ALACAH

CONSERVATION ENGINEERING

'How Lime Mortar Works'

Overview:

Introduction and Context

I. Physical Principles of Moisture Transport

II. The Behaviour of Lime-Mortared Masonry

III. Working with Carbonate Binders in Wet Climates

Summary

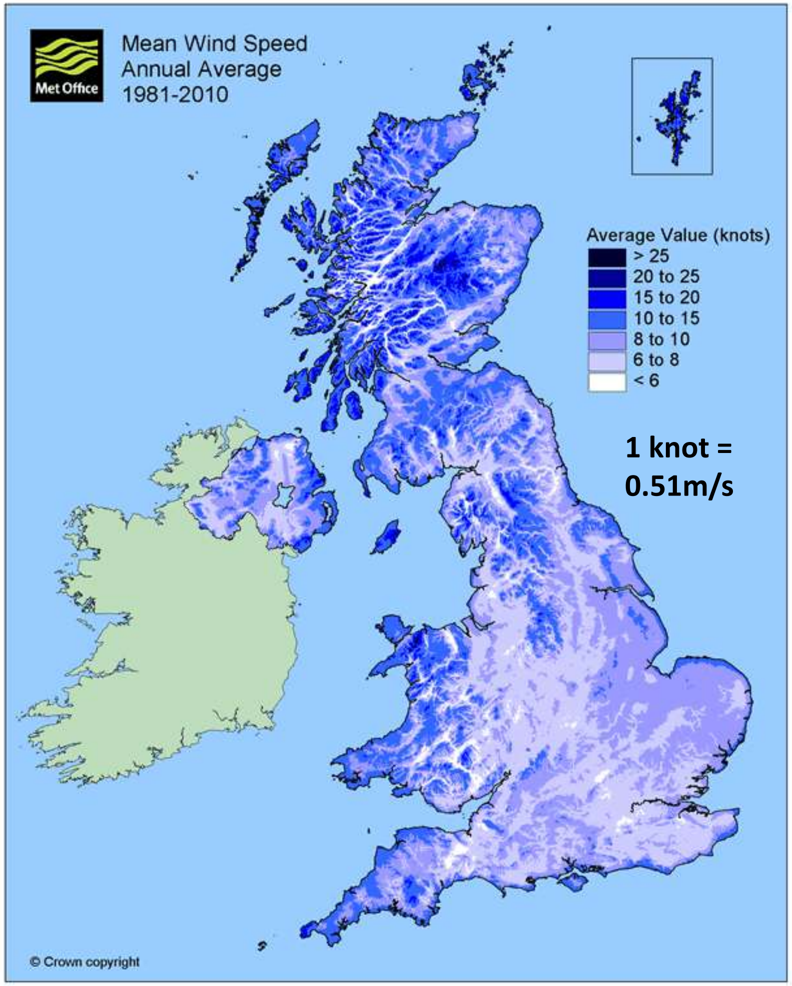
NORDISK KALKFORUM

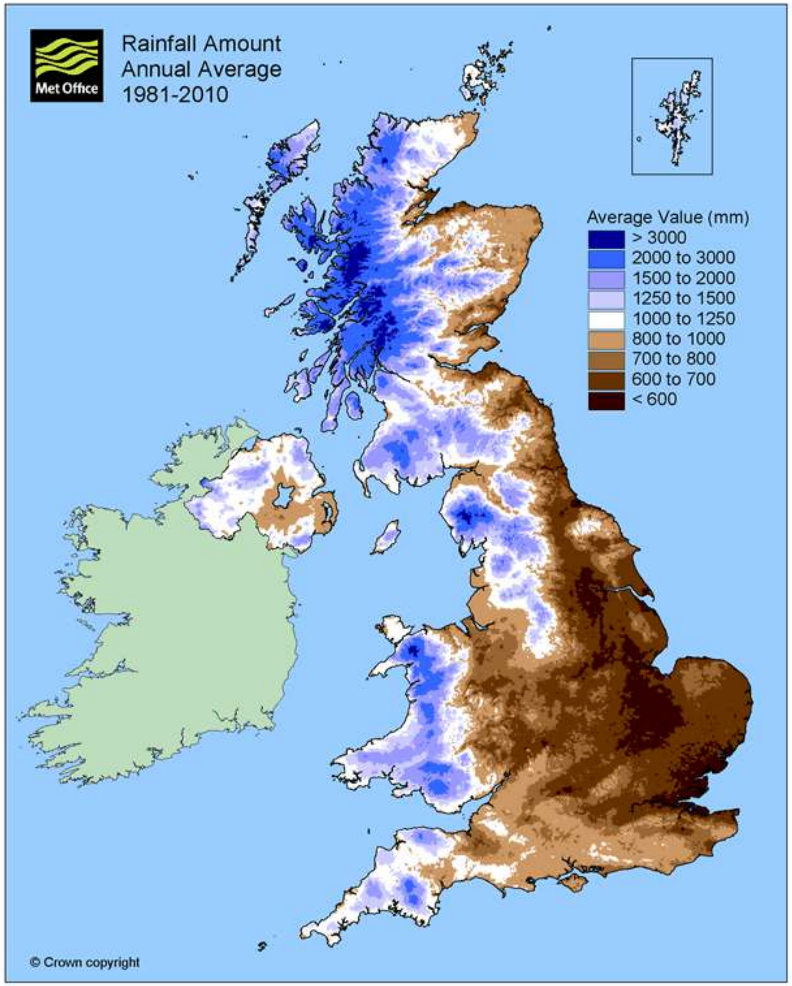
Section Overview

Introduction & Context

Introduction

Wind-driven rain exposure back home in UK:





West coast Scottish scene: wind 5-10m/s; rain 2000-3000mm

Introduction

Nordic climate:

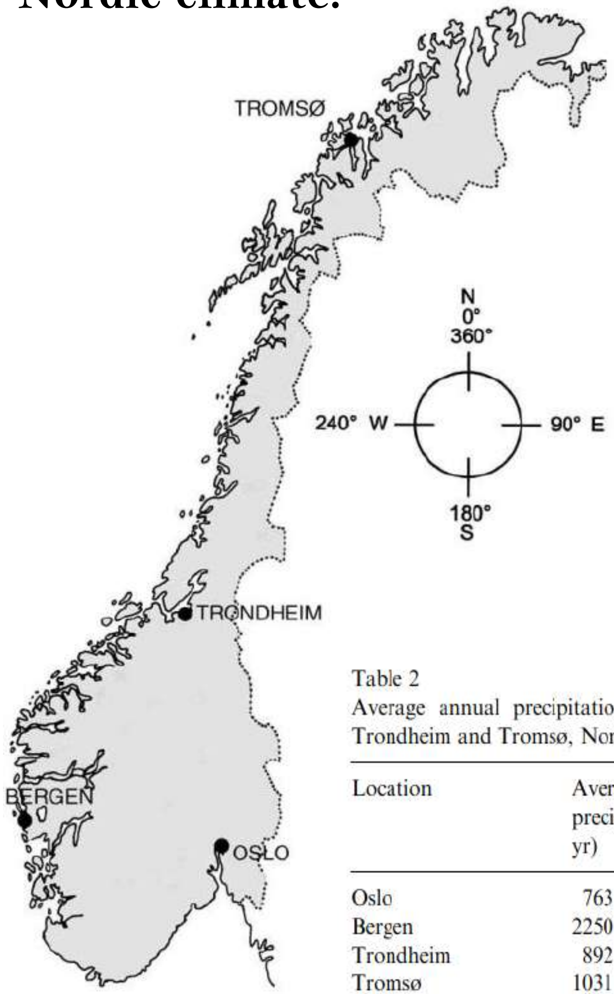
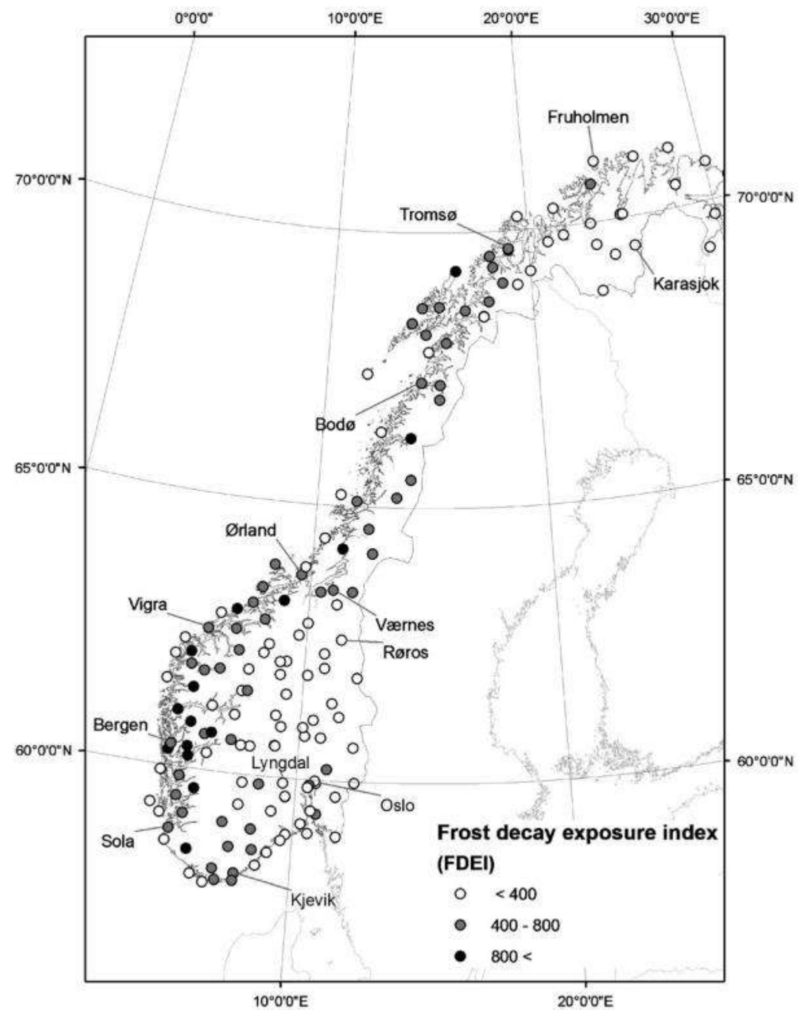


Table 2
Average annual precipitation and wind speed for Oslo, Bergen, Trondheim and Tromsø, Norway for normal period 1961–1990

Location	Average annual precipitation (mm/yr)	Average wind speed (m/s)
Oslo	763	2.7
Bergen	2250	3.5
Trondheim	892	3.9
Tromsø	1031	4.0

J.P. Rydock et al. / Building and Environment 40 (2005) 1450–1458



K.R. Lisø et al. / Building and Environment 42 (2007) 3547–3555

Bergen fairly similar…? Similar west-east divide in wind-driven rain exposure

Introduction

Principal agent of decay in UK masonry is soluble salts.

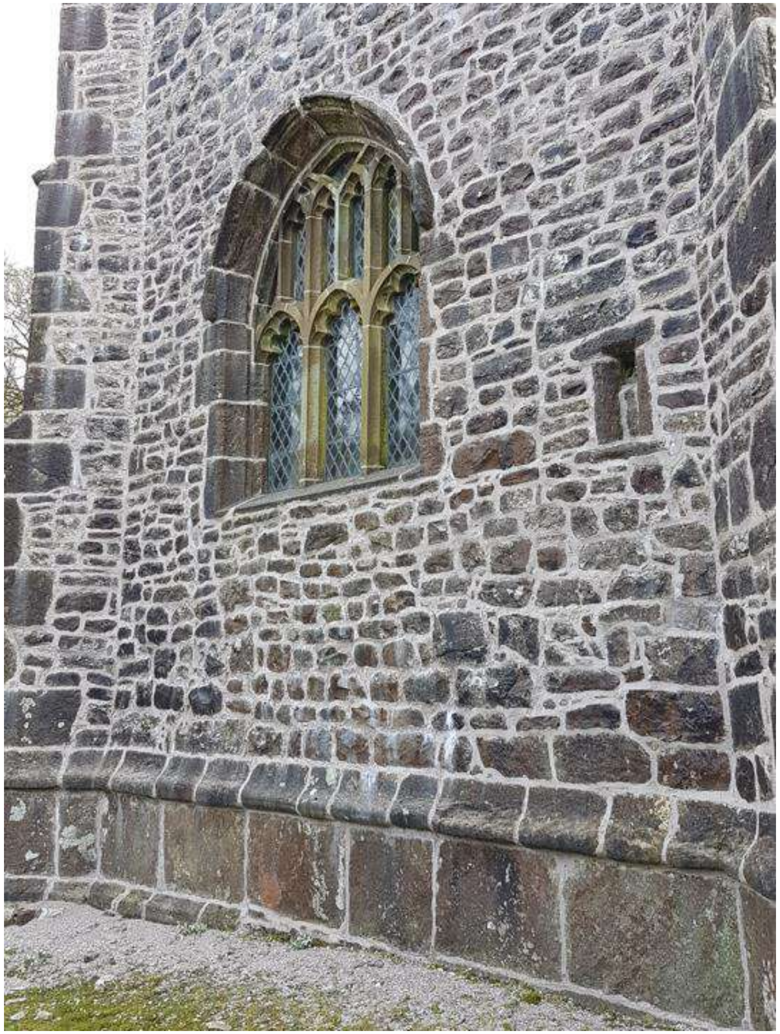
Introduction

Salts mobilised by wetting & drying cycles, all year round.

Turns engineering-strength stone into mush you can poke your finger into…

Introduction

Frost damage… hot-mixed lime mortars getting a bad press…

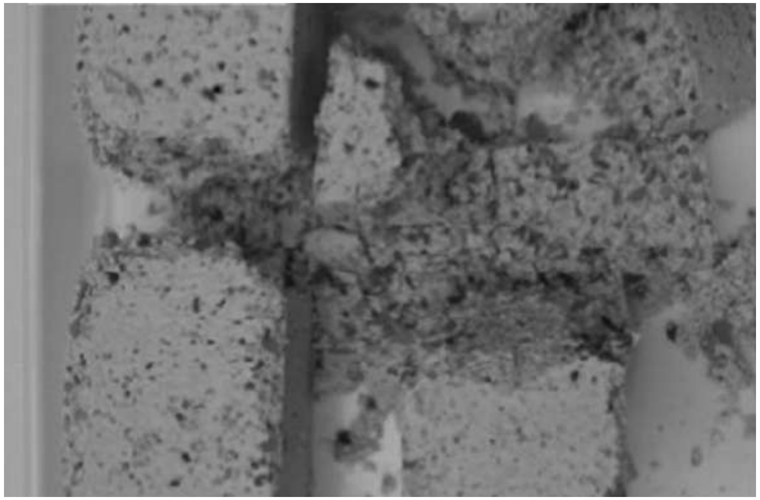


Introduction

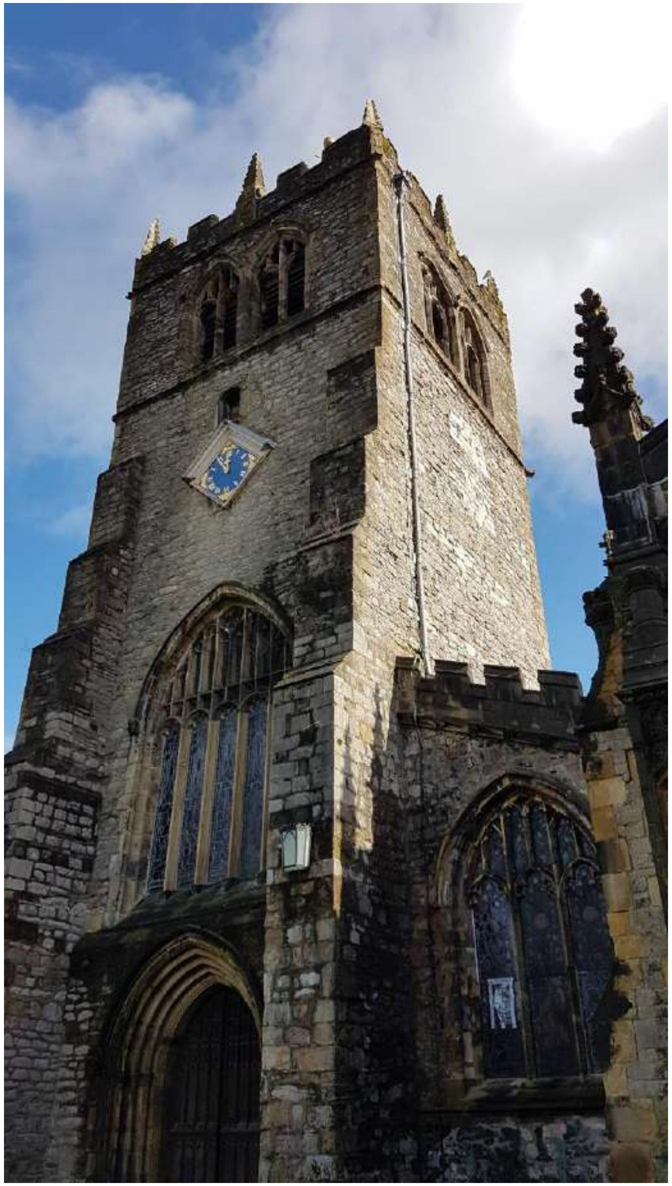
Two paradoxes:

1. **Wet buildings can be made dry by covering with an absorptive lime coating**

2. **Traditional lime mortars are demonstrably not frost resistant, but thousands of years of history in frosty climates tell us otherwise.**



