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MPA STUTTGART Otto-Graf-Institut
Materials Testing Institute University of Stuttgart

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www.smoohs.eu

Long-term Monitoring of Salt Movement in Masonry Materials

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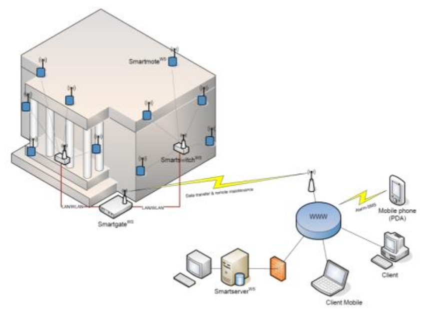
Motivation

SMooHS – Smart Monitoring of Historic Structures (www.smoohs.eu)

- ❑ Development of wireless monitoring systems



Smartmote (www.smartmote.de)

- ❑ Potential difference

Ion-selective electrodes
Silver/silver chloride

Sensor node installed in Schwäbisch Gmünd

- 8 channels
- R_i = 100 GΩ

Background

- Potential difference according to Nernst law

$$E_M = E_{AgCl} - E_{\text{Ref}} = E^0_{Ag/AgCl} - \frac{RT}{F}\ln a_{Cl^-} - E_{\text{Ref}}$$

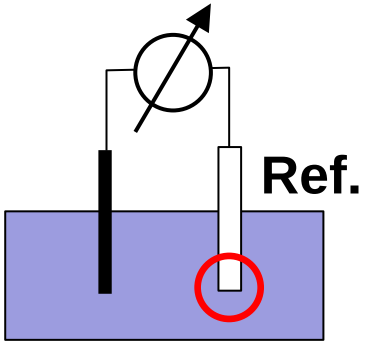
$$with\ a_{Cl^-} = \gamma_\pm c_{Cl^-}$$

- If $Ref = Ag/AgCl$, $T_M = T_{ref}$

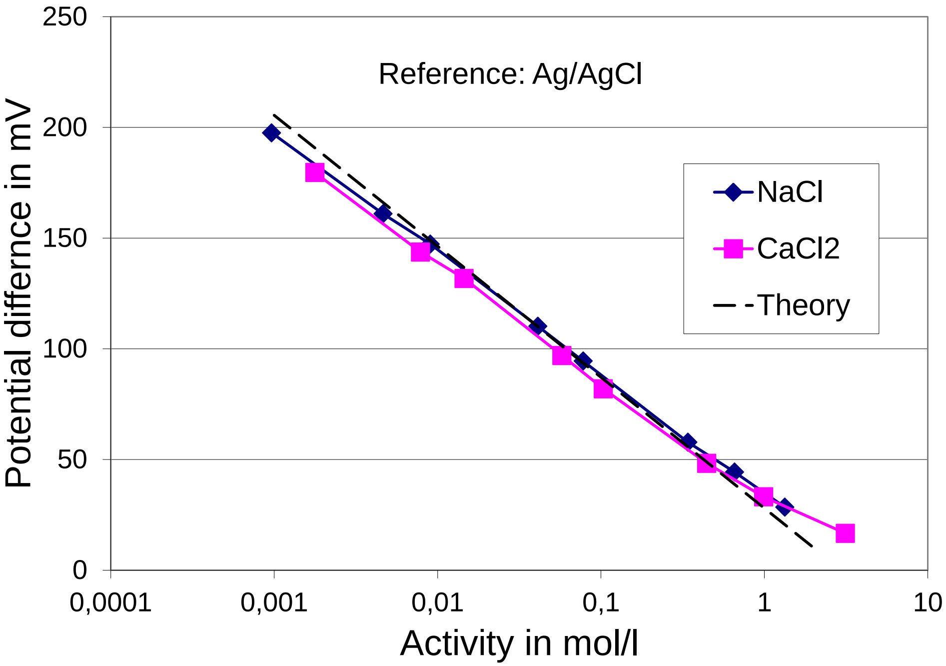
$$E_M = \frac{RT}{F}\left(\ln a^{Ref}_{Cl^-} - \ln a_{Cl^-}\right)$$

- Activity

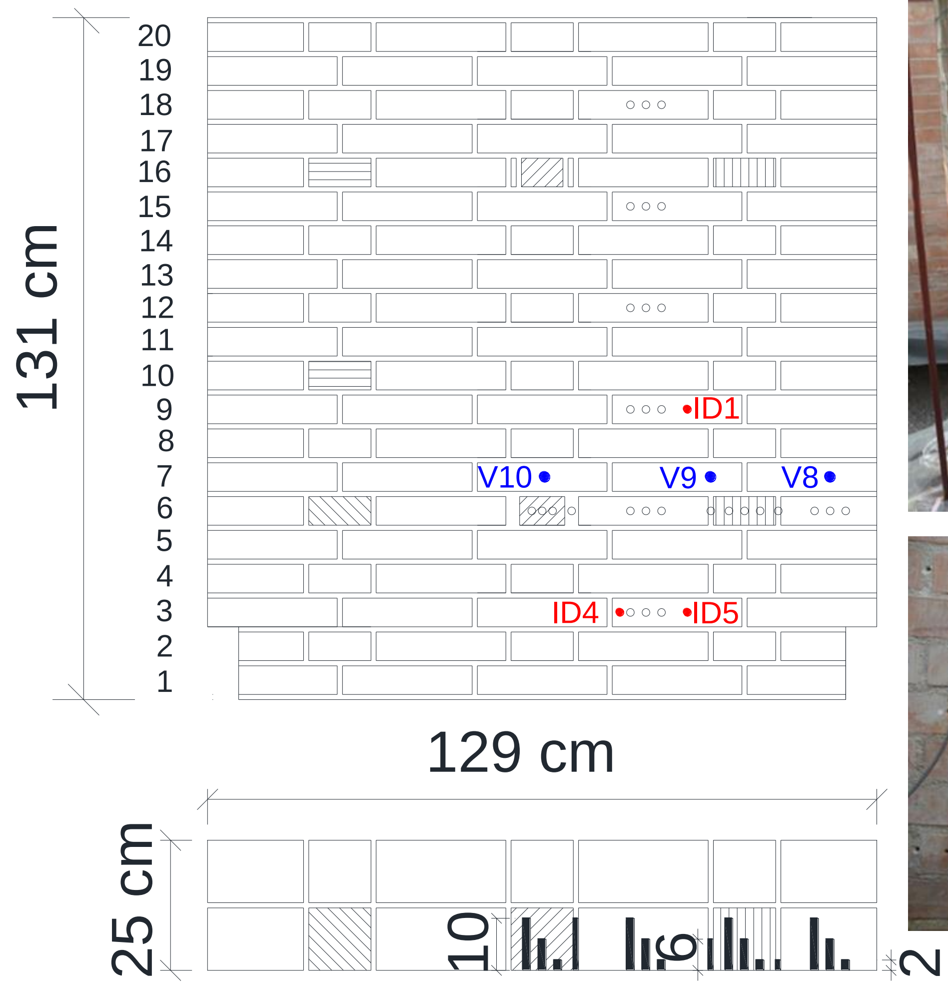
$$\ln a_{Cl^-} = \ln a^{Ref}_{Cl^-} - \frac{FE_M}{RT}$$



