MICROSTRUCTURAL INVESTIGATIONS OF SOILING PROCESSES IN DESERT LOCATIONS

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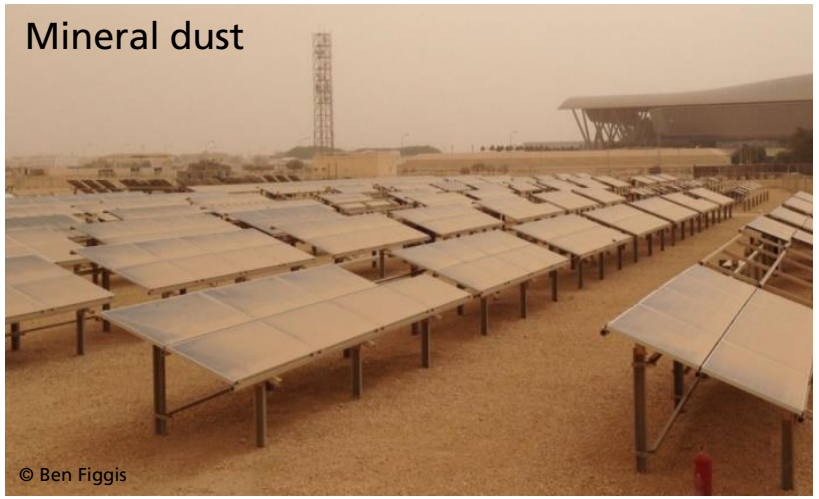
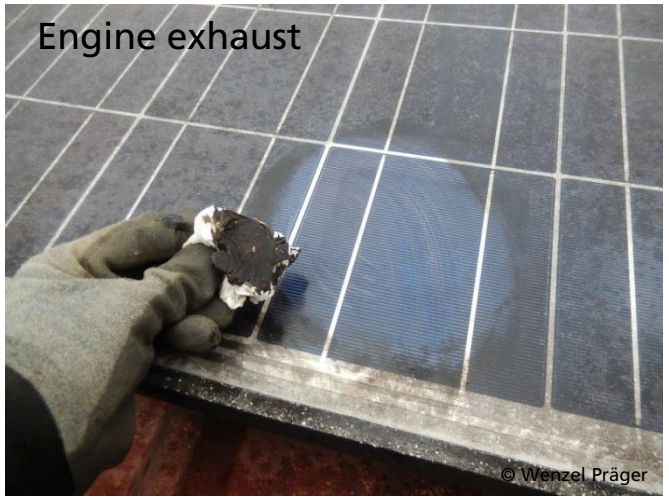
inDust user workshop

Munich, 2019/05/16

Introduction

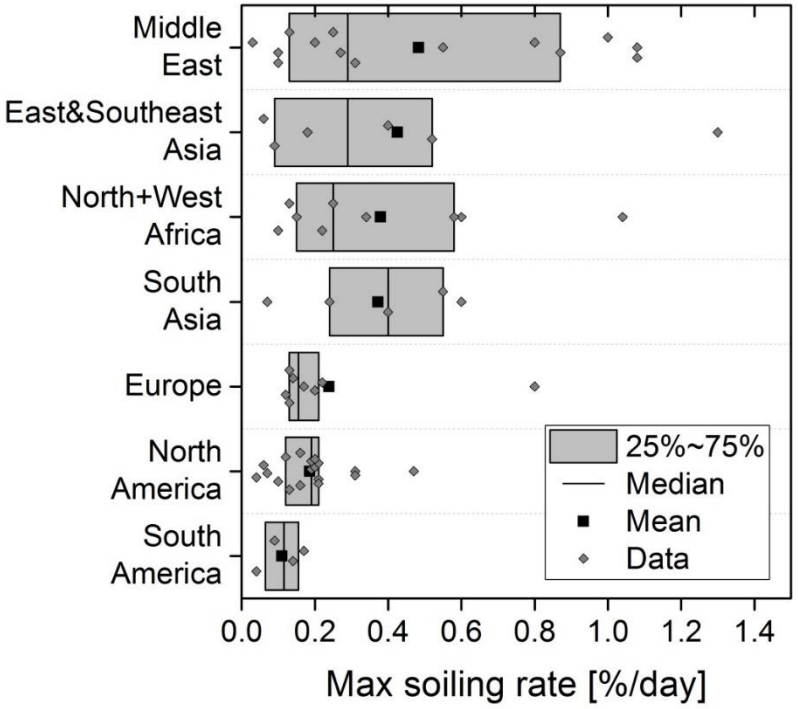
Soiling of PV modules - a detrimental problem for solar energy production

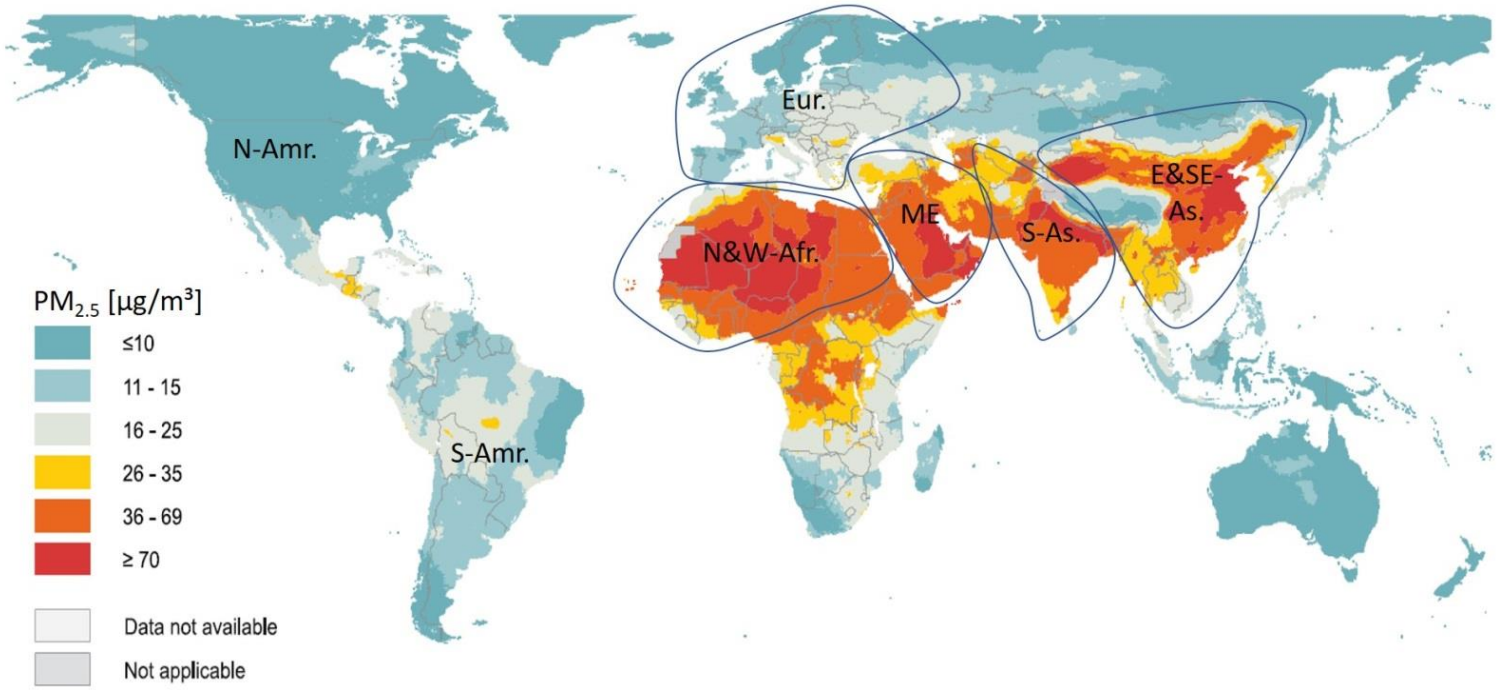




Introduction

Soiling of PV modules - a detrimental problem for solar energy production





- "Soiling is the 3rd most important PV performance factor, behind only insolation and temperature" (First Solar)
- Locations with **over 1% loss/day**

Ilse et al. „Fundamentals of soiling processes on photovoltaic modules", Renewable and Sustainable Energy Reviews 98 (2018) 239–254

