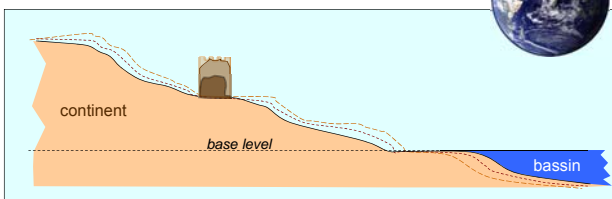


WEATHERING OF NATURAL BUILDING STONES

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 1

Concept of natural evolution on Earth



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 2

From the very moment when stones get in touch with atmosphere, they are subjected to weathering processes (because of non equilibrium & water cycle)
Buildings are also subjected to the natural laws
=> **their deterioration is inevitable!**

Definitions

Disorder (*Altération ou désordre*):

modification of material not necessarily meaning a marked reduction of material durability or static problems for the building

Deterioration (*Dégradation*):

modification meaning a marked reduction of the material durability and/or static problems for the building

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 3

Weathering is different on buildings from outcrops...



Hauterive (CH, NE)

(...because of extraction, work, exposure, contrasts,...)



Neuchâtel (CH, NE)

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 4

The weathering causes related to water

Natural causes	Anthropogen causes	
<ul style="list-style-type: none"> - dissolutions and chemical transformations by all sorts of waters - salts brought by marine sprays - salts brought by animals - dissolutions and chemical transformations by micro-organisms and plants 	<ul style="list-style-type: none"> - air pollution: acceleration and/or modification of natural processes - chemical cleanings - salts brought by agriculture - conservation products - salt-rich mortars 	Physico-chemical
<ul style="list-style-type: none"> - natural disasters (earthquakes, floods, cyclones,...) - frost - wind abrasion - growth of the roots of plants 	<ul style="list-style-type: none"> - shocks (accidents, vandalism) - extraction, cut and laying - use (<i>mise en œuvre</i>) (unsuited stone, layering, orientation, statics) - unsuited materials (too hard mortars) - water damage, fires - mechanical cleanings - wear (<i>usure</i>) 	Mechanical

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 5

Little history of air pollution and weathering observations

- **agro-pastoral age** (Neolithic – bronze to iron age): weak air pollution, development of the **farming** and **agriculture**
- **age of craftsmanship** (iron age to the 18th century): air pollution increases, related to the **craft industry**, **heating** with wood then with coal

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 6

Little history of air pollution and weathering observations

- **industrial age** (end of the 18th to 20th century): the industrial revolution starts at the end of 18th century. Use of **new types of energy, increased mechanization**. Modification and high increase in emissions (second half of the 19th century: beginning of the scientific work on building stone weathering)

- **urban age** (since the end of the 20th century): climax of the industrial society plus **automobile pollution** (after 1920 scientific research became very numerous (Germany, Austria, England, France, ...))

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 7

The main air pollutants dangerous for stones

SO₂ :

$\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_4$ (non-stoichiometric)

$\text{H}_2\text{SO}_4 + \text{CaCO}_3 \rightarrow \text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (non-stoichiometric)
(solubility = 0.014g/l) (solubility = 2.4g/l)

Sources: SO₂ is emitted during the combustion of fuels containing sulphur, such as coal and petroleum

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 8

The main air pollutants dangerous for stones

PM10 or PM2.5 (particulate matter/ *particules fines*):

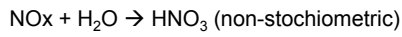
PM can contain S $\rightarrow \text{SO}_2 \rightarrow \text{H}_2\text{SO}_4$

Sources: PM are emitted during the incomplete combustion of fossil fuels or wood and come also from ground/stone erosion, quarries, pollens ...