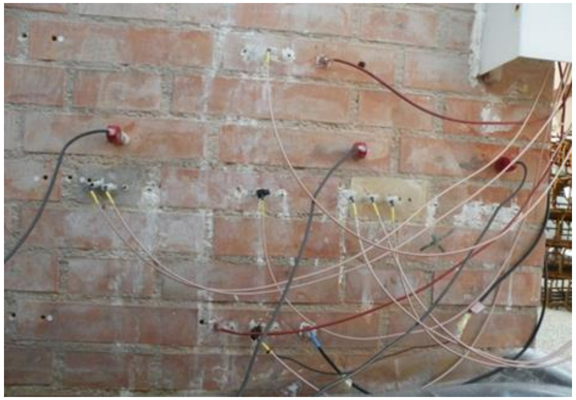
Junction potentials



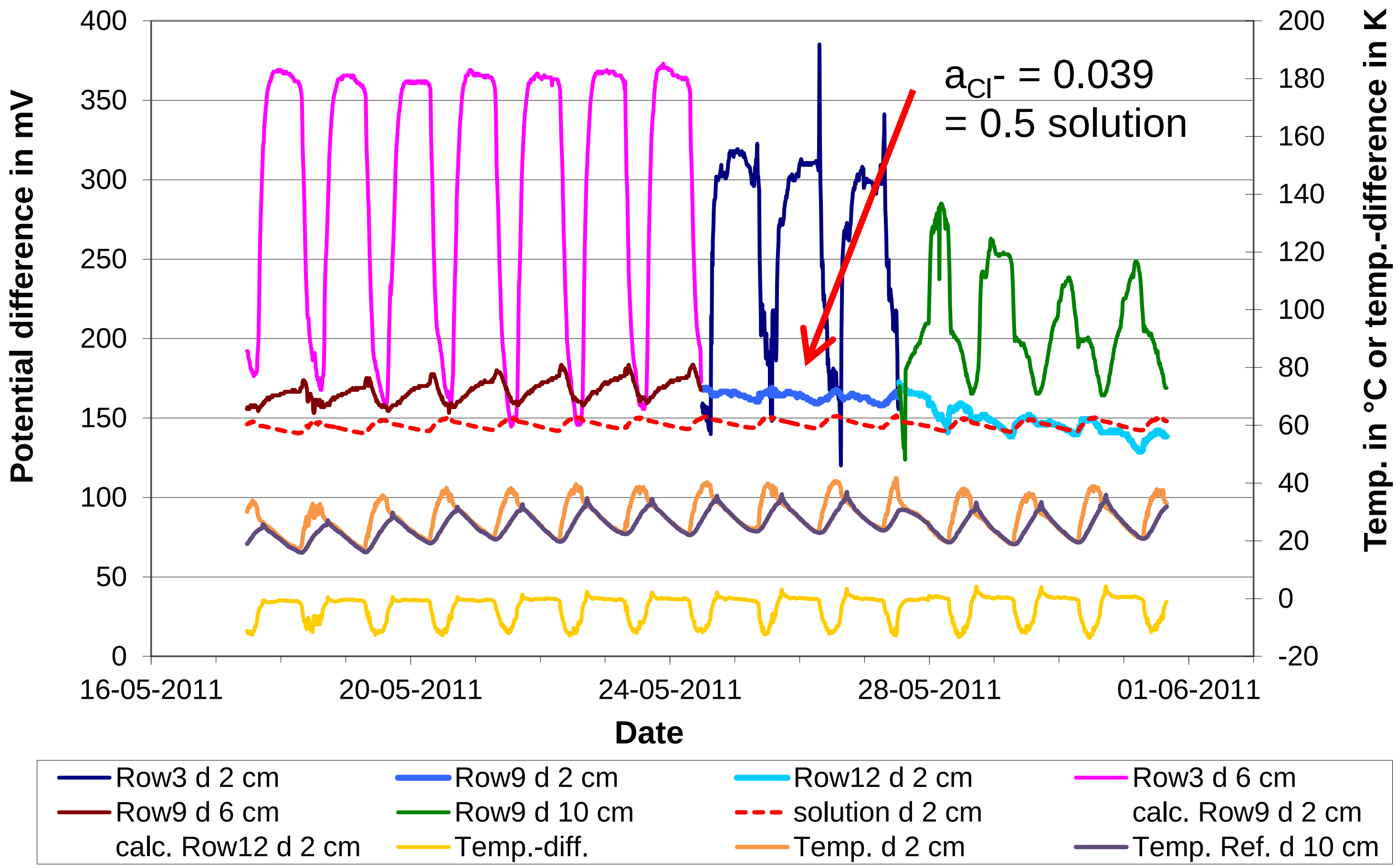
Methodology



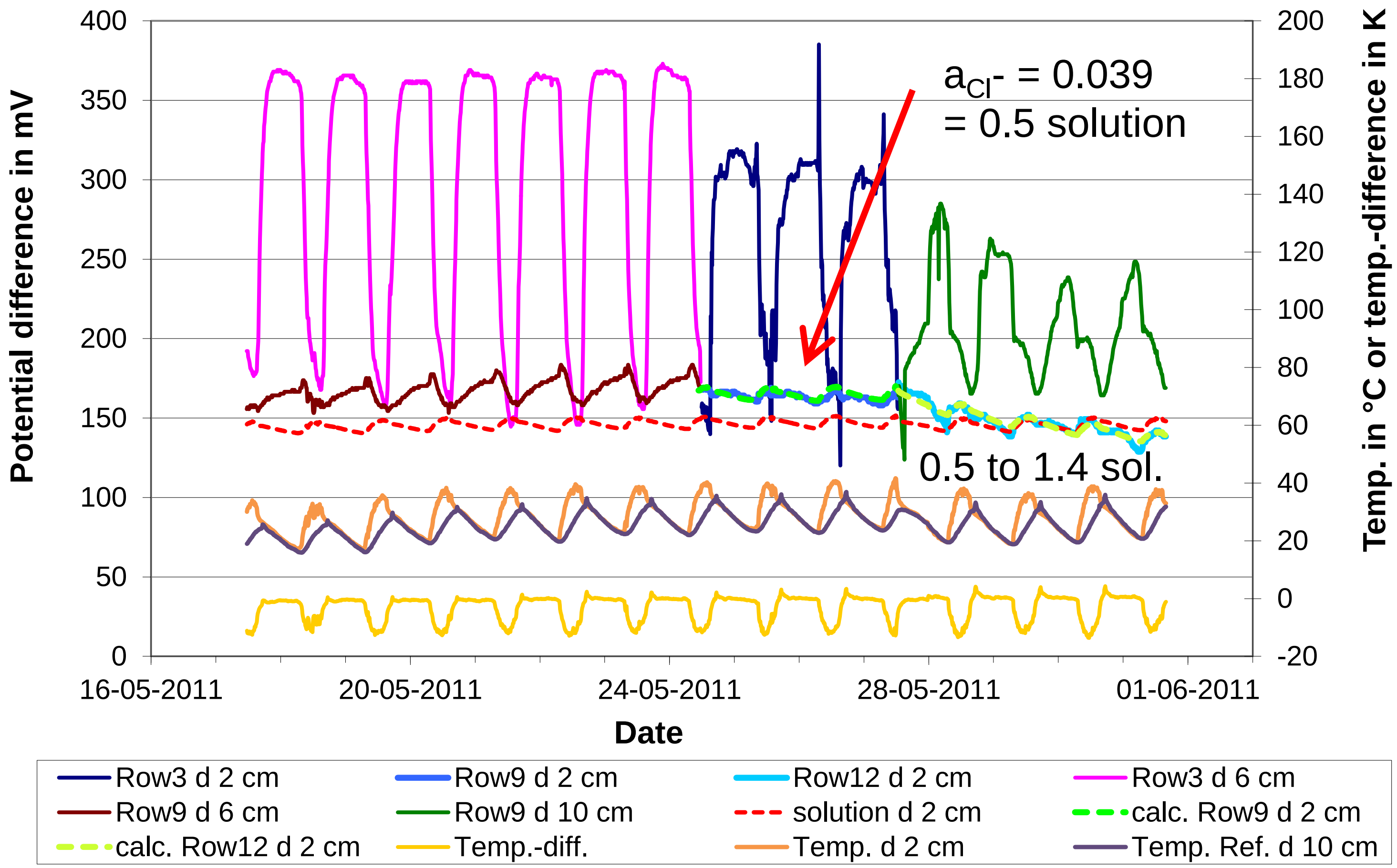
Efflorescence after 1st period of capillary suction