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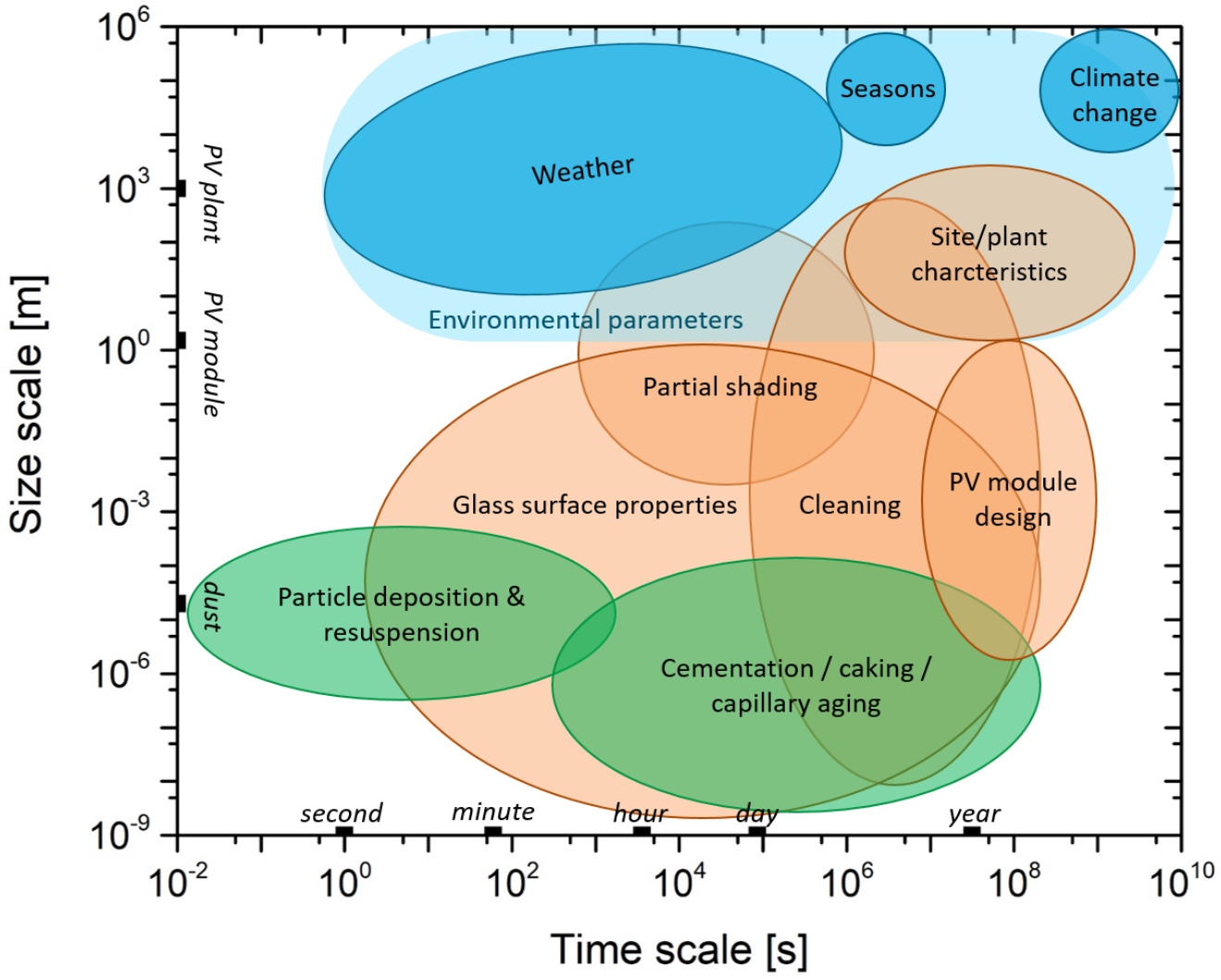
Introduction
Soiling – a truly complex problem

- Many influencing factors acting on different time and size scales
- Can be divided in:
  - Macroscopic environmental parameters
  - Controllable factors: module/plant/site characteristics
  - Microscopic soiling processes



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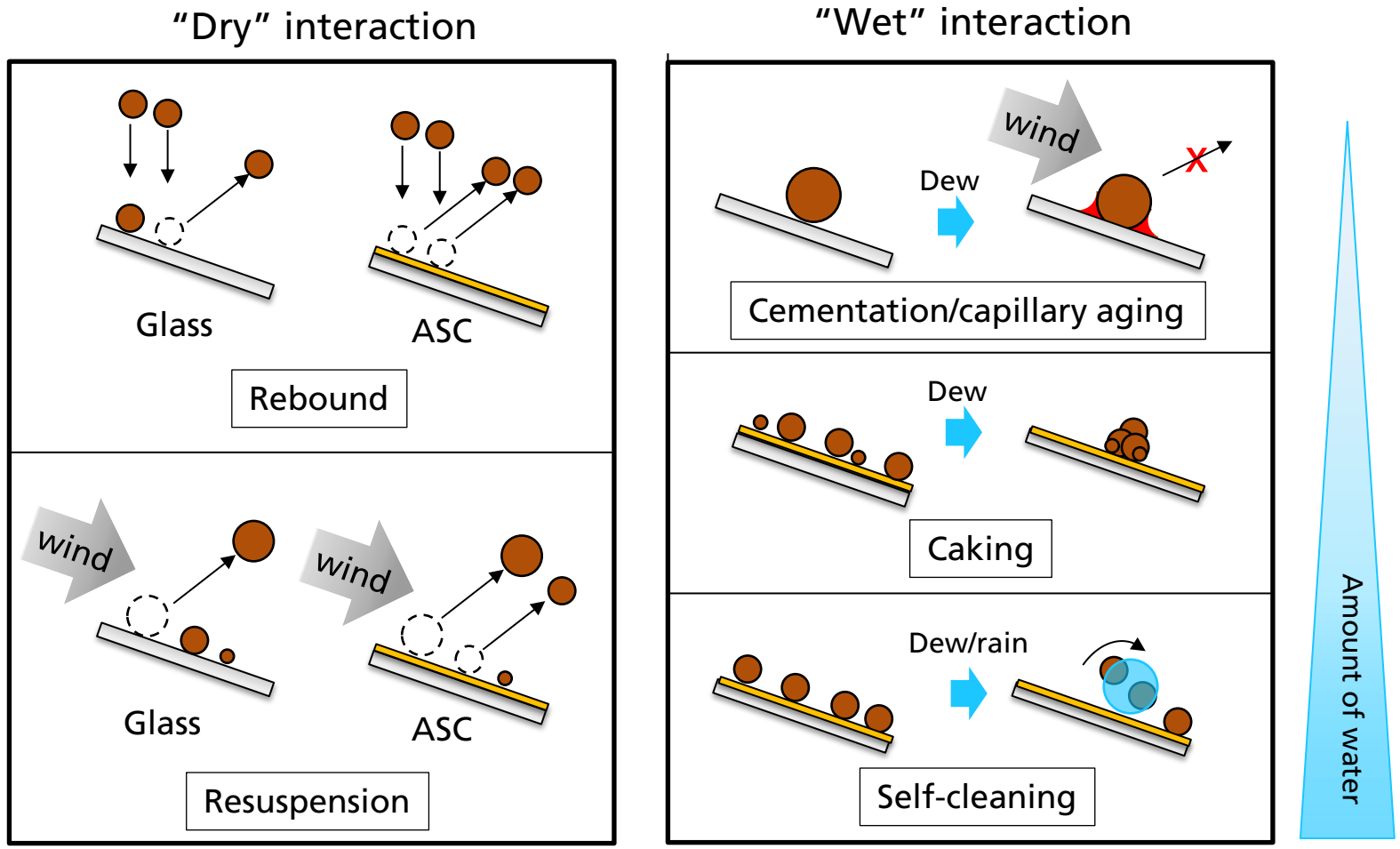
Physics of soiling

