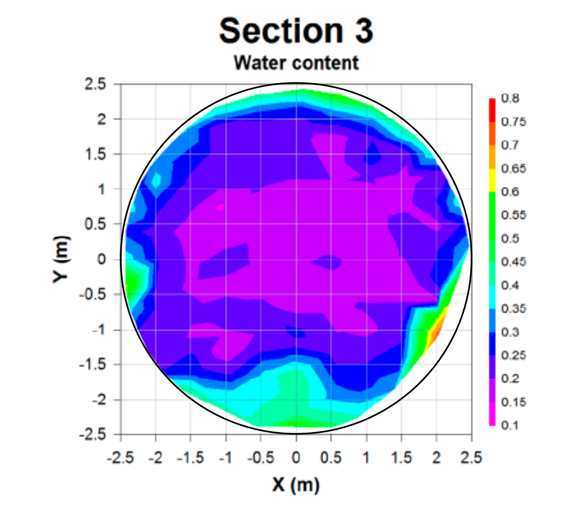


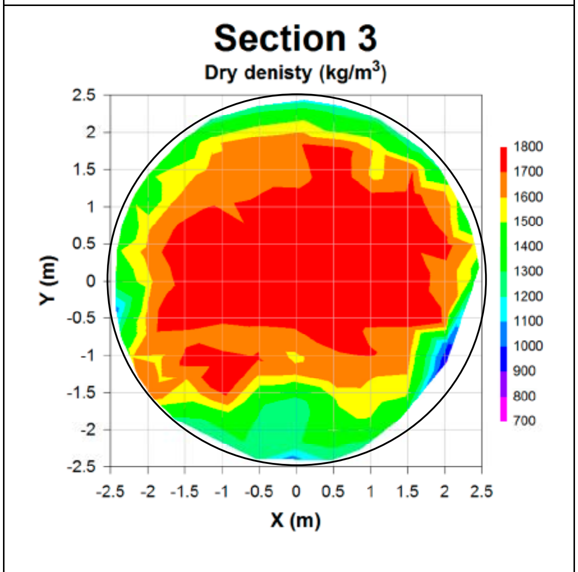
## Contour plots of water content, dry density and degree of saturation, Section 2