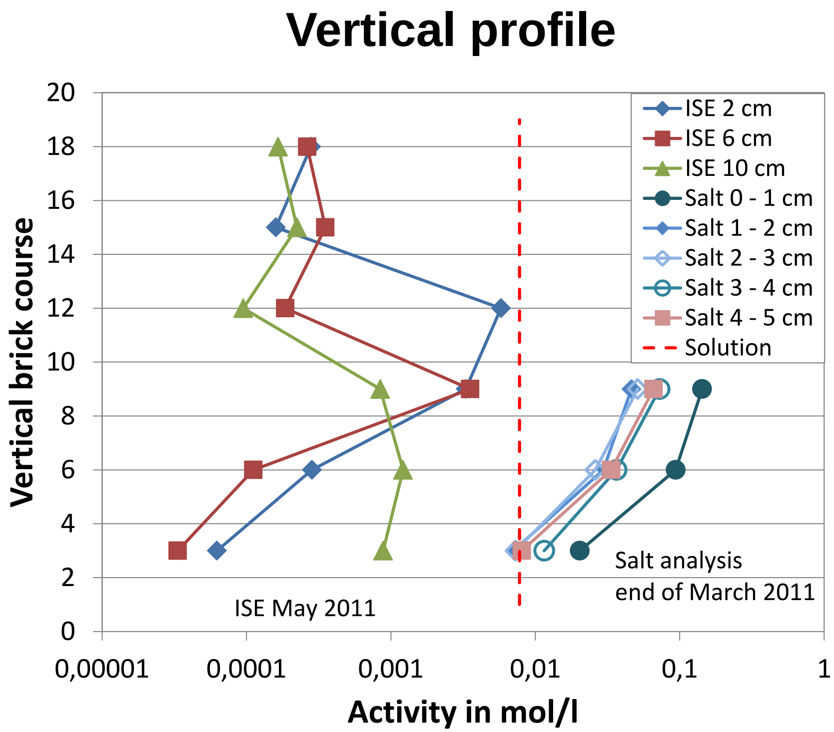
Results – sunny period in May 2011

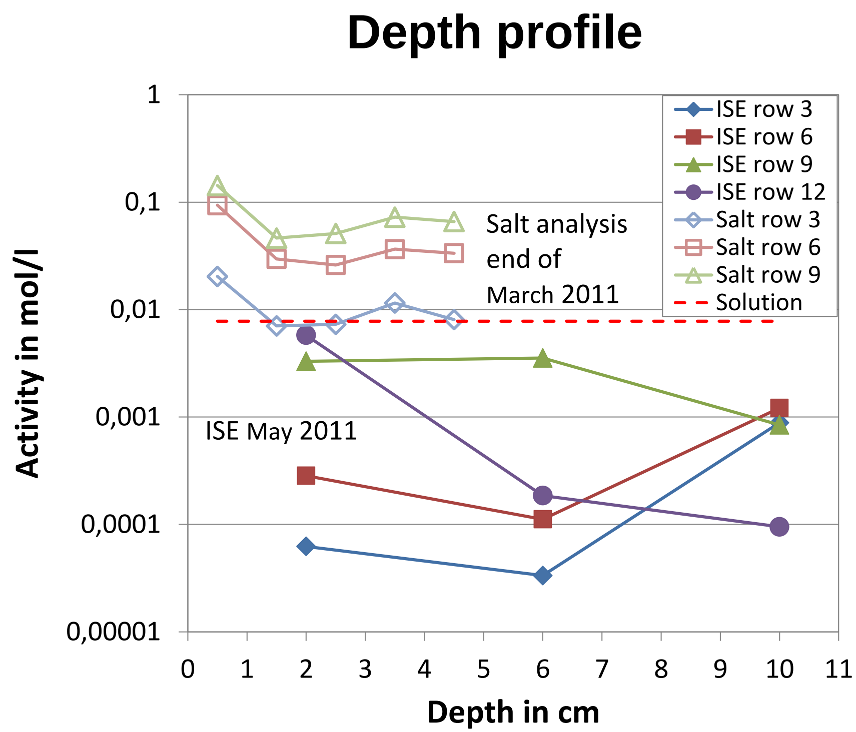


Results – sunny period in May 2011



Results – comparison with drill dust samples





- Activity drill dust calculated by
  - ion-analysis, bulk density 1790 kg/m^3, porosity 23.2 %, mean activity coefficients

Neuere Daten nach Gabrielli, Colla (2015)*

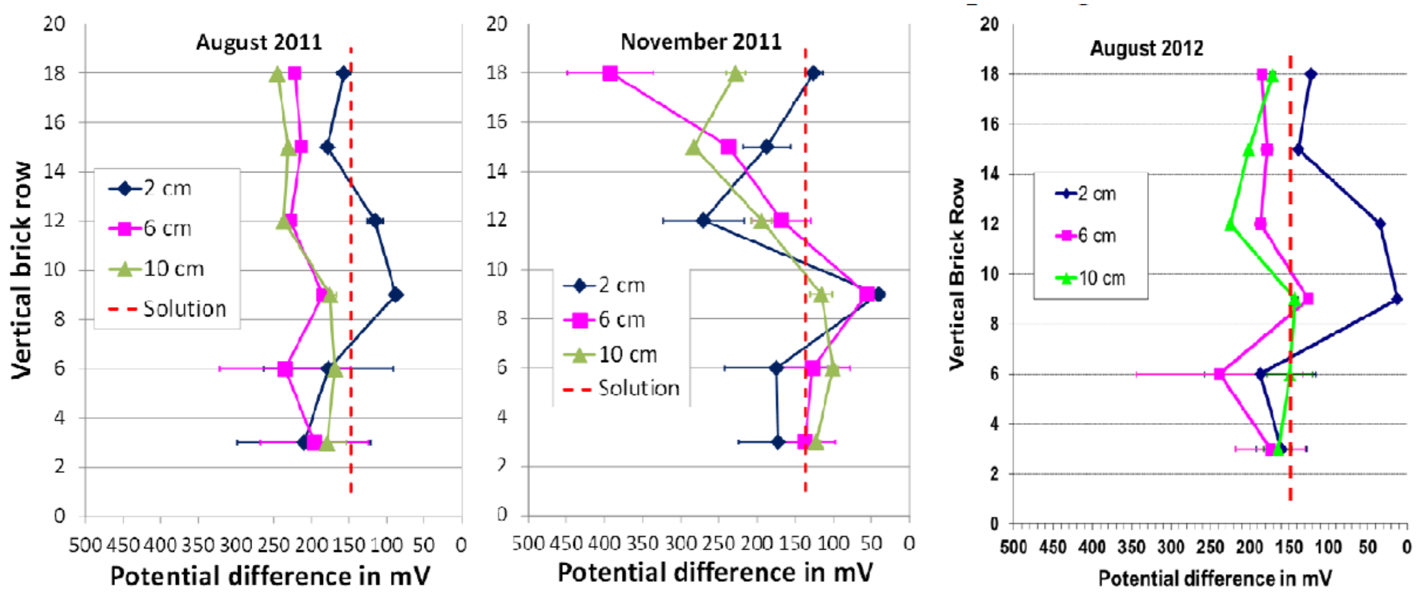
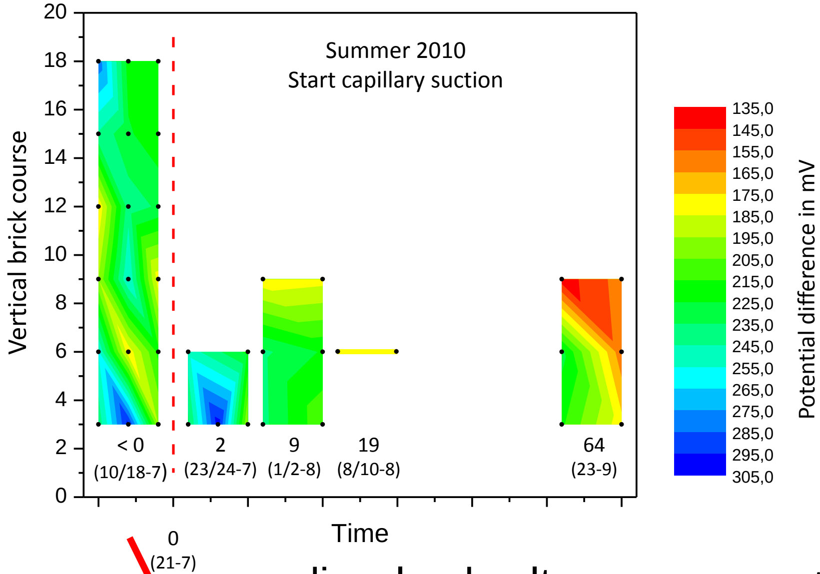


