LABORATÓRIO NACIONAL DE ENGENHARIA CIVIL

LABORATORY AND MICROSTRUCTURAL TESTS ON THE DETECTION AND PREDICTION OF AAR

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One Day Course on AAR
Lisbon, 14th February 2011

Concrete pathologies

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The concrete is not an "inert" material:

- It is a material in constant "evolution" and that is subject to more or less aggressive environment that surrounds it

- Main degradation causes:
  - Mechanical solicitations
    (fatigue due to repeated stresses)
  - Physical alterations
    (abrasion, thermal shocks, frost action)
  - Chemical alterations

Concrete chemical degradation causes

- Acid attack
- Sea-water and water attack
- Sulphate attack
- Biochemical attack
- Reinforcement corrosion
- Internal expansive reactions
  - **alkali-aggregate reaction (alkali-silica** and alkali-carbonate**)**
  - internal sulphate reaction

Alkali-silica reaction in concrete

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- The origin

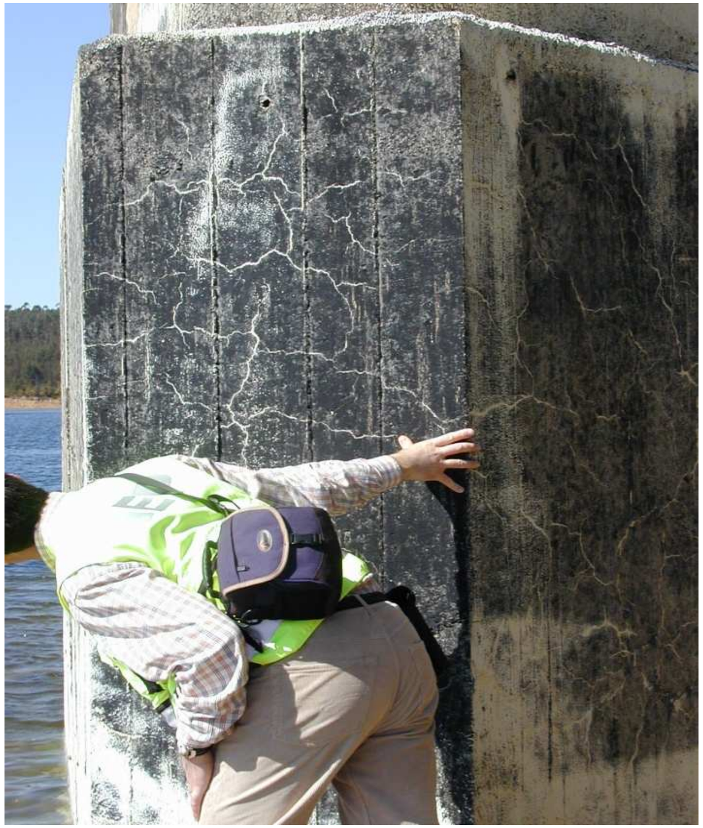
Reactivity between the cement and aggregates with poorly-crystallized or deformed silica forms

Rocks		Potential reactive minerals
Igneous	Granite Granodiorite	Strained quartz with undulatory extinction. Weathered feldspars with open intersticies.
	Rhiolyte Dacite Andesite Basalt	Siliceous glass, tridymite, cristobalite, opal.
	Obsidian Volcanic tuff	Siliceous glass or devitrified glass, with micro cracks.
Metamorphic	Gneiss Mica schist	Strained quartz with undulatory extinction. Microcrystalline quartz from alteration, weathered feldspars and mica minerals.
	Quartzite Hornfels	Quartz or opal in the matrix. Microcrystalline quartz, strained quartz with undulatory extinction or micro cracked quartz. Phyllosilicate minerals.
Sedimentary	Greywacke Siltite	Opal, microcrystalline quartz.
	Shale	Chalcedony, opal.
	Limestone Dolomitic limestone Dolomite	Existence of nodules of opal or of diffuse opal.