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 9

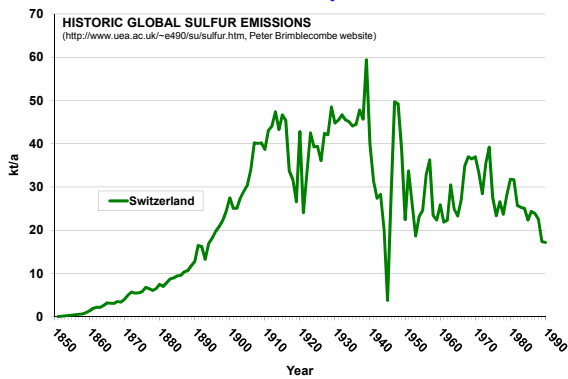
The main air pollutants dangerous for stones

NO_x (NO₂ + NO):

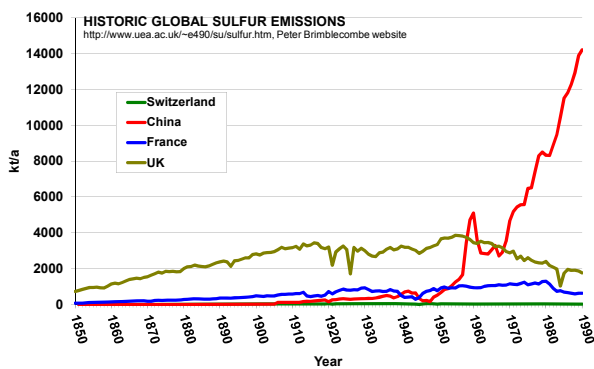


Sources: NO₂ is a secondary pollutant formed from NO. NO is formed itself from N₂ and O₂ during the combustion of fuels at high temperature

The evolution of the air pollution



The evolution of the air pollution

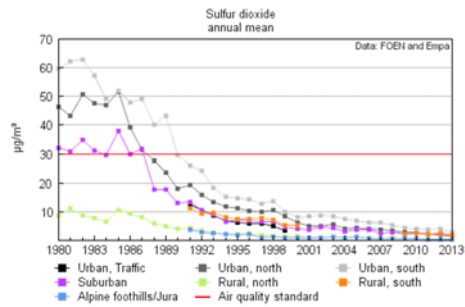




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The evolution of the air pollution

SO₂ concentration in Switzerland from 1980 to 2013



http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/01693/09016/index.html?lang=en / 10.11.2014

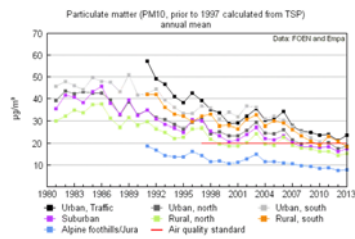
Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR / 13



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The evolution of the air pollution

PM10 concentration in Switzerland from 1981 to 2011



http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/01693/09009/index.html?lang=en / 19.9.2012

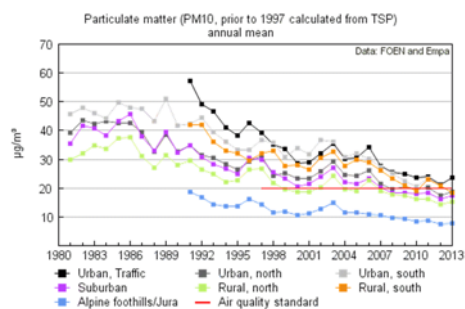
Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR / 14



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The evolution of the air pollution

NO₂ concentration in Switzerland from 1980 to 2013



http://www.bafu.admin.ch/luft/luftbelastung/blick_zurueck/01693/09015/index.html?lang=en / 10.11.2014

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR / 15

Weathering forms and mechanisms

The weathering factors modify:

- the chemistry
- the mineralogy
- the porosity structures

But in spite of the diversity of the natural stones, their deteriorations can be **grouped in a few classes** according to their morphology and the physicochemical mechanisms which characterize them.