Figure 4. Comparison of mean potential differences in August, November 2011 [11] and August 2012. The error bars show the standard deviation of single electrodes. The dotted red line indicates the calculated potential value of the 0.05%-wt. NaCl solution.

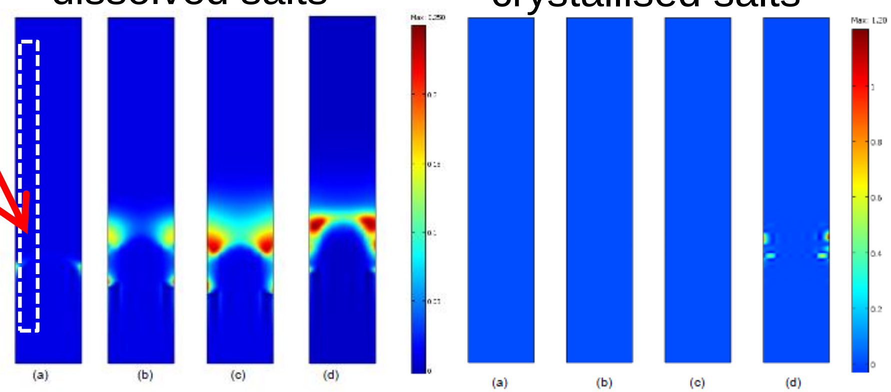
*) Gabrielli, E.; Colla, C.; Investigation of damp and salt distribution in outdoors full-scale masonry wall via wireless monitoring and radar testing; Key Engineering Materials Vol. 624 (2015) pp 155-162 © (2015) Trans Tech Publications, Switzerland

Genannte Lit. [11] Frick, J., Colla, C., Gabrielli, E., Gruener, F. Seasonal Monitoring of Salt Movement in Masonry Materials, Proc. of EWCHP 2012, 2nd European Workshop on Cultural Heritage Preservation, Kjeller, Norway, 24th -26th September, 2012, 27-34