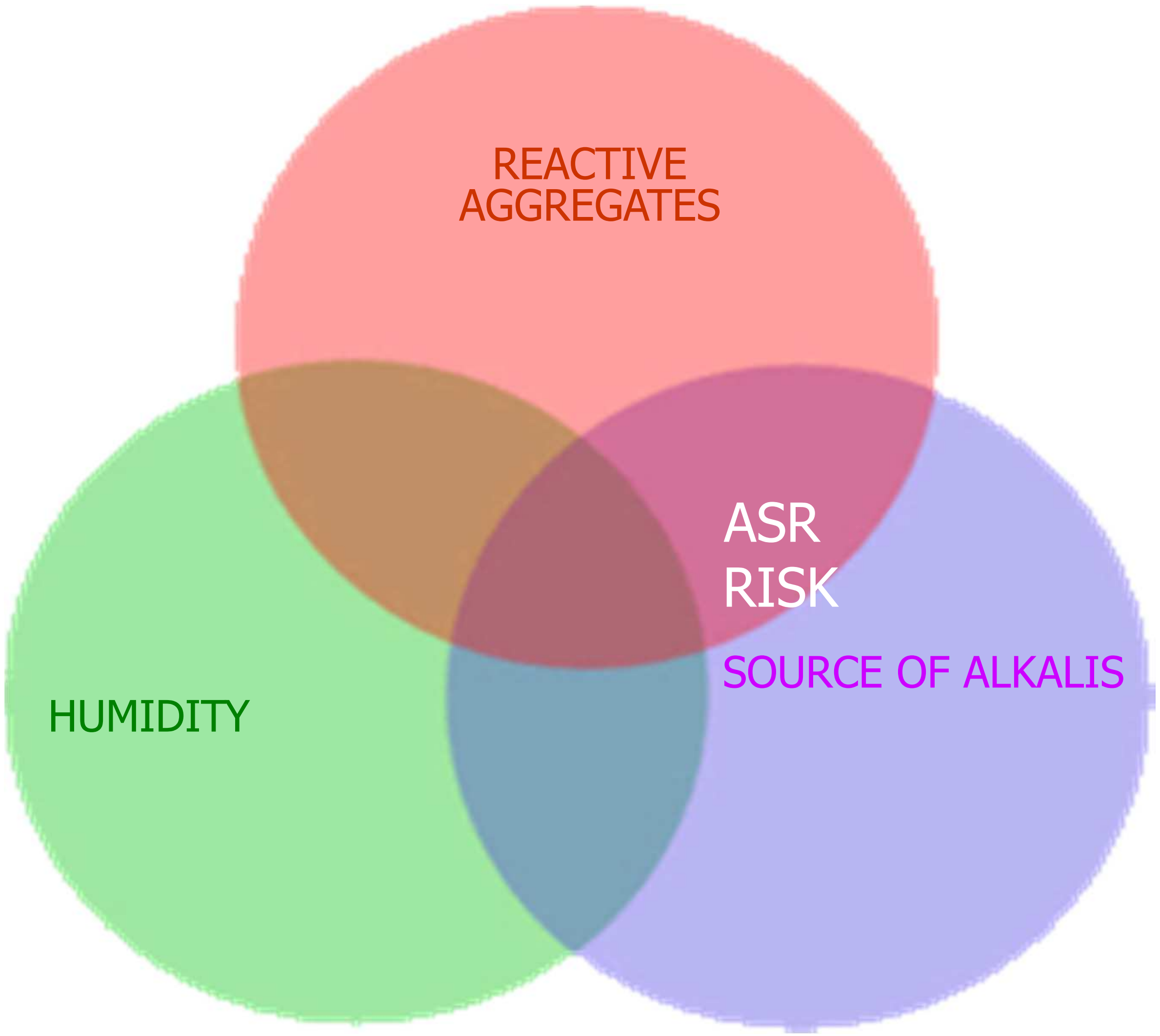
Alkali-silica reaction in concrete

- The main causes

  The silica from the aggregates and the moisture; the most sensitive areas of the structures are the areas in contact with water, exposed to inclement weather or poor drainage or deformed or not watertight



Essential conditions for ASR



First affected structure in Portugal by ASR

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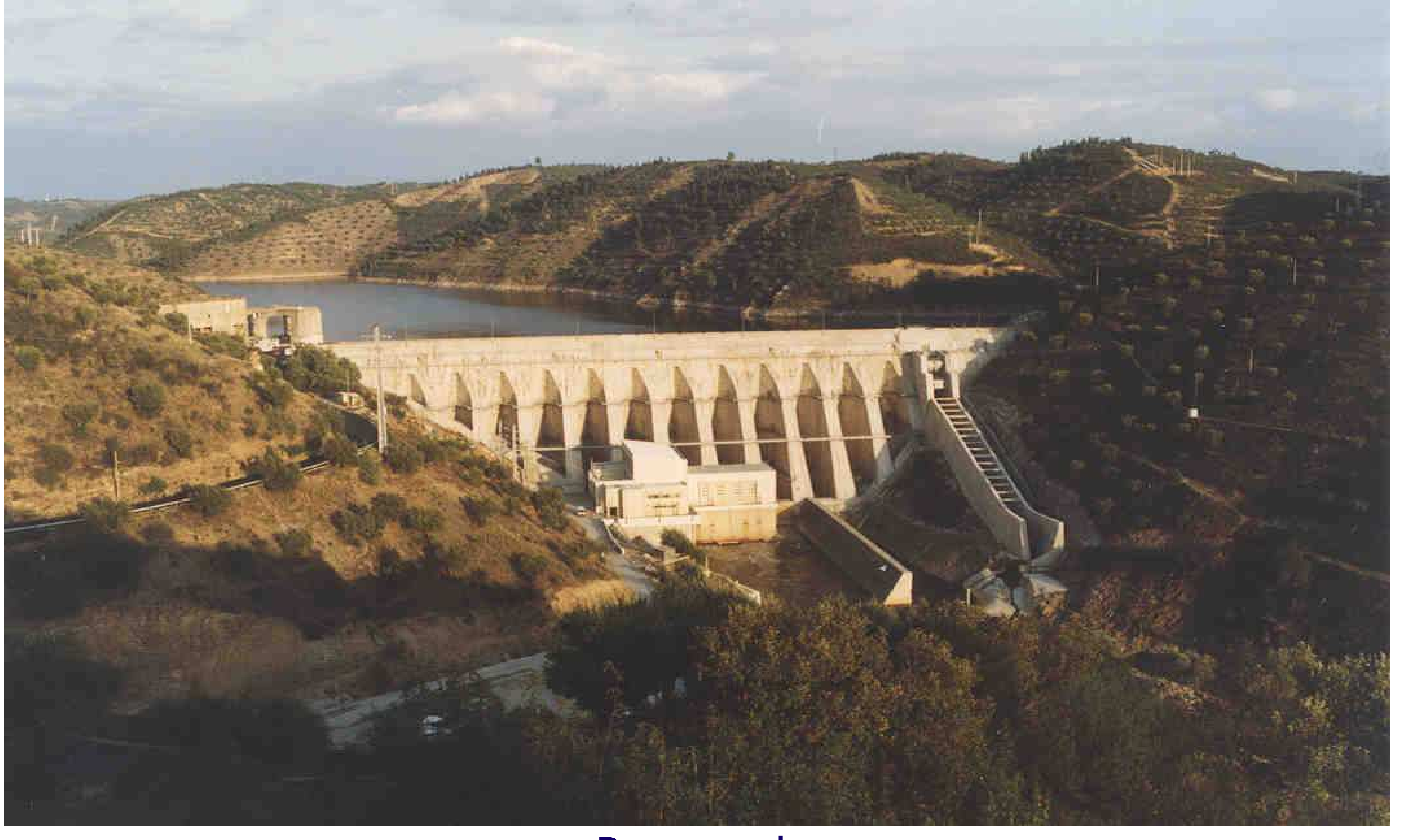

Pracana dam

ASR in Portugal

- In Portugal since the 90's several dams and bridges are being detected

- Need to make important repairs (Pracana dam, Duarte Pacheco Viaduct, etc.)
  - There is still not an effective method of treatment

Diagnosis and assessment of damage

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- General criteria

Some visuals signs of ASR are similar to those caused by other degradation process, such as freezing/thawing, sulphate attack, plastic or drying shrinkage, etc.

It is only with the detailed examination of the affected concrete structure that a good diagnostic will be made.

The detailed visual survey will generally be accompanied by sampling of one or several elements of the structure (deteriorated and non-deteriorated) to collect cores on which a series of tests will be done in the lab to assess the current condition and to evaluate the potential for future deterioration.

Diagnosis and assessment of damage

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- Investigation program
  - Examination of the existing records;
  - Visual inspection of the site to assess
    - The nature (type, location, etc.) and the extent of deterioration
    - The exposure conditions to whitch the structure (or their components) is submitted and to establish the tests to be performed and to sellect the zones to be sampled
  - Sampling and/or in-situ testing and monitoring
  - Laboratory testing of the samples collected
  - Compilation and analysis of the observations and tests results

Diagnosis and assessment of damage

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- Examination of the construction records
  - This is the preliminary and essential step in the investigation program.
  - The data to be consulted include:
    - Name and type of structure, owner ref. number, etc.;
    - The exact location and the functions of the structure;
    - Year of the construction, subsequent modifications or repairs (type, year, etc.);
    - Working files: plans, drawings and specifications, site testing records, etc. Information on the materials used in the concrete, the mix design used and the concrete characteristics.
    - Previous inspection reports and laboratory testing performed since the construction.
    - Comparison between the investigated structure and the others in the vicinity.
  - It is important that the person in charge of the isnpection survey knows the detailed information collected before the field investigation is planned.