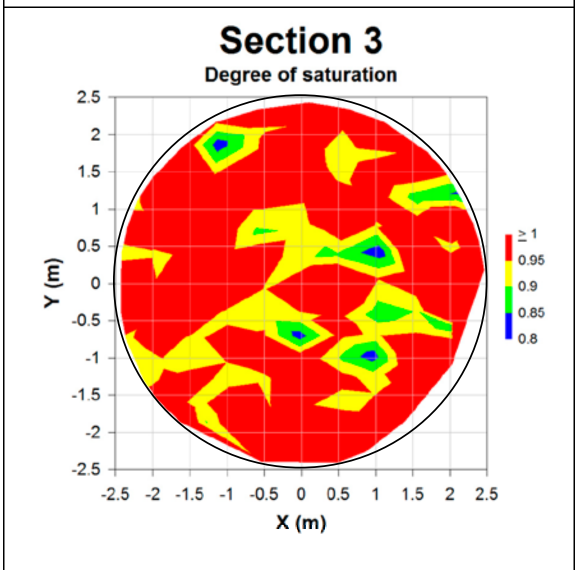


## Appendix 34

## Contour plots of water content, dry density and degree of saturation, Section 3

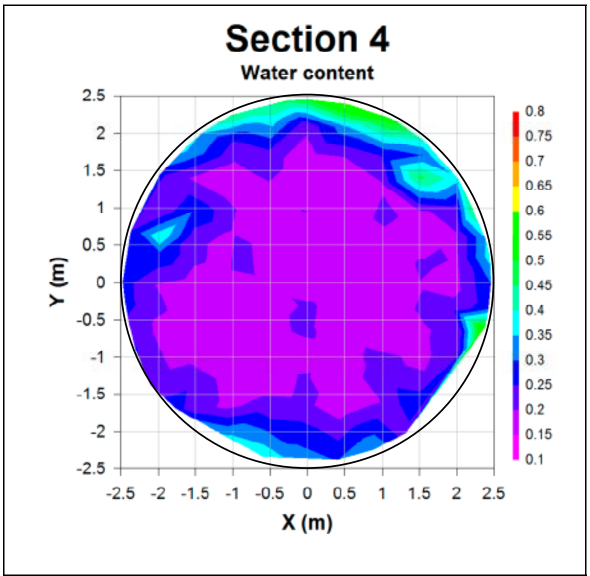


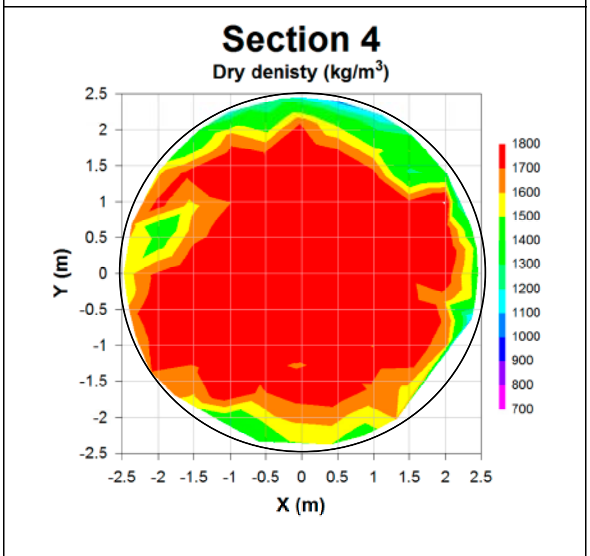



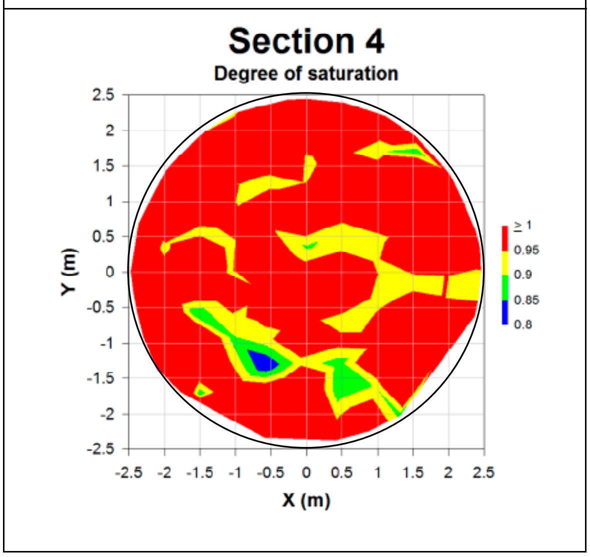



