THE SOLUBLE SALTS IN THE BUILT HERITAGE

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Principal ions of the harmful soluble salts:

Cations	Anions
Na^+ (sodium)	CO_3^{--} (carbonate)
K^+ (potassium)	HCO_3^- (hydrogencarbonate)
Ca^{++} (calcium)	SO_4^{--} (sulphate)
Mg^{++} (magnesium)	NO_3^- (nitrate)
NH_4^+ (ammonium)	Cl^- (chloride)
	$C_2O_4^{--}$ (oxalate)

Principal soluble salts in building stones (in CH):

	English	French	
Chlorides	halite sylvite	" sylvine	NaCl KCl
Nitrates	niter nitronatrite ammonium nitrate	salpêtre, nitre " , nitratine nitrate d'ammonium	KNO_3 $NaNO_3$ NH_4NO_3 (pH<7)
Sulphates	thenardite mirabilite gypsum epsomite arcanite	thénardite " gypse " "	Na_2SO_4 $Na_2SO_4.10H_2O$ $CaSO_4.2H_2O$ $MgSO_4.7H_2O$ K_2SO_4
Carbonates	calcite natron thermonatrite trona	" " " "	$CaCO_3$ (pH>7) $Na_2CO_3.10H_2O$ (pH>7) $Na_2CO_3.H_2O$ (pH>7) $Na_3H(CO_3)_2.2H_2O$ (pH>7)
Oxalates	weddellite whewellite	" "	$Ca(C_2O_4)\cdot 2(H_2O)$ $Ca(C_2O_4)\cdot(H_2O)$
Complex salts	ettringite darapskite	" "	$Ca_6Al_2(SO_4)_3(OH)_{12}.26H_2O$ $Na_3(SO_4)(NO_3)\bullet H_2O$

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Origin of the soluble salts:

Natural origins:

Sea water (all ions ≠ NO_3^-, NH_4^+)
Groundwaters (all ions)
Fresh waters (all ions)
Organic origin (NO_3^-, NH_4^+, oxalates $C_2O_4^{2-}$, $HC_2O_4^-$)

Natural building materials:

→ ex. : sandstone of Berne (≈ 0.1% Ca^{2+} et SO_4^{2-})

Origin of the soluble salts:

Restoration materials:

- cleaning products (formic acid, ammonium carbonate)
- conservation products (oxalates)
- additives of the conservation products (ammonia)

Air pollution (sulphate, nitrogen oxides, etc.)

- dry deposition
- wet deposition

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Origin of the soluble salts:

De-icing salts

- NaCl, $CaCl_2$,…

Alkali building materials

- Cement (Na^+, K^+, SO_4^{2-},…)
- Soluble glasses (Wasserglas) ($K^+ \pm Na^+ \pm Li^+$)
- Trass (Na^+, K^+, Mg^{2+},…)