Diagnosis and assessment of damage

- Visual inspection: macroscopic signs of ASR
  - Cracking is the most common sign of ASR

Diagnosis and assessment of damage

- Macroscopic signs of ASR
  - Deformations, movements and displacements

Diagnosis and assessment of damage

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- Macroscopic signs of ASR
  - Pop outs

Diagnosis and assessment of damage

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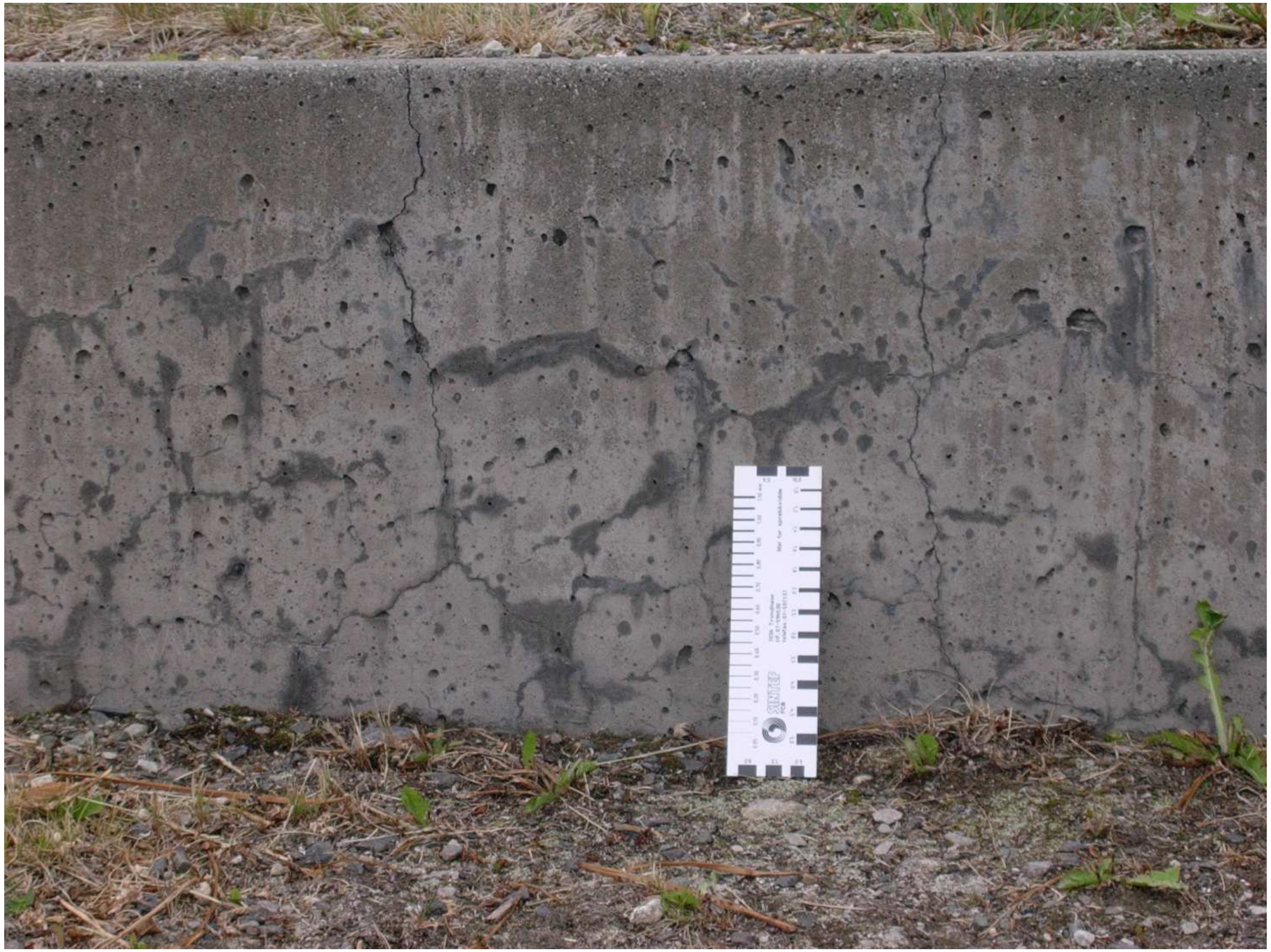
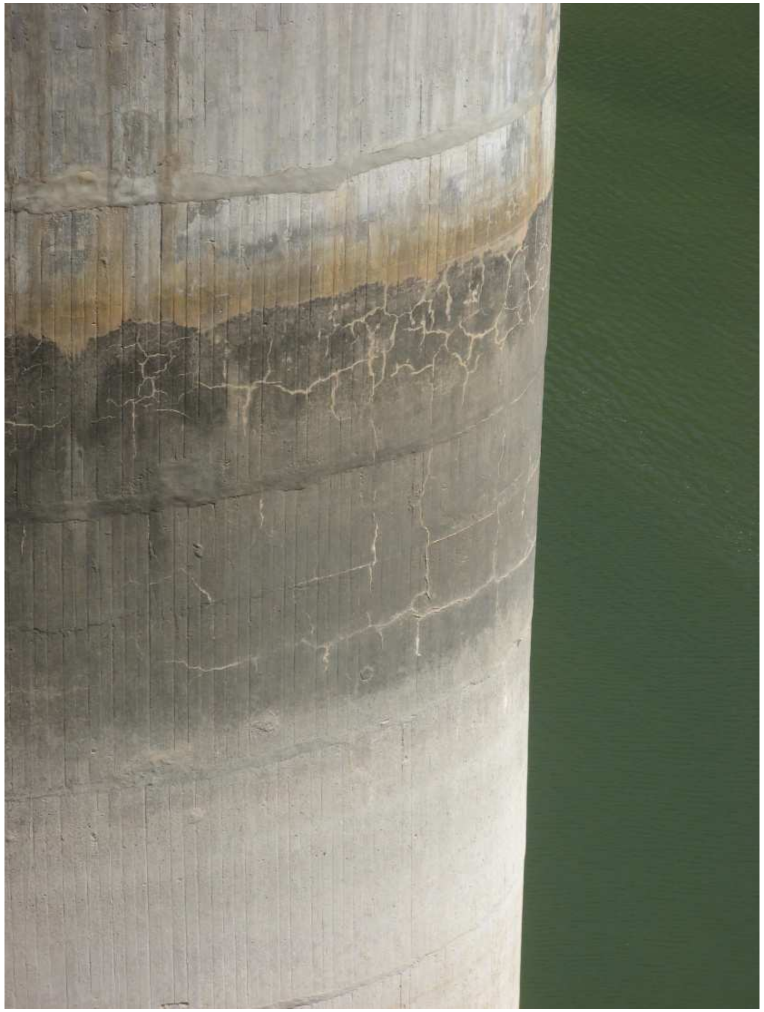
- Macroscopic signs of ASR
  - Cracking





