Clayey Pompeii Lab Report,

1st November 2017 to 31st July 2018,

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Contents

1. Introduction

The Project Clayey Pompeii tries to identify a locally available soil or a mixture of locally available soils, which can be used as a moisture barrier to reduce the ground moisture intrusion at the excavation sites of Pompeii. The overall aim of the project is to assess the suitability of locally available resources in order to further decrease the embodied energy of clay moisture barrier application. The most suitable material will be installed at the tomb D-N in the Via Nucerina Area of Porta Nocera necropolis at the excavation sites of Pompeii.

Further information about the project can be looked at in the report "Clayey Pompeii field-trip" by Martin Michette.

In the following report the author summarizes the steps from the collection of the samples to the final results of the lab analysis of the collected materials.

The work formed the author's Master's Thesis at the Department of Engineering Geology of the Technical University of Munich

2. Collection of barrier materials

The materials were collected in Salerno, Terzigno and Sorrento. Table 1 shows the collected materials and their collection sites. All soils were put into 10-liter buckets and stored in Filippo Ianniello's garage in Terzigno from 2nd October 2017 to the first week of November 2017. They were brought to Munich by Dr. Gerhard Lehrberger in the first week of November 2017.

The samples were not stored under air tight conditions. Therefore the natural water content could not be determined.

Table 1: Collected samples and their collection sites

soil:	**collection date:**	**collection site:**
Soil (AB)	28.09.2017	Pompeii
Black Pozzolana (BP)	02.10.2017	Terzigno
Pumice Pozzolana mix (BPM)	02.10.2017	Terzigno
Botarra Sand (BT)	15.03.2017	Pompeii
Fango (F)	02.10.2017	Terzigno
Majano Clay (MJ)	16.03.2017	Sorrento
Martino Clay (MT)	29.09.2017	Salerno
Red Pozzolana (RP)	16.03.2017	Terzigno
Slacked Lime (SK)	15.03.2017	Terzigno
Trasaella Clay (TR)	16.03.2017	Sorrento

3. Classifying tests

All soils were classified by DIN EN ISO 14688 and DIN 18196. Therefore the particle size distribution was analysed by sieve analysis and sedimentation. The soils with fine grain sizes (> 40 % of grain size < 0,063 mm) were also analysed for their Atterberg limits Flow limit w_L and Rolling limit w_P (DIN 18122.1). The results can be seen in table 2. The fine grained soils are marked bold. The Fango and the Slacked Lime are fine grained soils, but not binding. Therefore the Atterberg limits could not be determined.

Table 2: Classification of the soil samples

soil:	**soil type (DIN EN ISO 14688):**	**soil group (DIN 18196):**	**w_L [%]**	**w_P [%]**
Soil (AB)	grsiSa	SU*	-	-
Black Pozzolana (BP)	sigrSa	SU	-	-
Pumice Pozzolana mix (BPM)	grSa	GU	-	-
Botarra Sand (BT)	grSa	SE	-	-
Fango (F)	**clSi**	**UL**	-	-
Majano Clay (MJ)	**saclSi**	**OT**	**54,2**	**36,7**
Martino Clay (MT)	**clSi**	**TA**	**55,7**	**24,5**
Red Pozzolana (RP)	sigrSa	SW	-	-
Slacked Lime (SK)	**clSi**	**UL**	-	-
Trasaella Clay (TR)	**grclsiSa**	**TA**	**51,5**	**26,9**

The soils AB and MT were analysed due to their carbonate content by DIN 18129. The results are listet in table 3.

Table 3: Carbonate content of the soils AB and MT

soil:	**carbonate content [%]:**	**calcite content [%]:**	**dolomite content [%]:**
AB	2,44	2,37	0,07
MT	16,64	15,67	0,97

After the classifying tests some materials were considered to be not qualified for the project due to different issues, which can be seen in table 4. Soils which could be used as barrier materials are marked bold. None of the other soils were suitable on their own, but can be used as mixtures.

The MT soil is potentially swelling. This could be reduced by mixing it with the non-binding soils AB, BP or F. The soil SK is pure lime, which is potentially damaging for the stones of

the tomb due to lime precipitation. Therefore the SK soil cannot be installed in its pure form, but eventually in a mixture with the other mentioned soils.