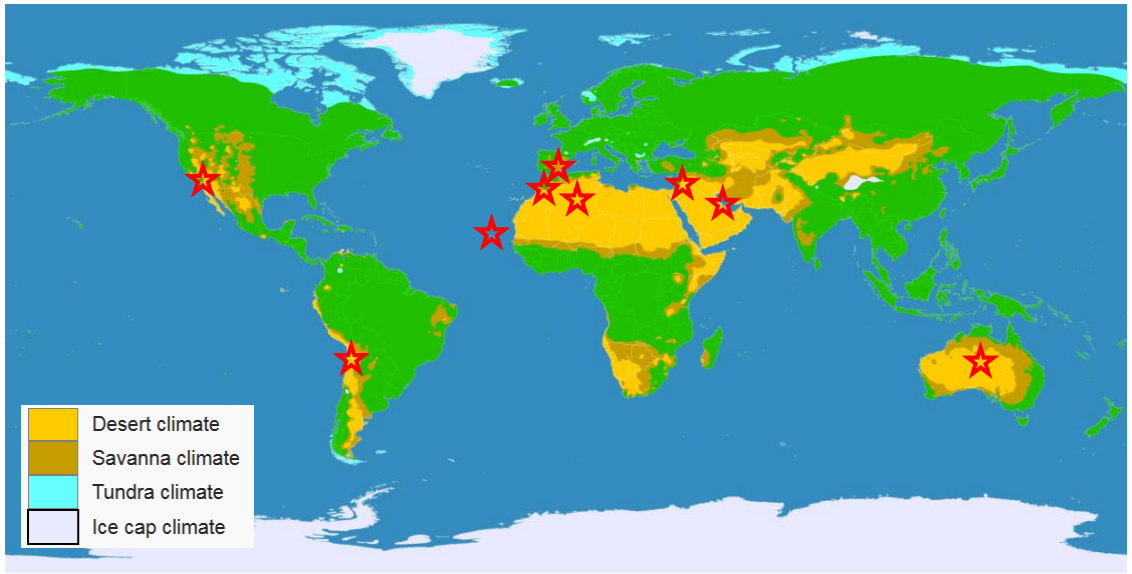
Mechanisms relevant for soiling and self-cleaning effects

- **Rebound**: particles bouncing off the surface during deposition
- **Resuspension**: particles removed by wind
- **Cementation/capillary aging**: strong dust adhesion by chemical bonds or increased contact area
- **Caking**: rearrangement and agglomeration of particles
- **Self-cleaning** by water running off the surfaces



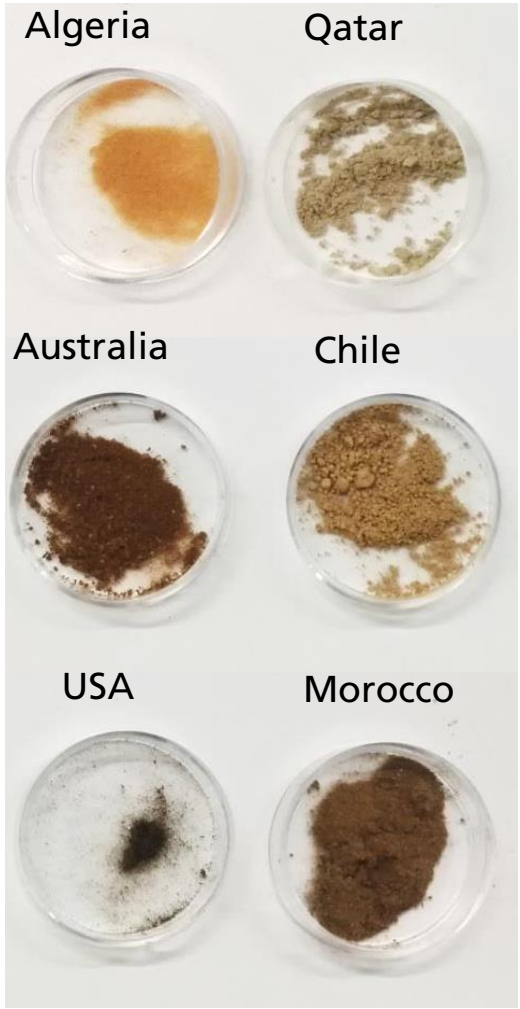
Comparative outdoor study
Soiling of glass coupons

- **Aim**: comparison of soiling processes in different desert regions
- Outdoor exposure of glass and plastic slides at 9 different desert areas
  - Fixed on PV modules → same temperature & tilt angle
  - Different periods of time (1, 3, 7, 14, 28 days)

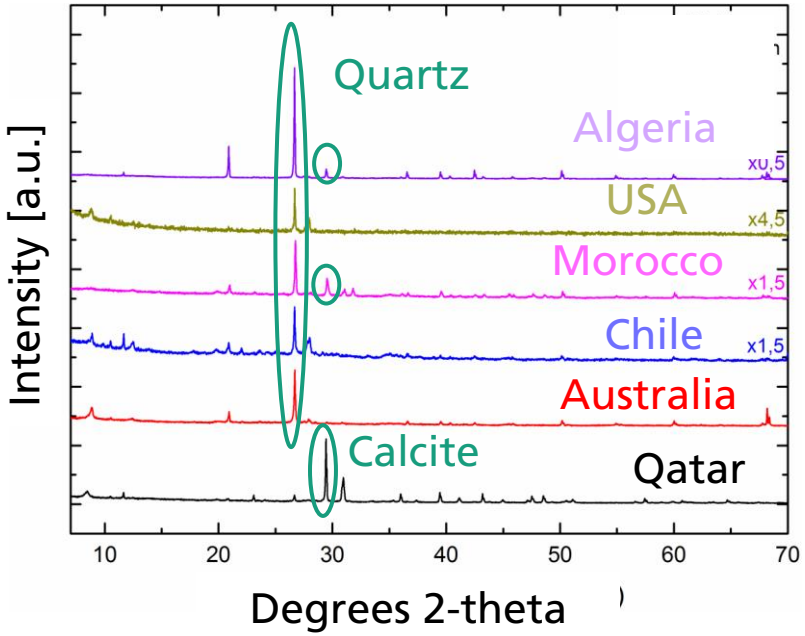


Dust samples collected from PV modules

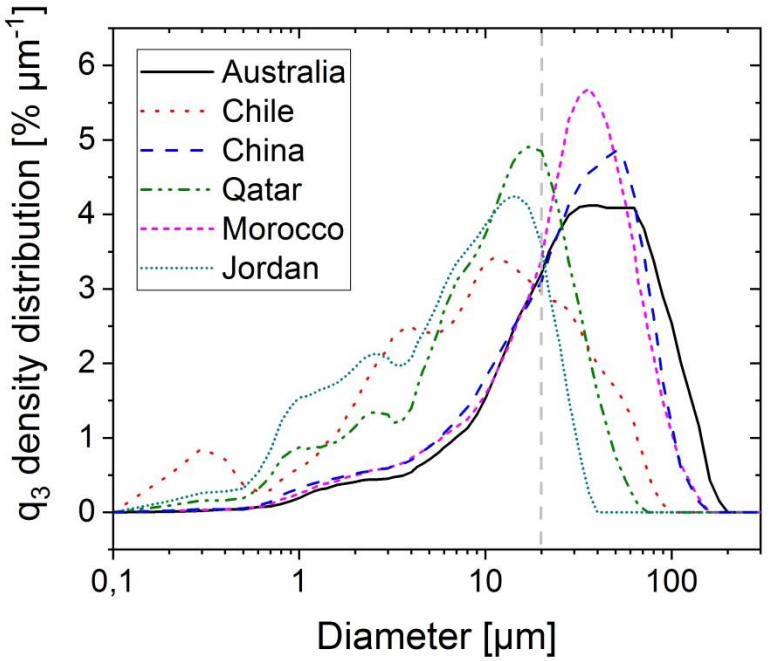
Composition and particle size distribution: dust ≠ dust