Fireproof materials

- Boron salts
- Wasserglass

The crystallization problem

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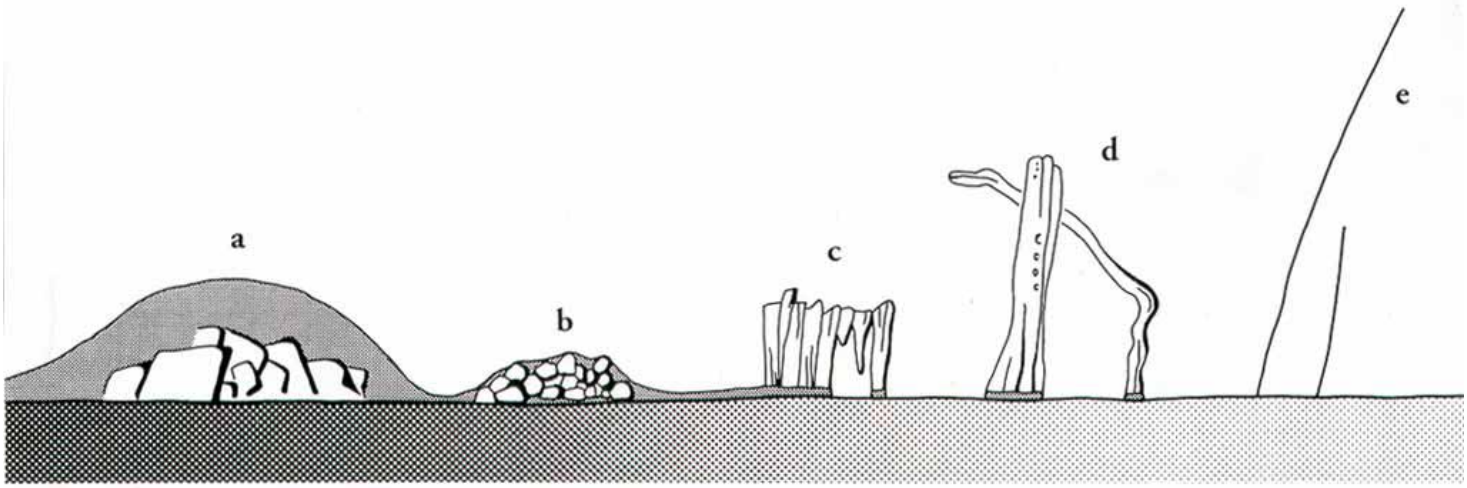
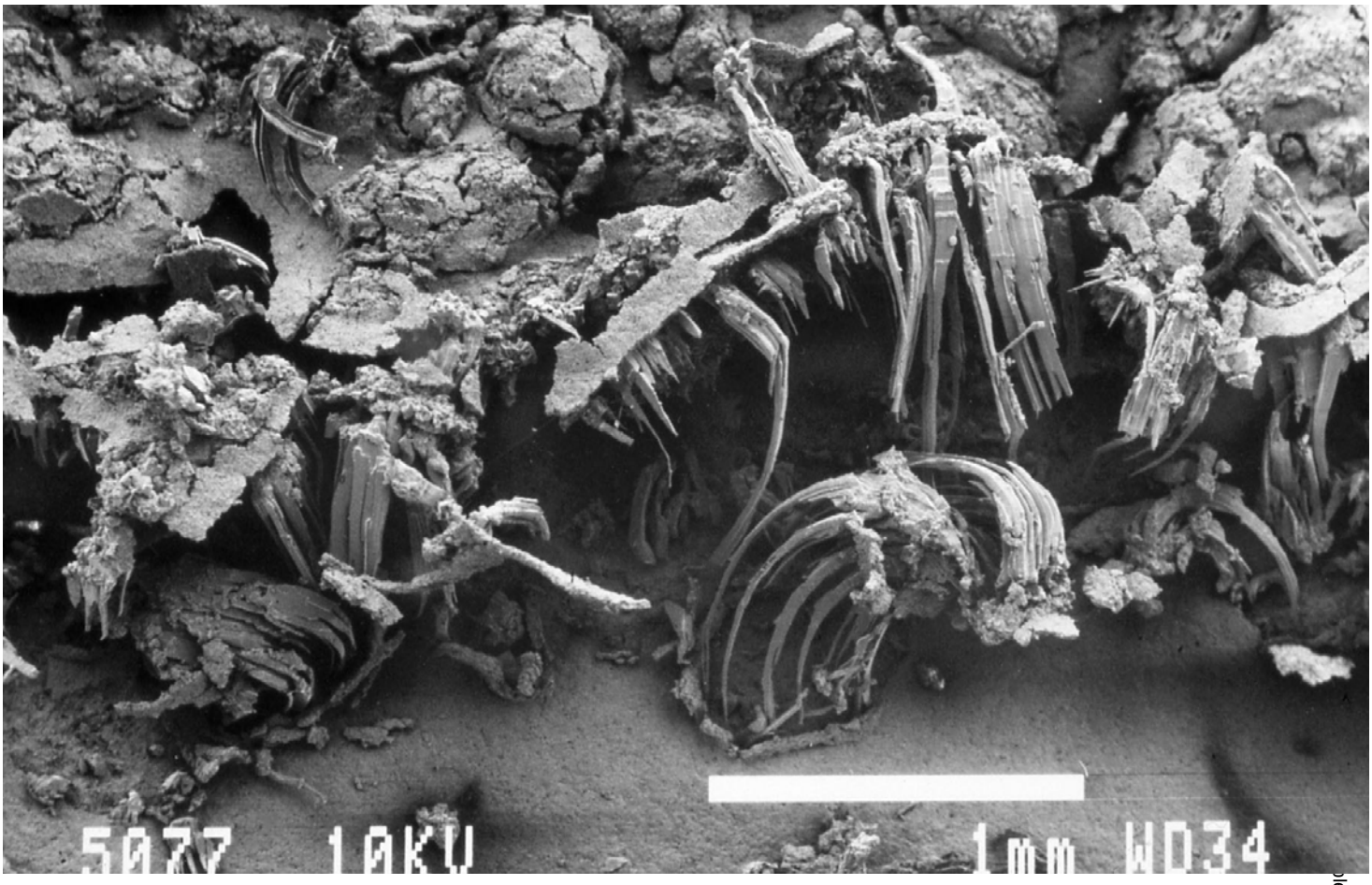
Nancy, 7.6.2008