# Appendix 35

## Contour plots of water content, dry density and degree of saturation, Section 4

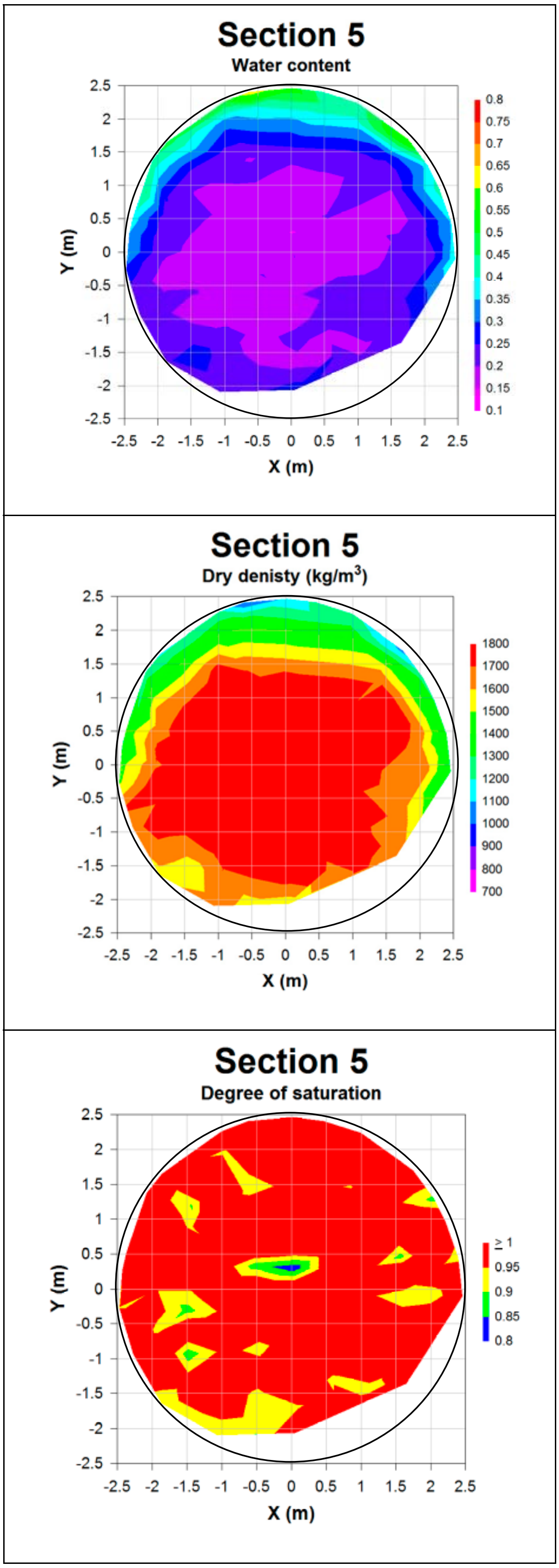


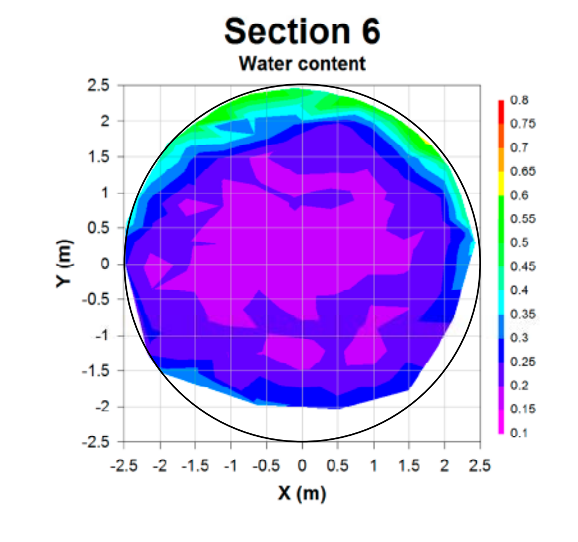
**Appendix 36**

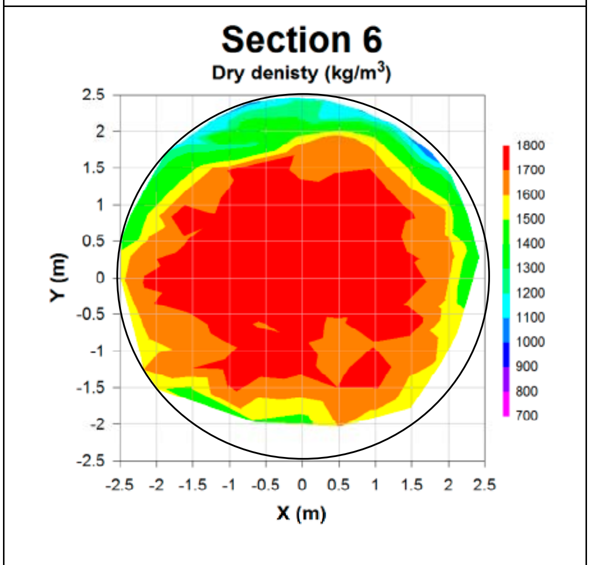
## Contour plots of water content, dry density and degree of saturation, Section 5