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 1/6

Weathering forms and mechanisms

Mineralogy is not a major factor which determines the weathering forms. Major factors are:

- **kind** (liquid or vapour) **and amount of water transfers** (=> porosity is very important)
- **exposure on the building** (which controls the water and pollutant supplies)

=> Identical weathering forms are observed on stones of various nature

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 1/7

Chromatic alteration / Stains (*taches*)

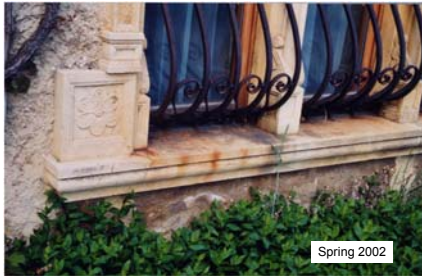
- Generally correlated with alien materials like: rust (*rouille*), copper salts (*sels de cuivre*), organic substances, painting, varnish...
- This phenomenon **does not strictly depend on exposure conditions of water supplies**.

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 1/8

Chromatic alteration

Stains

Cressier (CH, NE)
Pierre jaune
from Neuchâtel

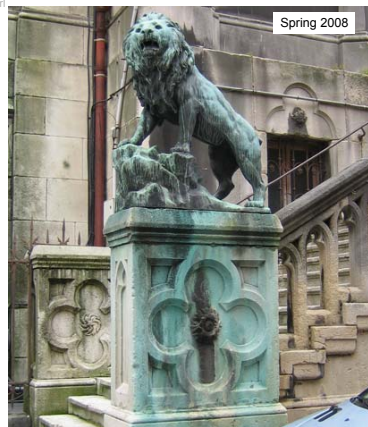


Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 19

Chromatic alteration

Stains

Nancy Cathedral
(France)
Limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 20

Chromatic alteration / Discolouration

- The original colour of a material changes because of processes like:
 - water penetration (more or less permanent coloured stains);
 - exposure to sunlight (fading);
 - formation of metallic oxide in the structure; ...but not because of a deposit.
- Does not depend on exposure conditions to water supplies.

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 21

Chromatic alteration

Discolouration

A flying buttress top,
south façade,
Lausanne cathedral
Arvel Limestone



Chromatic alteration

Discolouration

Epinal Basilica
(France)
sandstone



Chromatic alteration / Red staining (*Rubéfaction*)

- Chromatic alteration due to **local** oxidation of iron components on the stone surface often caused by a **fire**.
- This phenomenon **does not depend on weather exposure conditions**.

Chromatic alteration

Red staining

Abbey church
Romainmôtier (CH, VD)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/5

Chromatic alteration

Red staining

Collegiate church
Neuchâtel(CH, NE)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/6

Chromatic alteration / Patinas

- Black, brown, ocher, yellow
- Natural modifications of the building stones surface = normal “ageing” in outdoor environment
- Quite uniform very thin layer which sticks to the substrate from which it is chemically different (enriched in iron/clay minerals and/or in biogenetic calcium oxalates). Origin of the patina materials: endogenous (calcite, salts) and exogenous (soots, dust, micro-organisms, salts)
- Physical and colour modification but do not lead to a deterioration
- Can gradually evolve to the formation of crusts
- Usually take place in the zones protected from water supplies

Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/7

Chromatic alteration

Patina

City hall
Boudry (CH, NE)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/8

Chromatic alteration

Patina

Collegiate church
Neuchâtel (CH, NE)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/9

Chemical and/or mechanical erosion

- Loss of solid particles from the surface of material
- Formation of reliefs, anfractuosités, etc..
- Can be due to water, wind, too aggressive methods of cleaning...

Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 2/10

Erosion / Differential erosion

- Erosion of variable intensity on various sectors of the material
- Due to the inhomogeneity of the stone material
- Weathering type common on the sedimentary stones made of different strata
- Takes place in zones exposed to more or less direct water supplies and to wind

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 01

Erosion Differential erosion

A city wall of
Fribourg (CH, FR)
Burdigalian
Molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 02

Erosion Differential erosion

Collegiate church
Neuchâtel (CH, NE)
Pierre jaune
of Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 03

Erosion

Differential erosion

Bell tower, south side, Lausanne cathedral (CH, VD)
burdigalian molasse sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 2/4

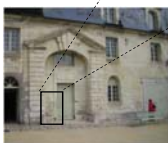
Erosion / Alveolization

- Appears mainly on very porous materials
- Formation of cavities (alveoles) of variable shapes and sizes (cells, lines, often centimeter size)
- Differential weathering possibly due to inhomogeneity of the stone material
- Appears on the surfaces exposed to strong winds where the crystallization of salts occurs underneath the surface, eroding it gradually
- Takes place in **zones exposed to direct water supplies and wind**

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 2/5

Erosion

Alveolization



Abbaye de Fontevraud
(France)
Loire Valley
Tuffeau stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 2/6



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Erosion

Alveolization

Chinon
(France,
Loire Valley)
Tuffeau stone



Materials and conservation of built cultural heritage – The weathering of fine natural building stones _ BR 127



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Erosion / Chemical and/or physical erosion of anthropogen origin

- More or less harmful erosion provoked by cleanings
- According to the chosen process of cleaning, erosion will be mechanical and/or chemical
- Does not strictly depend on the exposure conditions.

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 128



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Erosion

Anthropogen erosion

Neuchâtel
(CH, NE)
Pierre jaune
from Neuchâtel

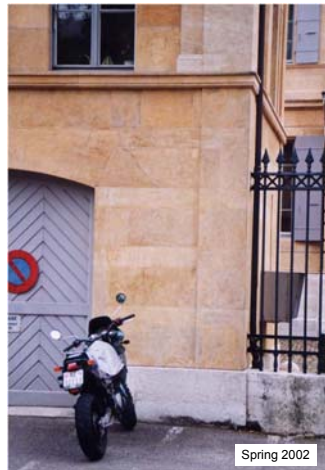


Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 129

Erosion

Anthropogen erosion

Neuchâtel (CH, NE)
Pierre jaune
from Neuchâtel



Erosion

Anthropogen erosion

Neuchâtel
(CH, NE)
Pierre jaune
from Neuchâtel



Erosion

Anthropogen erosion

Natural History
Museum of
Neuchâtel (CH, NE)
Pierre jaune of
Neuchâtel



Surface modifications linked to exogenous supplies / Crust

- Surface layer, of colour, structure, chemistry and mineralogy different from the substrate
- The constitutive products are exogenous (soots, dust, micro-organisms, salts) and endogenous (calcite, salts).
- At the beginning, the crust sticks very well onto the substrate
- In more advanced stages, it can come off the substrate, which have then a powdering surface
- Formed in sheltered zone, where water can never dissolve and wash materials accumulated on the surface.

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 4/3

Exogenous (and endogenous) deposits

Crust

Neuchâtel
Jehanne-de-Hochberg
street, (CH, NE)
Pierre jaune of Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 4/4

Exogenous (and endogenous) deposits

Crust

Epinal Basilica
(France)
Sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 4/5

Exogenous (and endogenous) deposits

Crust

(Nancy, France)
Savonnières
limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 468

Surface modifications linked to exogenous supplies / Film, pellicle, surface treatment

- Very thin covering or coating layer, usually homogeneous and of organic nature
- More or less easy to remove it from the substrate
- Does not strictly depend on the exposure conditions to water supplies.

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 477

Exogenous deposits

Film (antigraffiti)

D. de Rougemont Lycée,
Neuchâtel (CH, NE)
Jaumont limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 468

Exogenous deposits

Film (antigraffiti)

Neuchâtel (CH, NE)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 4/9

Exogenous supplies

Film (antigraffiti)

Neuchâtel
(CH, NE)
Pierre jaune
from Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 5/0

Exogenous supplies

Film (antigraffiti)

Geneva
(CH, GE)
(photo O.
Fawer)



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 6/1

Exogenous supplies

Film (paint layer)

Lausanne
(CH, VD)
(photo O.
Fawer)