Diagnosis and assessment of damage

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- Macroscopic signs of ASR
  - Efflorescence and exudations

Diagnosis and assessment of damage

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Sampling

The extent of the sampling will depend on various factors:

- objectives of the investigation program;
- the complexity of the structure;
- the extent of deterioration observed;
- number of lab tests to be done.

In order to evaluate the influence of exposure conditions it might be useful to collect cores from different components of the structure.

The diameter of the core will be determined by the maximum size of the aggregate (normally 150 mm).

Diagnosis and assessment of damage

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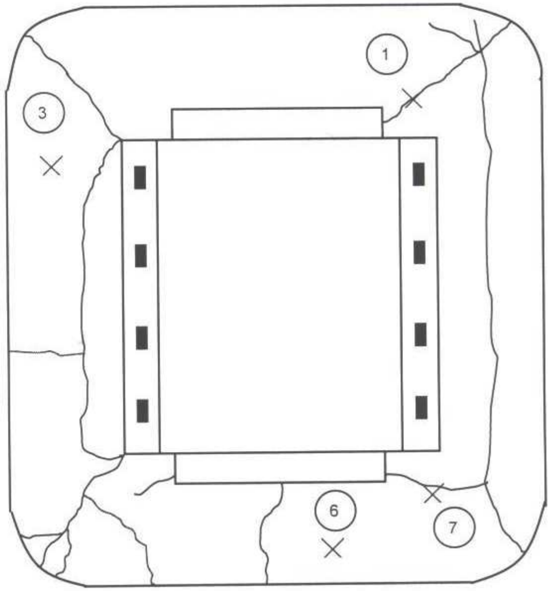
- Sampling

The length of the core should be representative of the internal maximum curing temperature reached by the concrete (could be > 1 m).

A sampling form has to be filled and accompanied with pictures showing the characteristics of the components sampled.

The samples collected should be marked, photographed and wrapped properly to prevent drying.



The location plan of cores

— Cracks observed

× Coring Location

Diagnosis and assessment of damage

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- Laboratory investigation
  - Main objectives:

    a) to recognise signs that may permit to determine which factor(s) are the cause of the observed deteriorations;

    b) to assess the current condition of the concrete;

    c) to determine to what extent the deleterious mechanism recognised will continue to affect the future degradation.

Diagnosis and assessment of damage

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- Macroscopic examination of the cores and hand samples

Diagnosis and assessment of damage

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- Microscopic examination and signs of ASR

  - Types of specimens
    - Polished sections
    - Broken surfaces
    - Thin sections

  - Signs
    - Microcracking
    - Loss of the cement paste-aggregate bond
    - Reaction products (gel)
    - Reaction rims