Black crust of gypsum on the Euville limestone

Relationship between crystal morphology and the substrate humidity of a porous material



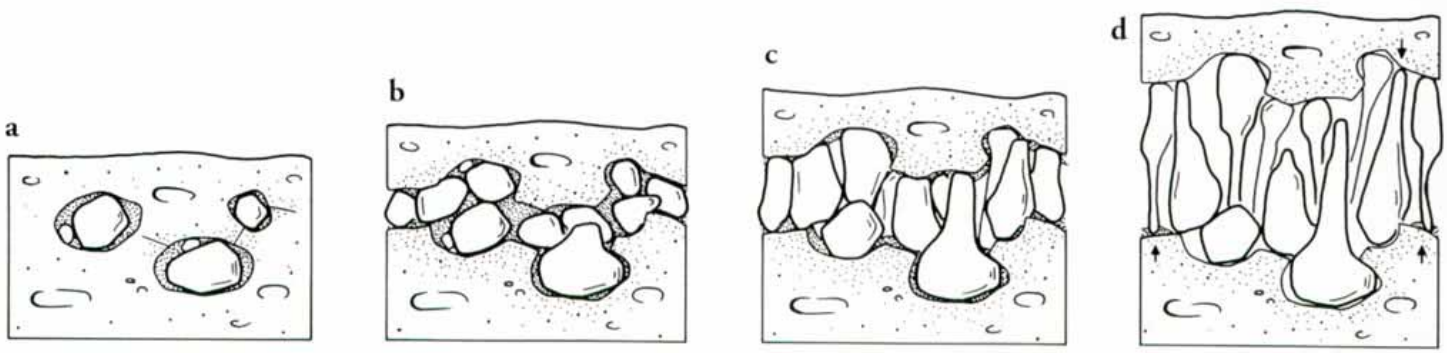
From: Arnold, A.; Zehnder, K. (1991): Monitoring wall paintings affected by soluble salts.- The Conservation of Wall Paintings. Proc. Symp. Courtauld Inst. Art & Getty Conservation Inst., London, July 13-16, 1987, 103-135.- The Getty Conservation Institute.



Paint layer on a ceramic with halite (NaCl) efflorescences (Laborexperiment)