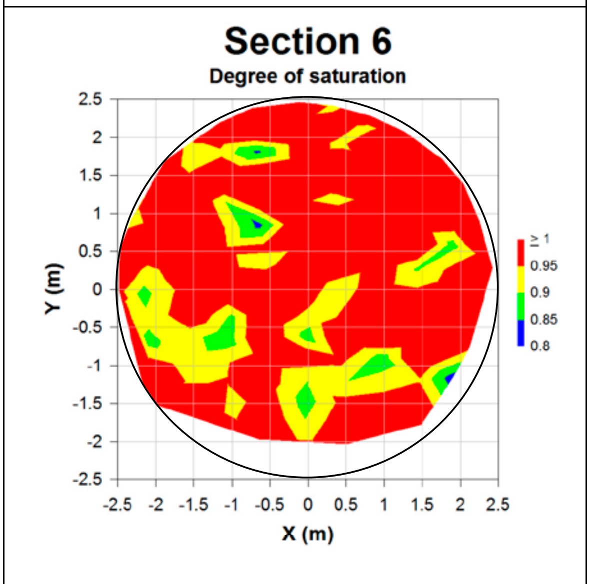


## Appendix 37

# Contour plots of water content, dry density and degree of saturation, Section 6



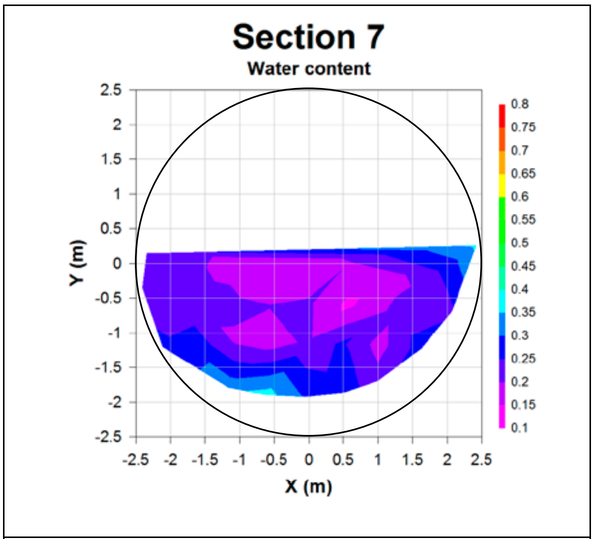



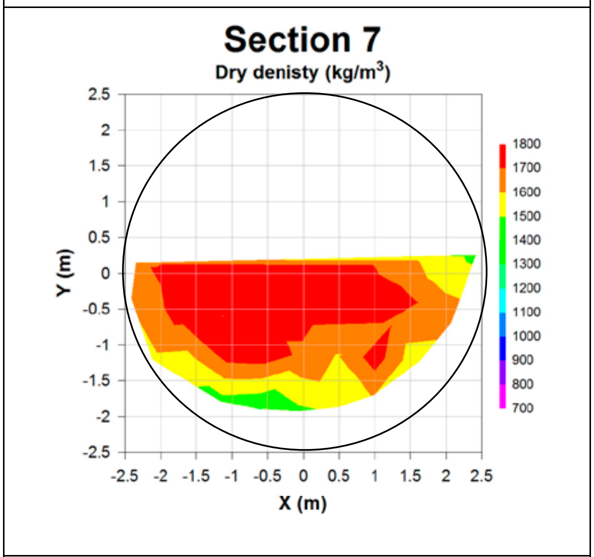