Diagnosis and assessment of damage

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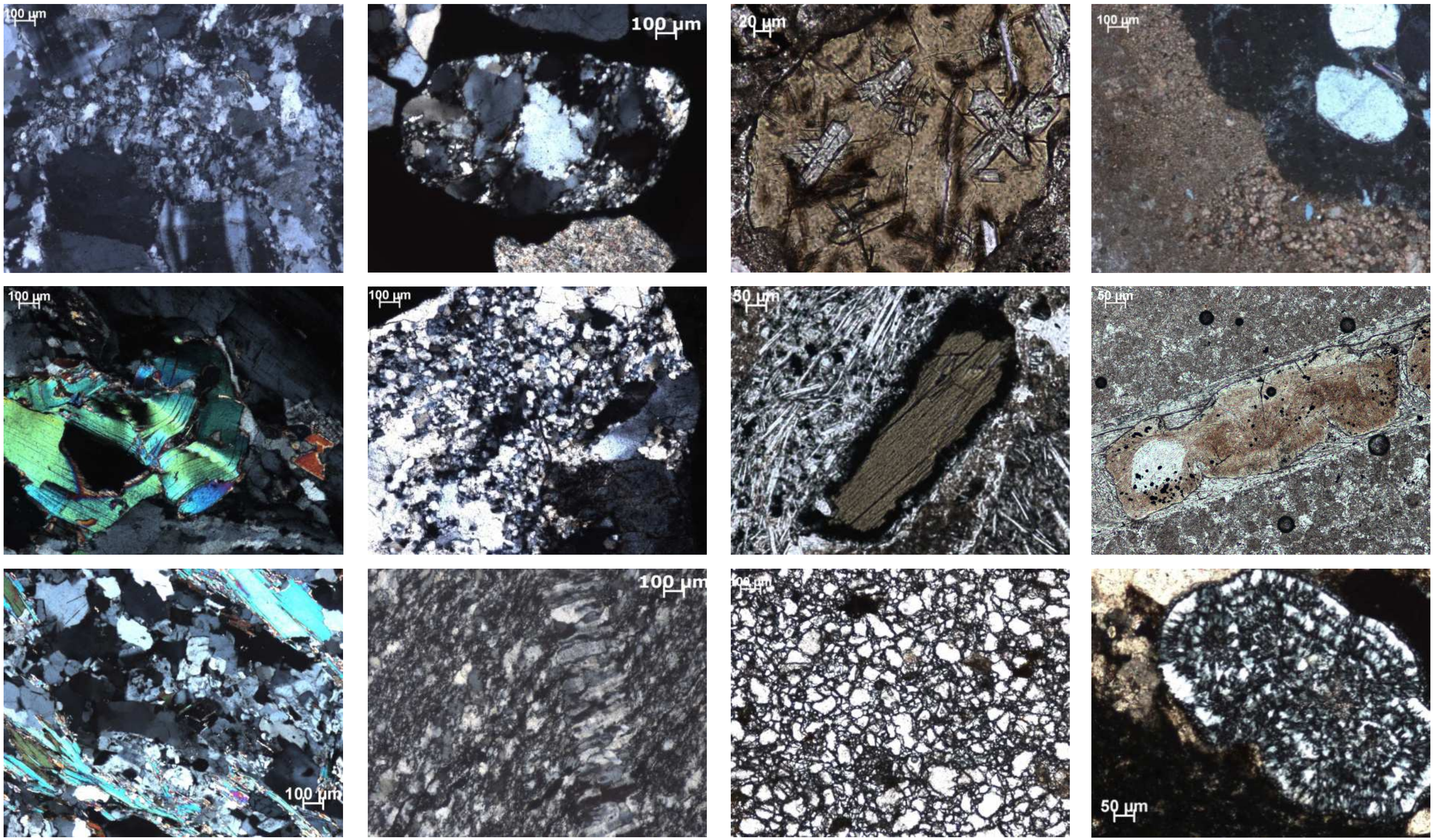
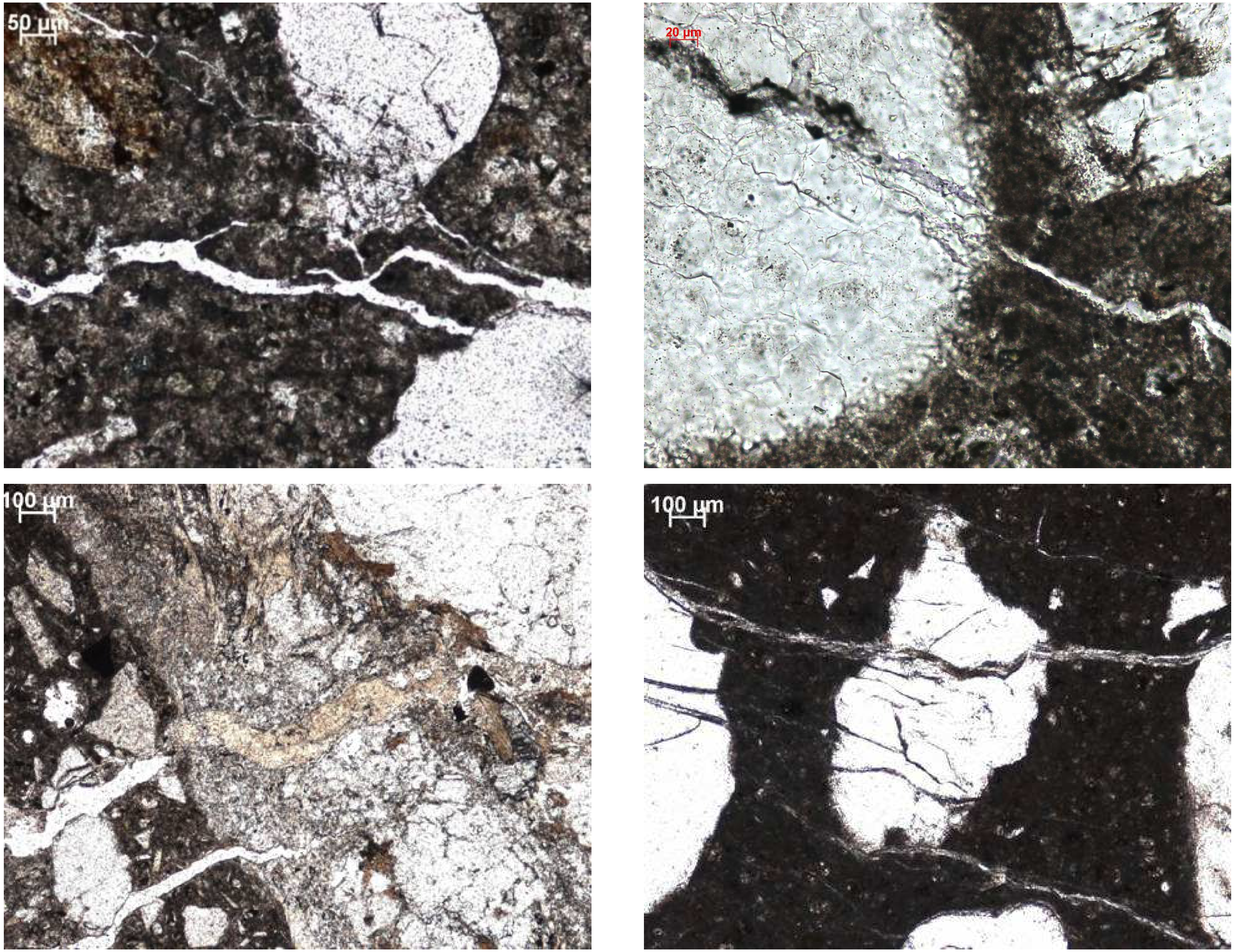
- Microscopic examination – identification of the aggregates



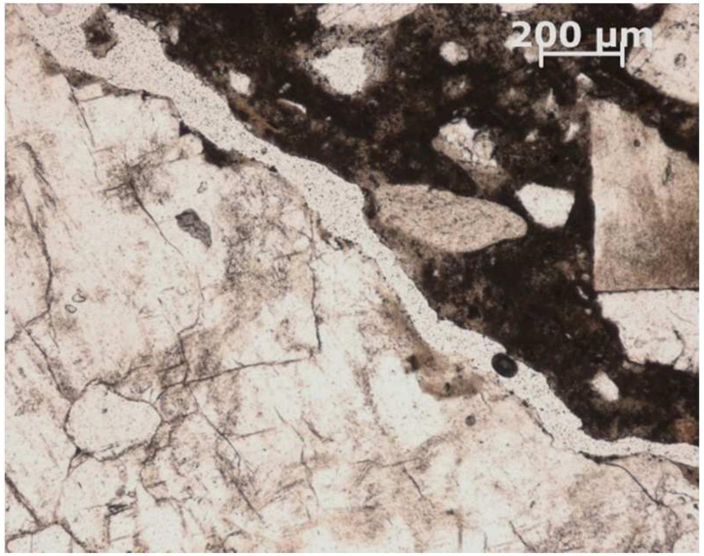
Diagnosis and assessment of damage

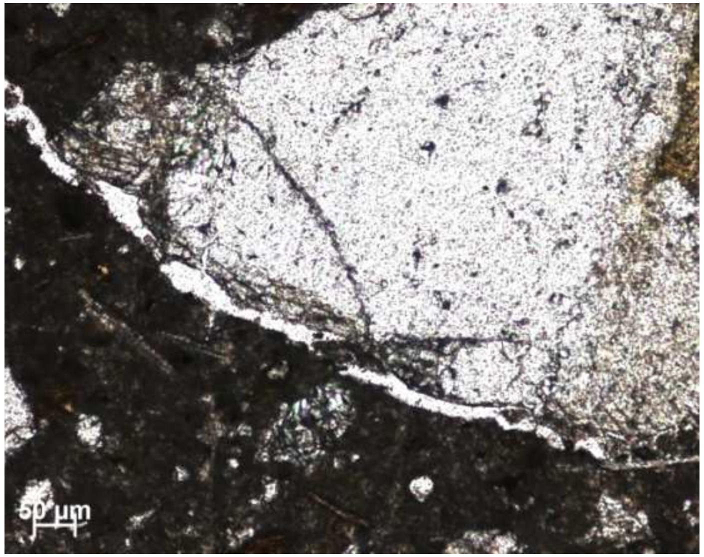
- Microscopic examination – micro cracks