Table 4: not siutable = fine; potential mixture components = bold

soil:	negative property:
Excavation Soil (AB)	**Not binding**
Black Pozzolana (BP)	**Not binding**
Pumice Pozzolana mix (BPM)	Too coarse
Botarra Sand (BT)	Not enough material
Fango (F)	**Not binding**
Majano Clay (MJ)	Not enough material, organic
Martino Clay (MT)	**Potentially swelling**
Red Pozzolana (RP)	Not enough material
Slacked Lime (SK)	**Potentially damaging**
Trasaella Clay (TR)	Not enough material, organic

4. Mixture selection

The five remaining soils were mixed in different compositions and relations. All the mixtures were then tested with the ball-dropping-test and the swelling-and-shrinking-test, both developed by Gernot Minke. These tests determine the right ratio of binding and non-binding components in a mixture of soils. Figures 1 – 6 show the results of the ball-dropping tests for all six mixtures. In Figure 7 and 8 the swelling and shrinking test of all six mixtures can be seen.

Figure 1: Ball-dropping-test of the mixture of MT and AB

Figure 2: Ball-dropping-test of the mixture of MT and BP

Figure 3: Ball-dropping-test of the mixture of MT and F

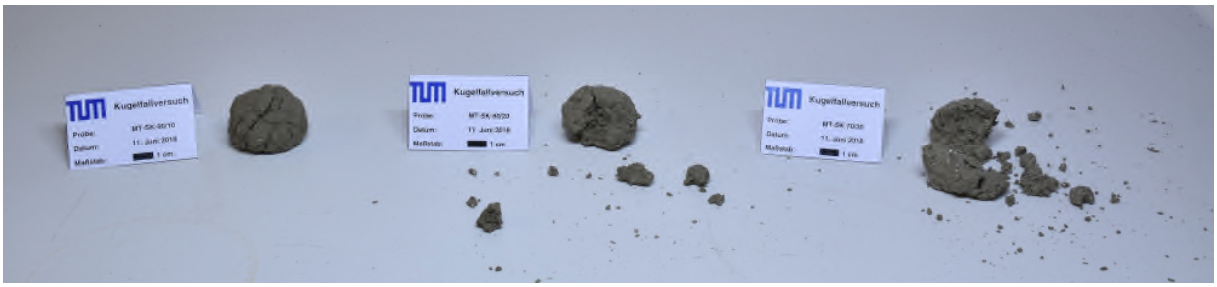

Figure 4: Ball-dropping-test of the mixture of MT and SK

Figure 5: Ball-dropping-test of the mixture of AB, F and BP

Figure 6: Ball-dropping-test of the mixture of MT, SK and BP

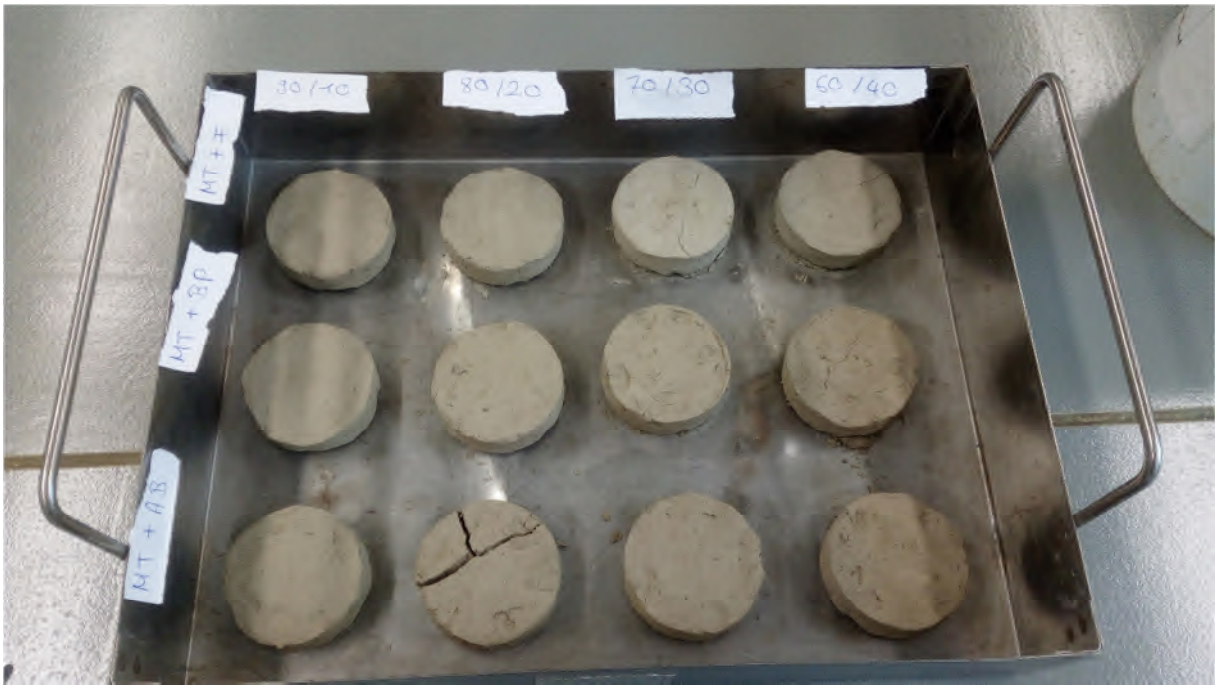

Figure 7: Swelling-and-shrinking-test of the mixtures of MT/F, MT/BP and MT/AB

Figure 8: Swelling-and-shrinking-test of the mixtures of AB/F/BP, MT/SK/BP and MT/SK

The Mixture of AB, F and BP is not suitable as a moisture barrier, because there are no binding materials in that mixture. All the other five mixtures are potentially suitable. Four mixtures were picked for further testing:

- MT-AB-70/30
- MT-BP-60/40
- MT-BP-70/30
- MT-SK-BP-60/20/20

The numbers at the end of every sample name are the ratios of the mixture. MT-AB-70/30 means 70 % MT and 30 % AB. All ratios are related to the dry weight of the materials.