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 62

Surface modifications due to exogenous supplies / Graffiti

- Results from the engraving, scratching or application of paint, ink or similar matter on the stone surface
- This phenomenon **does not depend on the exposure conditions to water supplies.**

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 63

Exogenous supplies

Graffiti

Ruelle Vaucher
Neuchâtel (CH, NE)
Pierre jaune from
Neuchâtel, bricks &
rendering (*crépi*)



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 64

Modification linked to stone decoherence / Granular disintegration

- Advanced state of decoherence characterized by the detachment of fragments of stone, grains or crystals under lightest mechanical stimulation
- Considerable reduction in the original mechanical resistance and a marked increase in porosity
- This phenomenon takes place in zones more or less exposed to water supplies

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/5

Decoherence Granular disintegration

Bell tower, west
Lausanne Cathedral
(CH, VD)
Aquitanian molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/6

Decoherence Granular disintegration

Musée d'Art et
d'Histoire
Fribourg (CH, FR)
Statue from the south
cathedral portal
Burdigalian molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/7

Modification linked to stone decoherence / Delamination (*délitage*)

- Physical separation of layers, plates, sheets following the bedding planes extension of laminated stones (sedimentary or metamorphic rocks)
- Easily formed when laminated stones are posed with their stratification parallel to the exposed surface
- Phenomenon supported by the presence of soluble salts, micro-organisms, and by cycles of freeze/thaw
- Takes place in zones more or less exposed to water supplies

Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 163

Decoherence Delamination

Salle du Grand Conseil,
Neuchâtel (CH, NE)
Pierre jaune from
Neuchâtel



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 159

Decoherence Delamination

Morat (CH, FR)
walkway on the
city wall
Burdigalian molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 160

Modification by stone decoherence / Scaling (exfoliation)

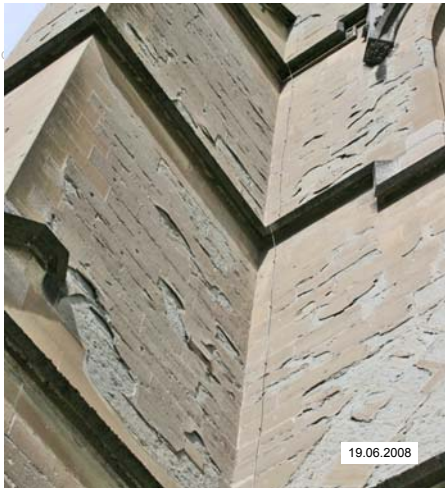
- Detachment of stone layers (scales/*plaques*) parallel to the stone surface BUT not following any stone structure
- These layers have a homogeneous thickness from a few millimetres to a few centimetres
- Takes place in zones exposed to direct water supplies

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 61

Decohesion

Scaling

Fribourg
Cathedral
(CH, FR)
Burdigalian
molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 62

Decoherence

Scaling

Chaumont castel
France, Loire Valley
Tuffeau stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 63



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Photos P. Jaggi_30.09.2005

Decoherence

Scaling (because of water repellent)

Rue de l'Evoile
Neuchâtel (CH, NE)
Burdigalian molasse
sandstone





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Modification linked to water supplies / Rising damp

- Caused by water absorption by capillarity from the ground at the base of walls or from a surface of retention
- Moisture goes through the walls, wets the internal and external surfaces where a horizontally limited stain is visible
- Takes place in zones where water supplies from the wall bases (or from a surface of retention) are important.

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 65



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Water supplies

Rising damp? (remontées capillaires ?)

Kaysersberg castle,
France, Haut Rhin



Autumn 2000

Kapellbrücke, Luzerne,
(CH, LU)



31.08.2010

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 66

Modification linked to water and salts supplies / Damp patches (*taches humides*)

- The material surface shows wet spots or zones of different color, generally darker
- Can be caused for example by the penetration of water (by rising damp) and/or by the hygroscopic behaviour of salt.