Mineral composition



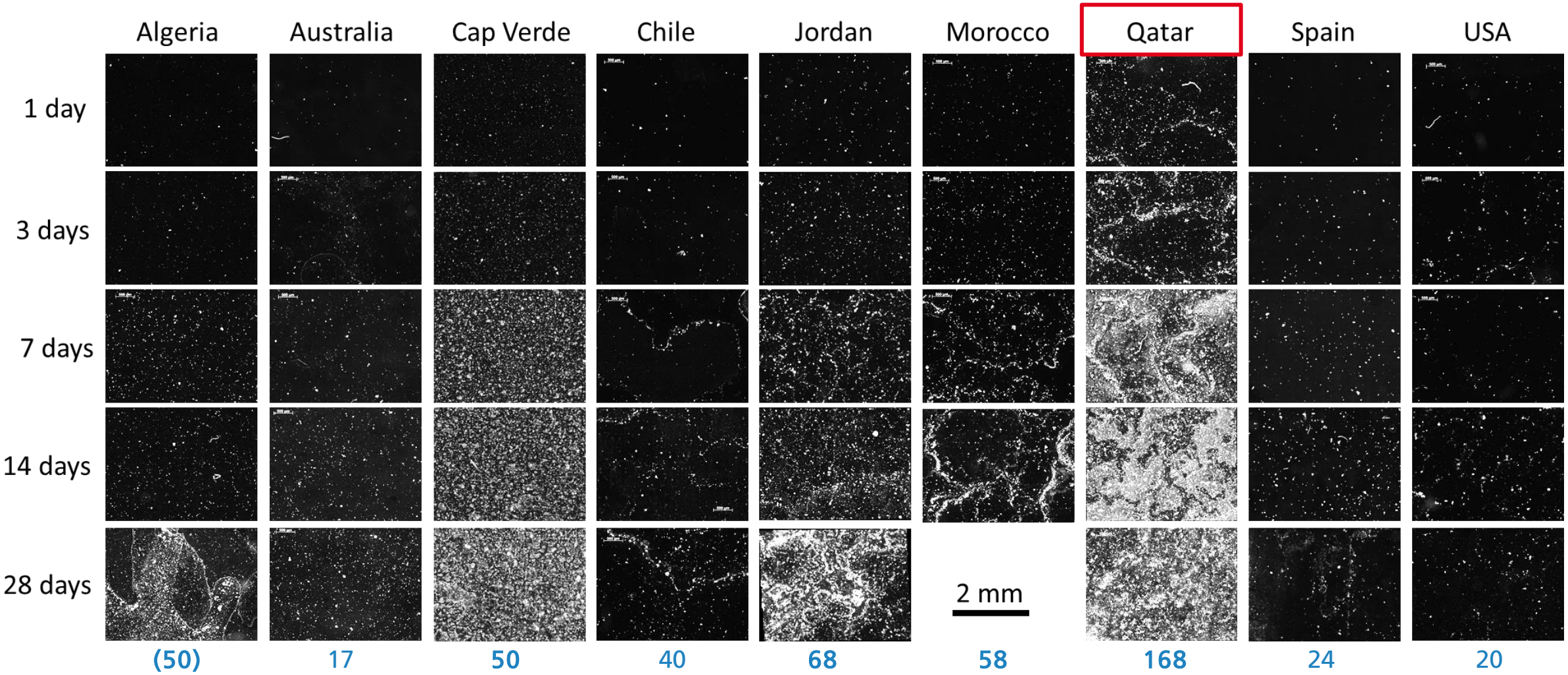
Particle size distribution



- Dust characteristics are site-dependent!

Outdoor exposure of glass slides

Impressions from light microscopy



Annual mean PM10 [µg/m³], WHO database

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Results of microstructural investigations

Surface morphology investigated by Scanning Electron Microscopy (SEM)

Qatar

Dew events on **22 / 28** days for

2016/10/16-2016/11/14

Following results shown for borosilicate glass samples, 1 day and 28 days outdoor exposure (October 2015, horizontal position) at Solar Test Facility in Doha, Qatar

Ilse et al. "Microstructural analysis of the cementation process during soiling on glass surfaces in arid and semi-arid climates." *physica status solidi (RRL)-Rapid Research Letters* 10.7 (2016): 525-529.