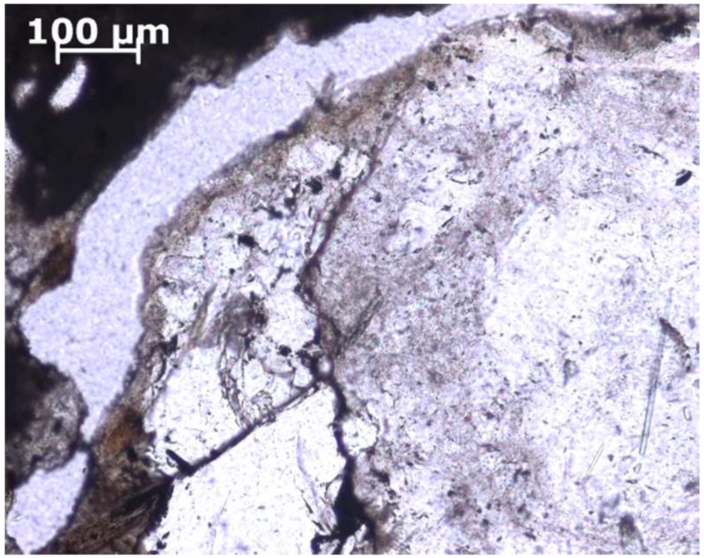


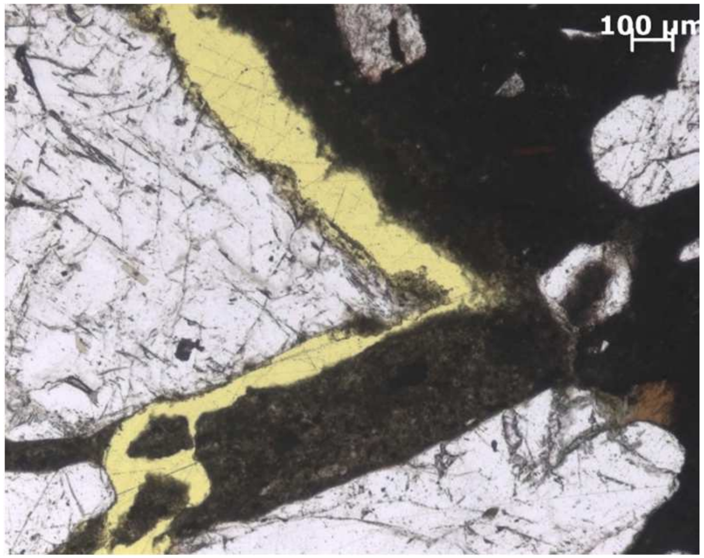
Diagnosis and assessment of damage

- Microscopic examination – debonding









Diagnosis and assessment of damage

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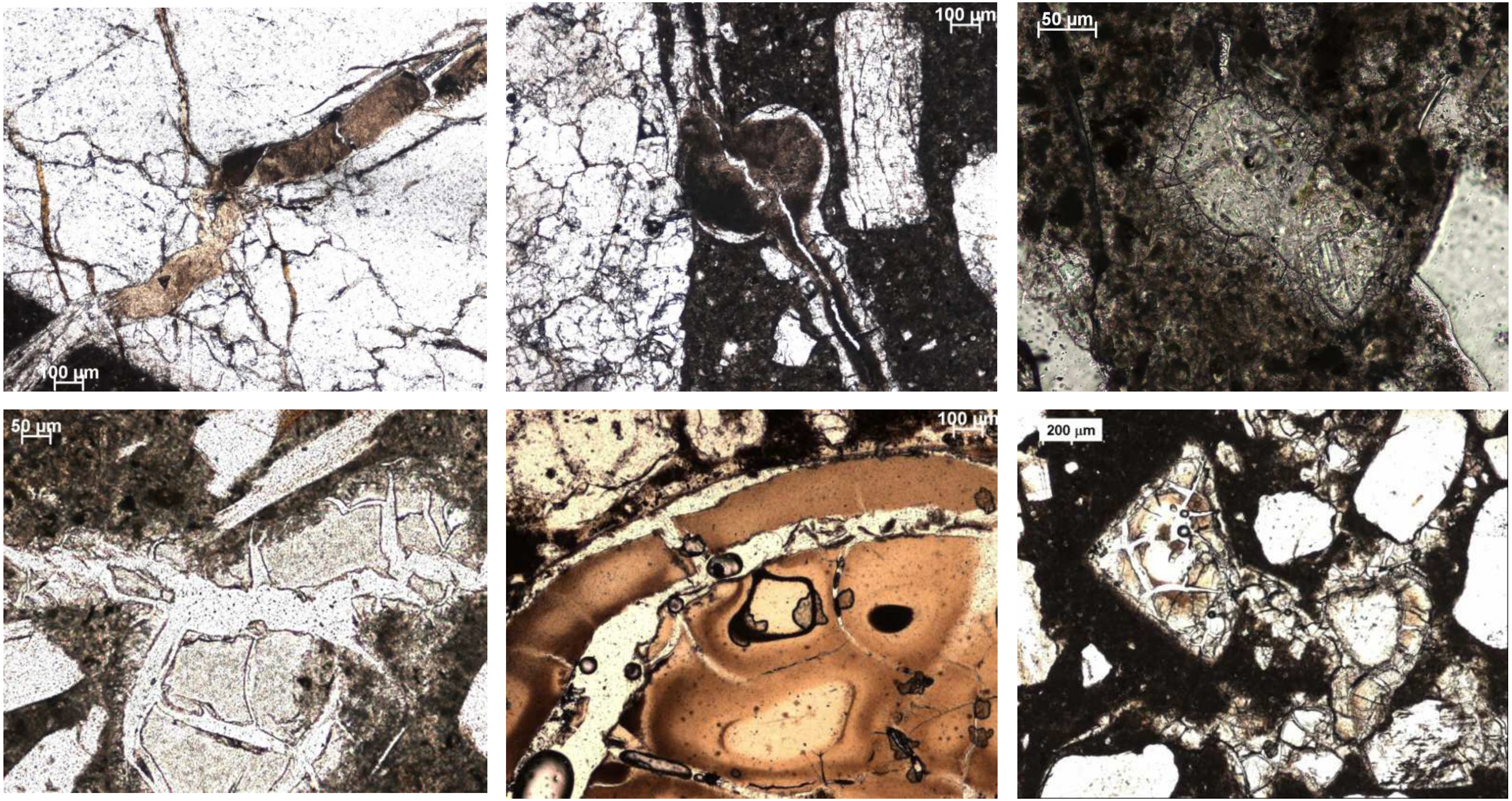
- Microscopic examination – alkali-silica gel