Nunes & Slizkova (2016)

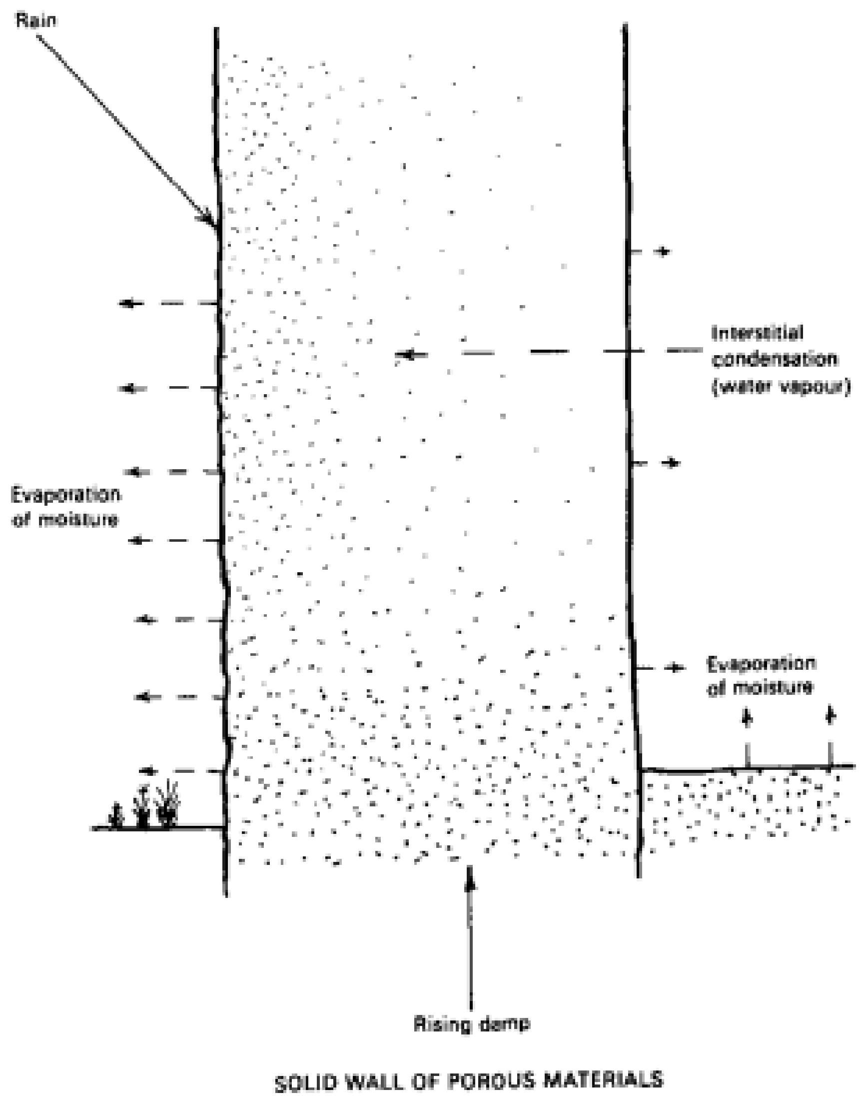


Section Overview

I. Physical Principles of Moisture Transport

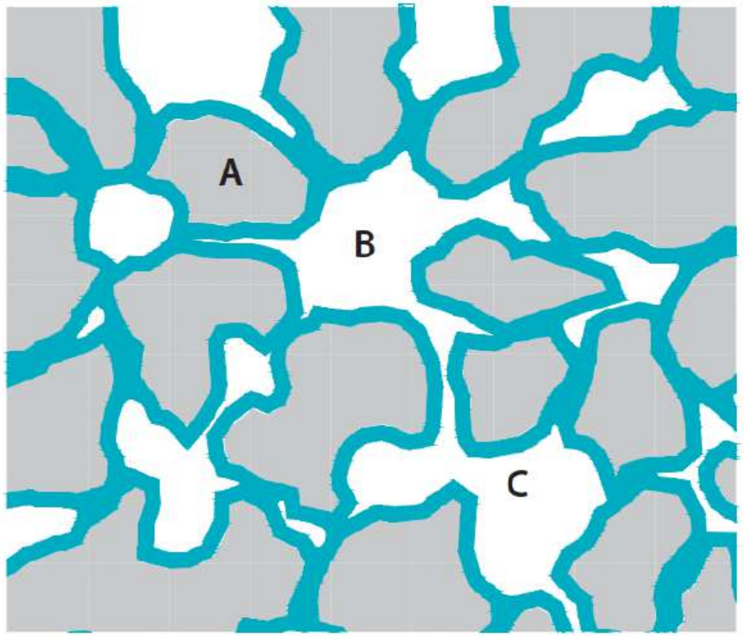
Physical Principles of Moisture Transport

SPAB on solid walls:



Physical Principles of Moisture Transport

Fig. 2 Cross-section through porous material showing spontaneous water distribution without movement. A) Solid phase; B) pores; C) water adhering to pore walls.



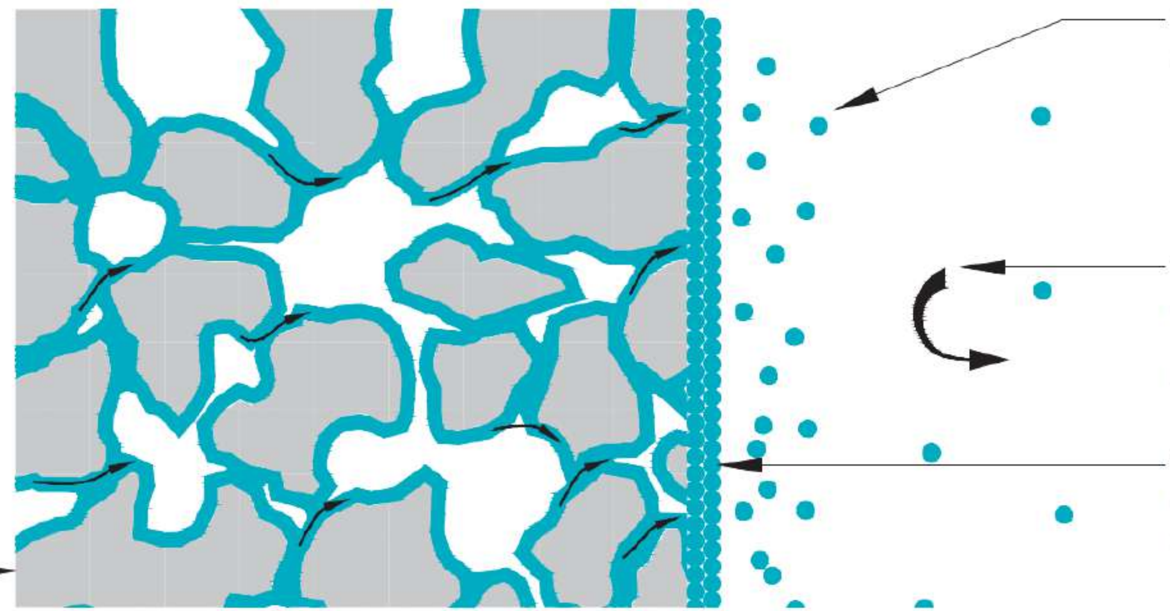
Water distribution without movement

Some physical principles:

- **Water molecules adhere to "wettable" solids**
- **Water molecules self-coherent**
- **Creates a 'film' which wets the pore walls**

Physical Principles of Moisture Transport

Fig. 3 Cross-section through porous material showing capillary flow towards drying front.



Water distribution with movement

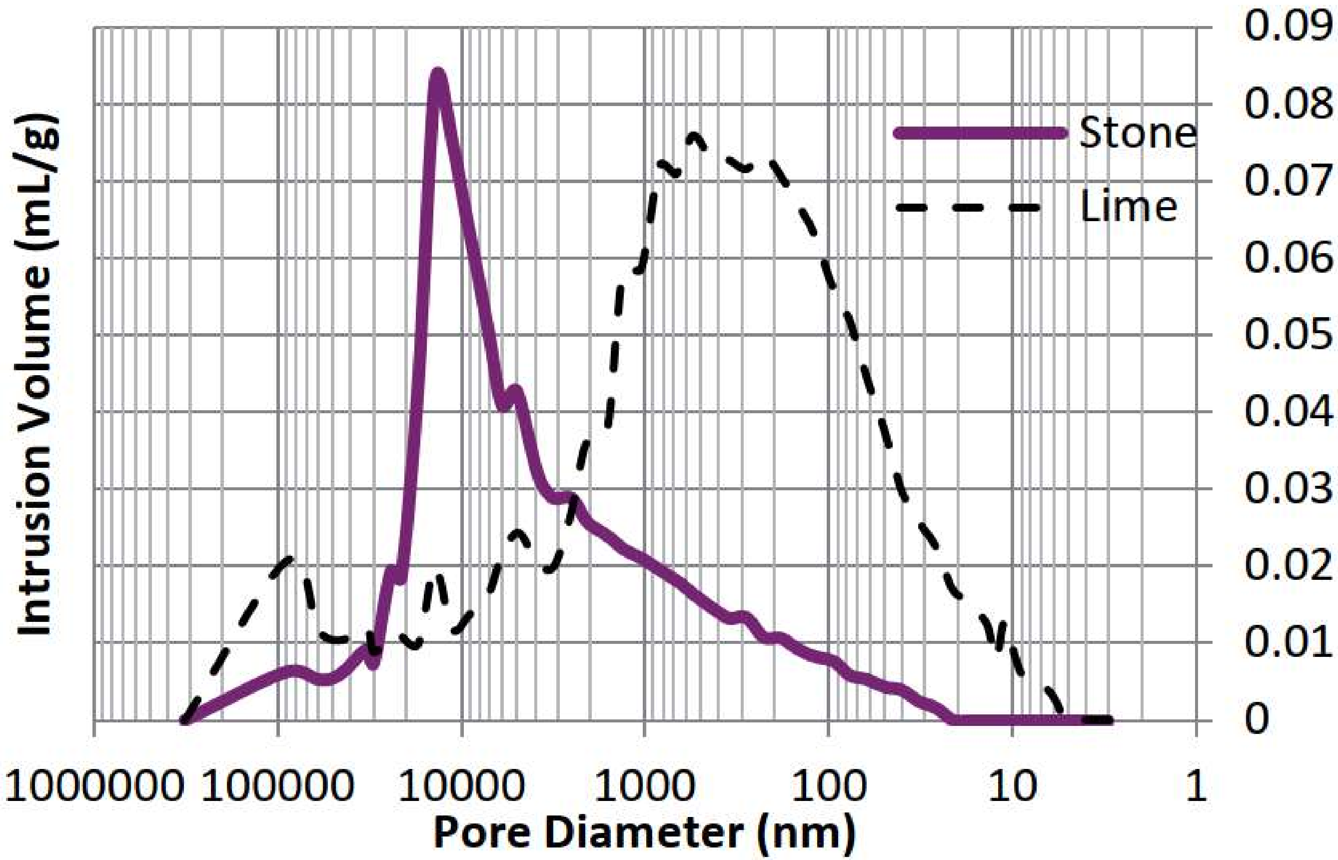
Physical Principles of Moisture Transport

Capillary drying conditions:

1. **Optimal microstructure (porosity, pore size distribution, pore interconnectivity)**
2. **Wettable surface chemistry of solid matrix**
3. **Wind blowing across the surface**

Physical Principles of Moisture Transport

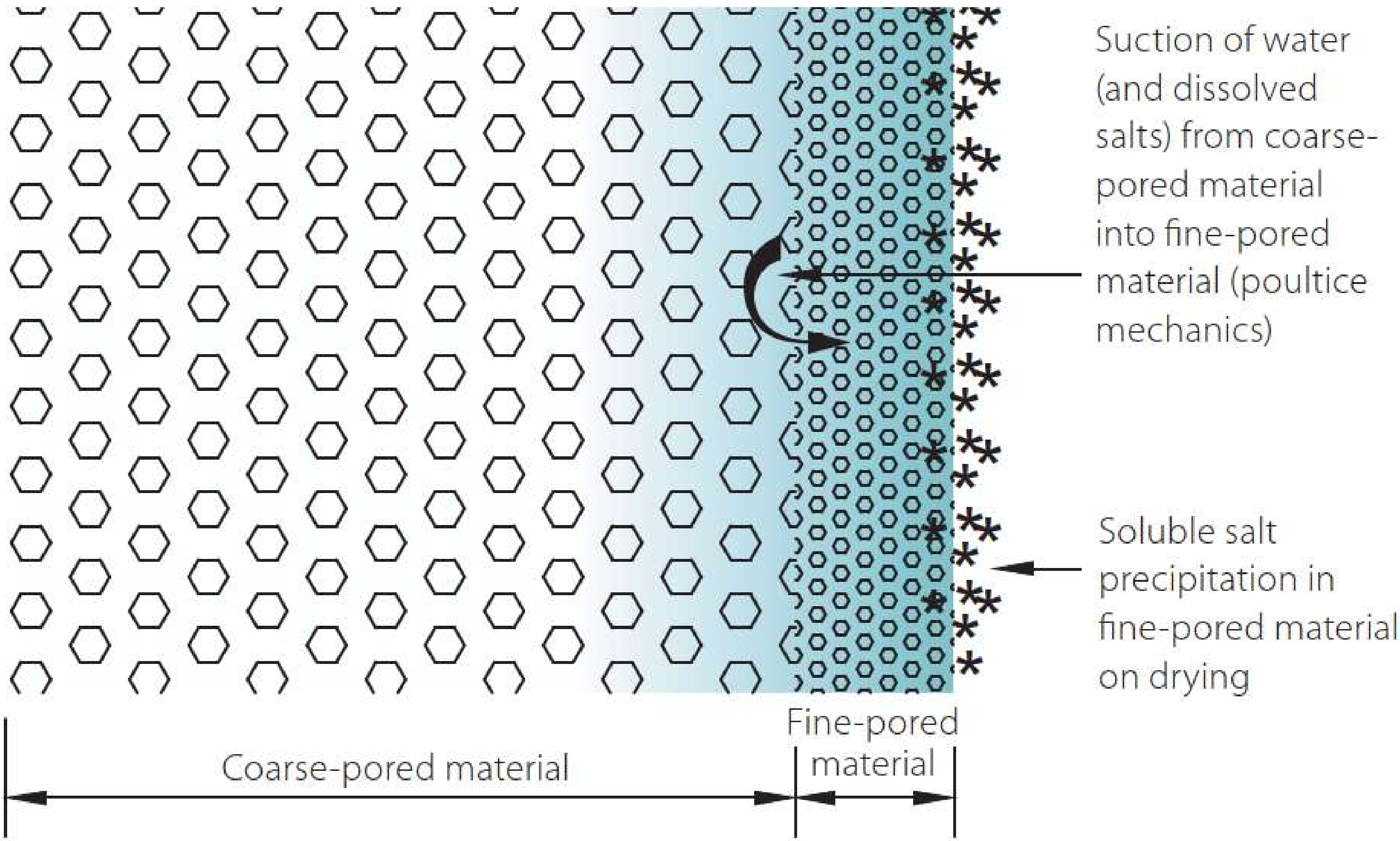
What about multi-layered porous materials???



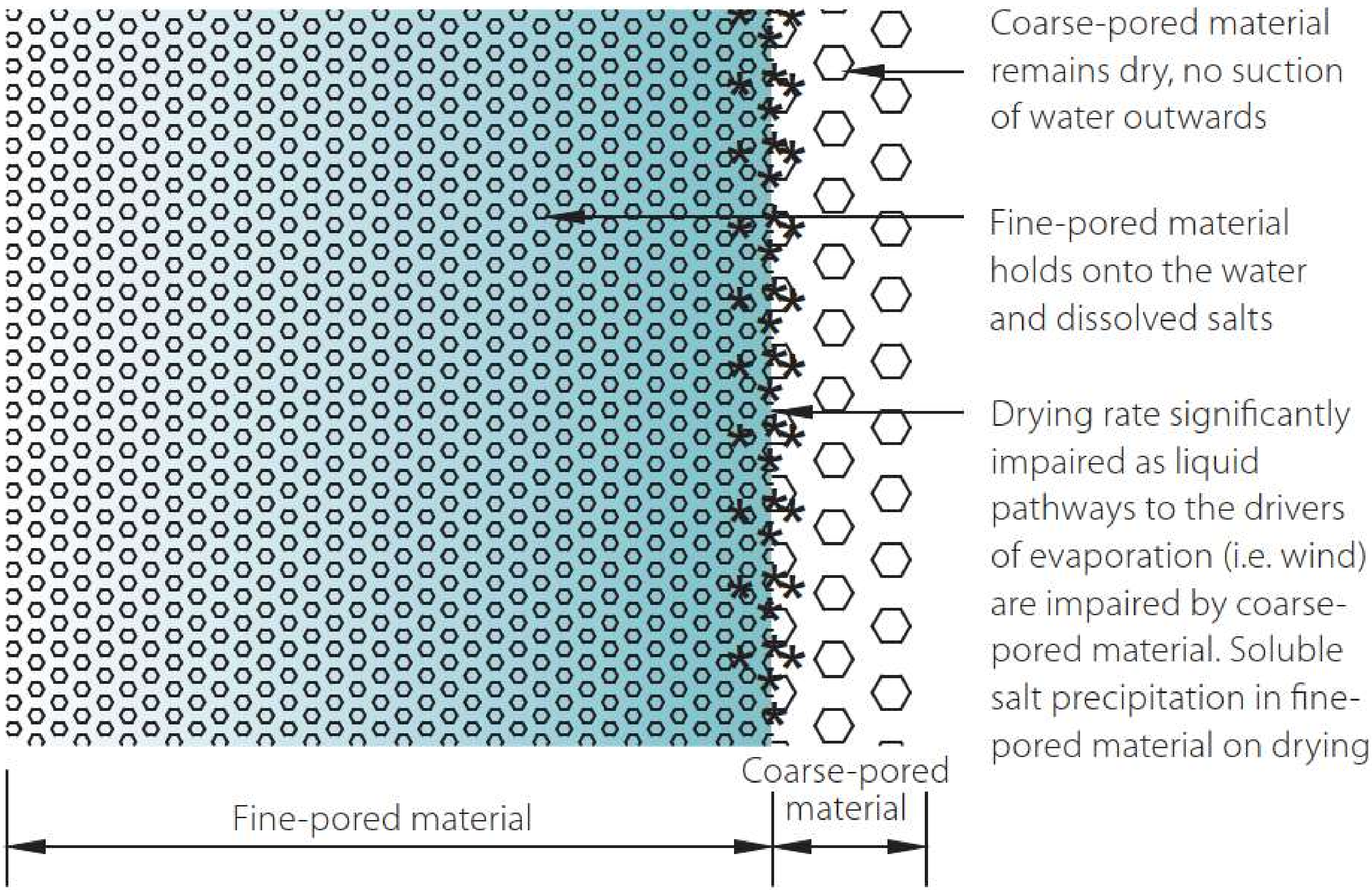
Two porous materials of distinctly different pore size in intimate contact….