معهد قطر لبحوث البيئة والطاقة
Qatar Environment & Energy Research Institute
عضو في مؤسسة قطر
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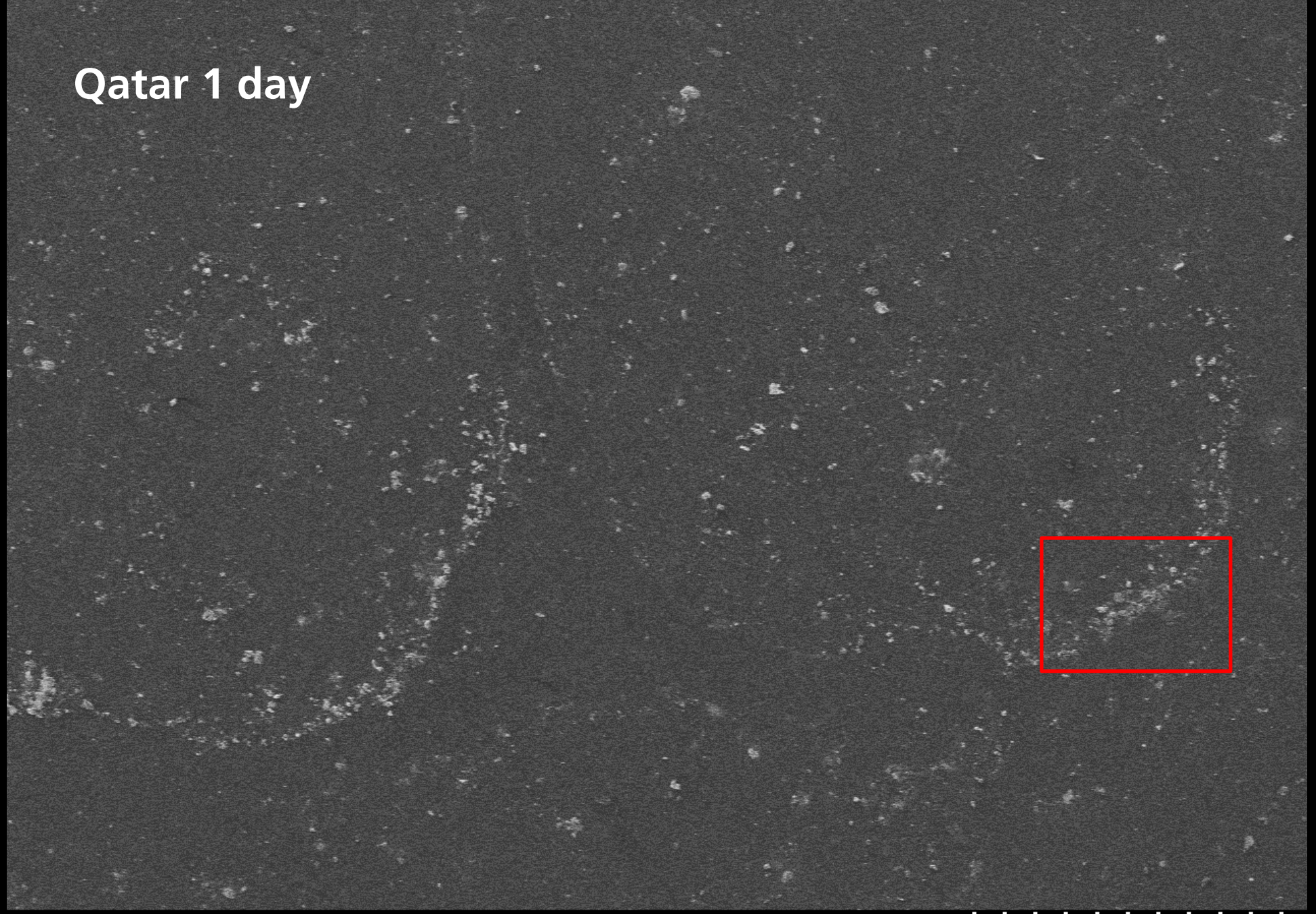