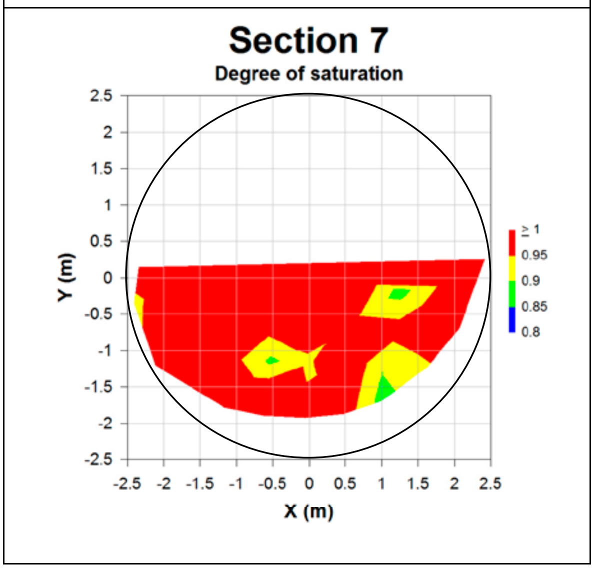
## Appendix 38

# Contour plots of water content, dry density and degree of saturation, Section 7

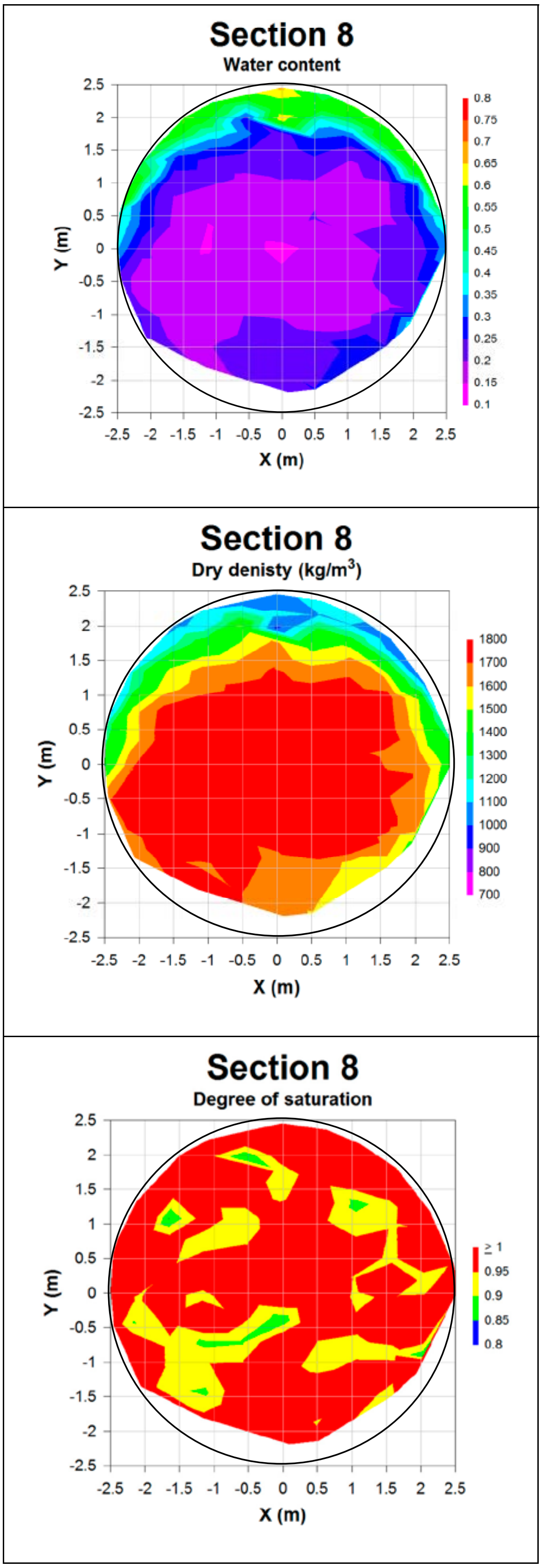
### Note samples were only taken on the lower part of this section