Physical Principles of Moisture Transport

…and you have a poultice.

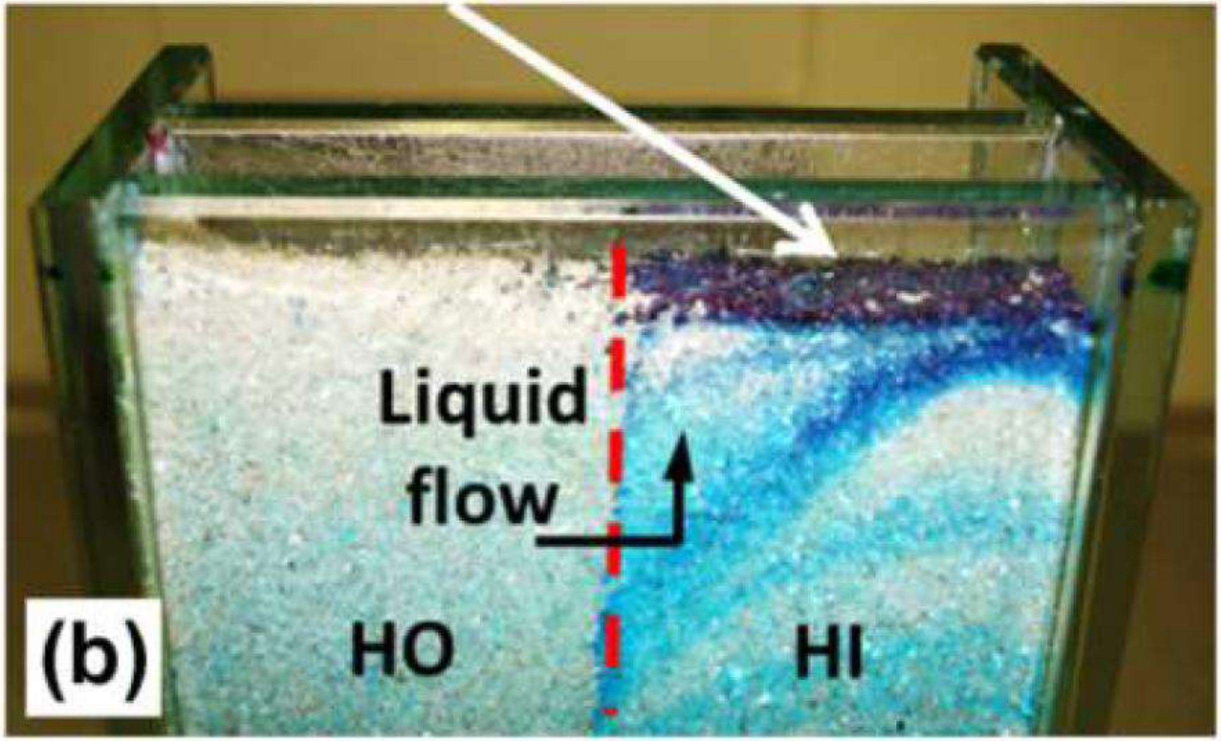


Physical Principles of Moisture Transport



Physical Principles of Moisture Transport

What about surface chemistry of the solid matrix?



Or & Shokri (2013)

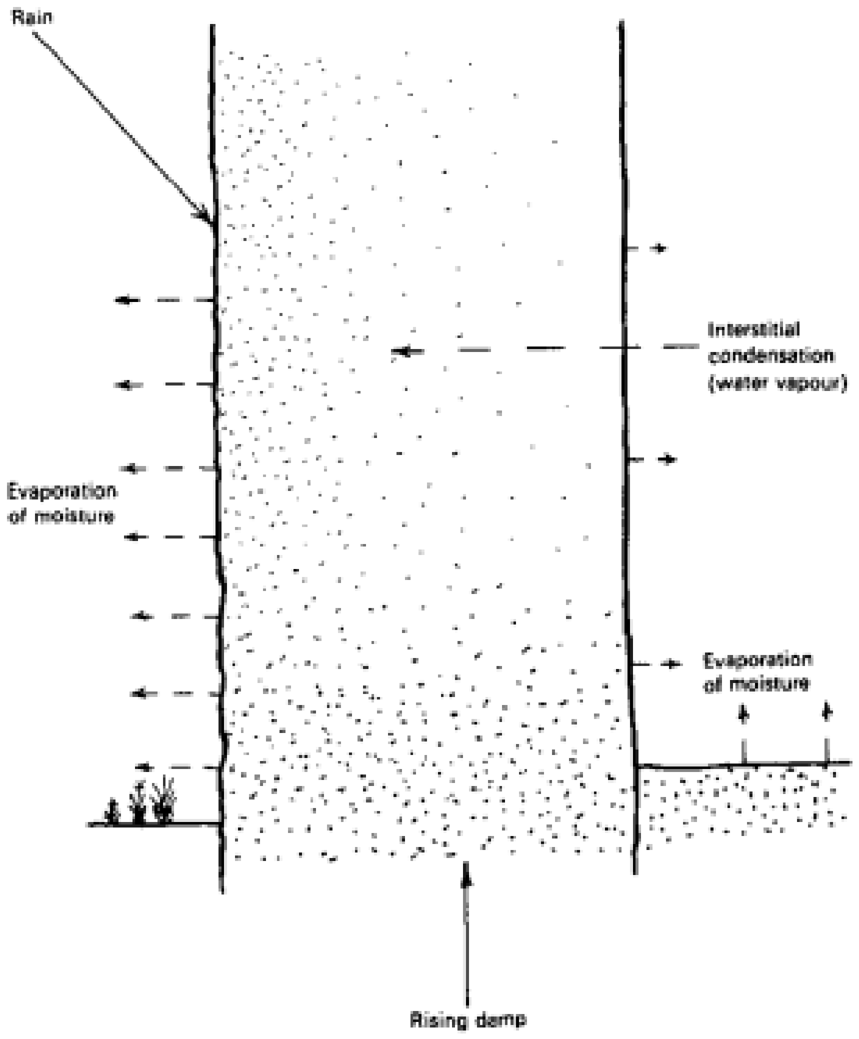
Capillary drying and poulticing require alignment of optimal microstructure, <u>wettable surface chemistry</u>, and wind…

Section Overview

II. The Behaviour of Lime-Mortared Masonry

The Behaviour of Lime-Mortared Masonry

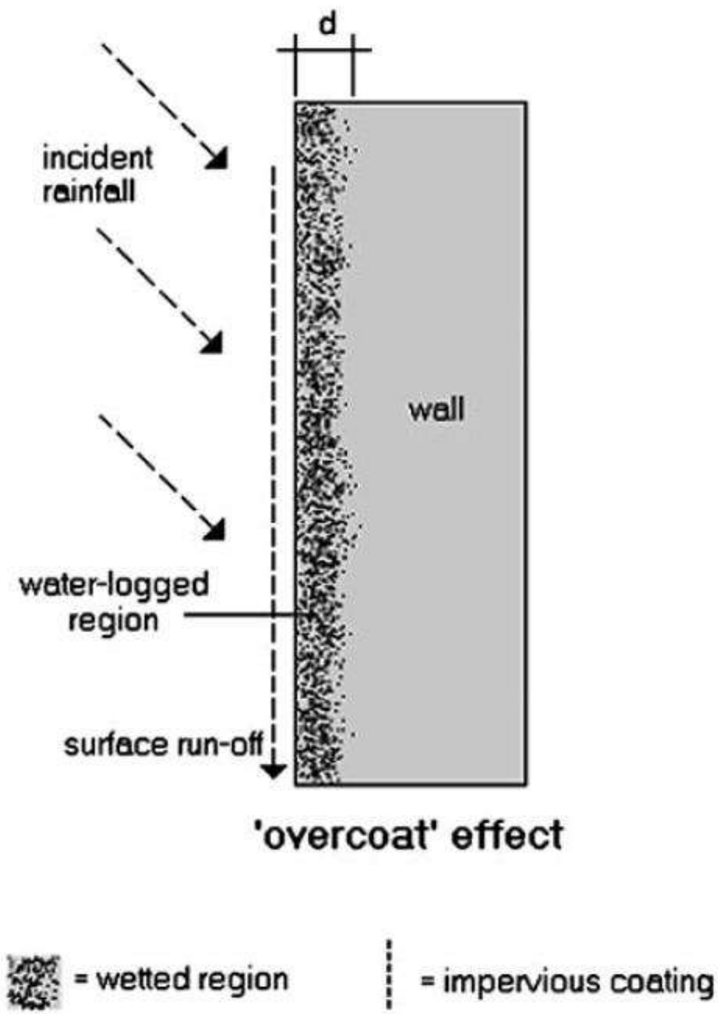
SPAB:



SOLID WALL OF POROUS MATERIALS

The Behaviour of Lime-Mortared Masonry

Traditional solid walls are thick absorbent buffers between environments

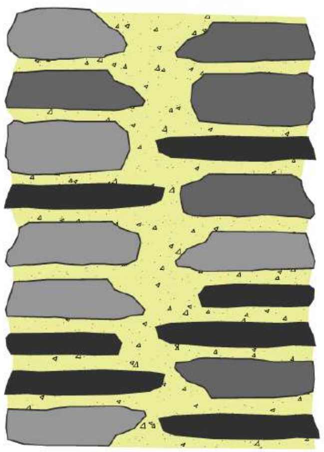


- **'Overcoat' analogy advanced by Hall & Djerbib (2006)**
- **Depth 'd' was demonstrated by Sass & Viles (2010) to primarily occur within the first 100mm of the wall**
- **Barely any change in moisture content beyond 200mm depth occurred in a well-built wall**

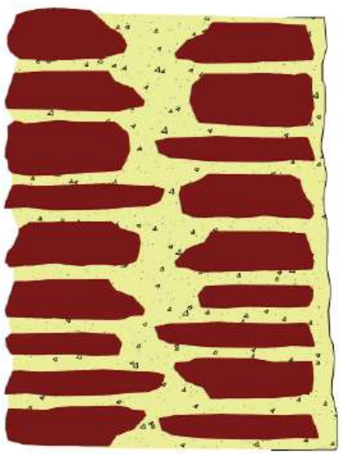
**** Caveat being well-built…***

The Behaviour of Lime-Mortared Masonry

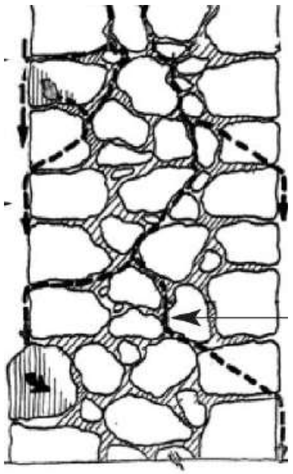
Deal with three contexts:



A: Non-porous stone bare rubble wall

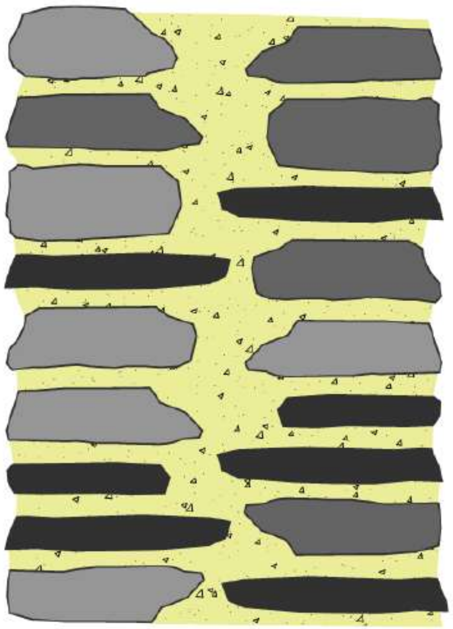


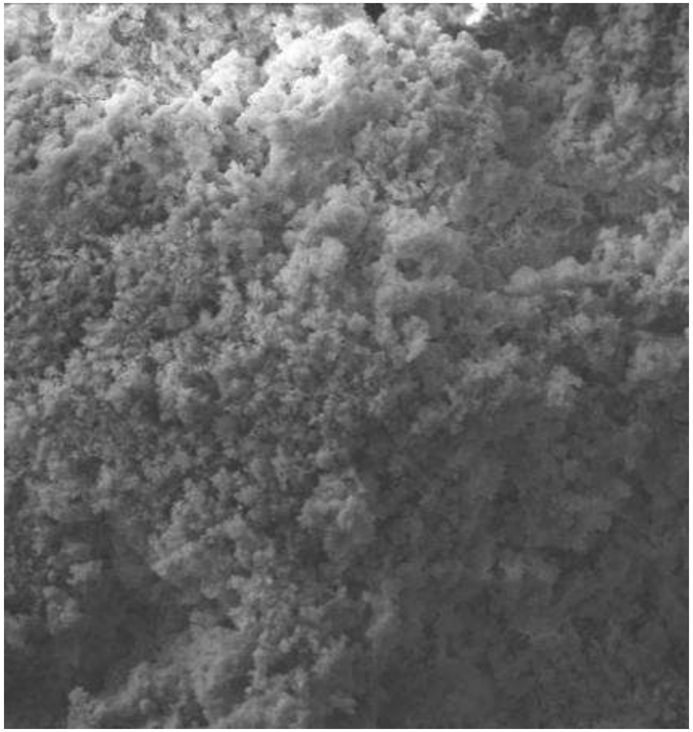
B: Porous stone rubble wall, harled



C: Bare rubble wall with voided core

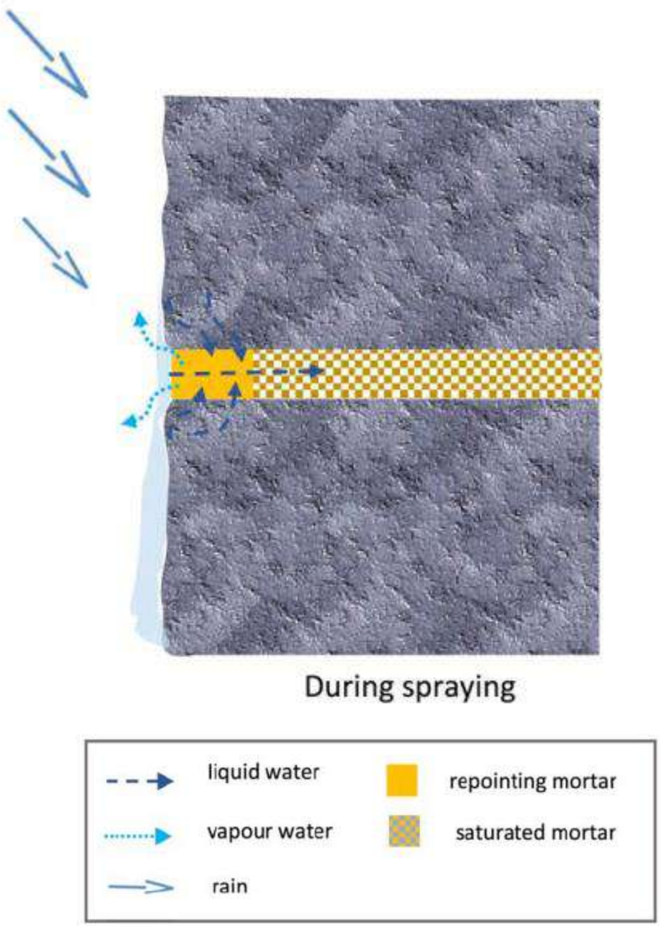
The Behaviour of Lime-Mortared Masonry





The Behaviour of Lime-Mortared Masonry

Mortar is a microporous sponge built into the wall

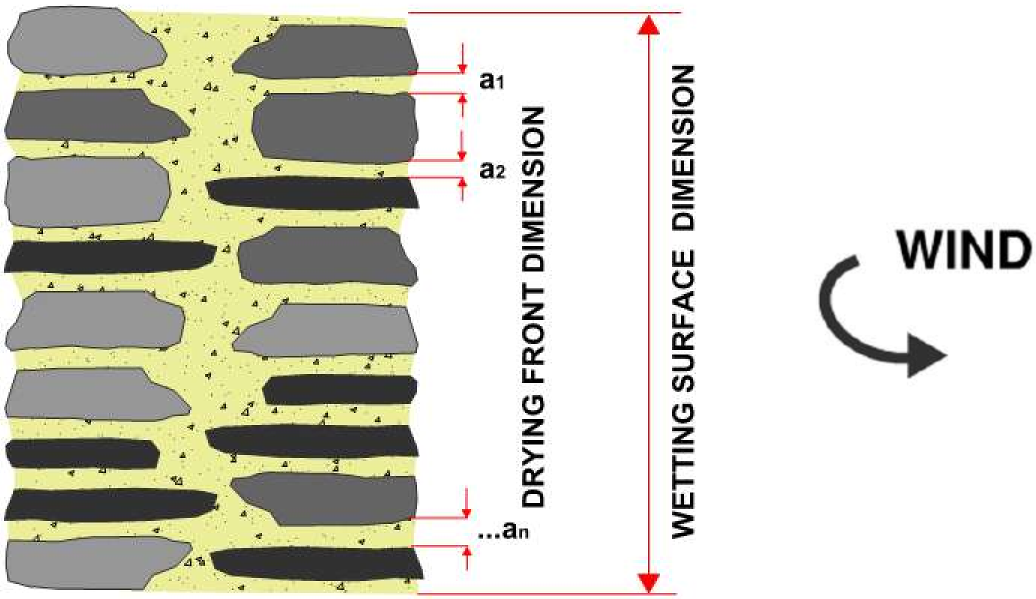


- **In heavy rainfall, outer portion of mortar saturates, holds water, and reduces further water ingress by increasing surface runoff (Fusade et al. 2019)**
- **"Overcoat effect"**
- **Quickly reverts to non-saturated conditions exploiting capillary drying regime**
- **Capillary drying vital for deep drying – the mortar <u>should</u> stay wetter for longer to maintain that liquid film pathway**