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 87

Water and salts supplies

Damp patches

Ballenberg museum (CH, BE)
(farmhouse from Tessin)



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 88

Water and salts supplies

Damp patches

Montheron temple (CH, VD)



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 89

Modification linked to water and salts supplies / Subflorescence, efflorescence

- **Subflorescence**: accumulation of salt crystals just under the external surface of building stones. They are **HARMFUL**: the pressure exerted by crystals can cause damages
- **Efflorescence**: any visible salt deposit on the surface of the building stones (=> **LESS HARMFUL**) (washed by every water supply)
- **Caused by the salt concentration and precipitation in the water evaporation zones**

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 70

Water and salts supplies

Damp patches + efflorescences

Berne (CH, BE)
Nydegg bridge,
south side
Burdigalian molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 71

Water and salts supplies

Efflorescences

City wall of Nancy
(France)
Bricks



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 72

Water and salts supplies

Efflorescences

Chur
(CH, GR)



Photo C. Bläuer

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 7/3

Modification of biological origin / Algae, bacteria

- In general at the stone surface, outside the buildings, but also inside
- Require water (liquid supplies or condensation), a certain luminosity and the adequate nutrients
- Form powdery deposits (more or less visible macroscopically) made up of filaments. They usually are green, red, pink, brown or black.

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 7/4

Biology

Algae

Lausanne
Cathedral (CH, VD)
Border between
burdigalian molasse
sandstone and
the dense
Arvel limestone



10.05.2005

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 7/5

Biology

Algae

Sully-sur-Loire castel
France, Loire Valley
Tuffeau stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 7/8

Biology

Algae

Epinal Basilica
France
Sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 7/7

Biology

Algae or bacteria

Sully-sur-Loire castel
France, Loire Valley
Tuffeau stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones. BR 7/8



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Biology

Algae

Chambord
castel
France,
Loire
Valley
Tuffeau
stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 7/9



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Modification of biological origin / Lichen, mosse

- **Lichen** develop on the exposed parts of the building stones and present a flaking aspect; they usually are orange, green, gray or black.
- **Moss** develop on the exposed parts of the building stones, in the form of green cushions or of hairy tufts. They plunge their roots in the substrate. These roots produce acids which dissolve certain minerals or the binder of the mortars.

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 8/0



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Biology

Algae, lichen

Loches
castel,
France,
Loire
Valley,
Tuffeau
stone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/1

Biology

Algae, lichen, mosses

Neuchâtel
Hôtel
du Peyrou
(CH, NE)
limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones... BR 82

Biology

Algae, lichen, mosses

Neuchâtel
Rue de
la Main
(CH, NE)
limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones... BR 83

Modification of biological origin / Plants

- In the badly-maintained mortars

Or

- On the architectural elements where enough earthy materials can accumulate

Materials and conservation of built cultural heritage – The weathering of the natural building stones... BR 84



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Biology

Plants (grass and shrubs)

Reims Cathedral
(France)
Limestone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 85



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Physical and/or mechanical modification / Splinter (*éclat, esquille*)

- Fragments of variable shapes and forms, separating from masonry, often starting from corners or from the joints of mortar
- Fragments consist of unchanged material
- Can result from damage caused by the use of a too hard mortar, an accident, vandalism,...

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 86



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Mechanical modifications

Splinter

Montheron Temple
(CH, VD)
Burdigalian molasse
sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 87

Physical and/or mechanical modification/ Bursting (*éclatement*)

- Caused by the swelling of a mortar
- Or
- Metal elements inside masonry

Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/3

Mechanical modifications

Bursting

Epinal Basilica,
France
Sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/3

Mechanical modifications

Bursting

Colombier
(CH, NE)
Pierre jaune



Materials and conservation of built cultural heritage – The weathering of the natural building stones – BR 6/3

Physical and/or mechanical modification / Crack, fracture *(fissure, fracture)*

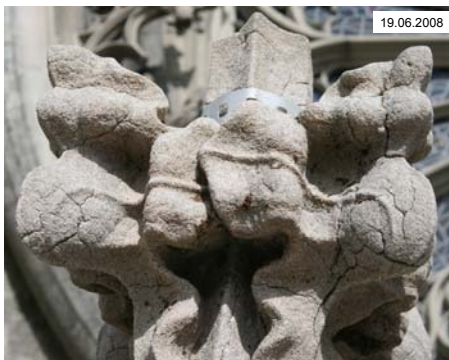
- Discontinuity which separates macroscopically one part of the stone of another, with or without relative displacement of the two parts
- Can be limited at the material surface or can affect the material in depth
- Can result from static problems, use of a too hard mortar, accident...

Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 01

Mechanical modification

Crack, fracture (frost)

Fribourg
Cathedral
(CH, FR)
Sandstone



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 02

Mechanical modification

Crack, fracture (static)

Prague
(Czech Republic)



Materials and conservation of built cultural heritage – The weathering of the natural building stones _ BR 03

Weathering forms cartography

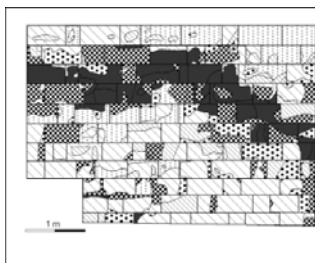
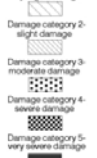


Fig. 31. Map of damage categories. El-Merdani Mosque, southern wall, Cairo (Egypt).



Fig. 30. El-Merdani Mosque, southern wall, Cairo (Egypt).



FITZNER B., HEINRICH K., 2002. Damage diagnosis on stone monuments – weathering forms, damage categories and damage indices. In R. Prikyl & H.A. Viles (eds), *Understanding and managing stone decay*. The Karolinum Press, Charles University in Prague p11-56

Bibliography

- Shaeffer R.J. (1932)** – The weathering of natural building stones - Building Research, Special Report. Published by his Majesty's Stationery Office, 149p.
- Jeannette D. (1997)** - Structures de porosité, mécanismes de transfert des solutions et principales altérations des roches des monuments - In « La pietra dei monumenti in ambiente fisico e culturale », R.A. Lefèvre, Edipuglia, p 49-77.
- Collectif (sous la direction de M. Rautureau) 2001** - Tendre comme la pierre - Ed. Région Centre, 116 p.
- Fitzner, B. & Heinrichs, K. (2002):** Damage diagnosis on stone monuments - weathering forms, damage categories and damage indices.- In Prikyl, R. & Viles, H. A. (ed.): Understanding and managing stone decay, Proceeding of the International Conference "Stone weathering and atmospheric pollution network (SWAPNET 2001)", 11-56, Charles University in Prague, The Karolinum Press (http://www.stone.rwth-aachen.de/wgn_cse.htm#p_00318 /10.11.2014)
- ICOMOS-ISCS (2008):** Illustrated glossary on stone deterioration patterns, English-French version (*Monuments and Sites: XV*), 78 pages (http://international.icomos.org/publications/monuments_and_sites/15/index.htm/ / 10.11.2014)
- Siegesmund, S. & Snethlage, R (Eds.) 2011:** Stone in architecture. Properties, durability. 4th ed., Springer Verlag, 552p.
- Brimblecombe P. (2008)** Air pollution history in R. S. Sokhi *World Atlas of Atmospheric Pollution*, Anthem Press, London, 7-18. (<http://www.uea.ac.uk/~p490/www.htm/> / 10.11.2014, P. Brimblecombe website)
- Elements** (international magazine) "Atmospheric Particles", August 2010, vol. 6, No 4 (<http://elements.geoscienceworld.org/content/vol6/issue4/index.dtl> / 10.11.2014)
- Lisci M., & al. (2003):** Lichens and higher plants on stone: a review. *International Biodeterioration & Biodegradation*, 51, 1-17 (Full text can be requested here : http://www.researchgate.net/publication/228468619_Lichens_and_higher_plants_on_stone_a_review /10.11.2014)