Results – start of capillary suction



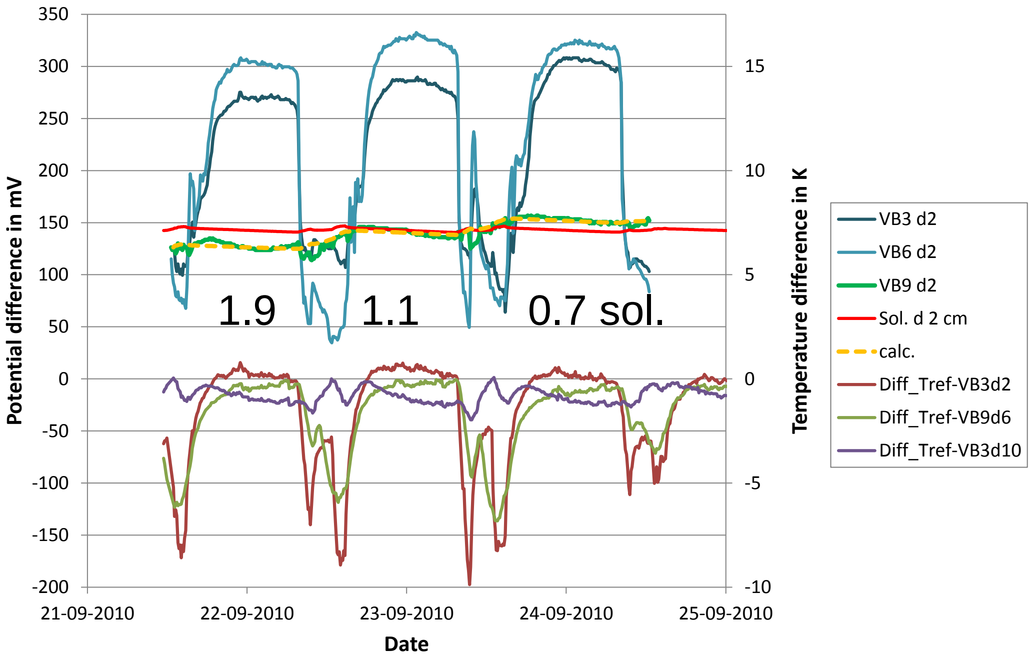
dissolved salts | crystallised salts

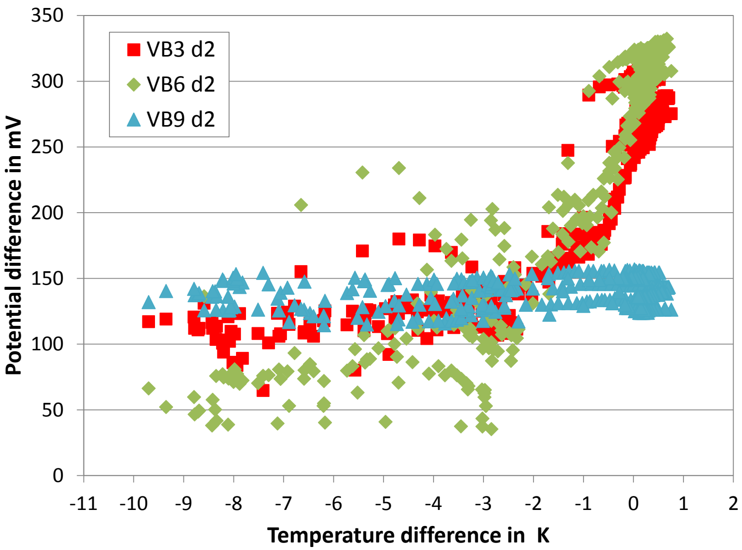


15 30 45 60 | 15 30 45 60

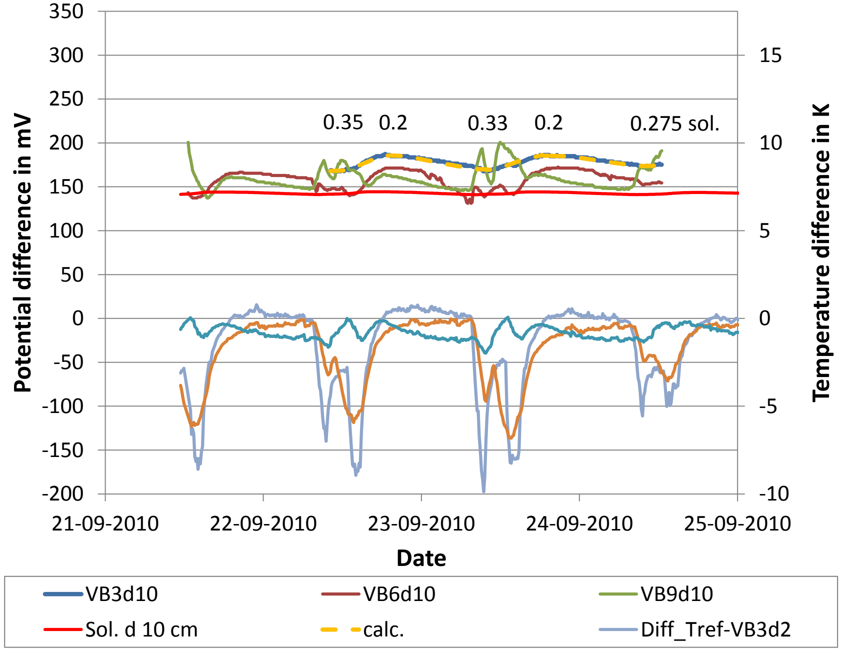
Castellazi et al. 2013

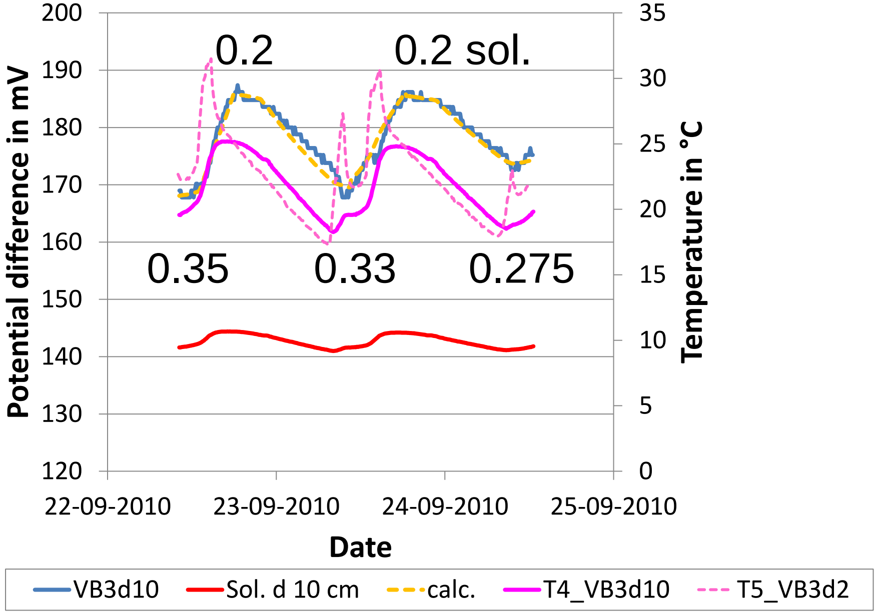
Results – correlation potential with temperature



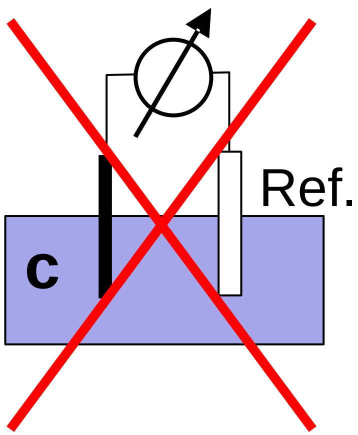


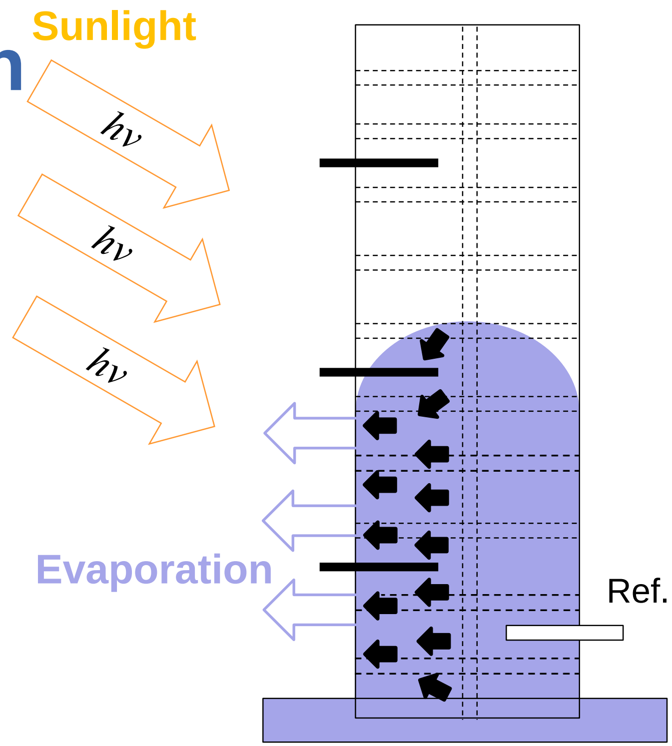
Results – behaviour near base at depth 10 cm

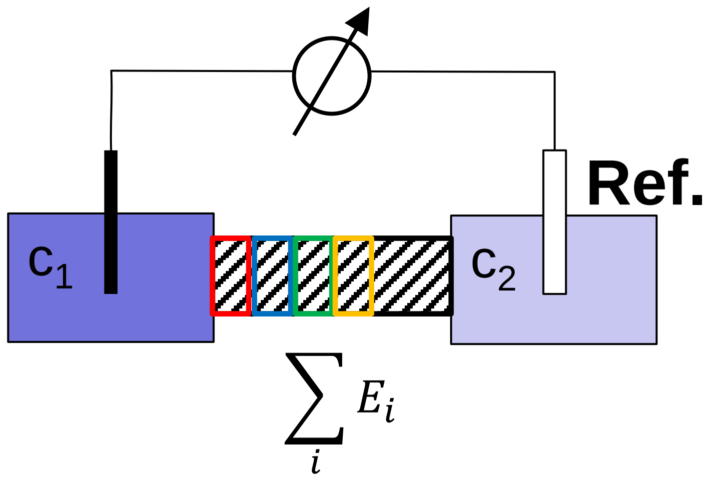




Discussion







- ❑ Near surface and crystallisation level
  - ➢ Nernst behaviour occur, but measured potentials too low (brine level)
    - ▪ Disturbing potentials of constant or low varying type
- ❑ Strong daily oscillations in solution saturated regions near to the surface
  - ➢ Insight in ongoing transport processes

Conclusions and future work

- The method is valuable to provide a qualitative understanding of salt movements in real buildings
- Some “disturbing” effects give insight in ion transport processes
- A quantitative understanding is possible if “disturbing” potentials could be assessed
  - Experiments in well-defined environments ongoing
  - Comparison with modelling and simulation
- Indoor environments show less variations: example chapel in Schönbrunn palace, Vienna
- Method could be used to monitor desalination measures
- Aim: new robust electrodes for other relevant ions (sulphates, nitrates, etc.)