5. Mixture testing

The four selected mixtures, as well as the soils AB and MT, were further tested for their suitability as a moisture barrier in Pompeii. There are two important values, which can be used as measures for the suitability of the mixtures and soils. The first value is the hydraulic conductivity, which has to be as low as possible. The second value is the volumentric change of the material, which also has to be as low as possible, so that shrinkage does not rupture the barrier and increase hydraulic conductivity. Any swelling pressure must also be counteracted by neighbouring soil layers or built fabric.

Both values are evaluated by five tests, which are explained below

5.1 Hydraulic conductivity

To evaluate the hydraulic conductivity of the materials they have to be installed with proctor density and with the optimum water content. Therefore the proctor test is to be conducted before the test for hydraulic conductivity takes place.

In the proctor test (DIN 18127) the material is compressed with five different water contents. The optimum water content is the water content of that test, in which the material is compacted to the highest density (proctor density).

The material is now installed in another metal cylinder with the values of the proctor test and tested for their hydraulic conductivities under these conditions (DIN 18130). The results of both tests are shown in table 5. The soil AB was not installed with proctor density in the cylinder for the hydraulic conductivity test. The compaction curves fort he five soils and mixtures can be seen in Figure 9 - 13

Table 5: Results from the proctor test and the hydraulic conductivity test

soil/mixture:	**proctor density [g/cm³]**	**water content [%]**	**hydr. Conductivity [m/s]**
AB	-	-	$1{,}8 \times 10^{-5}$
MT	1,64	22,0	$3{,}2 \times 10^{-11}$
MT-AB-70/30	1,58	21,7	$1{,}2 \times 10^{-7}$
MT-BP-60/40	1,63	20,1	$7{,}0 \times 10^{-10}$
MT-BP-70/30	1,65	21,0	$1{,}3 \times 10^{-9}$
MT-SK-BP-60/20/20	1,62	18,0	$3{,}7 \times 10^{-7}$