Diagnosis and assessment of damage

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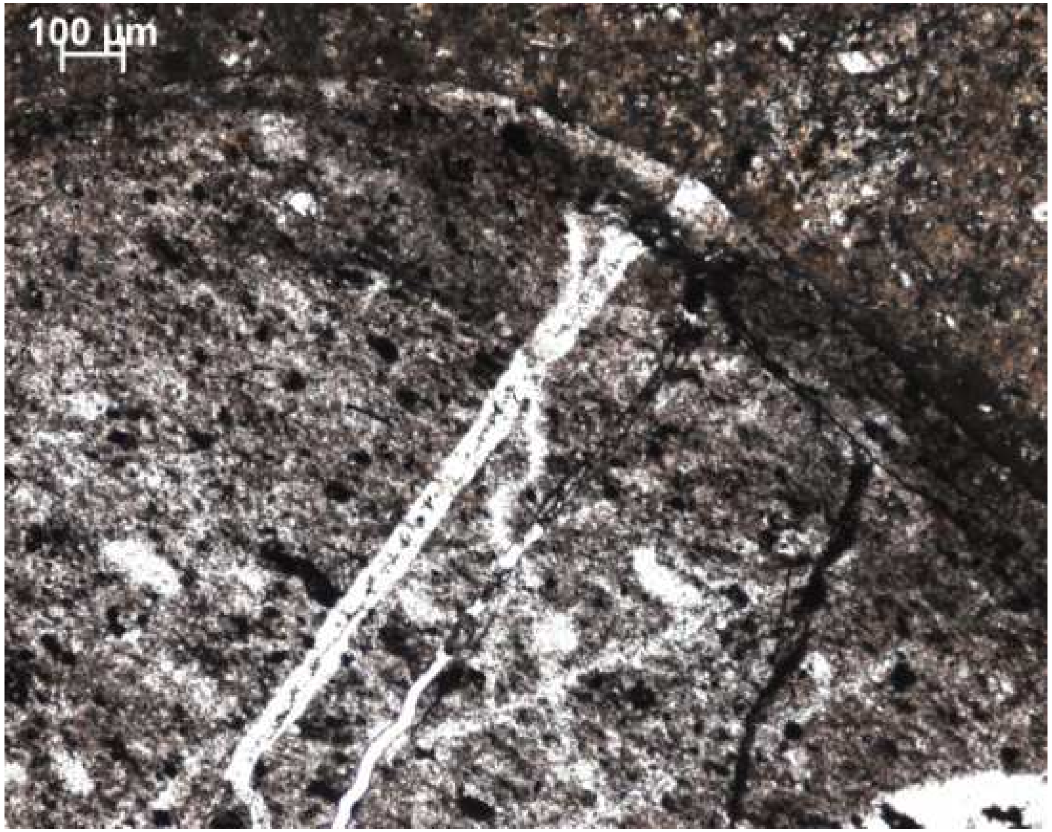
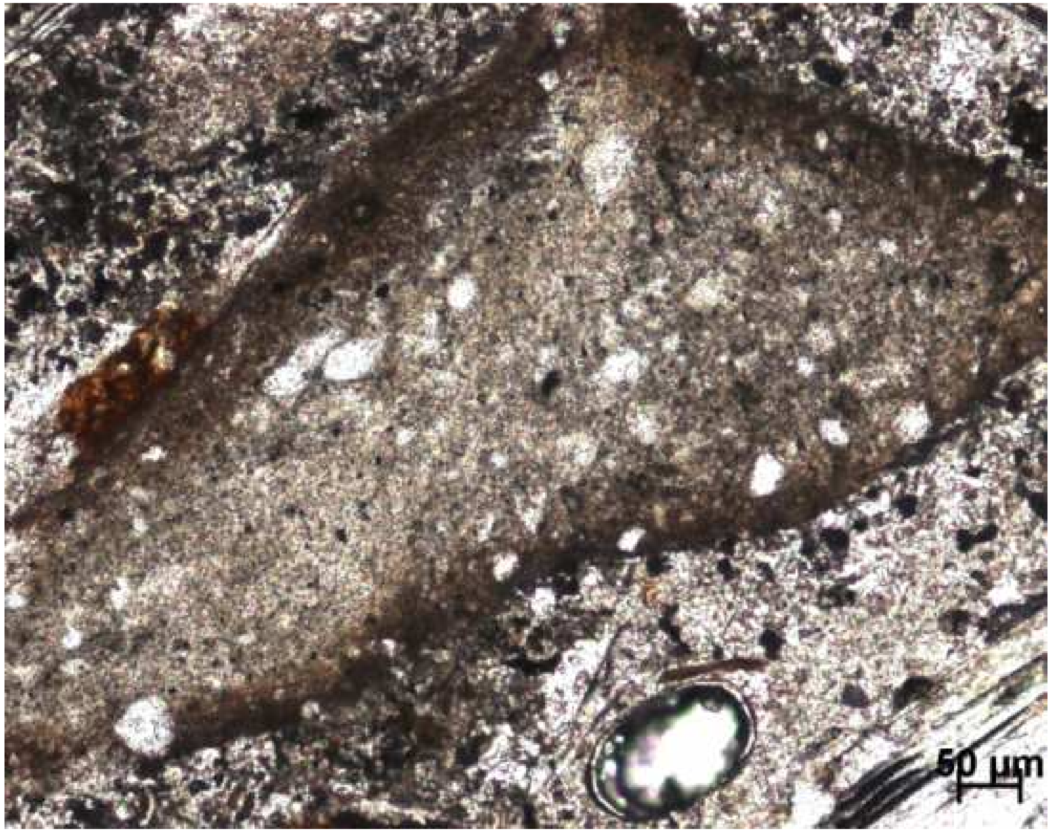
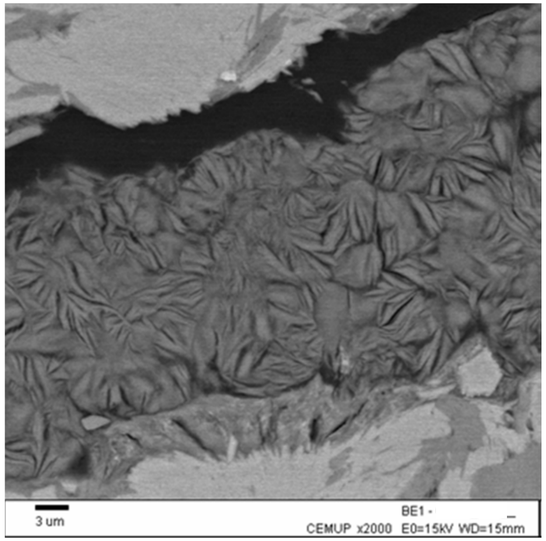
- Microscopic examination - rims