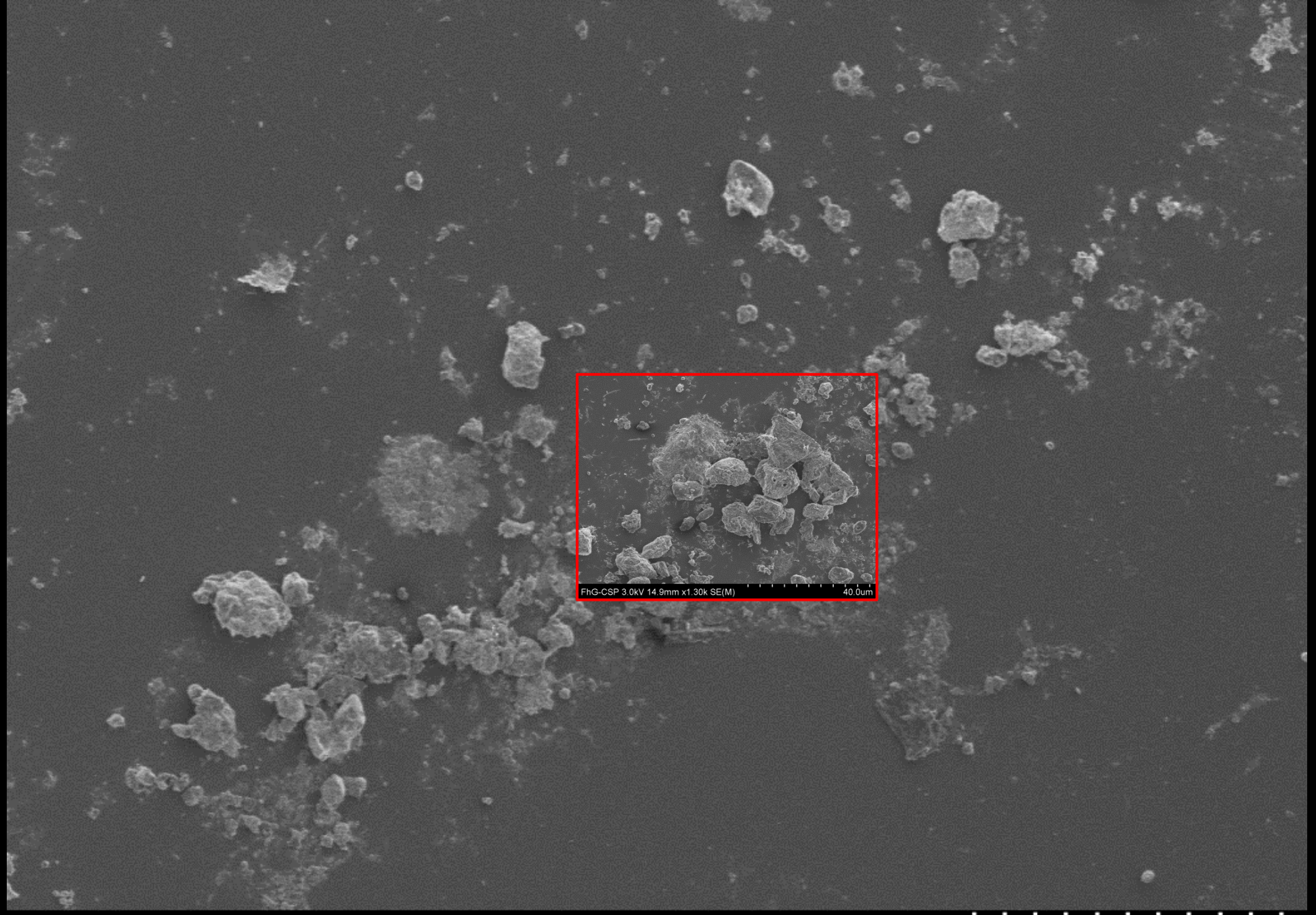
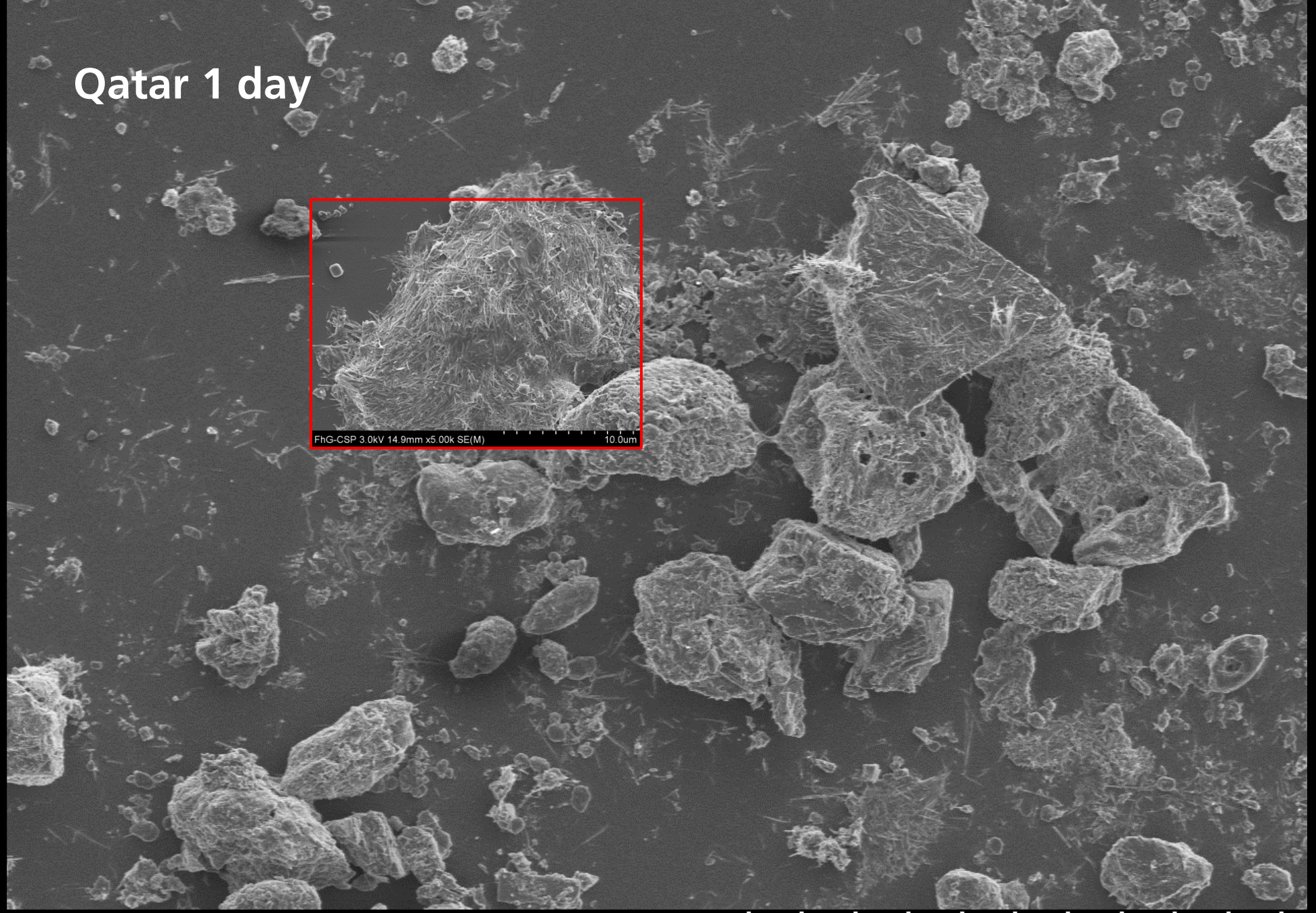
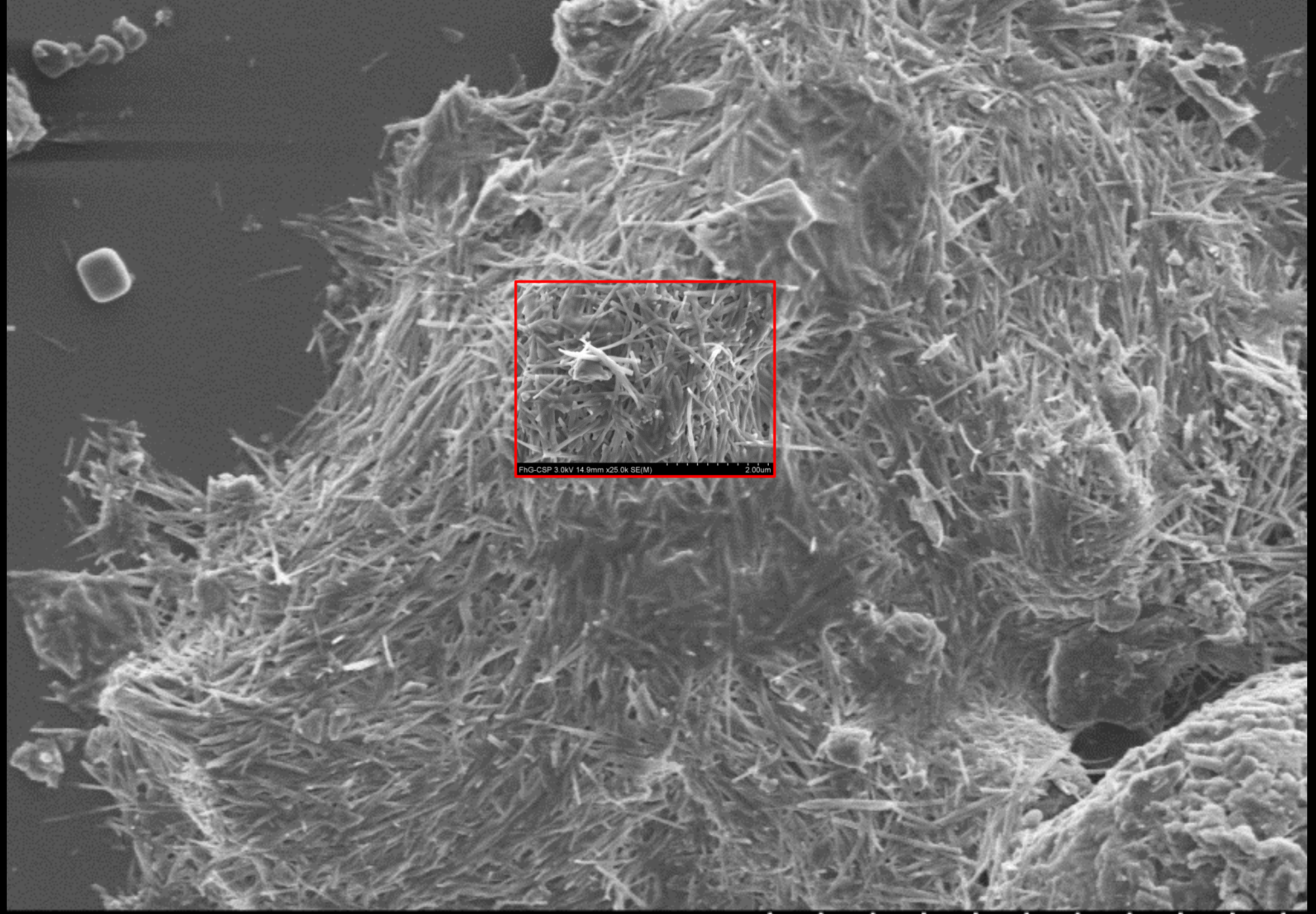
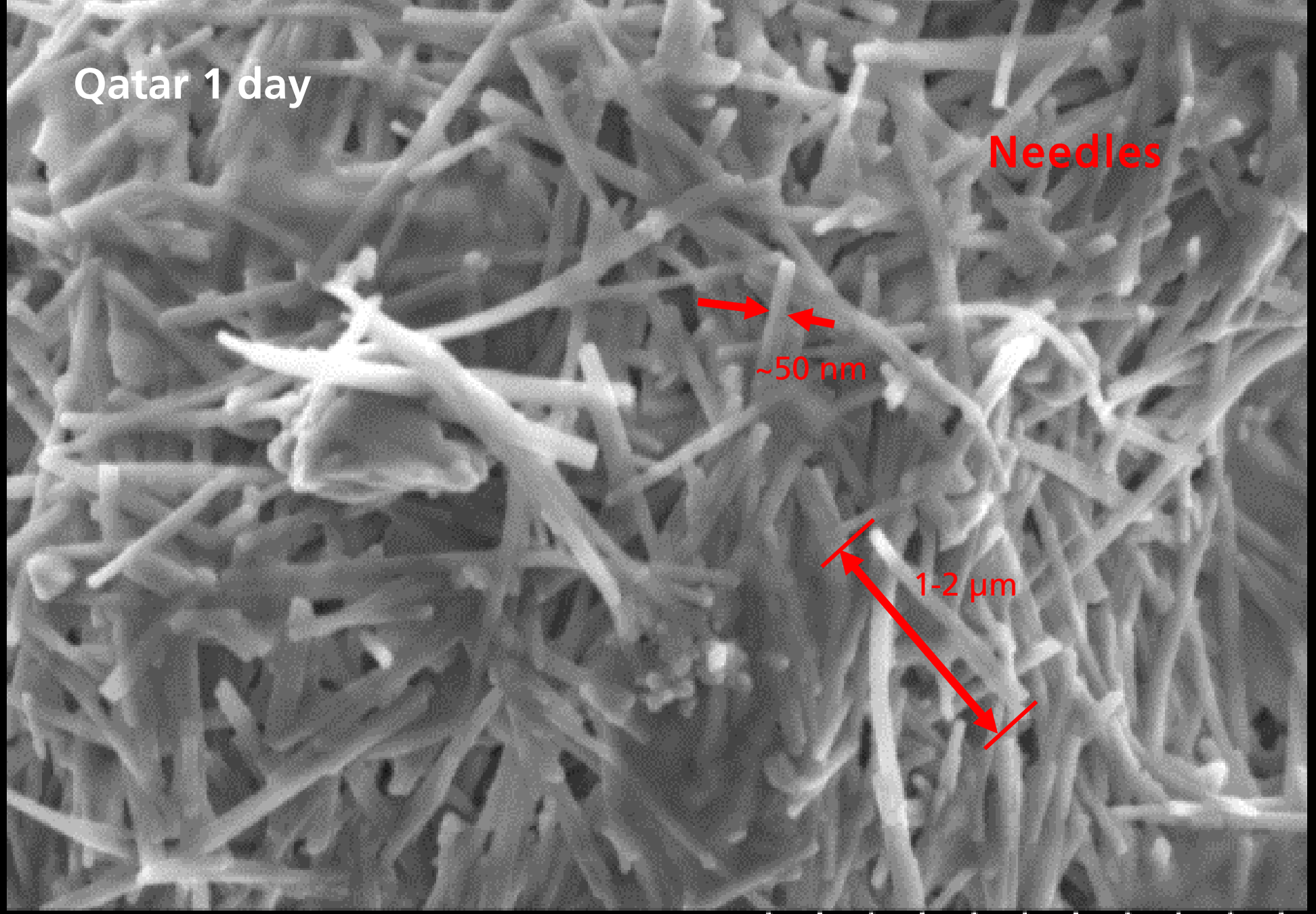
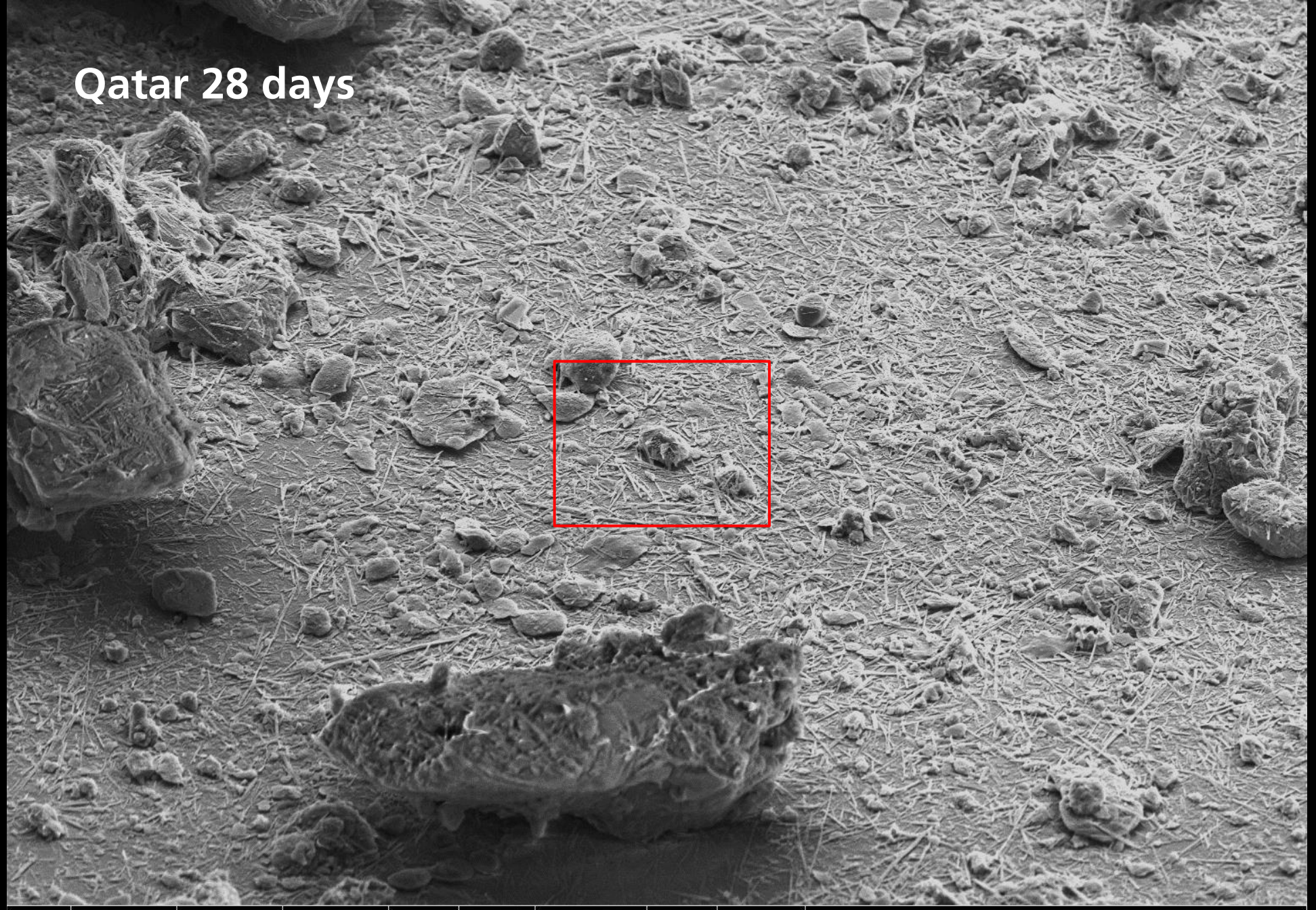