Acknowledgements

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  - University of Bologna: Camilla Colla, Elena Gabrielli
  - MPA Stuttgart: Friedrich Grüner
  - Contact: Jürgen Frick, Email: juergen.frick@mpa.uni-stuttgart.de

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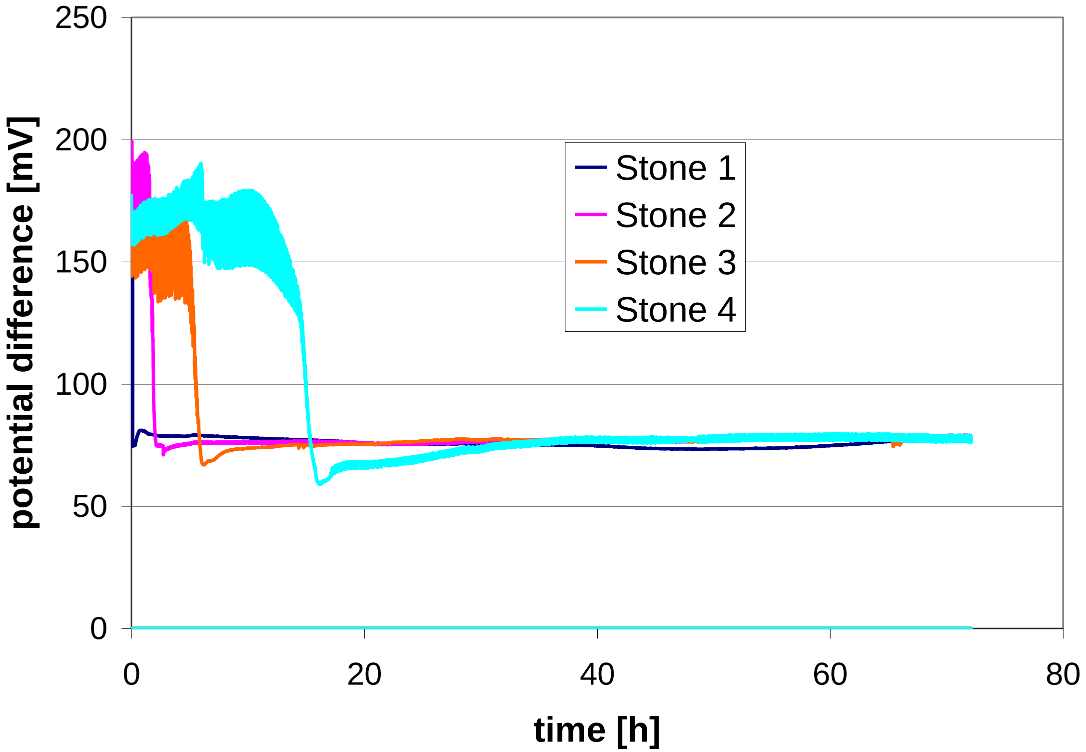
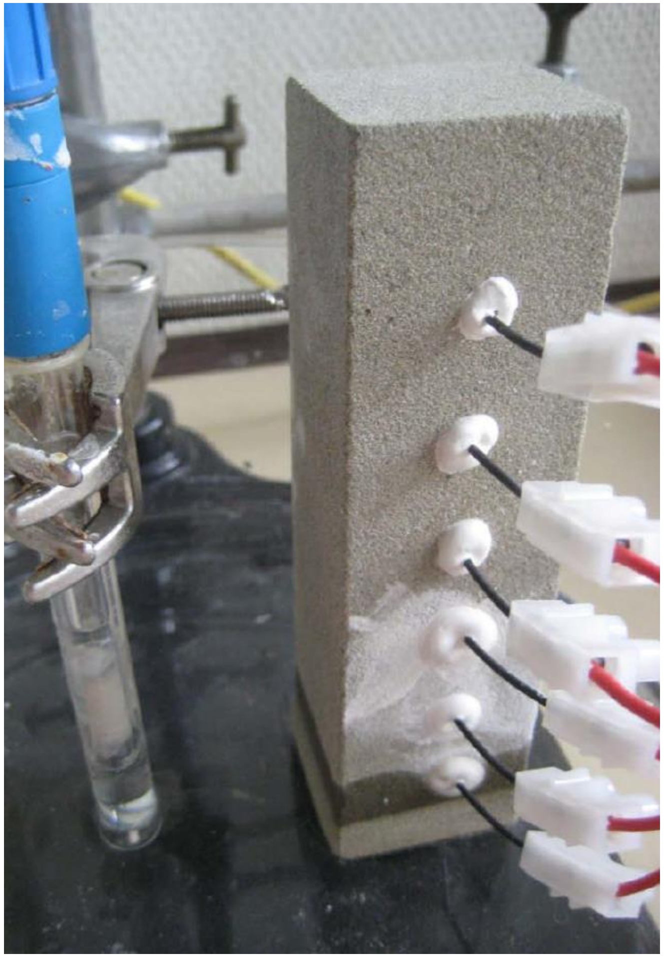
Weitere Folien zu Kompressen Entsalzung

- Vorgetragen auf der NDTMS 2011, 15. bis 18. Mai 2011 in Istanbul
- Zugehörige Literatur:
  - Frick, J.; Lehmann, F.; Menzel, K.; Pakdel, H.; Krüger, M.: Monitoring of salt content in mineral materials using wireless sensor networks, Nondestructive Testing of Materials and Structures, Proc. NDTMS-2011, May 15-18, 2011, Istanbul, Turkey, eds. O. Buyukozturk, M.A. Tasdemir, O. Gunes, & Y. Akkaya, RILEM Bookseries 6 (2012) 1103-1109.