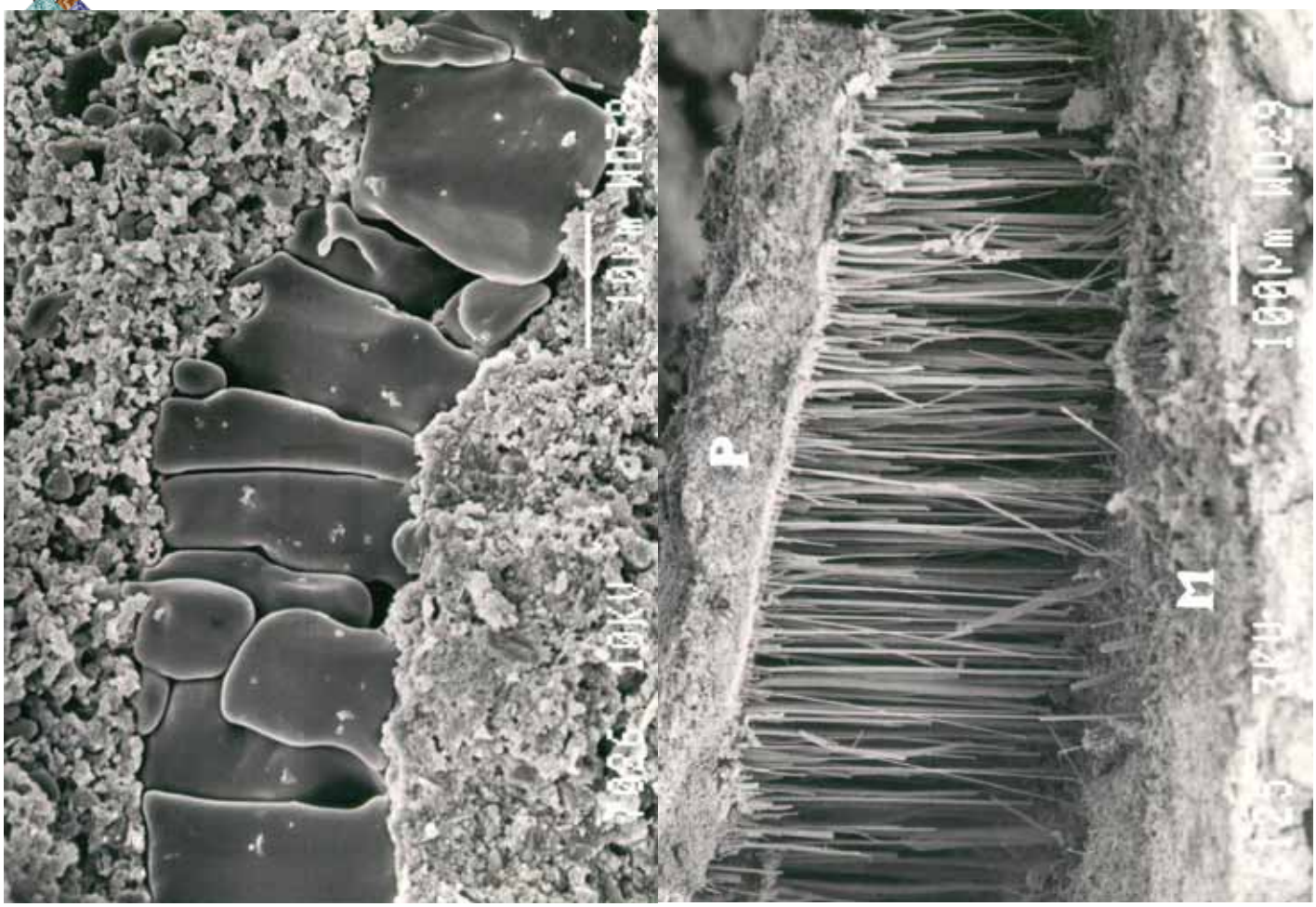
Photo Konrad Zehnder

Model of disruption process by crystallizing salts



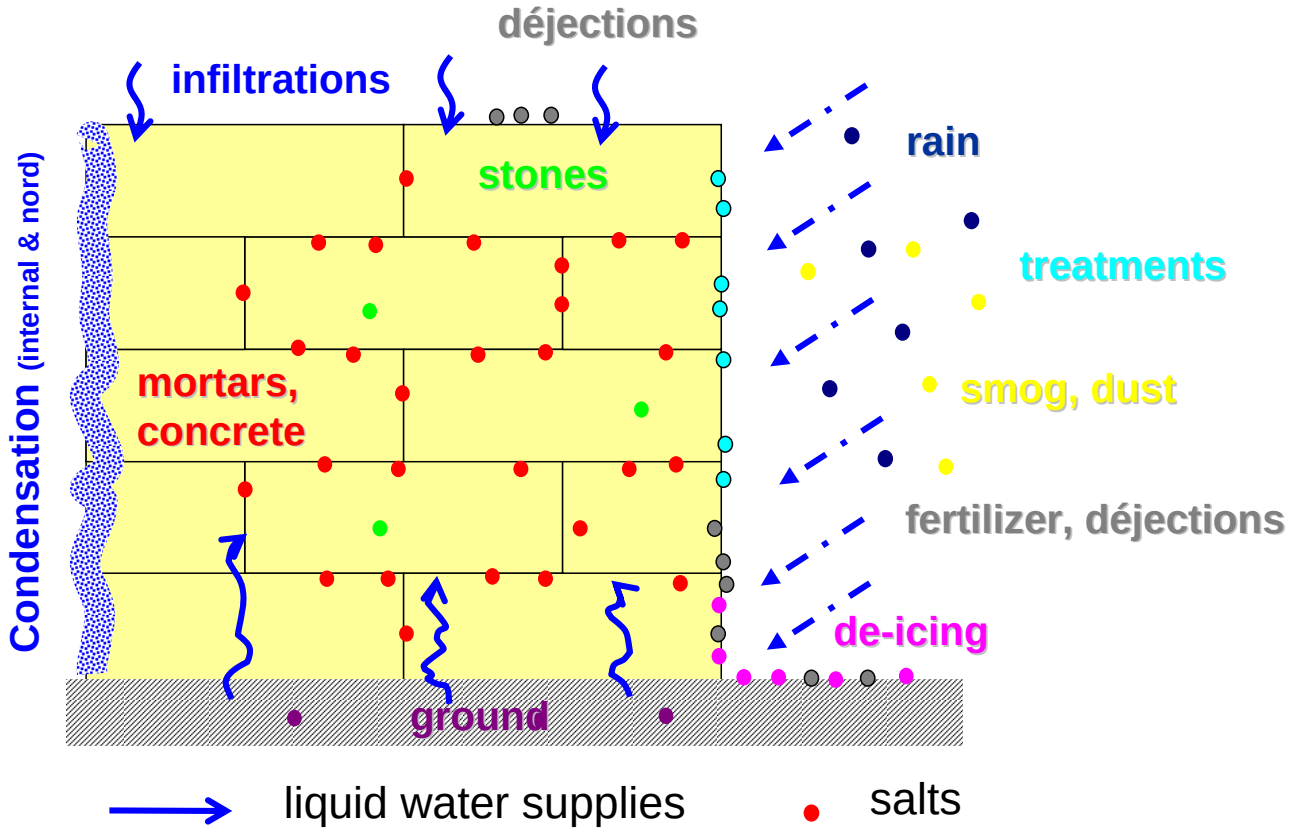
aus: Arnold, A.; Zehnder, K. (1991): Monitoring wall paintings affected by soluble salts.- The Conservation of Wall Paintings. Proc. Symp. Courtauld Inst. Art & Getty Conservation Inst., London, July 13-16, 1987, 103-135.- The Getty Conservation Institute.