Qatar 1 day
FhG-CSP 3.0kV 14.7mm x30 SE(M)
1.00mm


FhG-CSP 3.0kV 14.9mm x1.30k SE(M)
40.0um
FhG-CSP 3.0kV 14.9mm x300 SE(M)
100um


Qatar 1 day
FhG-CSP 3.0kV 14.9mm x5.00k SE(M)
10.0um
FhG-CSP 3.0kV 14.9mm x1.30k SE(M)
40.0um

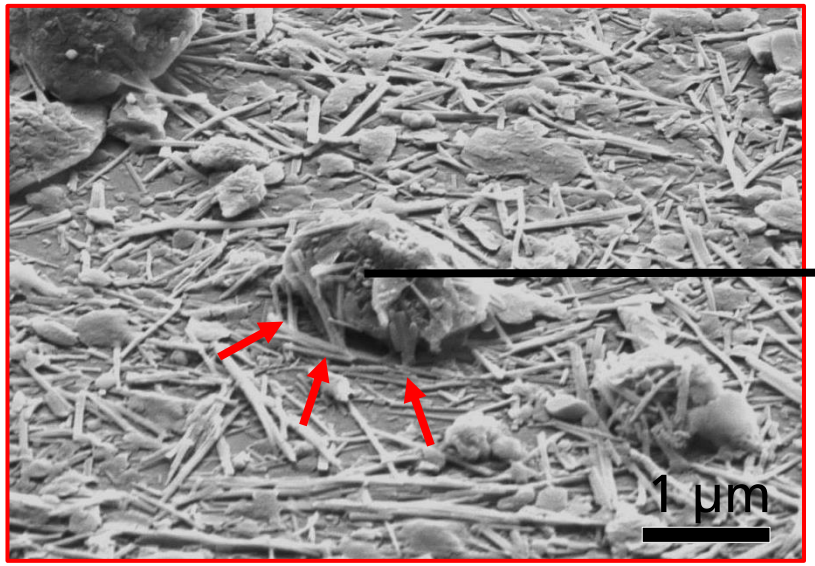

FhG-CSP 3.0kV 14.9mm x25.0k SE(M)
2.00um
FhG-CSP 3.0kV 14.9mm x5.00k SE(M)
10.0um

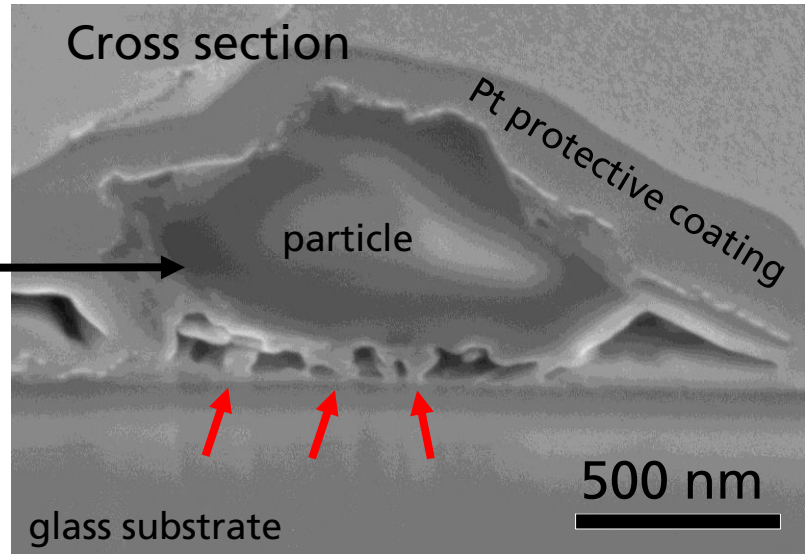

Qatar 1 day
Needles
~50 nm
1-2 µm
FhG-CSP 3.0kV 14.9mm x25.0k SE(M)
2.00um

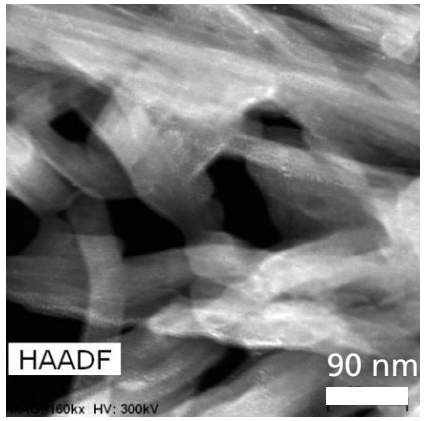

Qatar 28 days
HV
4.00 kV
WD
9.9 mm
mag
5 000 x
det
ETD
mode
SE
HFW
41.4 µm
tilt
52 °
curr
23 pA
10 µm

Results of microstructural investigations

Surface morphology investigated by SEM & FIB







- Nanoscopic needles promote adhesion of bigger dust particles
- Needles can be attributed to **Palygorskite** (clay mineral) [1] $(Mg,Al)_2Si_4O_{10}(OH) \cdot 4(H_2O)$
- Development via solution-precipitation processes during dew events → cementation

[1] Ilse et al. "Microstructural analysis of the cementation process during soiling on glass surfaces in arid and semi-arid climates." *physica status solidi (RRL)-Rapid Research Letters* 10.7 (2016): 525-529.

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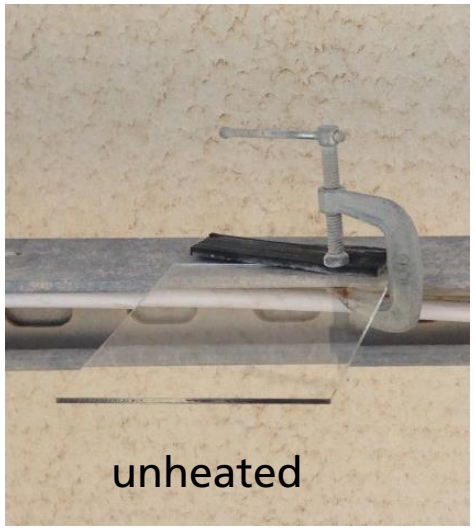
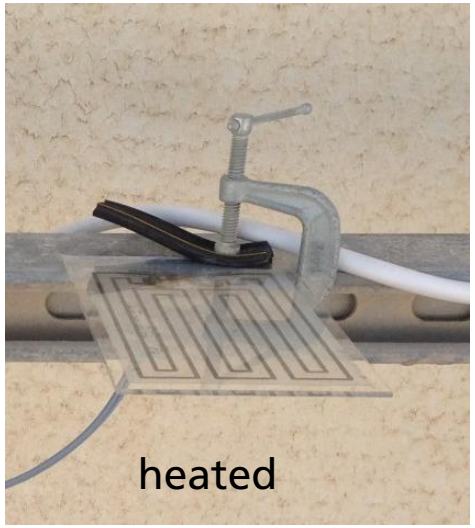
Outdoor heating experiments in Qatar desert environment

Heating experiment

Setup

- Outdoor exposure of borosilicate glass samples for 4 weeks in Qatar environment
- One sample was heated with heater pad at 12 W (~10-25 K warmer than reference)
- Temperature of reference module below dew point during 2 nights





Ilse et al., IEEE J. Photovolt. 8 (1) (2018) 203–209.