Fusade et al. (2019)

The Behaviour of Lime-Mortared Masonry

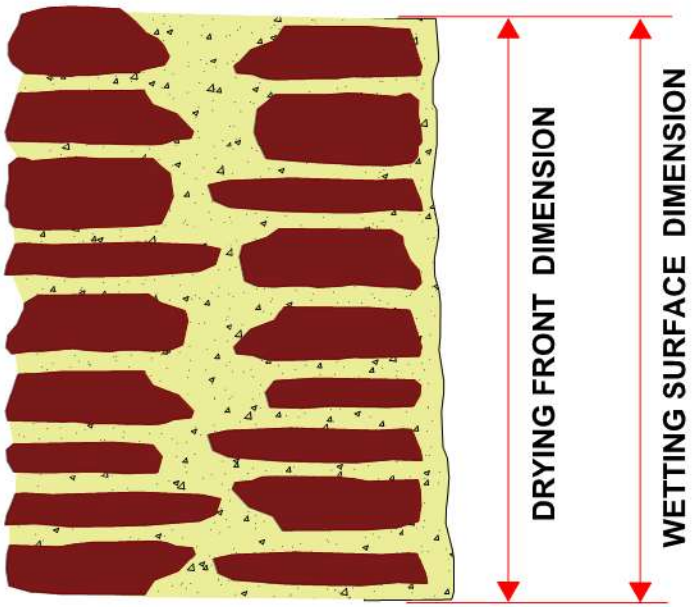
Mortar is a microporous sponge built into the wall



In context A the mortar joints do all the work

The Behaviour of Lime-Mortared Masonry

Context B: Sandstone wall with lime harling



Size of drying front magnified – levelled playing field

The Behaviour of Lime-Mortared Masonry

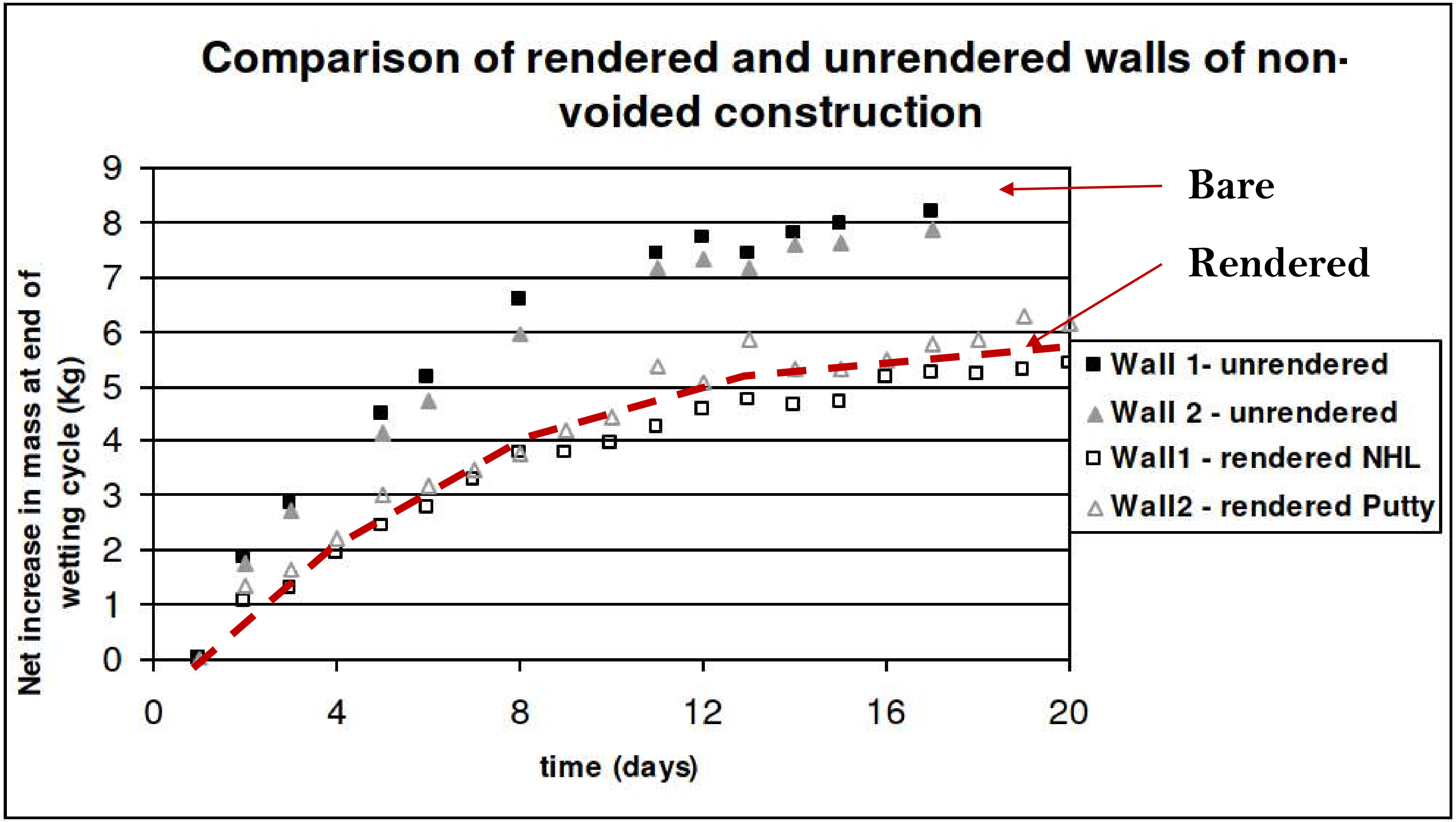
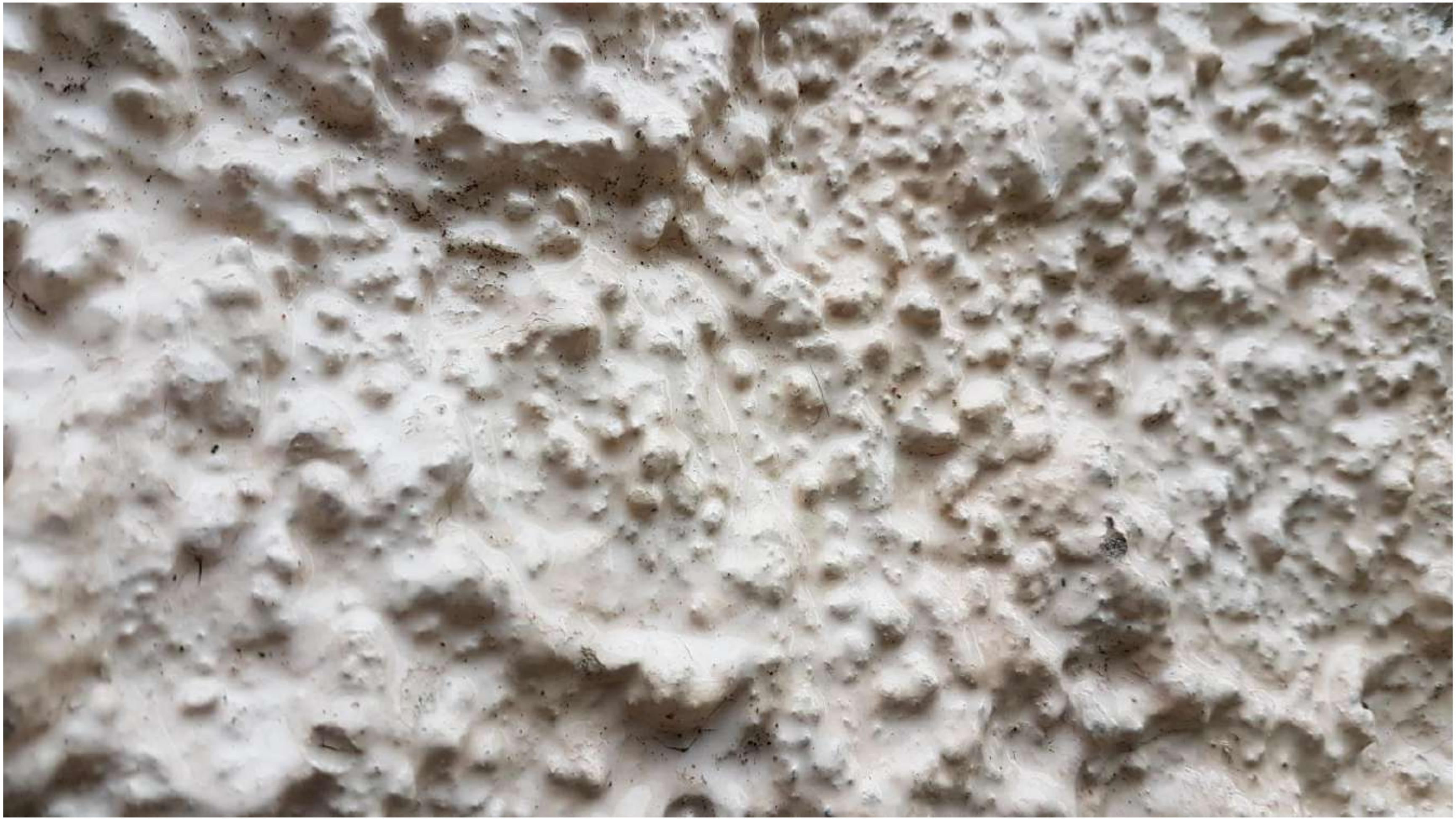


Figure 16 Graph to show performance of the same walls pre and post application of render

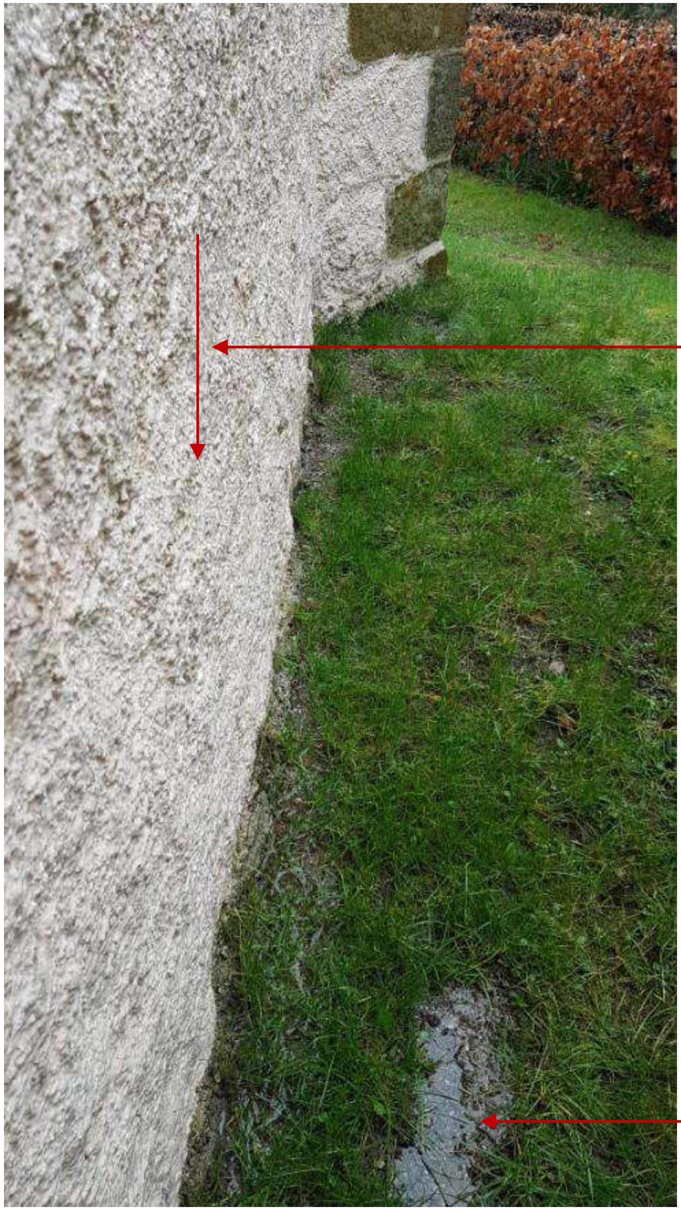
Laycock & Wood, 2014

The Behaviour of Lime-Mortared Masonry

Overcoat behaviour: outer surface becomes water-logged, film forms, extra rainfall either splashes off or runs down film (you can hear it gurgle…)



The Behaviour of Lime-Mortared Masonry



Film

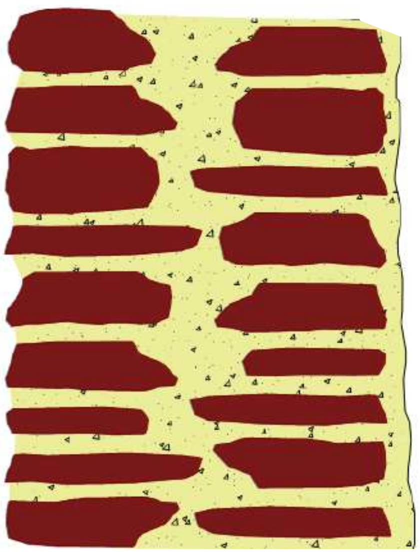
Windward side soaked

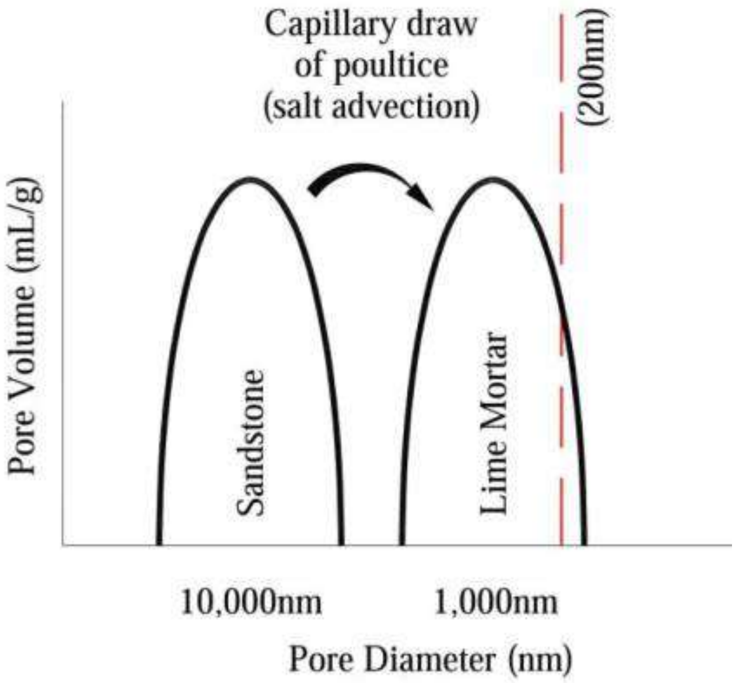
Sheltered side bone dry

Puddle

The Behaviour of Lime-Mortared Masonry

Context B: Sandstone wall with lime harling

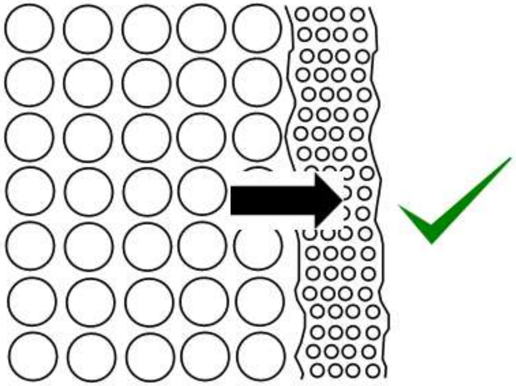


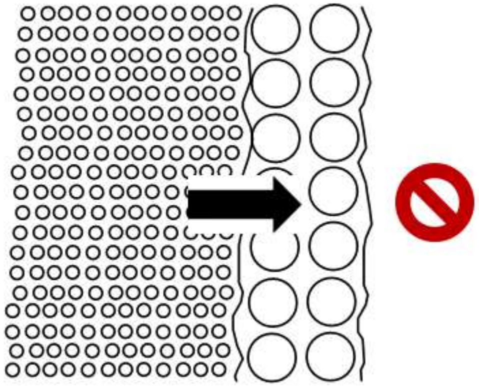


Fine pored material on coarse pored substrate creates a poultice

The Behaviour of Lime-Mortared Masonry

A fine-pored material wicks water from coarse-pored (advection);
The reverse is not true – back-diffusion unfavourable



