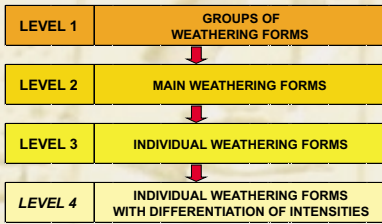


Weathering damage on Pharaonic sandstone monuments in Upper Egypt

Classification of weathering forms

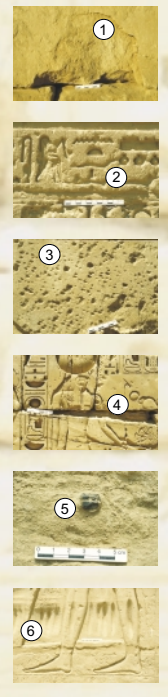
Bernd Fitzner, Kurt Heinrichs & Dennis La Bouchardiere

Weathering forms are the visible results of weathering processes, which are initiated and controlled by weathering factors. Weathering forms represent an important parameter for the characterization, quantification and rating of stone weathering. A survey of weathering forms on the Pharaonic sandstone monuments in Upper Egypt was made. A wide range of weathering forms was observed characterizing loss of stone material, discoloration / deposits, detachment of stone material and fissures / deformation. A classification scheme of weathering forms - accompanied by a photoatlas - was developed as basis for their objective and reproducible registration. Damage categories and damage indices were established for the rating of weathering damage. All weathering forms - considering their type and intensity - were related to damage categories.

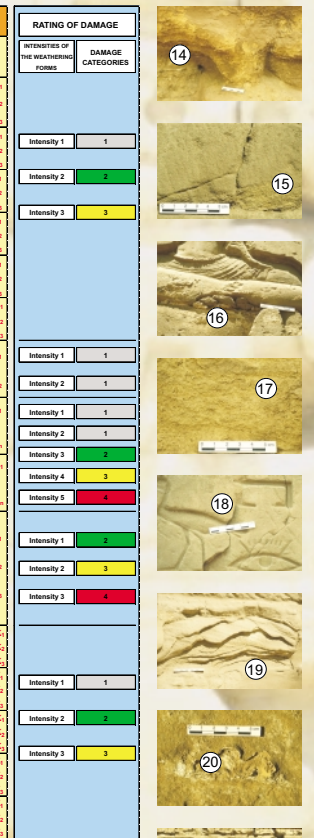


Classification of weathering forms

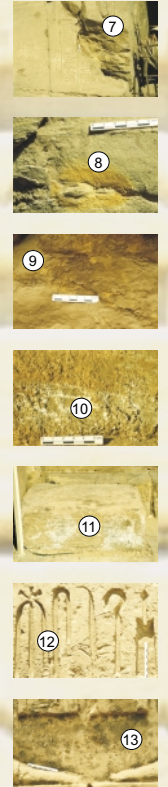
GROUP 1 OF WEATHERING FORMS LOSS OF STONE MATERIAL			
MAIN WEATHERING FORMS	INDIVIDUAL WEATHERING FORMS	INTENSITIES OF INDIVIDUAL WEATHERING FORMS	RATING OF DAMAGE
BACK WEATHERING Uniform loss of stone material parallel to the original stone surface.	W Back weathering due to loss of scales Uniform loss of stone material parallel to the stone surface due to contour scaling	SW 1 Depth of back weathering (cm) Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: 5 - 10 Intensity 6: 10 - 25 Intensity 7: > 25	SW 1 1 2 3 4 5 6 7
	R Rounding / notching Relief by rounding of edges or notching / hollowing out. Concave or convex relief forms.	Ro 2 Depth of relief (cm)	Ro 1 1 2 3 4 5 6 7
	R Relief in the form of alveoles. Form comparable to honeycombs.	Ra 3 Depth of relief (cm)	Ra 1 1 2 3 4 5 6 7
	R Weathering dependent on structural features such as bedding, foliation, banding etc. Frequently striped pattern.	IR 4 Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: 5 - 10 Intensity 6: 10 - 25 Intensity 7: > 25	IR 1 1 2 3 4 5 6 7
	R Weathering out of stone components Relief due to selective weathering of sensitive stone components (e.g. particles, scales of ironoxide etc.) or due to break out of compact stone material (e.g. hole-shaped forms).	IRh 5 Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: 5 - 10 Intensity 6: 10 - 25 Intensity 7: > 25	IRh 1 1 2 3 4 5 6 7
	R Cleaning out of stone components Relief in the form of protruding compact stone components (e.g. knobs, protrusions) due to selective weathering.	Rh 6 Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: 5 - 10 Intensity 6: 10 - 25 Intensity 7: > 25	Rh 1 1 2 3 4 5 6 7
	R Relief in the form of anthropogenic impact Relief in the form of scratches etc.	aR 7 Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: 5 - 10 Intensity 6: 10 - 25 Intensity 7: > 25	aR 1 1 2 3 4 5 6 7
BREAK OUT Loss of compact stone fragments.	O Break out due to anthropogenic impact Break out due to wear, vandalism etc.	ao 1 Volume of break out (cm ³) Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	ao 1 1 2 3 4 5 6 7
	O Break out due to constructional causes	bo 2 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	bo 1 1 2 3 4 5 6 7
	O Break out due to static causes	so 3 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	so 1 1 2 3 4 5 6 7
	O Break out due to natural causes	no 4 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	no 1 1 2 3 4 5 6 7
	O Break out due to earthquakes, intersection of fractures etc.	eo 5 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	eo 1 1 2 3 4 5 6 7
	O Break out due to non-recognizable causes	oo 6 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	oo 1 1 2 3 4 5 6 7
	O Break out due to non-recognizable causes	oo 7 Intensity 1: < 10 Intensity 2: 10 - 125 Intensity 3: 125 - 500 Intensity 4: 500 - 1000 Intensity 5: 1000 - 2500 Intensity 6: > 2500	oo 1 1 2 3 4 5 6 7