Photos: Konrad Zehnder

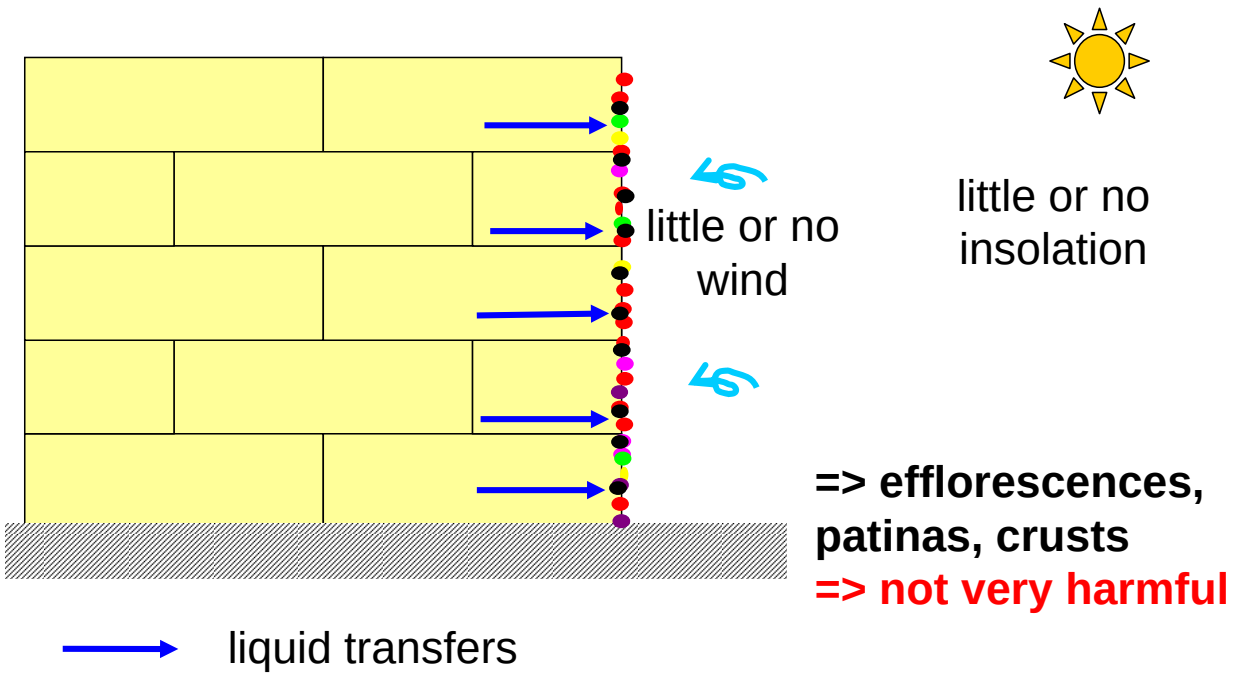


Nitronatrite ($NaNO_3$) in ceramic (lab. experiment)

Origin of salts and water in buildings



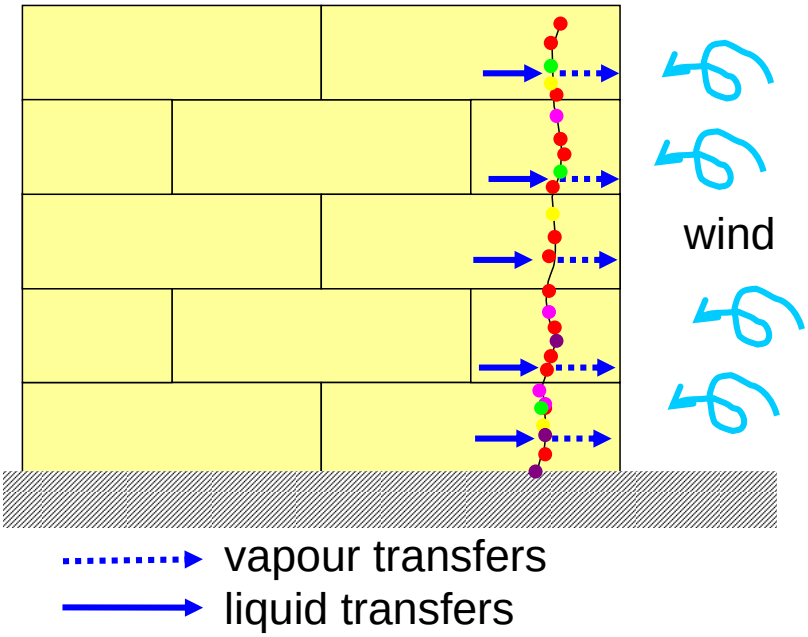
Evolution of water and salts in case of slow drying

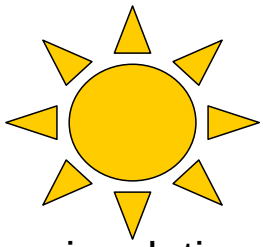


=> efflorescences, patinas, crusts

=> not very harmful

Evolution of water and salts in case of fast drying





=> scaling, blistering, granular disintegration, differential weathering

=> very harmful

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The hygroscopicity (or deliquescence) problem

Deliquescence humidity: the relative humidity above which a material absorbes humidity from the air and dissolves