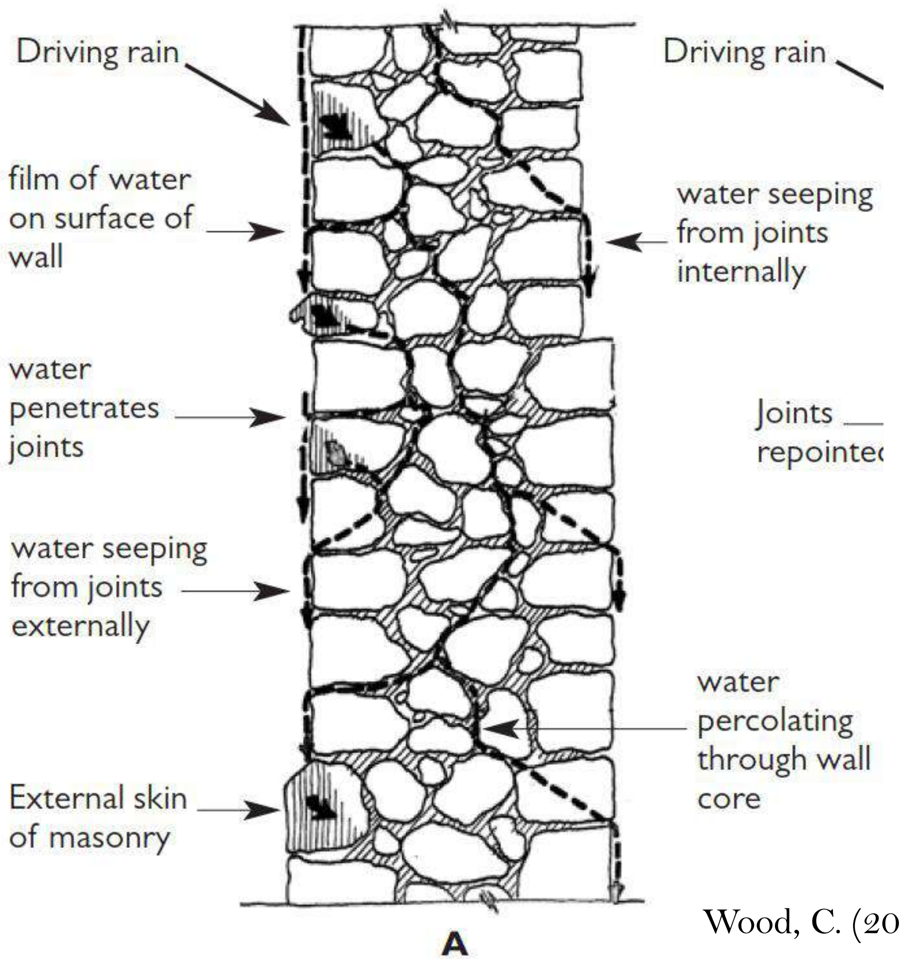


The Behaviour of Lime-Mortared Masonry

Paradox No. 1 – solved!

The Behaviour of Lime-Mortared Masonry

Context C… Real rubble-cored walls:

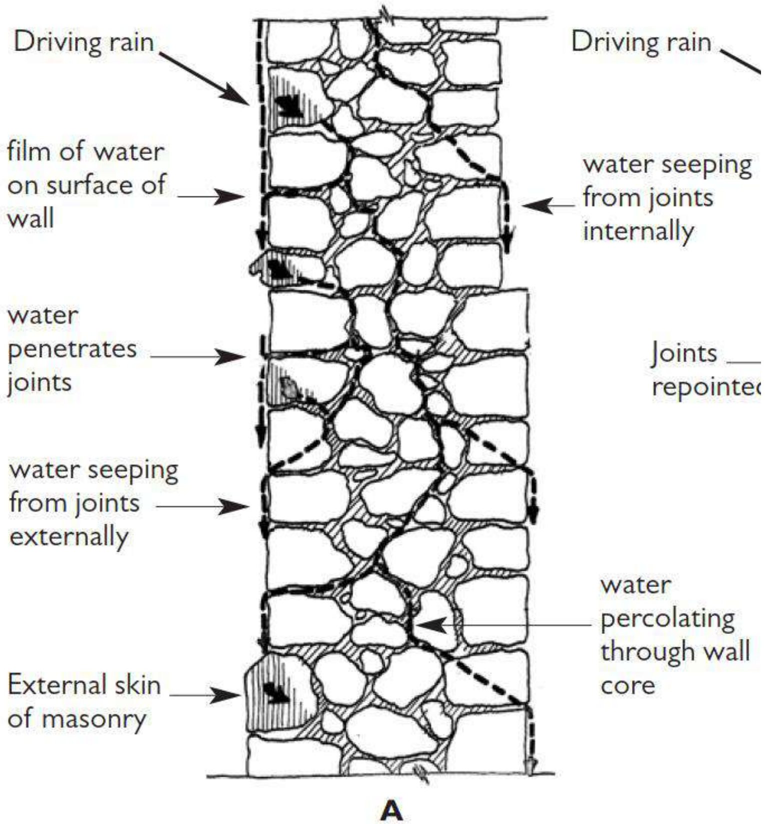


Wood, C. (2012)

Voiding of the core severs hydraulic contact across the wall profile.

The Behaviour of Lime-Mortared Masonry

Effective drying at depth in real walls…



ENGLISH HERITAGE

DAMP TOWERS CONFERENCE

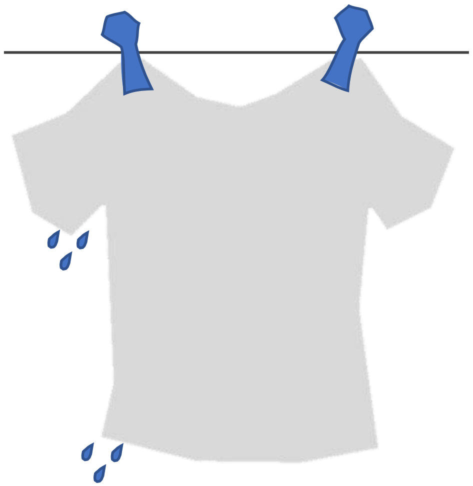
18TH APRIL 2013

ENGLISH HERITAGE

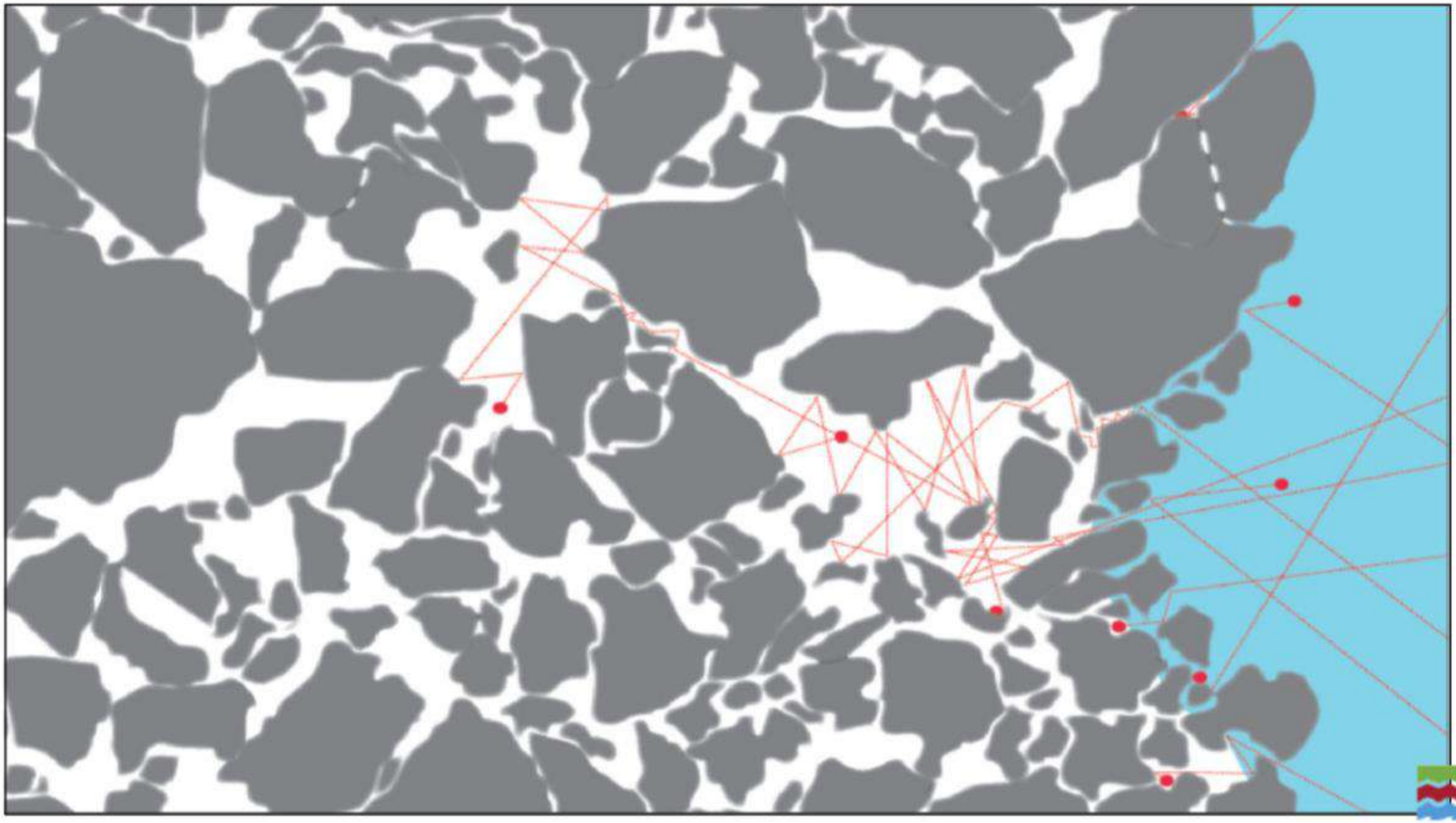
Capillary drying condition 1… (microstructure – interconnectivity!)

VAPOUR PERMEABILITY IS A NONSENSE

- **Traditional buildings 'breathe' by convective drying**
- **NOT by vapour permeability of the walling material**
- **Wrap your wet washing in a Gore-Tex tent and see what happens**
- **Wet clothes**