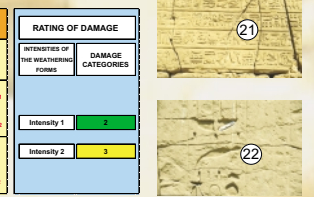
GROUP 3 OF WEATHERING FORMS DETACHMENT			
MAIN WEATHERING FORMS	INDIVIDUAL WEATHERING FORMS	INTENSITIES OF INDIVIDUAL WEATHERING FORMS	RATING OF DAMAGE
GRANULAR DISINTEGRATION Detachment of smallest stone particles (stone powder).	G Granular disintegration into sand Detachment of individual grains or small grain aggregates.	Gp 14 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	Gp 1 1 2 3
	G Crumbly disintegration into sand Detachment of larger compact stone pieces in the form of crumbs.	Gc 15 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	Gc 1 1 2 3
CRUMBLY DISINTEGRATION Detachment of larger compact stone pieces of irregular shape.	P Crumbing Detachment of larger compact stone pieces in the form of splinters.	Pu 16 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	Pu 1 1 2 3
	P Spitting Detachment of larger compact stone pieces in the form of splinters.	Ph 17 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	Ph 1 1 2 3
FLAKING Detachment of small, thin stone pieces (flakes) parallel to the stone surface.	F Single flakes Detachment of one layer of flakes parallel to the stone surface.	ef 18 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	ef 1 1 2 3
	F Multiple flakes Detachment of several thin flakes parallel to the stone surface.	mf 19 Mass of detaching stone material Intensity 1: low Intensity 2: medium Intensity 3: high	mf 1 1 2 3
CONTOUR SCALING Detachment of larger, glossy stone pieces parallel to the stone surface, but not following any stone structure.	S Scale due to tooling of the stone surface Detachment of mainly thin scales due to tooling of the stone surface.	qs 20 Thickness of the scale (cm) Intensity 1: > 0.5 Intensity 2: 0.5 - 1 Intensity 3: > 1	qs 1 1 2 3
	S Single scales Detachment of one layer of scales.	es 21 Thickness of the scales or the stack of scales (cm) Intensity 1: < 0.5 Intensity 2: 0.5 - 1 Intensity 3: 1 - 3 Intensity 4: 3 - 5 Intensity 5: > 5	es 1 1 2 3 4 5
DETACHMENT OF STONE LAYERS DEPENDENT ON STONE STRUCTURE Detachment of larger stone sheets or plates following the stone structure.	X Spilling up Detachment of larger stone layers (sheets, plates) following any stone structure (bedding, etc.), but not the stone surface.	Xv 22 Number of detaching stone layers resp. spalls Intensity 1: low Intensity 2: medium Intensity 3: high	Xv 1 1 2 3
	X Detachment of larger stone sheets or plates following the stone structure.	Xs 23 Number of detaching stone layers resp. spalls Intensity 1: low Intensity 2: medium Intensity 3: high	Xs 1 1 2 3
DETACHMENT OF CRUSTS WITH STONE MATERIAL Detachment of crusts with stone material sticking to the crust.	dkK Detachment of a dark-colored crust tracing the stone surface	dkK 24 Mass of detaching material Intensity 1: low Intensity 2: medium Intensity 3: high	dkK 1 1 2 3
	dkK Detachment of a dark-colored crust changing the stone surface	dkK 25 Mass of detaching material Intensity 1: low Intensity 2: medium Intensity 3: high	dkK 1 1 2 3
	hkK Detachment of a light-colored crust tracing the stone surface	hkK 26 Mass of detaching material Intensity 1: low Intensity 2: medium Intensity 3: high	hkK 1 1 2 3
	hkK Detachment of a light-colored crust changing the stone surface	hkK 27 Mass of detaching material Intensity 1: low Intensity 2: medium Intensity 3: high	hkK 1 1 2 3