Fribourg, Notre-Dame basilica, 2.11.2008

Kaysersberg castel, Alsace, France, 8.05.2008

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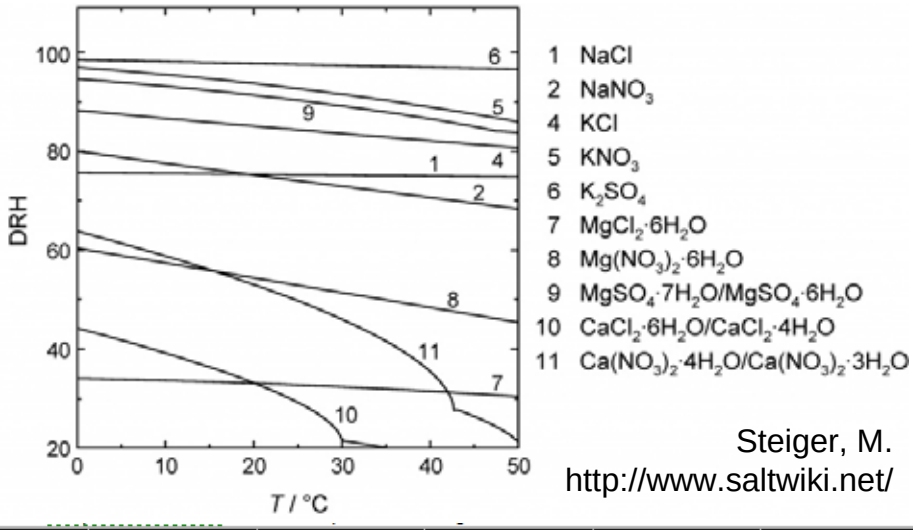
(http://www.trekearth.com/gallery/Europe/France/East/Alsace/Kaysersberg/photo909171.htm)

Deliquescence humidity & temperature



Steiger, M.
http://www.saltwiki.net/

Salz	0 °C	10 °C	20 °C	30 °C	40 °C	50 °C
NaCl	75.9	75.6	75.4	75.2	75.0	74.8
$NaNO_3$	80.1	77.7	75.3	72.8	70.4	68.0
Na_2SO_4	98.8(1)	97.8(1)	95.6(1)	90.1(1)	87.9	88.4
KCl	88.3	86.7	85.0	83.5	82.1	80.7
KNO_3	97.0	95.5	93.7	91.5	88.9	85.9
$MgCl_2 \cdot 6H_2O$	34.1	33.7	33.1	32.4	31.5	30.5
$Mg(NO_3)_2 \cdot 6H_2O$	61.3	58.6	55.7	52.5	49.2	45.7
$MgSO_4 \cdot 7H_2O$	94.5	93.1	91.3	89.1	86.3	83.2(2)
$CaCl_2 \cdot 6H_2O$	44.3	39.4	33.3	21.6(3)	18.4(3)	16.3(4)
$Ca(NO_3)_2 \cdot 4H_2O$	63.8	58.8	53.1	46.0	35.5	21.3(5)

(1) $Na_2SO_4 \cdot 10H_2O$, (2) $MgSO_4 \cdot 6H_2O$, (3) $CaCl_2 \cdot 4H_2O$, (4) $CaCl_2 \cdot 2H_2O$, (5) $Ca(NO_3)_2 \cdot 3H_2O$