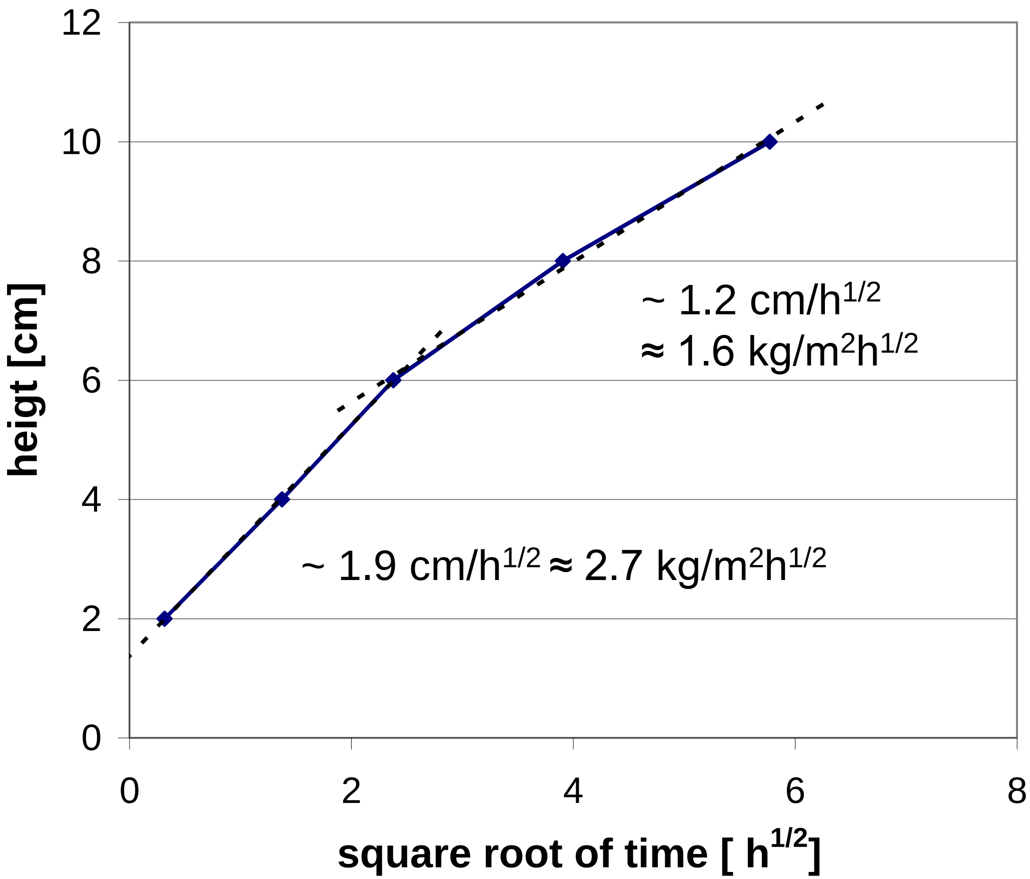
Capillary suction Sander Schilfsandstein





Solution: NaCl 0.01 mol/kg
Elektrodes embedded with gipsum
(Diploma thesis Pakdel)

First arrival solution at electrodes



Literature data "Sander Schilfsandstein":

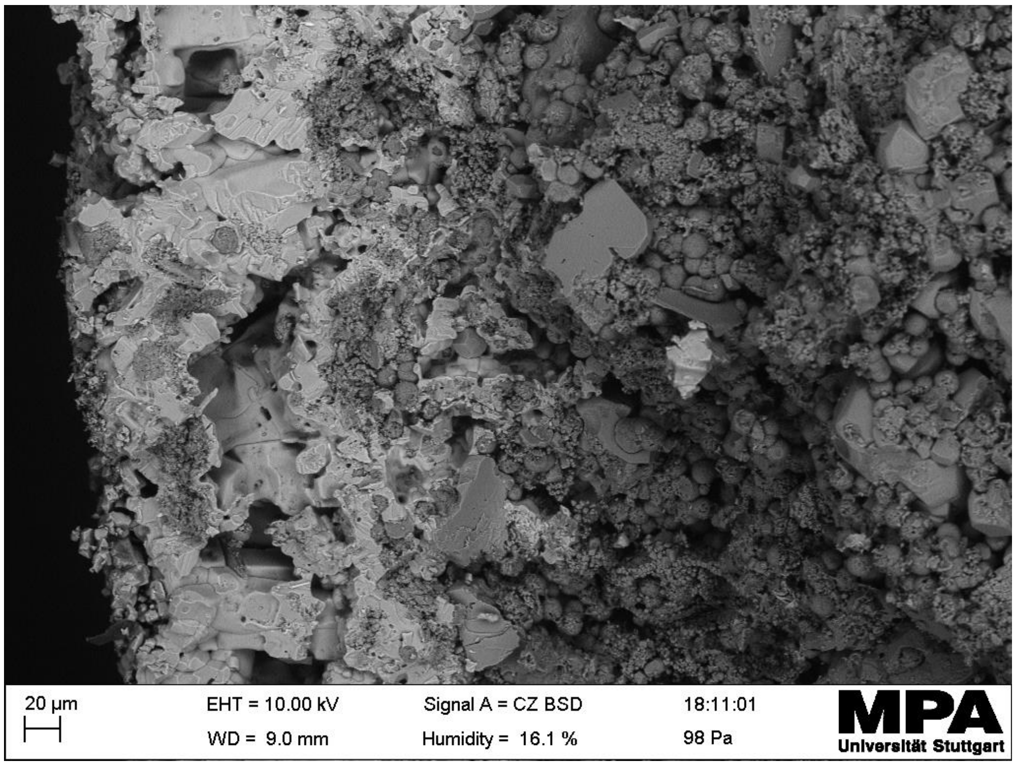
Grimm "Denkmalgesteine":
Water apsorption normal pressure
6.45 mass-%
Bulk density 2.13 g/cm^3

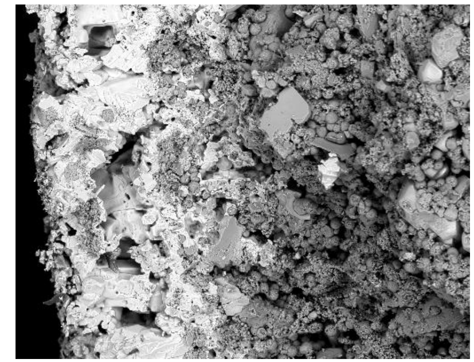
BMFT-Project Stones (TU Dresden):
W-absorption coefficients
Parallel bedding 2.5 $kg/m^2h^{1/2}$
Perpendicular bedding 3.3 $kg/m^2h^{1/2}$
Bulk density 2.20 g/cm^3

Dimensions probe:
4 x 4 x 15 cm^3

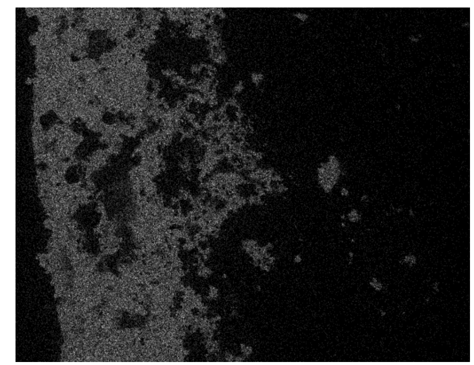
Example: NaCl enrichement due to capillary suction

Salt crystals in the stone matrix (Tuffeau)