GROUP 2 OF WEATHERING FORMS DISCOLORATION / DEPOSITS			
MAIN WEATHERING FORMS	INDIVIDUAL WEATHERING FORMS	INTENSITIES OF INDIVIDUAL WEATHERING FORMS	RATING OF DAMAGE
DISCOLORATION Alteration of the original stone color.	D Chromatic alteration / coloring due to chemical weathering of minerals (e.g. rusting of iron compounds), due to intrusion / accumulation of colorants or due to staining by biogenic pigments.	Dc 8 Degree of change of color Intensity 1: low Intensity 2: high	Dc 1 1 2 3
	I Soiling by particles from the atmosphere Poorly adhesive, mainly grey to black deposits of dust etc.	pl 9 Mass of deposits or degree of covering of the surface Intensity 1: low Intensity 2: high	pl 1 1 2 3
SOILING Dirt deposits on the stone surface.	I Soiling by particles from water Poorly adhesive, mainly grey to brown deposits of dust, soil or mud particles.	wf 10 Mass of deposits or degree of covering of the surface Intensity 1: low Intensity 2: high	wf 1 1 2 3
	I Soiling by droppings from birds, e.g. from sparrows.	gf 11 Mass of deposits or degree of covering of the surface Intensity 1: low Intensity 2: high	gf 1 1 2 3
LOOSE SALT DEPOSITS Poorly adhesive deposits of salt aggregates.	E Efflorescences Poorly adhesive deposits of salt aggregates on the stone surface.	Ex 12 Mass of deposits (E _v , E _s) or degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	Ex 1 1 2 3
	E Subefflorescences Poorly adhesive deposits of salt aggregates below the stone surface, e.g. in the zones of detachment of scales.	Es 13 Mass of deposits (E _v , E _s) or degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	Es 1 1 2 3
CRUST Strongly adhesive deposits on the stone surface.	C Dark-colored crust tracing the surface Compact deposit, grey- to black-colored, tracing the morphology of the stone surface. Mainly due to deposition of pollutants from the atmosphere.	dkC 14 Degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	dkC 1 1 2 3
	C Dark-colored crust changing the surface Compact deposit, grey- to black-colored, changing the morphology of the stone surface. Mainly due to deposition of pollutants from the atmosphere.	dkC 15 Degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	dkC 1 1 2 3
	C Light-colored crust tracing the surface Compact deposit, light-colored, tracing the morphology of the stone surface. Mainly due to precipitation processes. Light-colored crusts with impurities.	hkC 16 Degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	hkC 1 1 2 3
	C Light-colored crust changing the surface Compact deposit, light-colored, changing the morphology of the stone surface. Mainly due to precipitation processes. Light-colored crusts of salt.	hkC 17 Degree of covering of the surface (E _h) Intensity 1: low Intensity 2: high	hkC 1 1 2 3
BIOLOGICAL COLONIZATION Colonization by micro-organisms or higher plants.	B Microbiological colonization Colonization by microfungi (algae, lichens) and bacteria, diatoms.	Bl 18 Degree of covering of the surface Intensity 1: low Intensity 2: high	Bl 1 1 2 3
	B Colonization by higher plants	Bh 19 Degree of covering of the surface Intensity 1: low Intensity 2: high	Bh 1 1 2 3



GROUP 4 OF WEATHERING FORMS FISSURES / DEFORMATION			
MAIN WEATHERING FORMS	INDIVIDUAL WEATHERING FORMS	INTENSITIES OF INDIVIDUAL WEATHERING FORMS	RATING OF DAMAGE
FISSURES Individual fissures or systems of fissures due to natural or constructional causes.	L Fissures independent of stone structure Individual fissures or systems of fissures independent of structural features such as bedding etc.	vl 20 Number and dimension (length, width) of fissures Intensity 1: low number and small dimension Intensity 2: high number or large dimension	vl 1 1 2 3
	L Fissures dependent on stone structure Individual fissures or systems of fissures dependent on structural features such as bedding etc.	sl 21 Number and dimension (length, width) of fissures Intensity 1: low number and small dimension Intensity 2: high number or large dimension	sl 1 1 2 3



WEATHERING FORMS
Detailed description of individual weathering phenomena with quantification of their intensities

DAMAGE CATEGORIES
Definition of damage categories, relating of weathering forms to damage categories

DAMAGE INDICES
Definition of damage indices, calculation of damage indices from proportion of damage categories

DAMAGE INDICES
Conclusive quantification and rating of damage

0	no visible damage
1	very slight damage
2	slight damage
3	moderate damage
4	severe damage
5	very severe damage

LINEAR DAMAGE INDEX $D_{LI} = \frac{\sum (A_i \cdot B_i) + \sum (C_i \cdot D_i) + \sum (E_i \cdot F_i)}{100}$	
PROGRESSIVE DAMAGE INDEX $D_{PI} = \frac{\sum (A_i \cdot B_i) + \sum (C_i \cdot D_i) + \sum (E_i \cdot F_i) + \sum (G_i \cdot H_i) + \sum (I_i \cdot J_i)}{100}$	

Rating of damage