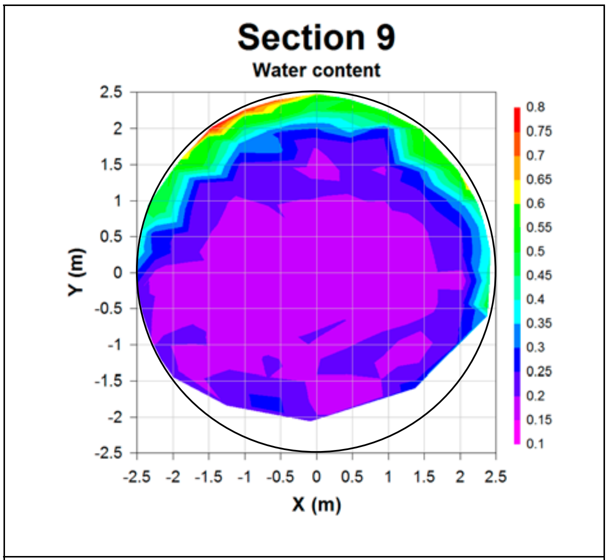



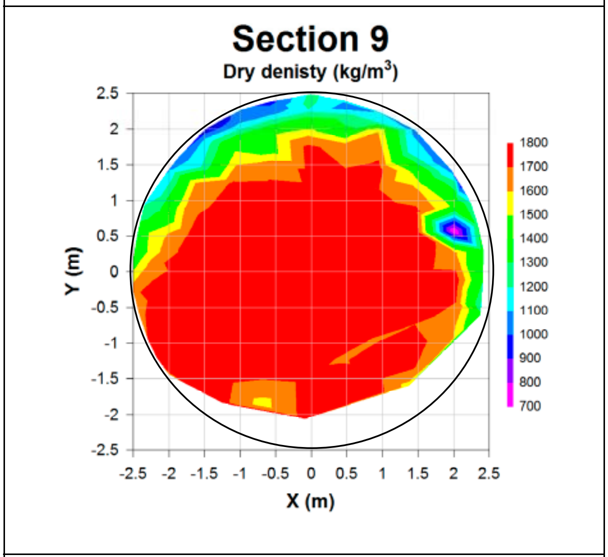



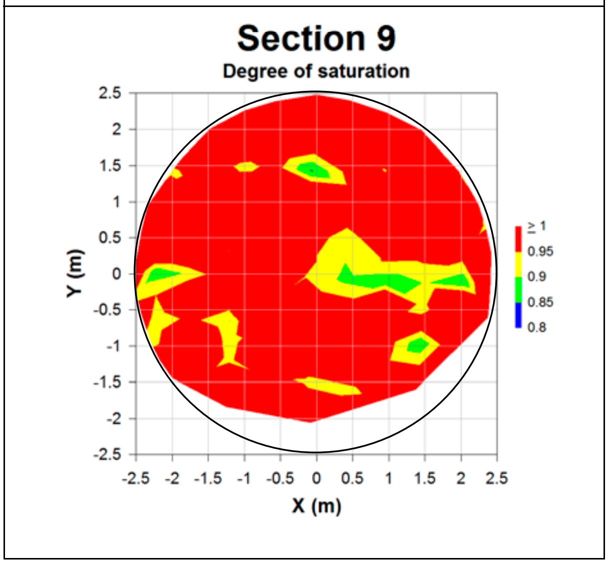
## Contour plots of water content, dry density and degree of saturation, Section 8



## Contour plots of water content, dry density and degree of saturation, Section 9

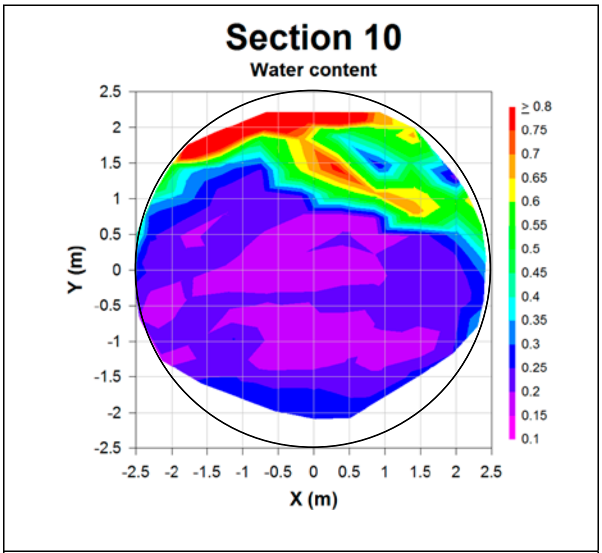


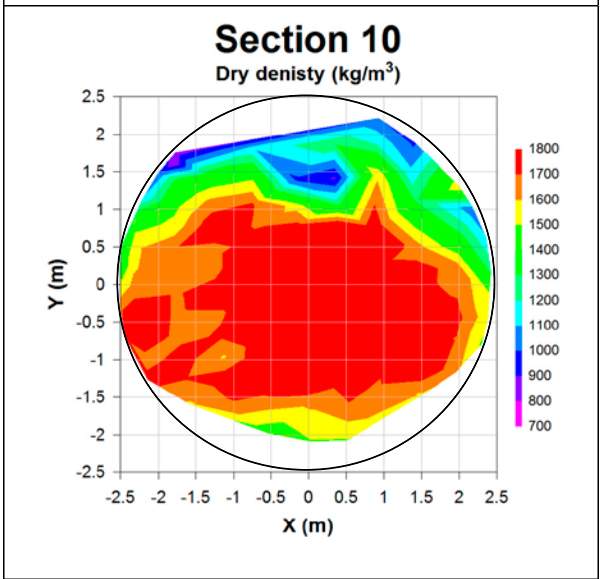



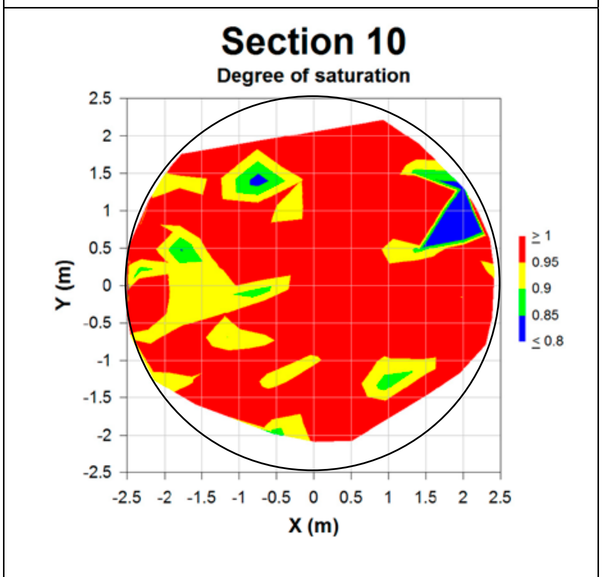



# Appendix 41

## Contour plots of water content, dry density and degree of saturation, Section 10



## Appendix 42

# Contour plots of water content, dry density and degree of saturation, Section 11