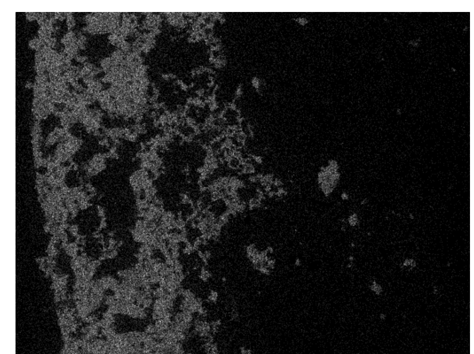




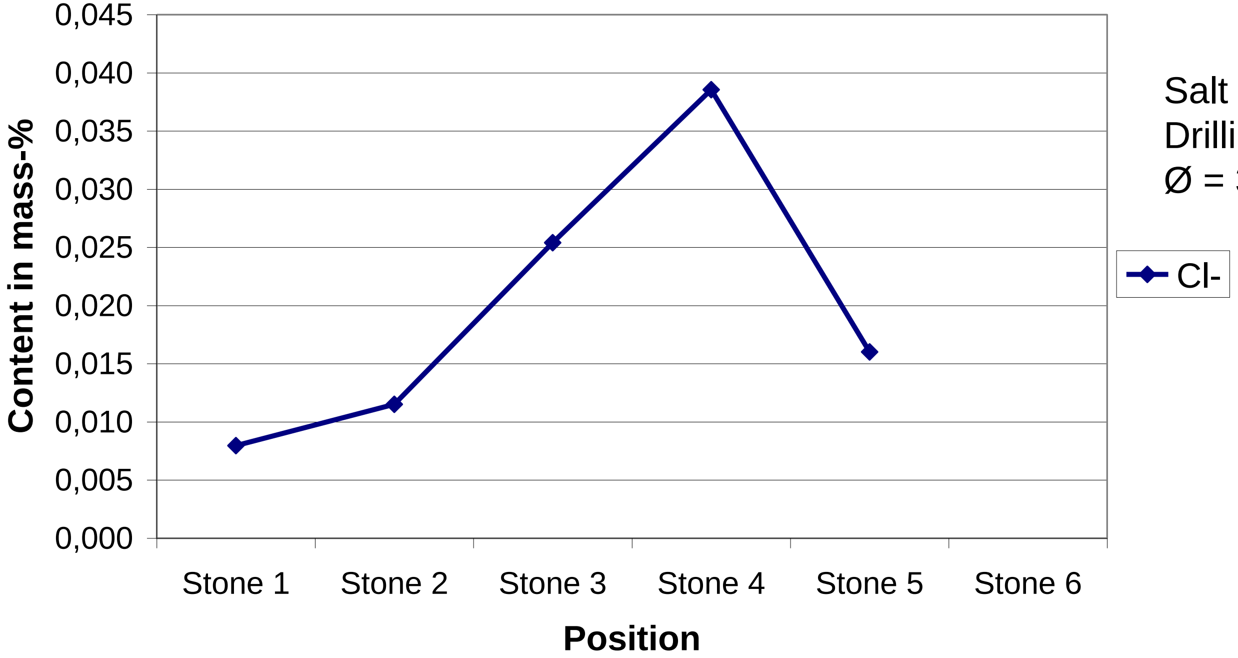
Cl



Na



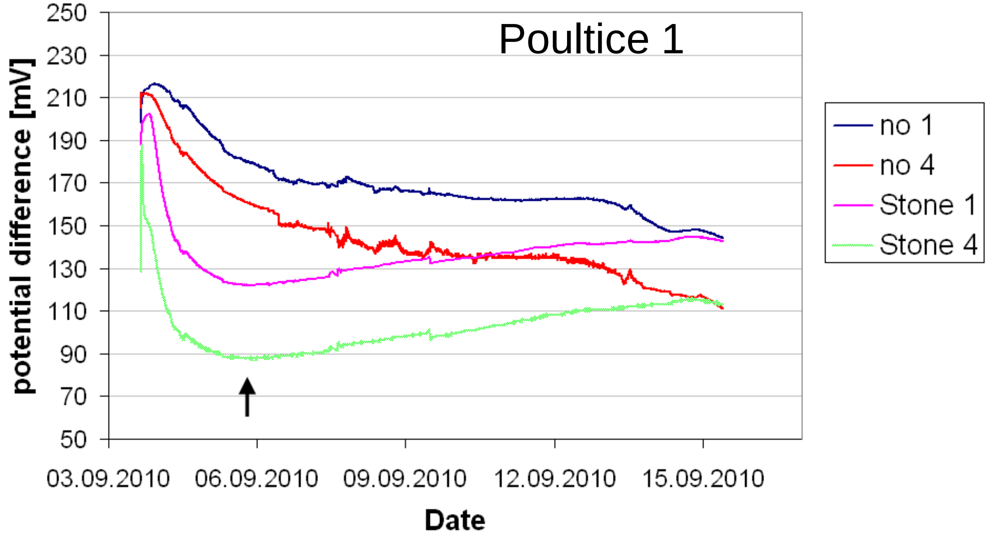
Sander Schilfsandstein

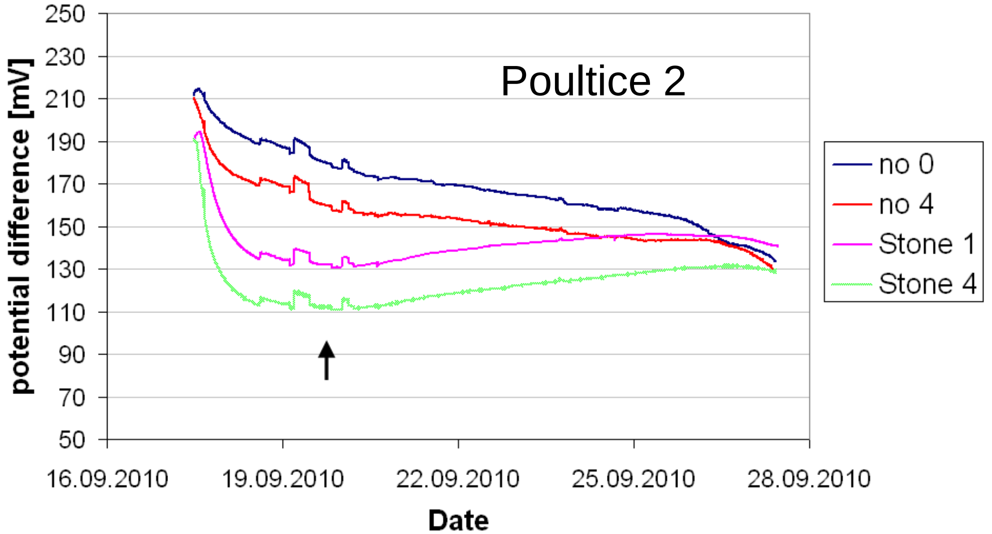


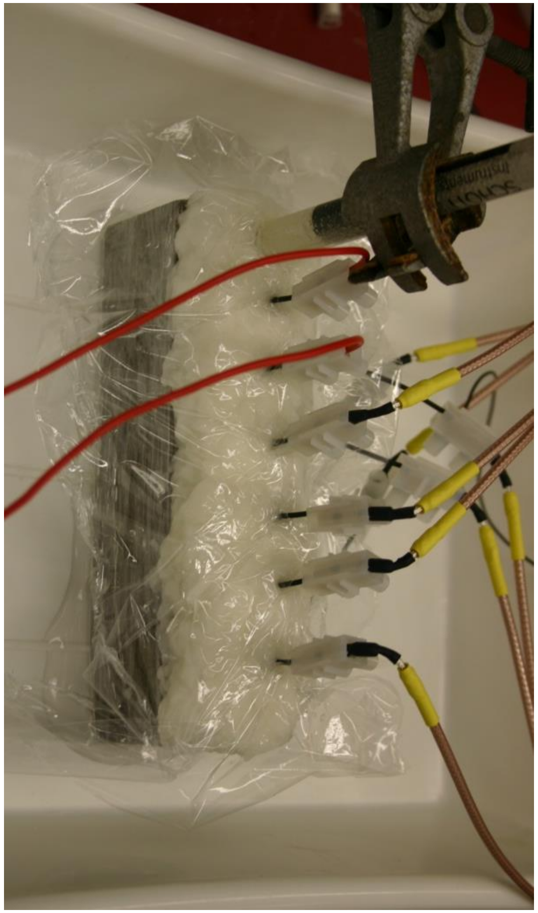
Salt content
Drilling powder 0 to 1.5 cm
Ø = 3 mm

Capillary Suction

Desalination – poultices 1 + 2







Comparison salt content and potential