Formula	Molecular mass (g/mol)	% H2O (w)	Name FR	Name EN	solubility (g/l) / 20°C	Relative humidity of deliquescence or equilibrium (%)
(NH4)2Mg(SO4)2.6H2O	360.6	30.0	boussingaultite	boussingaultite	159 (0°C), 1300 (100°C)	
Ca(C2O4).2H2O	164.13	22.0	weddellite	weddellite	~ 0	
Ca(C2O4).H2O	146.11	12.3	whewellite	whewellite	~ 0	
Ca(HCO2)2	130.11	0.0	formiate de calcium	calcium formate	162 (0°C)	
Ca(NO3)2.4H2O	236.15	30.5	nitrocalcite	nitrocalcite	2660	56,5% (10°C), 53,6% (20°C), 50,5% (25°C)
Ca3Si(OH)6(CO3)(SO4).12H2O	622.61	34.7	thaumasite	thaumasite		
Ca6Al2(SO4)3(OH)12.26H2O	1255.09	37.3	ettringite	ettringite		
CaCl2.6H2O	219.08	49.3	antarctitite	antarcticite	5360	33,7% (10°C), 30,8% (20°C), 22,4% (30°C)
CaCO3	100.09	0.0	calcite	calcite	0.014 (25°C)	
CaMg(CO3)2	184.41	0.0	dolomite	dolomite	0,078 (18°C)	
CaMg2Cl6.12H2O	517.59	41.8	tachyhydrite	tachyhydrite		
CaSO4.0,5H2O	145.15	6.2	hémihydrate, bassanite	Plaster of Paris	3	
CaSO4.2H2O	172.17	20.9	gypse	gypsum	2.14	
K2Ca(SO4)2.H2O	328.42	5.5	syngénite	syngenite	2.5	
K2Ca5(SO4)6.H2O	872.96	2.1	görgeyit	görgeyite		
K2Mg(SO4)2.6H2O	402.76	26.8	picromérite	picromerite	250	
K2SO4	174.5	0.0	sulfate de potassium	arcanite	111.5	98,2% (10°C), 97,6% (20°C), 97% (30°C)
K3Na(SO4)2	332.42	0.0	glaserite	glaserite		
K3Na7Mg2(SO4)6(NO3)2.6H2O	1135.3	9.5	humberstonite	humberstonite		
KAl3(OH)6(SO4)2	414.21	0.0	alunite			
KCl	74.56	0.0	sylvine	sylvite	344	86,8% (10°C), 84,3% (25°C)
KHCO3	100.12	0.0	bicarbonate de potassium	Potassium bicarbonate	333	
KNO3	101.11	0.0	nitrate de potassium, salpêtre	niter	315	94,6% (20°C), 93,6% (25°C)
Mg(HCO2)2.2H2O	150.37	24.0	formiate de magnésium	magnesium formate	140 (0°C)	
Mg(NO3)2.6H2O	256.41	42.2	nitromagnésite	nitromagnesite	705	57,4% (10°C), 54,4% (20°C), 51,4% (30°C)
Mg5(CO3)4(OH)2.4H2O	467.63	15.4	hydromagnésite	hydromagnesite		
MgCl2.6H2O	203.31	53.2	bischofite	bischofite	543	33,5% (10°C), 33,1% (20°C), 32,4% (30°C)
MgCO3	84.32	0.0	magnésite	magnesite	0.106	
MgCO3.3H2O	138.37	39.1	nesquehonite	nesquehonite	1.79 (16°C)	
MgCO3.5H2O	174.4	51.7	lansfordite	lansfordite		
MgSO4.6H2O	212.47	50.9	hexahydrite	hexahydrite	660	
MgSO4.7H2O	246.48	51.2	epsomite	epsomite	710	90,1% (20°C) 94% (30°C)
MgSO4.H2O	138.39	13.0	kiesérite	kieserite	684 (100°C)	
Na10Ca3(SO4)8.6H2O	1226.72	8.8	hydroglauberite	hydroglauberite		
Na2CO3.10H2O	286.14	63.0	natron	natron	215.8	96,5% (15°C), 97,9% (20°C), 88,2% (25°C), 83,2% (30°C)
Na2CO3.H2O	124	14.5	thermonatrite	thermonatrite	330	71% (35°C)
Na2Mg(SO4)2.4H2O	334.48	21.5	blödite	astrakhanite		
Na2SO4	142.04	0.0	thénardite	thenardite	162	
Na2SO4.10H2O	322.19	55.9	mirabilite	mirabilite	900	93,6 (20°C) ; 90% (23°C) ; 87% (25°C)
Na3(SO4)(NO3).H2O	245.05	7.4	darapskite	darapskite		
Na3H(CO3)2.2H2O	226.03	15.9	trona	trona	130 (0°C)	
NaCl	58.44	0.0	halite	halite	358	75,7 (10°C), 73,3 (25°C)
NaHCO3	84	0.0	hydrogénocarbonate de sodium	baking soda	96	
NaNO3	84.99	0.0	nitronatrite	nitratine	880	77,5% (10°C), 75,2% (20°C), 74,3% (25°C)
NH4NO3	80.04	0.0	nitrate d'ammonium, ammonitrate	Ammonium nitrate	1787	65% (20°C), 61,8% (25°C)