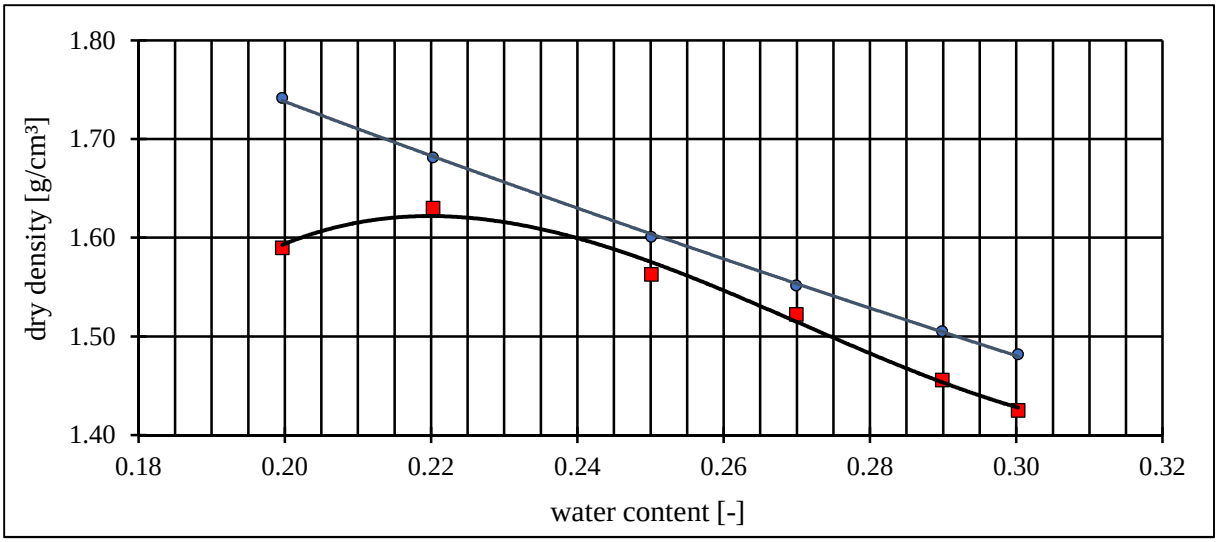

Figure 9: compaction curve of the soil MT

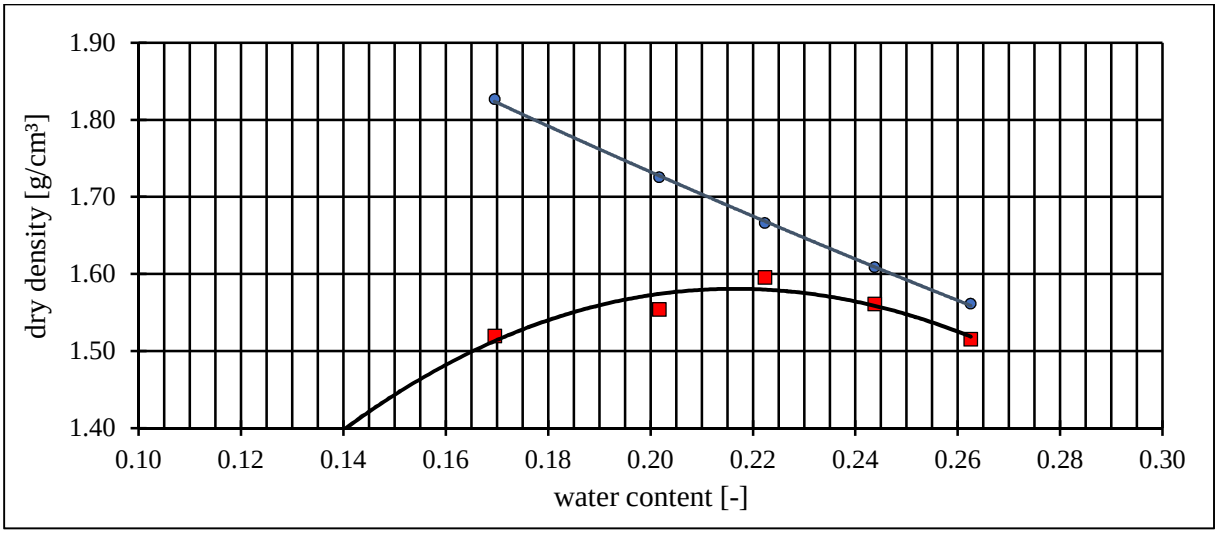

Figure 10: Compaction curve of the mixture MT-AB-70/30

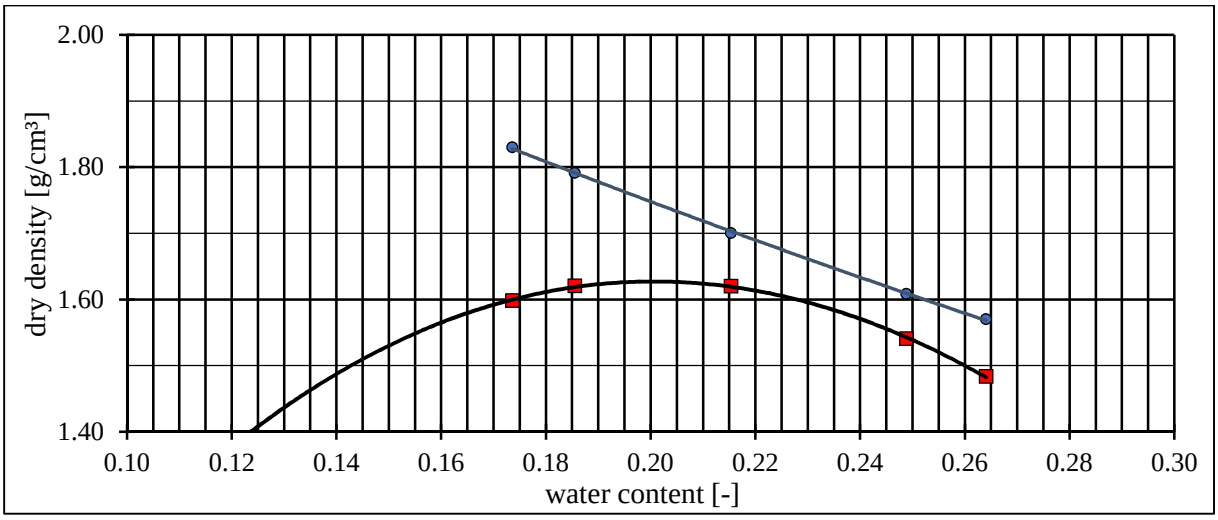

Figure 11: Compaction curve of the mixture MT-BP-60/40

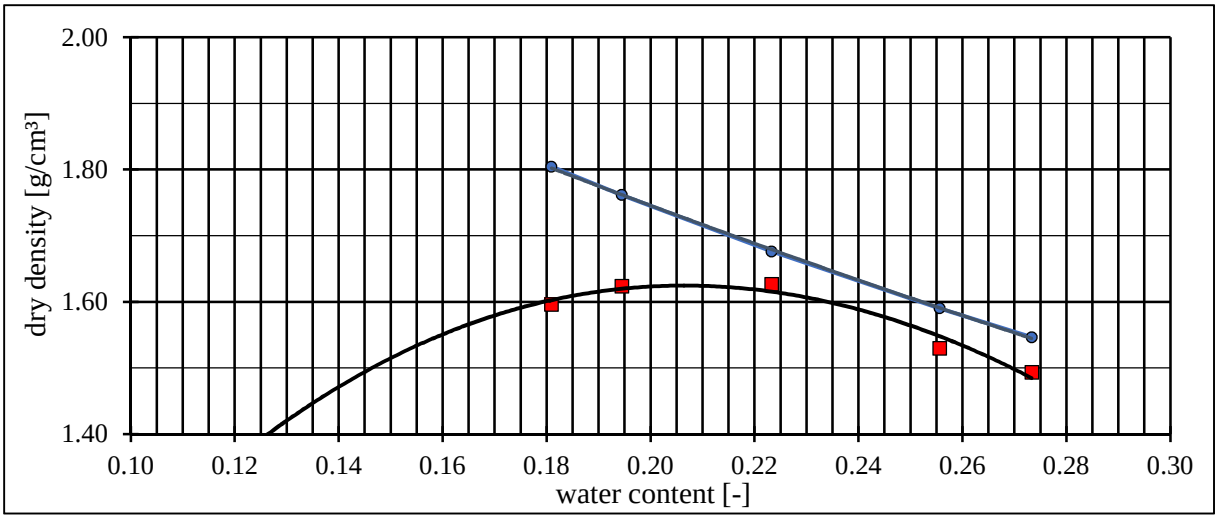

Figure 12: Compaction curve of the mixture MT-BP-70/30

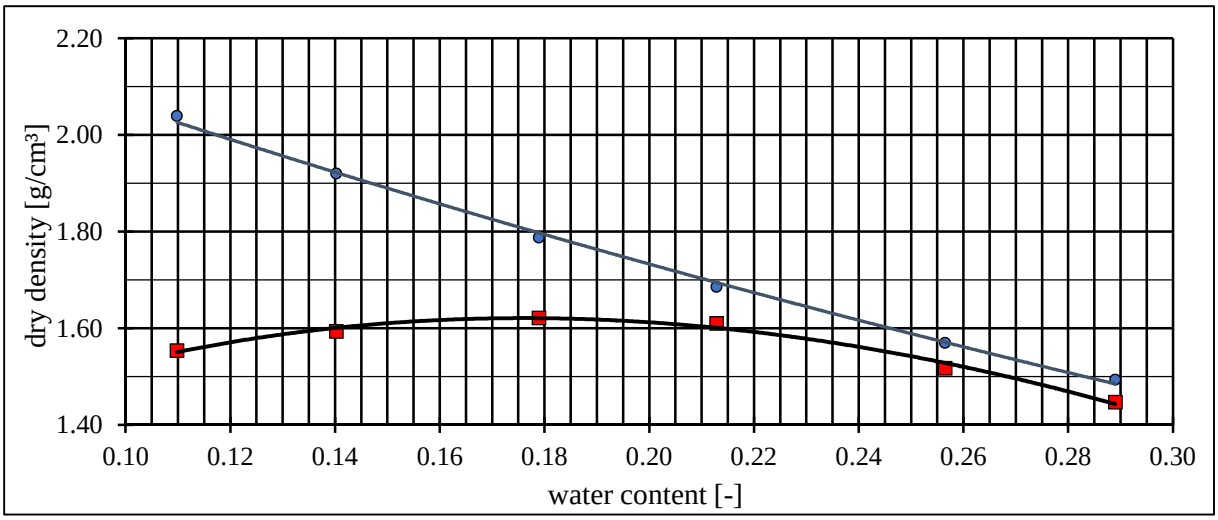

Figure 13: compaction curve of the mixture MT-SK-BP-60/20/20

5.2 Volumetric changes

The volumetric changes were evaluated with three different tests, the shrinking limit test (DIN 18122-2), the compression test (DIN 18135) and the powder-swelling test, invented by Kurosch Thuro (awaiting results).

The compression test was conducted in February and March 2018. The test does not give actual swelling values, but shows, that the soil MT does swell more, than any of the other soils. Due tot he results of this test, further testing was carried out on mixtures designed to mitigate the swelling of MT.

The results of the shrinking limit test are shown in table 6. The difference between the shrinking limit and the rolling limit of a soil is an indicator for the suitability of the material as a moisture barrier, as this suggests very little volumetric change occurs below the plastic limit. The lower the value of this difference, the more suitable the material. The differences are also shown in table 6.