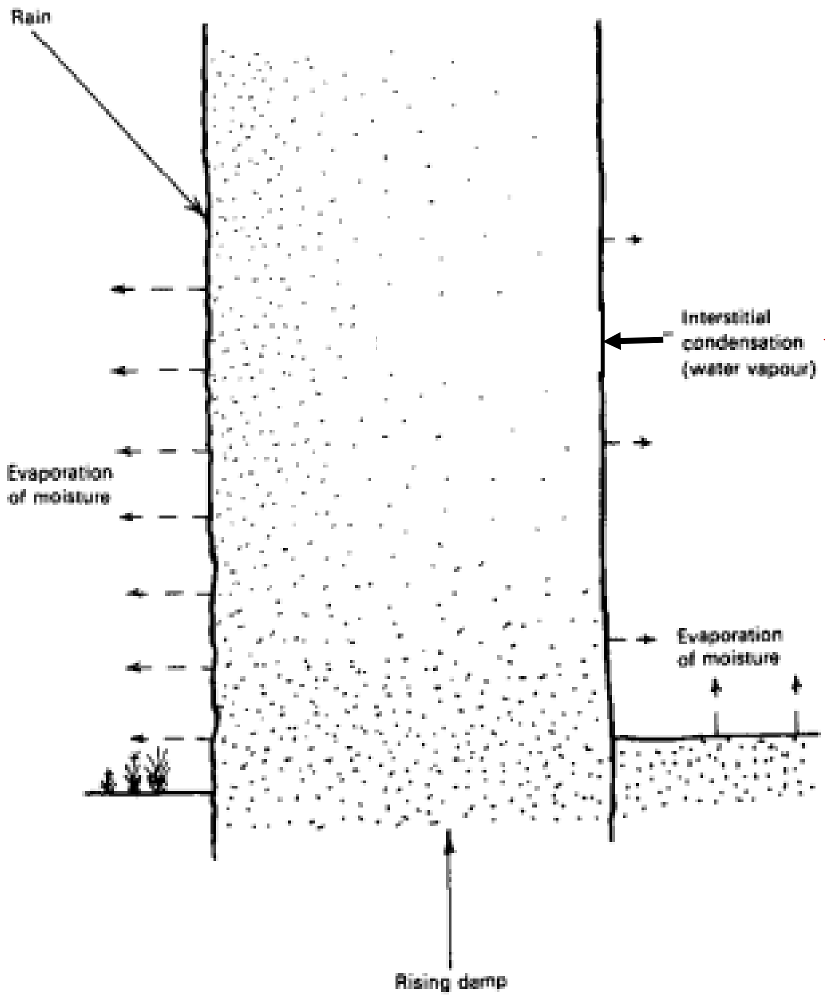


The Behaviour of Lime-Mortared Masonry



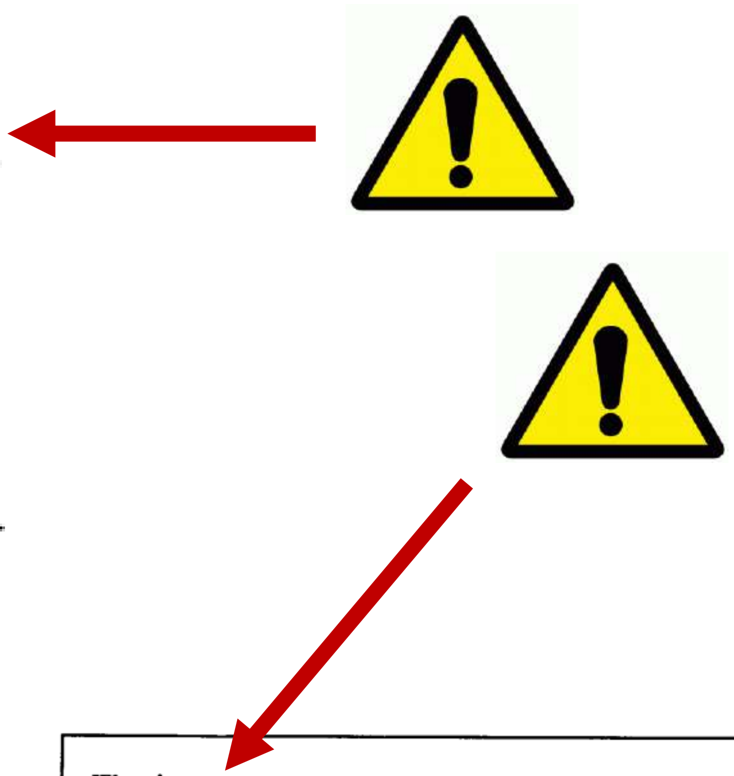
Robyn Pender…

The Behaviour of Lime-Mortared Masonry



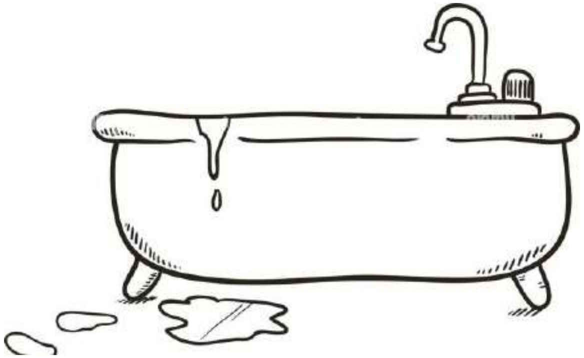
SOLID WALL OF POROUS MATERIALS

SPAB News, Spring 1986
Revised December 1987

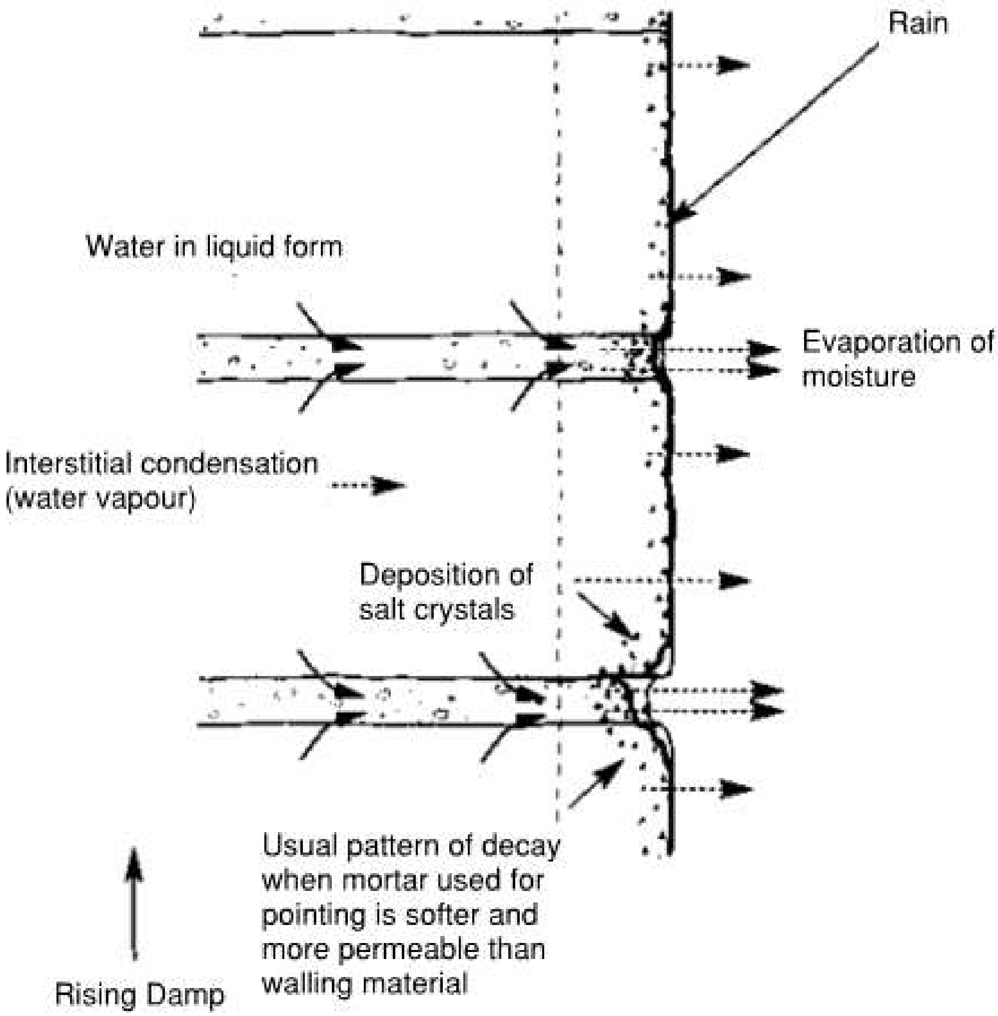


Warning
The term "breathing" is now being applied to many products which are only slightly vapour permeable. In general, no synthetic modern materials should be applied to the masonry or plaster surfaces of historic buildings. If in any doubt contact SPAB.

Whenever there is a long-term propensity for ingress in combination with impinged drying, wet buildings are inevitable



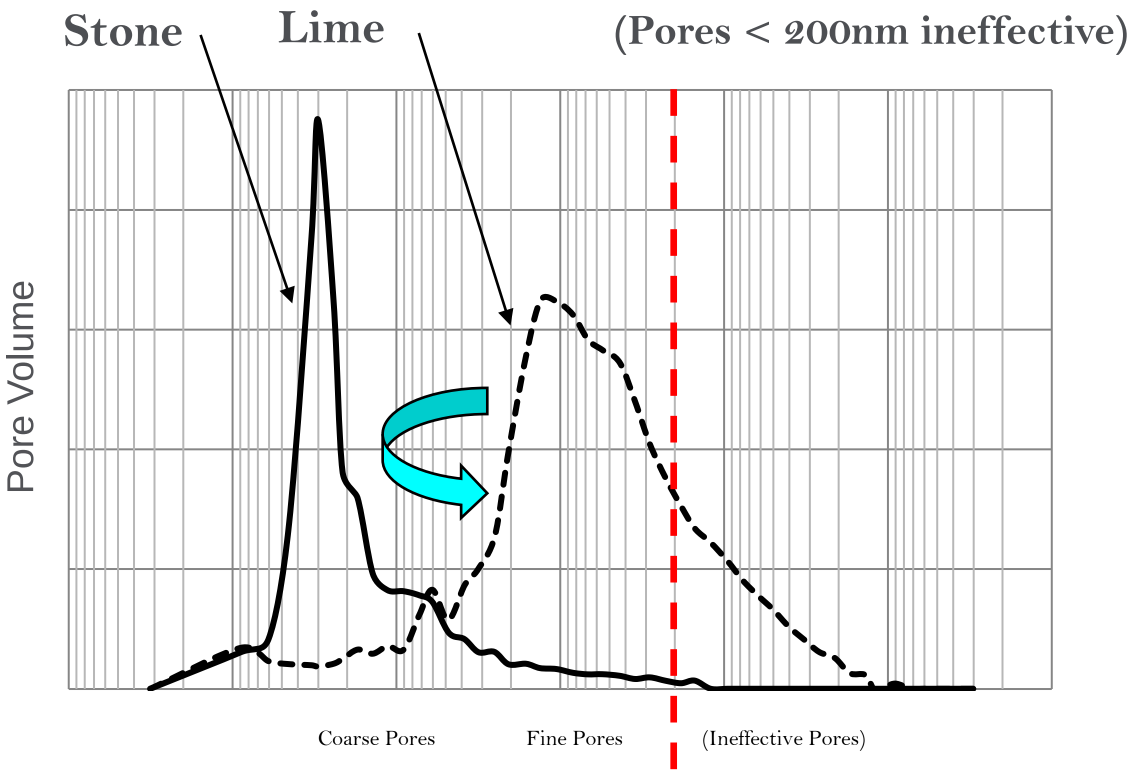
The Behaviour of Lime-Mortared Masonry

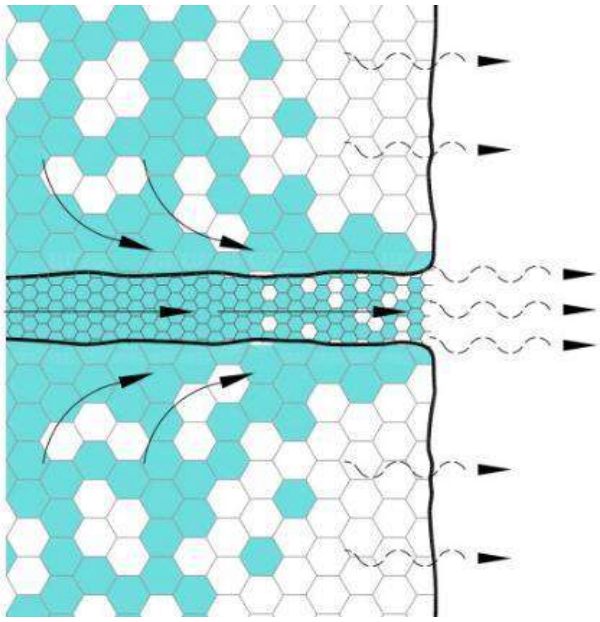


The Behaviour of Lime-Mortared Masonry

What's going on here?

The Behaviour of Lime-Mortared Masonry

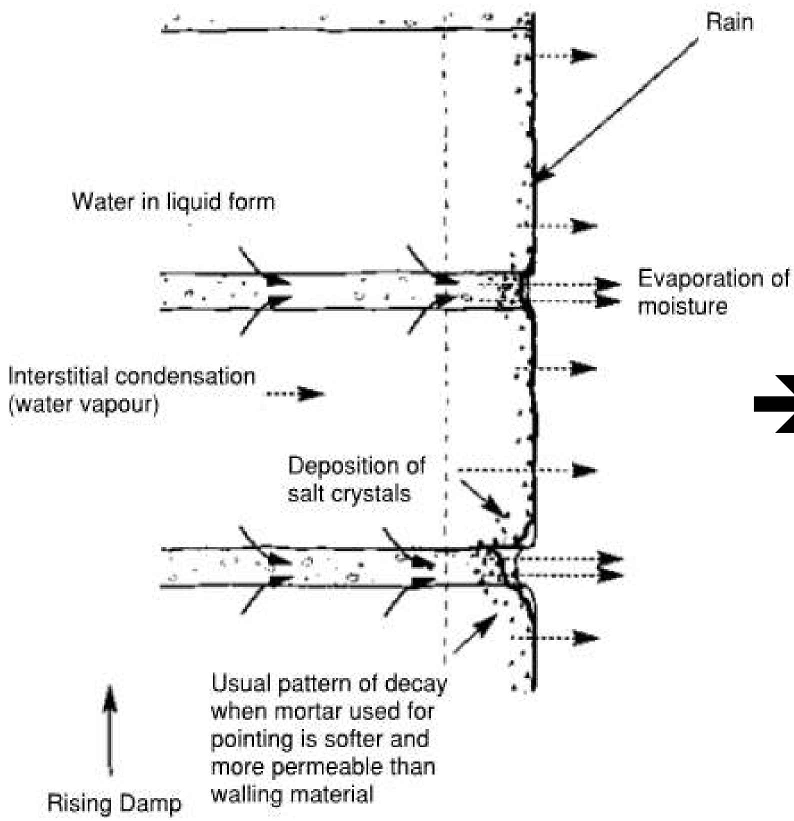




Soluble salts advected, evaporation front forced away from the surface of the stone.

The Behaviour of Lime-Mortared Masonry

Relative microstructure of fine-pored mortar vs. coarse-pored masonry units (poultice mechanics)



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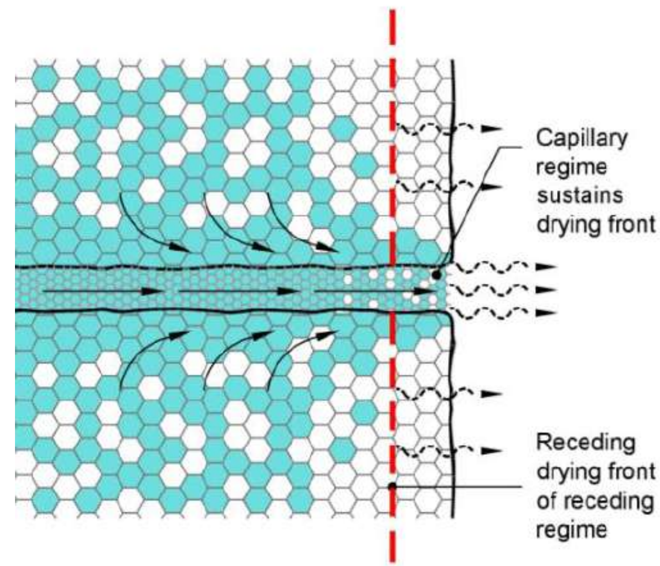
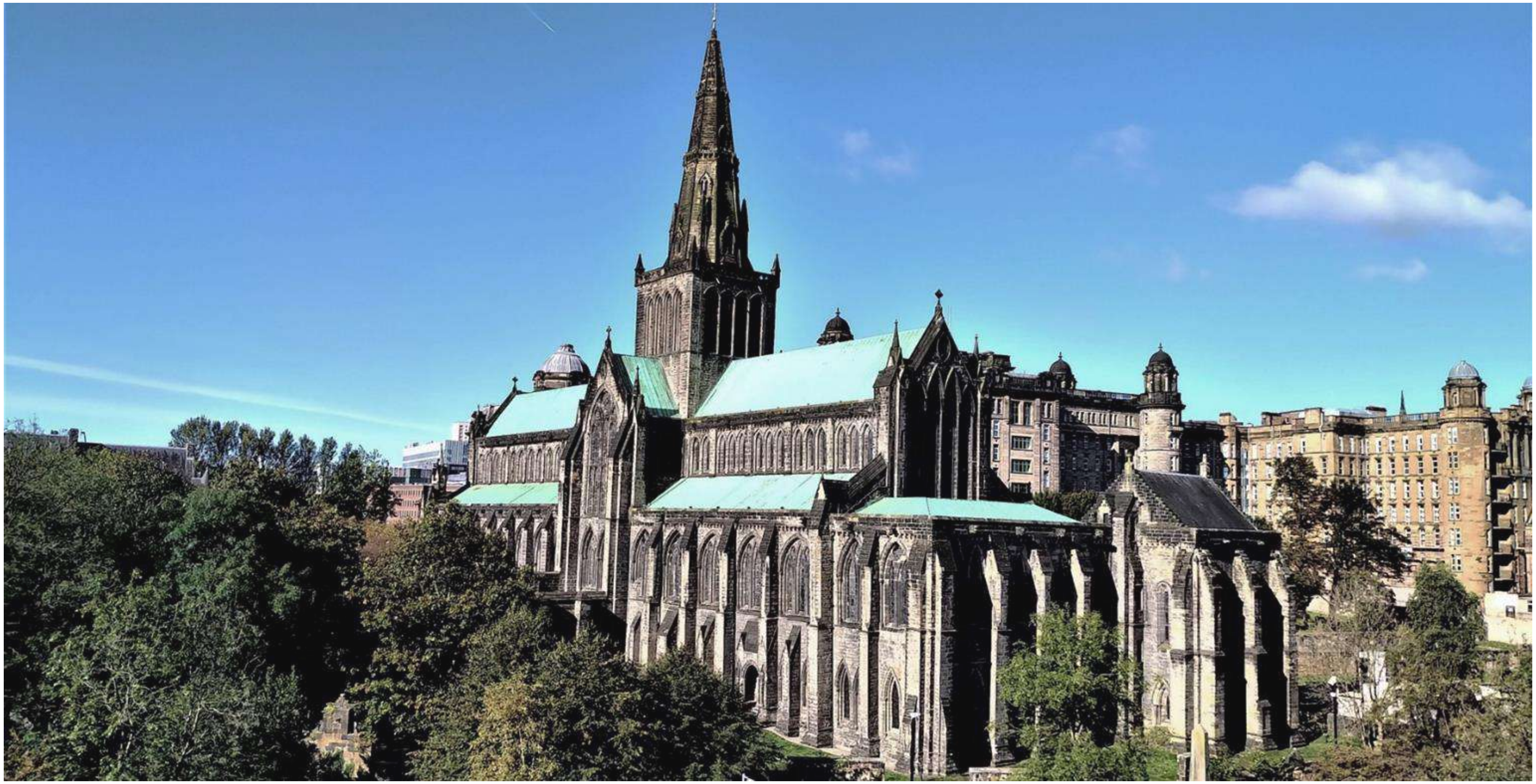


The Behaviour of Lime-Mortared Masonry

Sacrificiality in real time!

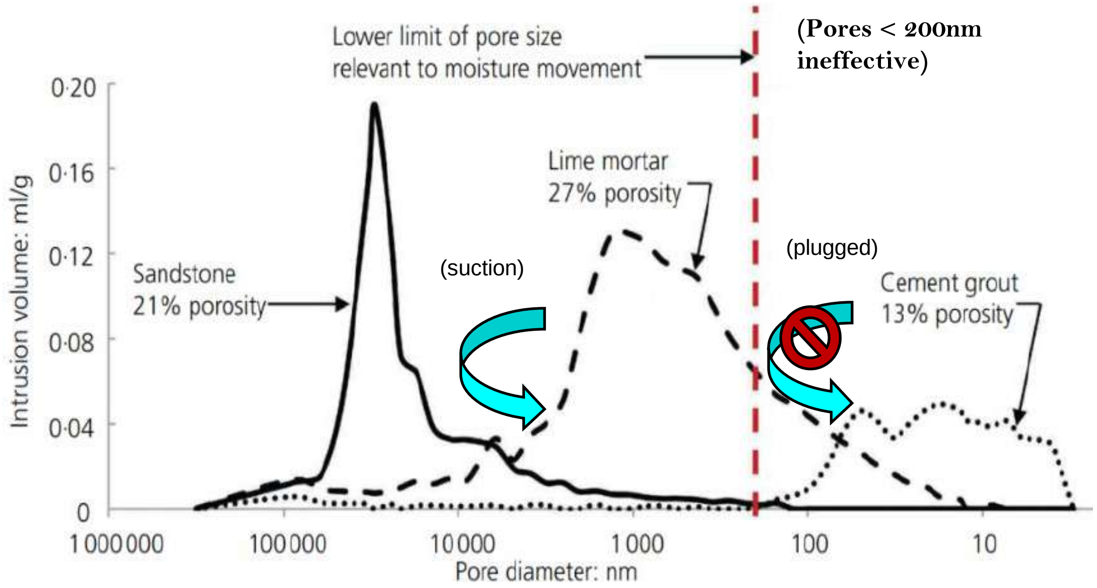
The Behaviour of Lime-Mortared Masonry

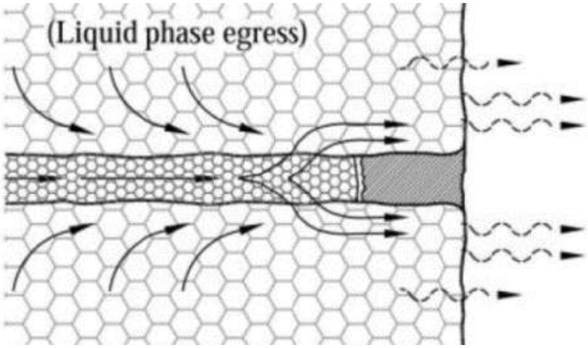
Glasgow Cathedral:



The Behaviour of Lime-Mortared Masonry

Accelerated decay:



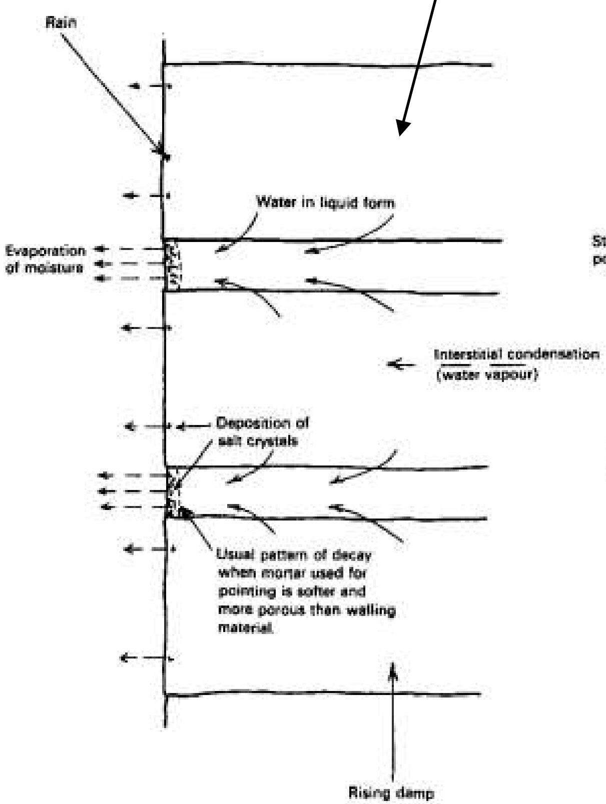


The Behaviour of Lime-Mortared Masonry

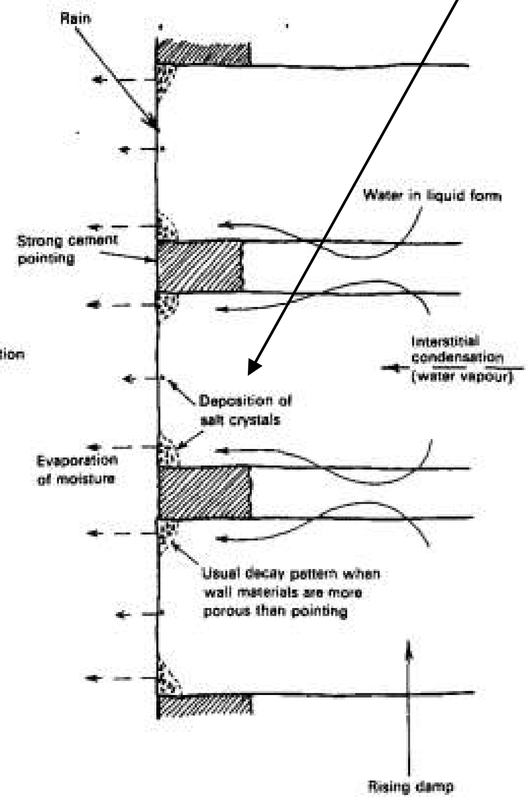
SACRIFICIAL WEATHERING OF LIME MORTAR DRIVEN BY POULTICE FUNCTIONALITY

CEMENTS CAUSED SUCH DAMAGE BECAUSE OF THEIR DISRUPTIVE EFFECT ON THE DRYING FRONT (FORCED SALTS INTO STONE)

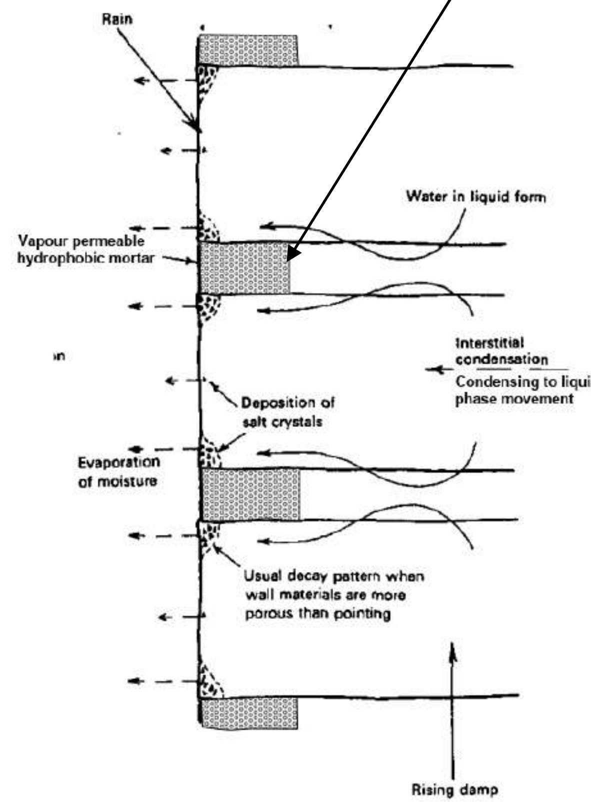
"VAPOUR-OPEN/CAPILLARY-CLOSED" POINTING MORTAR



WALL BUILT OF POROUS MATERIALS



EFFECT OF IMPERVIOUS POINTING



EFFECT OF VAPOUR PERMEABLE HYDROPHOBIC POINTING

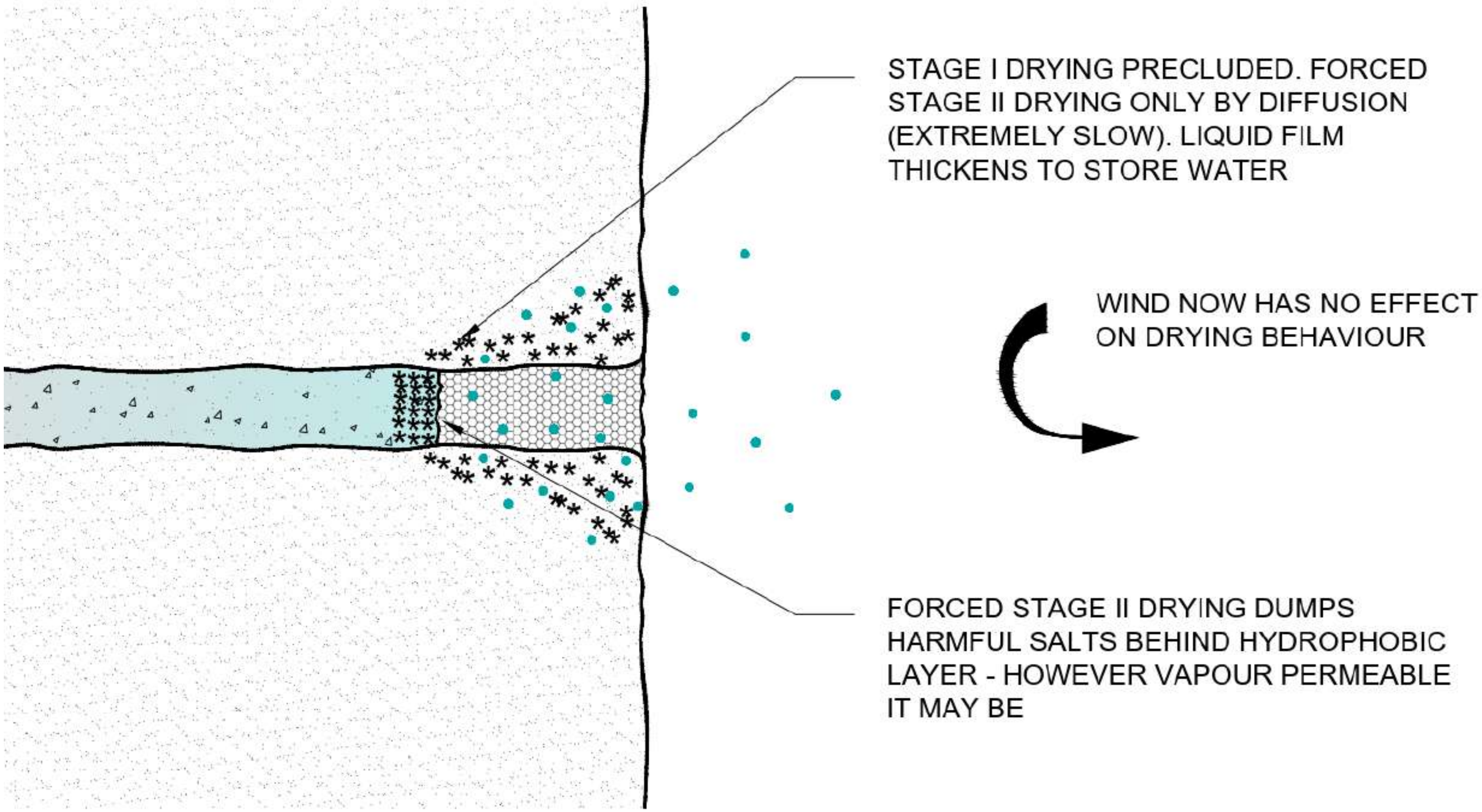
SPAB, 1986

SPAB, 1986

ANGRY CONSERVATION ENGINEER, 2022

The Behaviour of Lime-Mortared Masonry

Remember capillary drying / poulticing condition 2… surface chemistry!!

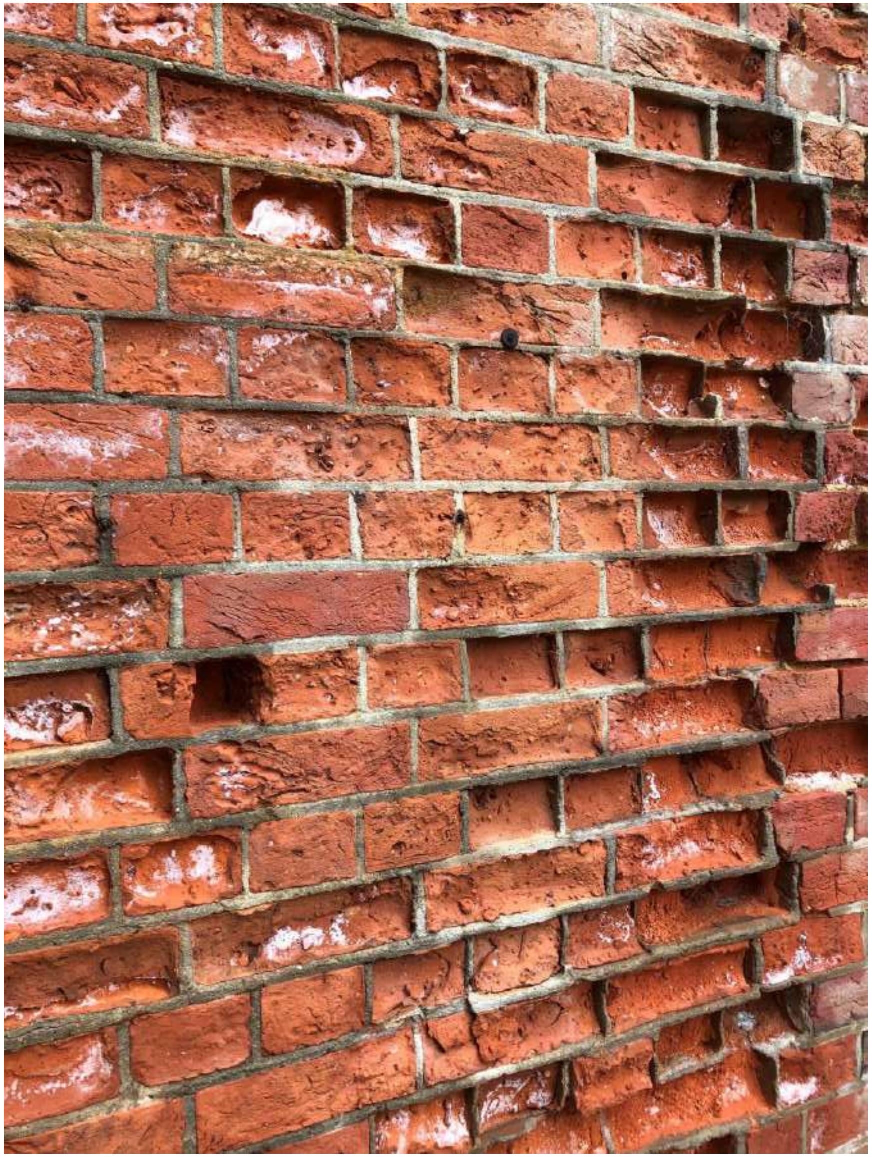


The Behaviour of Lime-Mortared Masonry

ADMIXTURES, PROPRIETARY AND PRE-MIXED ‘LIME’ MORTARS ARE A SERIOUS RISK TO OUR HISTORIC BUILDINGS

- **Many (<u>MANY</u>) suppliers are chemically modifying the mortars with admixtures which profoundly alter the properties of the mortar**
- **They don’t tell you**
- **If you ask, they say it’s just the working properties but the final properties are unaffected**
- **They’re wrong**
- **Wet, decaying masonry**

The Behaviour of Lime-Mortared Masonry



We're right back here.

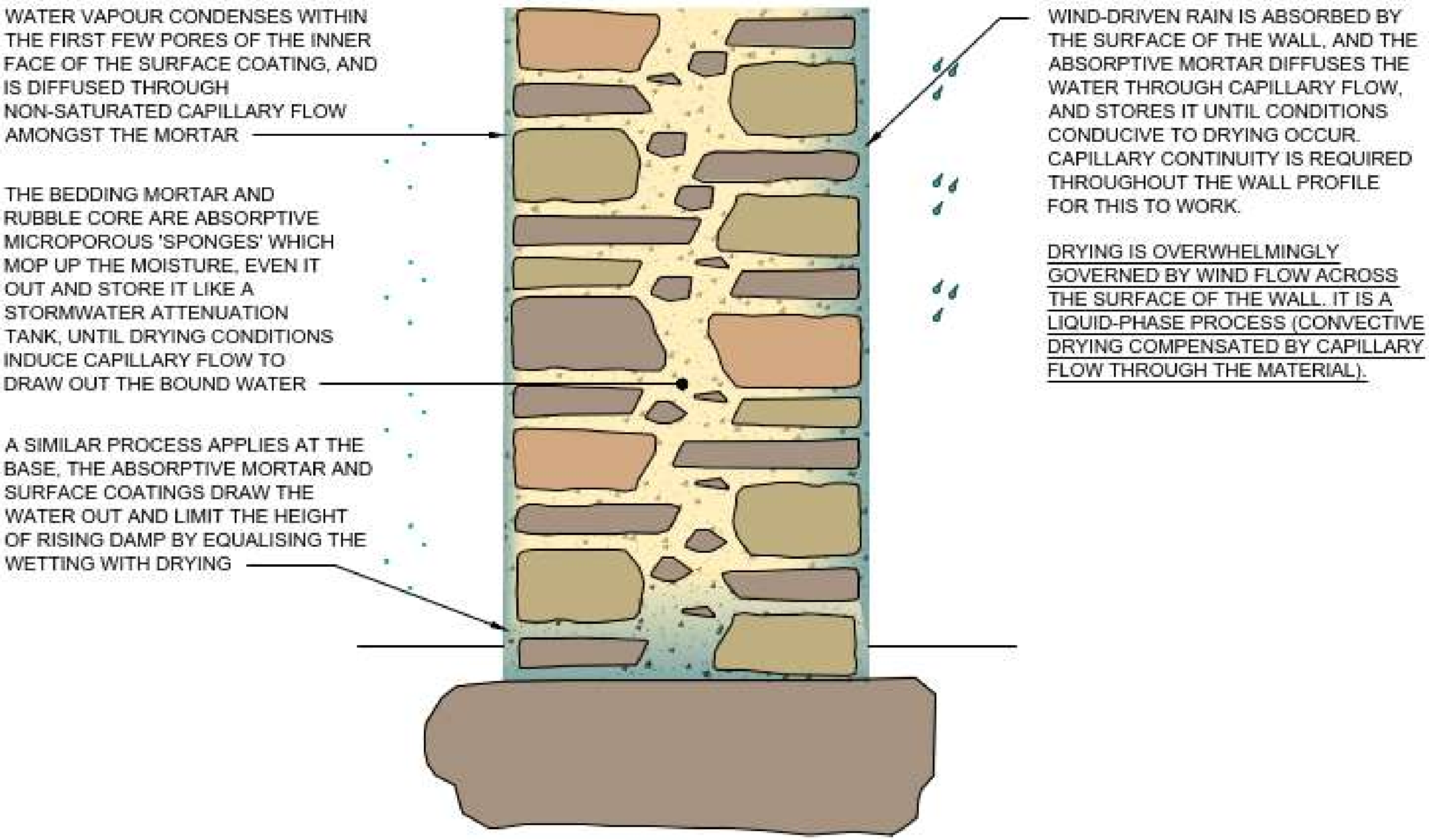
<u>Doctrine matters.</u>

Section Overview

III. Working with Carbonate Binders in Wet Climates

Working with Carbonate Binders in Wet Climates

Goal of repair intervention… to reinstate the original healthy function of that good old solid wall.



Working with Carbonate Binders in Wet Climates

Broadly speaking, minimise water ingress, maximise water egress.
Some sore lessons learned:

1. **Intercept ALL vertical rainfall.**

2. **Recognise pre-existing water content of substrate.**

3. **Consider optimising mortar for carbonation & capillary drying.**

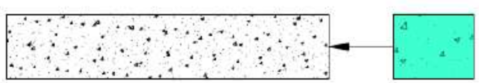
4. **Be honest with context… will an air lime ever work if context remains long term damp/saturated?**

Working with Carbonate Binders in Wet Climates

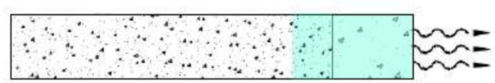
Carbonation…

- Optimum carbonation conditions RH 40-80%
- Ball park rate ca.1mm / month outside – in
- Carbonation impossible at RH 100%
- Air in pores of damp porous materials RH practically 100%...