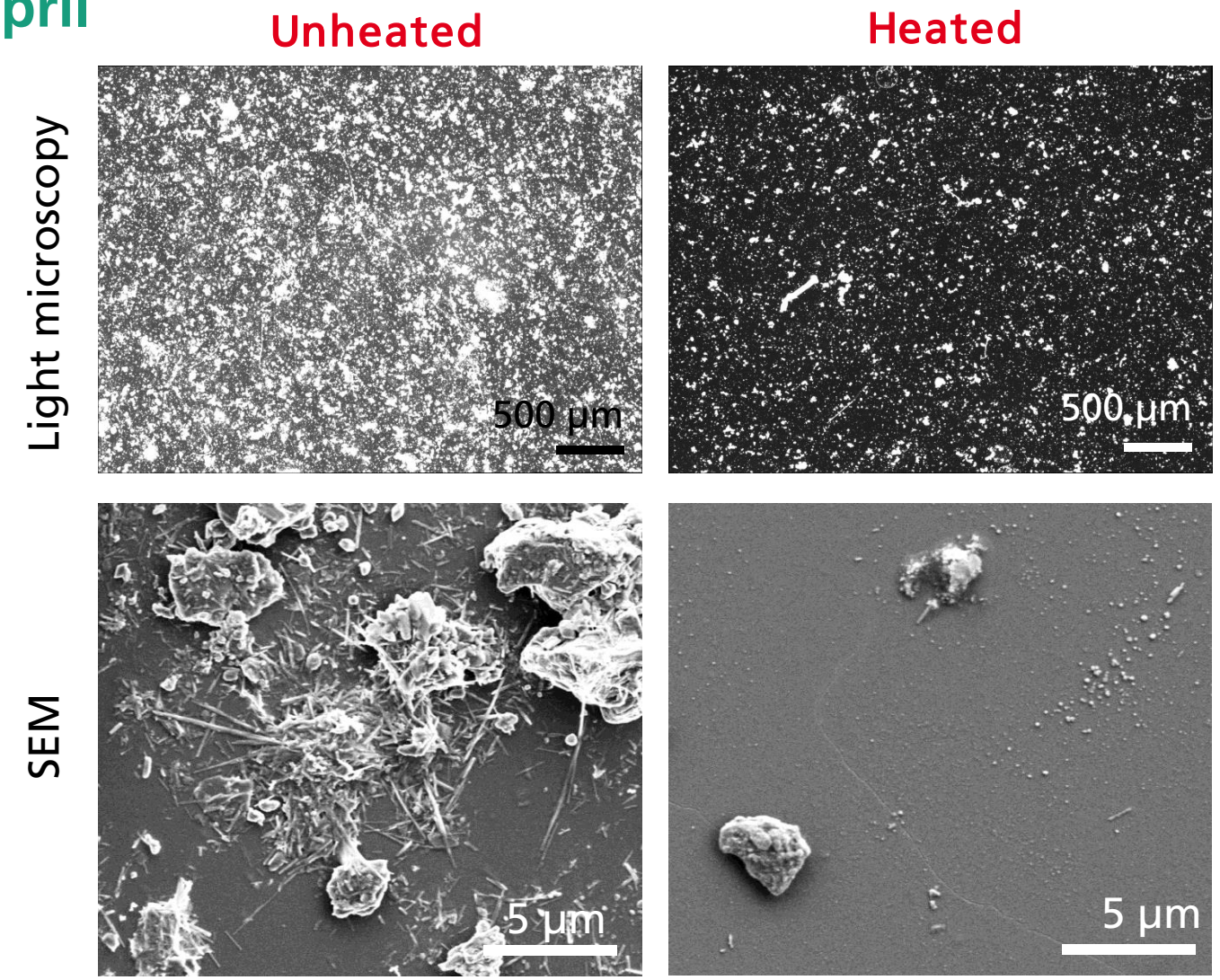
Outdoor heating experiments in Qatar desert environment

Heating experiment A) – March-April

Results from light microscopy and Scanning Electron Microscopy (SEM)

- **65 %** reduction of surface coverage & optical losses by heating
- Significantly reduced amount of needle structures if sample is heated → no cementation

→ Soiling mitigation by heating approaches?



Ilse et al. Comprehensive analysis of soiling and cementation processes on PV modules in Qatar. Sol. Energy Mater. Sol. Cells; 186:309–23 (2018).

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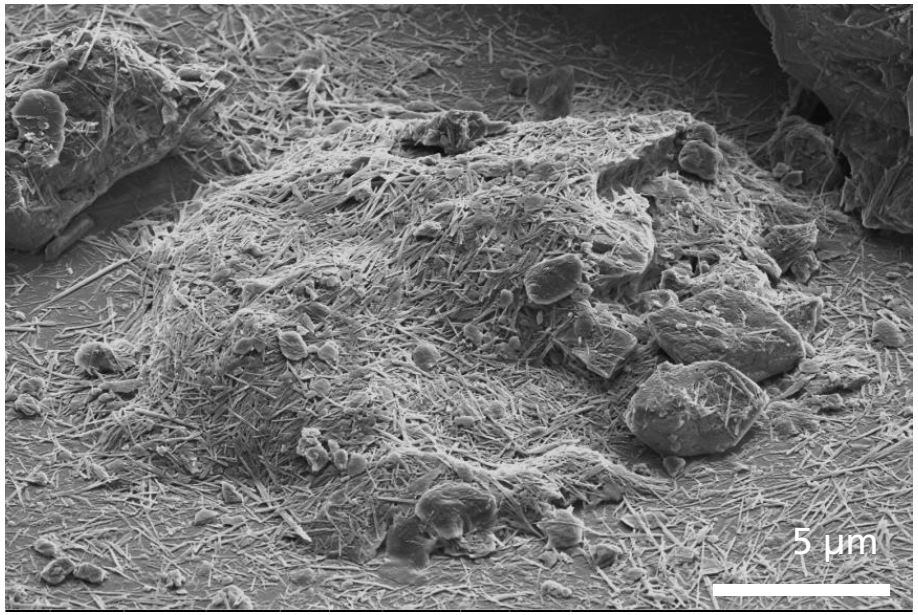
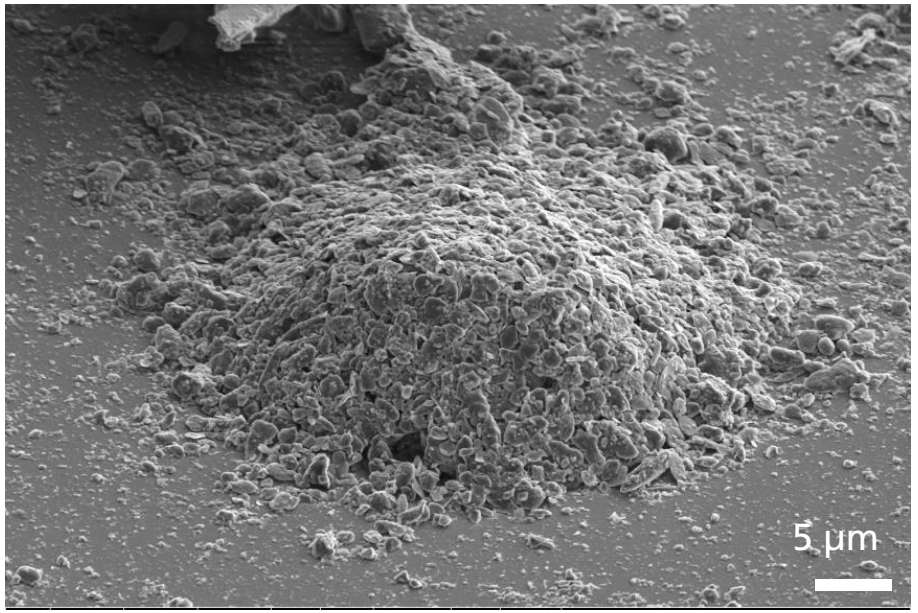
Summary

Qatar



- Needles → clay mineral palygorskite [1]
- Solution-precipitation → cementation

Chile



- Small platelets → clay mineral kaolinite [2]
- Rearrangement → caking

Dust + clay mineral + dew ➡ Hardly removable by wind or rain

[1] Ilse et al. Sol. Energy Mater. Sol. Cells; 186:309–23 (2018).
[2] Ilse et al., IEEE J. Photovolt. 8 (1) (2018) 203–209.

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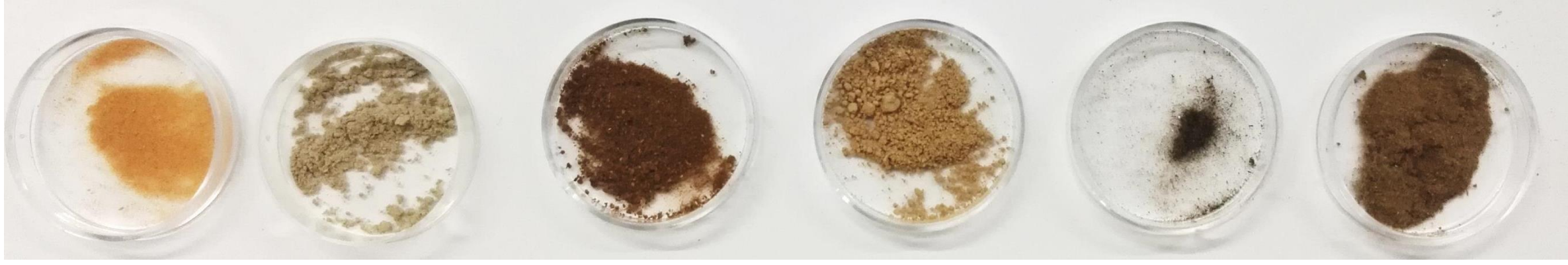
Thank you for your attention!



Federal Ministry of Education and Research
Federal Ministry for Economic Affairs and Energy

This work was supported by the Federal Ministry for Economic Affairs and Energy (BMWi) within the project “Fidelitas” (funding no. 0325735C) and the Federal Ministry of Education and Research (BMBF) within the project “Wüstenmodul” (funding no. 03FH014IX4).

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Thanks to our Partners!

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