In table 7 the results of the tests of each mixture are compared. The tests for hydraulic conductivity and volumetric change show, that the mixture MT-BP-60/40 is the best option

for an installation at tomb ND and the Porta Nocera necropolis in the excavations of Pompeii. The hydraulic conductivity is the lowest of all mixtures and the difference between shrinking and rolling limit is also very low. The measured hydraulic conductivity is within the region of industrially produced Bentonite mixtures such as Dernoton and Bentofil and other naturally occuring clays known to have been used as moiosture barriers. The material shows no signs of lime precipitation or other stone damaging reactions.

Table 6: Results of the shrinking and rolling limit test and their differences

soil/mixture:	**Rolling limit w_P [%]**	**Shrinking limit w_S [%]**	**Difference $w_P - w_S$ [%]**
MT	24,5	19,6	4,9
MT-AB-70/30	21,4	19,9	1,5
MT-BP-60/40	21,7	20,0	1,7
MT-BP-70/30	21,8	19,9	1,9
MT-SK-BP-60/20/20	33,6	25,5	8,1

Table 7: Comparing of hydraulic conductivity, shrinking-rolling limit difference and compatability of all mixtures

Mixture	**Hydr. conductivity [m/s]**	**Difference $w_P - w_S$ [%]**	**Compatibility**
MT-AB-70/30	$1{,}2 \times 10^{-7}$	1,5	high
MT-BP-60/40	$7{,}0 \times 10^{-10}$	1,7	high
MT-BP-70/30	$1{,}3 \times 10^{-9}$	1,9	high
MT-SK-BP-60/20/20	$3{,}7 \times 10^{-7}$	8,1	low

6. Summary

The author, Tamara Breuninger, and Martin Michette from the University of Oxford collected samples of some soils in the region of Pompeii for testing as a potential moisture barrier for the excavation site of Pompeii with the help of Filippo Ianniello.

From November 2017 to July 2018 the materials were evaluated at the Department for Engineerging Geology at the TU Munich. In these evaluations the materials were first classified. The results were used to narrow the samples down to the most promising soils. The remaining soils were mixed in different compositions and relations. After conducting the ball-dropping- and swelling-and-shrinking-test on every mixture four mixtures where selected for futher testing. The hydraulic conductivity and the volumetric changes of those mixtures were evaluated with the result, that the mixture MT-BP-60/40 is the most suitable material for an installation at tomb ND at the Porta Nocera necropolis in the excavation site of Pompeii.

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