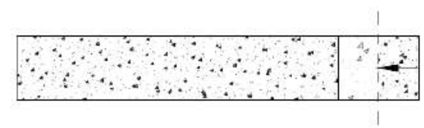
Normal carbonation:



Application

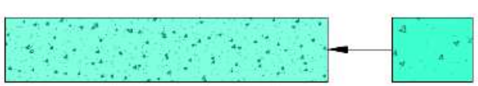


Day(s)

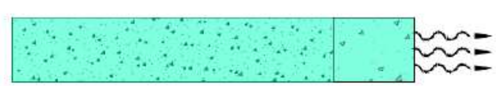


Rate ~1mm/mth

Carbonation where damp substrate:



Application



Days – months – years…?

Rate ~1mm/mth

Working with Carbonate Binders in Wet Climates

Battling with carbonation…

Working with Carbonate Binders in Wet Climates

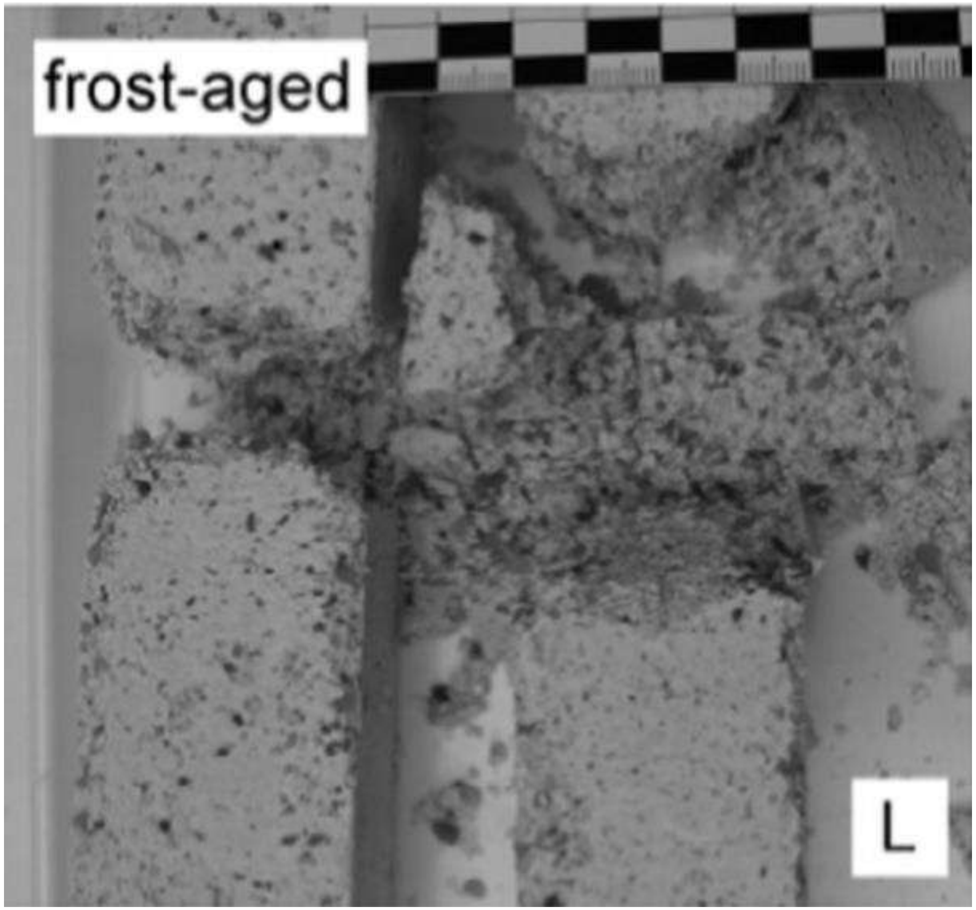
Damp substrates inhibit carbonation until they dry out

Working with Carbonate Binders in Wet Climates

Impinged carbonation leaves lime mortar liable to frost damage

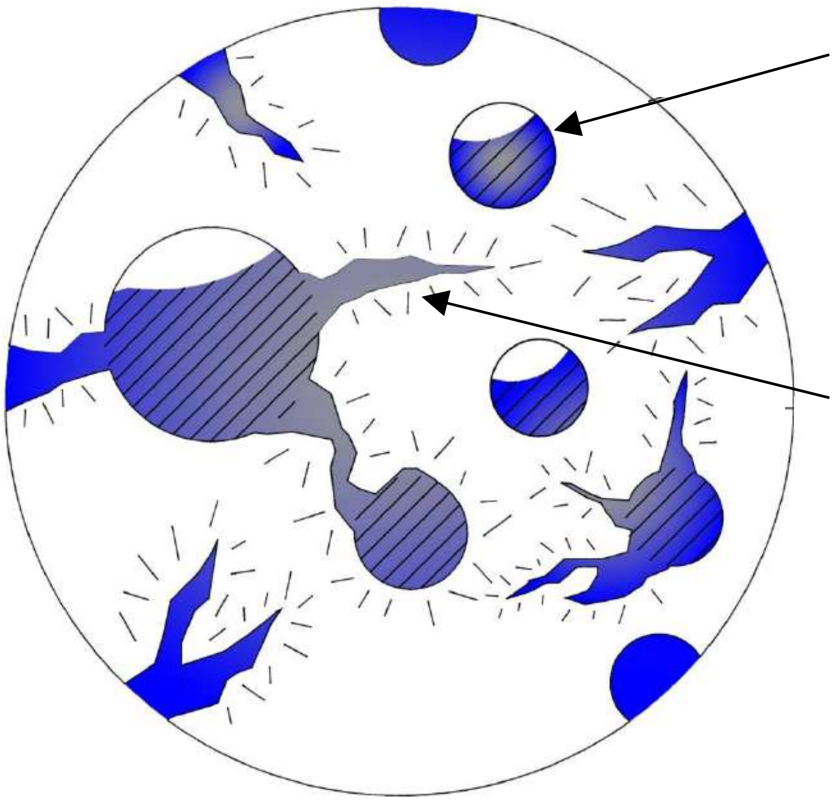
Working with Carbonate Binders in Wet Climates

Frost damage to lime mortars:



- **Test in view is forced saturated freezing**
- **Expanded spongey crumbly character.**
- **Zero remaining strength and poor bond to pretty much anything, even itself**

Working with Carbonate Binders in Wet Climates



Frost Resilience

Ice favours large pores which don't saturate fully

Water held in the smallest pores requires temperatures well below freezing

Unfrozen water in small pores / throats displaced by frost expansion, creating hydraulic pressure against pore walls

cycles takes precedence over temperature extremes

If it isn't wet, it can't freeze! Lime keeps the masonry dry, avoids attack.

Working with Carbonate Binders in Wet Climates

- Uncarbonated mortar highly vulnerable to frost damage
- Carbonated mortar very durable, as it keeps the masonry dry and avoids frost damage from ever occurring
- Make no mistake – lime mortar will die if forced to freeze, whether carbonated or otherwise. It is frost ***resilient***, not frost resistant.

Paradox No. 2 – solved!

Working with Carbonate Binders in Wet Climates

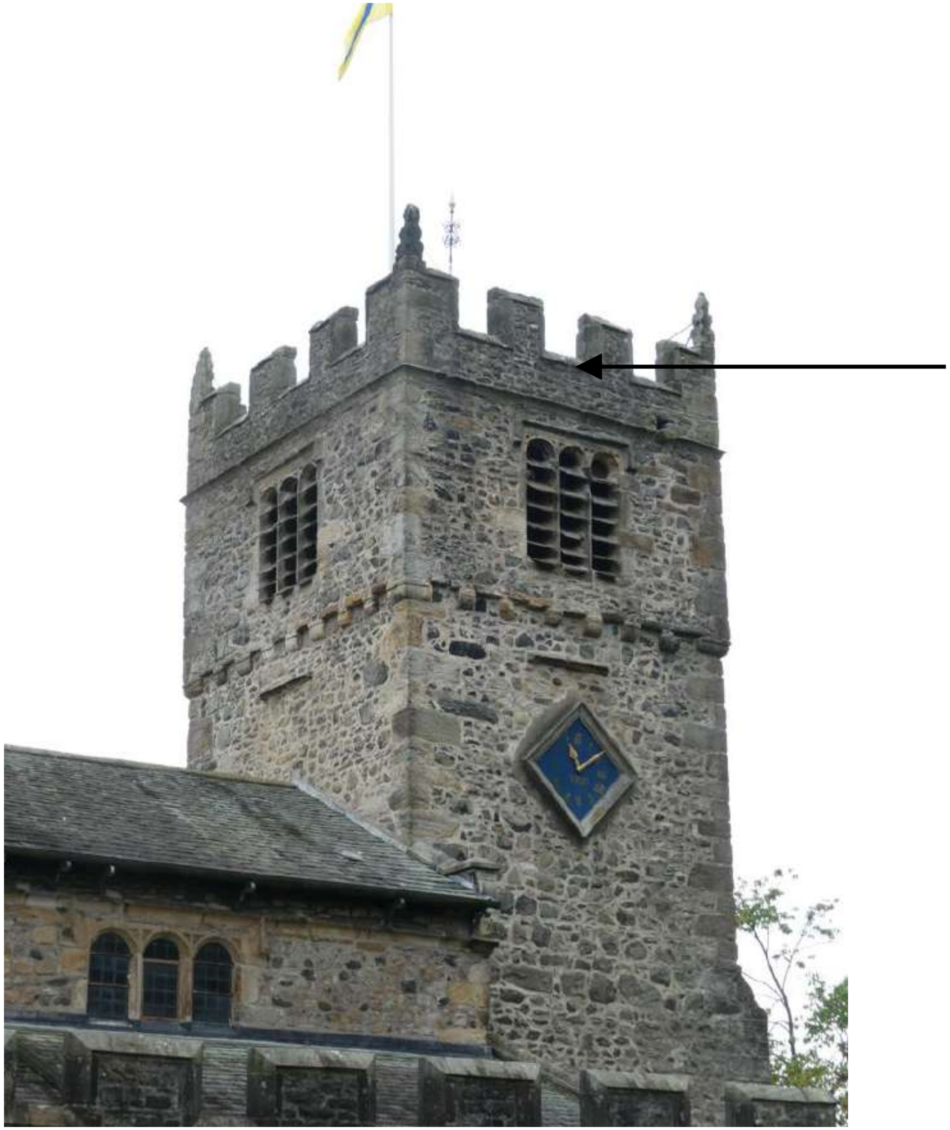
Lest there be any doubt… lime is a wonder-material but it cannot do the impossible. Recipe for success:

1. **Detailing**

2. **Detailing**

3. **<u>DETAILING</u>**

Working with Carbonate Binders in Wet Climates

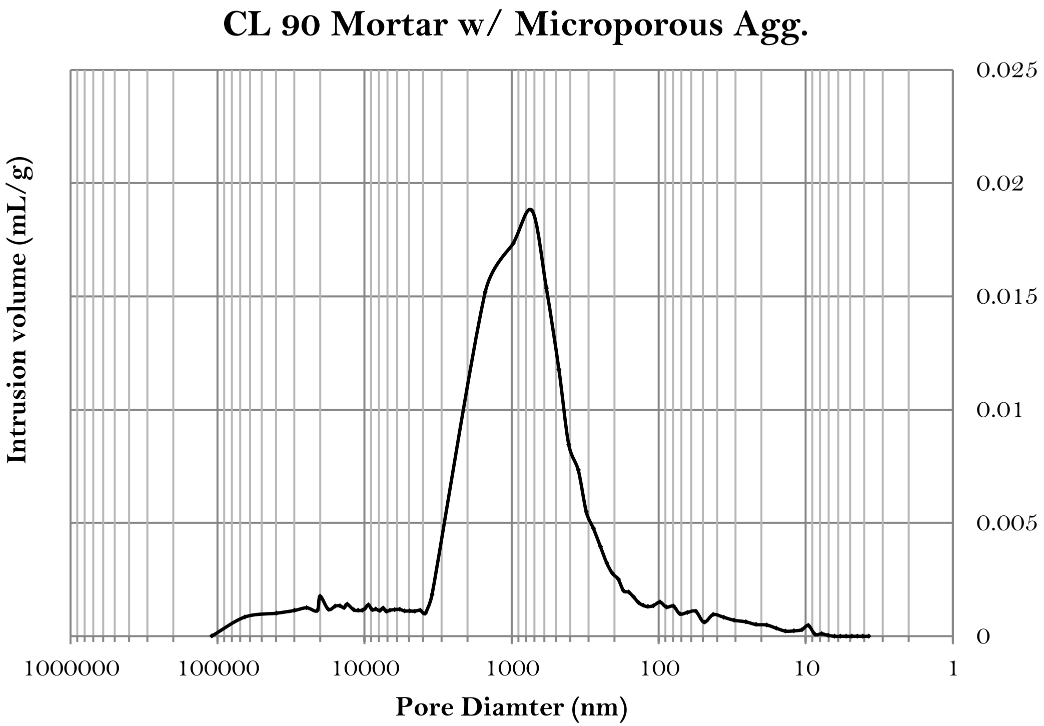


Working with Carbonate Binders in Wet Climates

Working with Carbonate Binders in Wet Climates

Calcitic aggregates:

- Pre-carbonated microstructural sponge built into the depth of the mortar work



Scannel et al. 2017

Potential to fine-tune or whole-hog optimise a mortar for technical performance

Working with Carbonate Binders in Wet Climates

Practical application

- Castle walls 3m thick… damp
- Combine microporous limestone sand and coal ash to accelerate carbonation
- Tented scaffold to keep it dry

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Working with Carbonate Binders in Wet Climates

1. **Intercept ALL vertical rainfall.**
   - Temporary and permanent works conditions
   - Copings, string courses, hood moulds – replace where efficacy impaired
   - Enhance detail if inherently deficient (lead weatherings etc).
   - Wall tops… forget air lime – natural cement to throw water off

2. **Recognise pre-existing water content of substrate.**
   - Turn the tap off, then let the bath drain down
   - Build time into programme to dry out
   - Remember lime is a poultice… it's the last thing to dry!

3. **Consider optimising mortar for carbonation & capillary drying.**
   - Microporous aggregates accelerate carbonation but only after the substrate water has been sucked out

4. **Be honest with context… will an air lime ever work if context remains long term damp/saturated?**
   - Opportunity to tone down free lime while maximising capillary drying

‘How Lime Mortar Works’

Summary:

I. **Physical Principles of Moisture Transport**

II. **The Behaviour of Lime-Mortared Masonry**

III. **Working with Carbonate Binders in Wet Climates**

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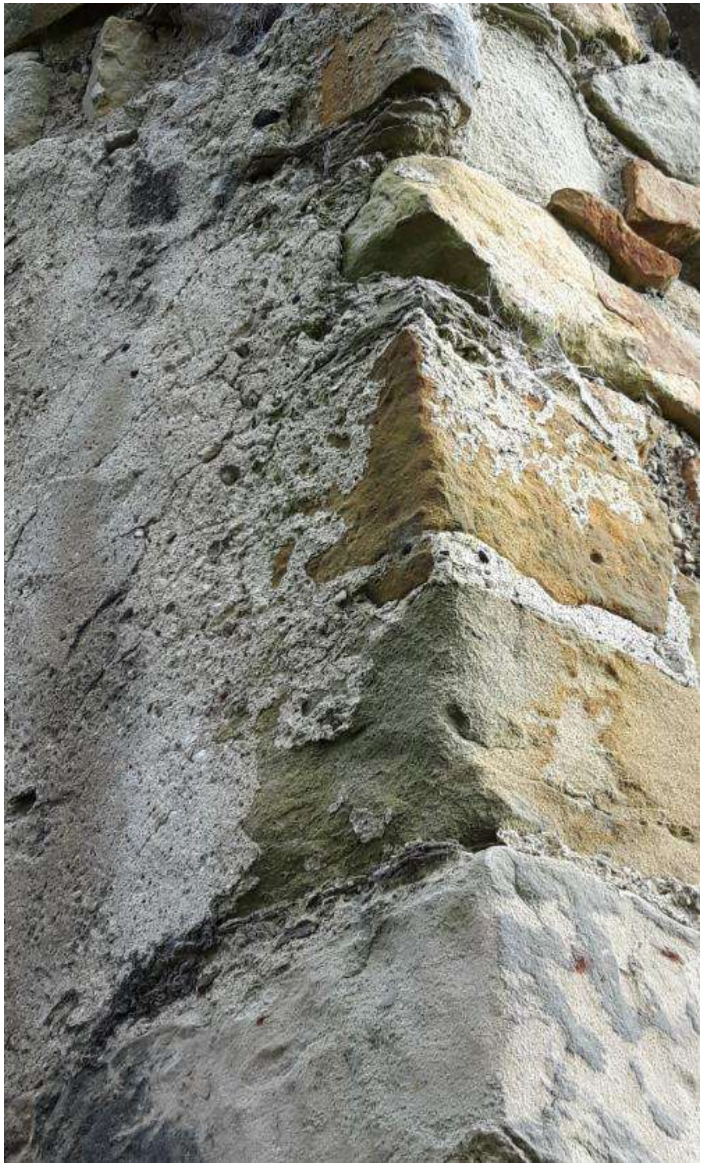

Questions…?

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