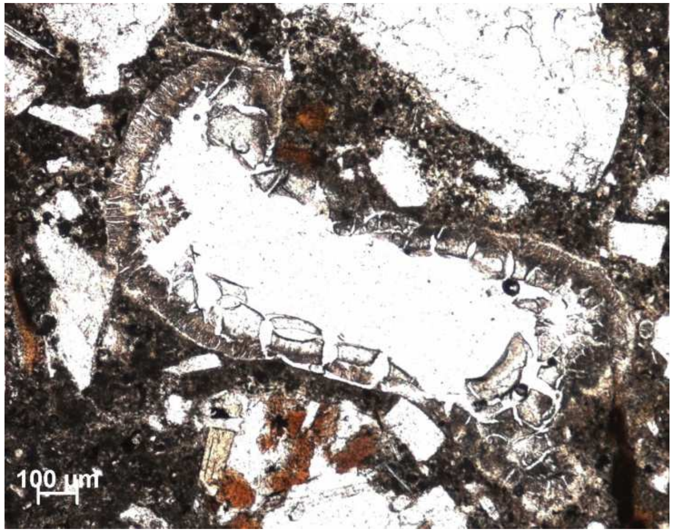


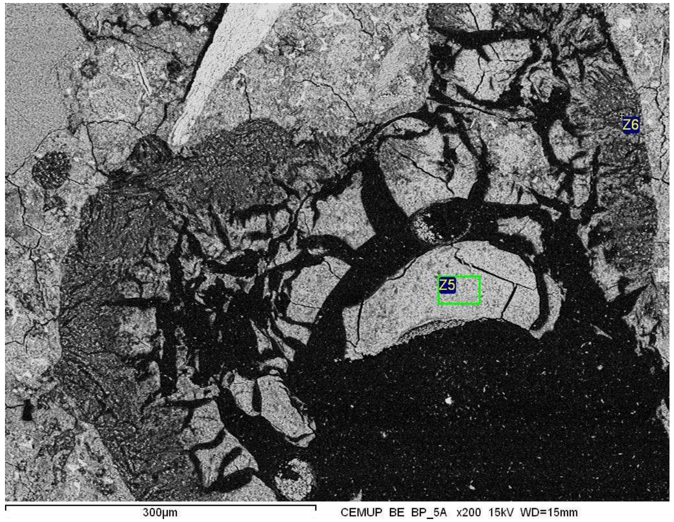


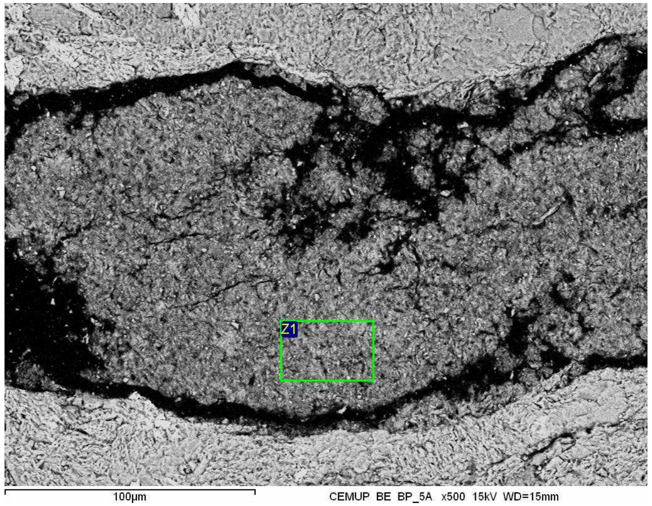
Diagnosis and assessment of damage

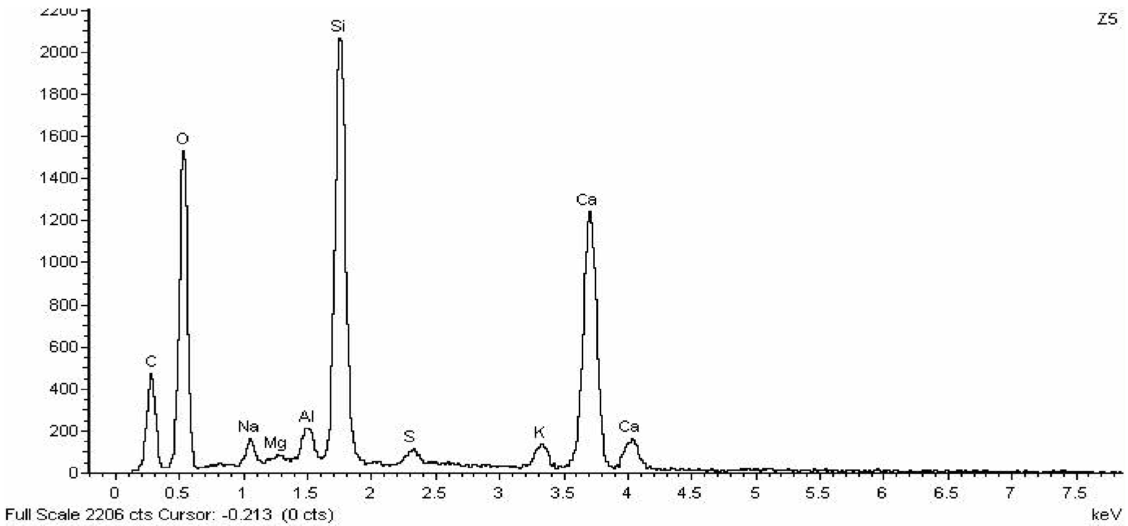
- Microscopic examination by SEM/EDS (thin sections)





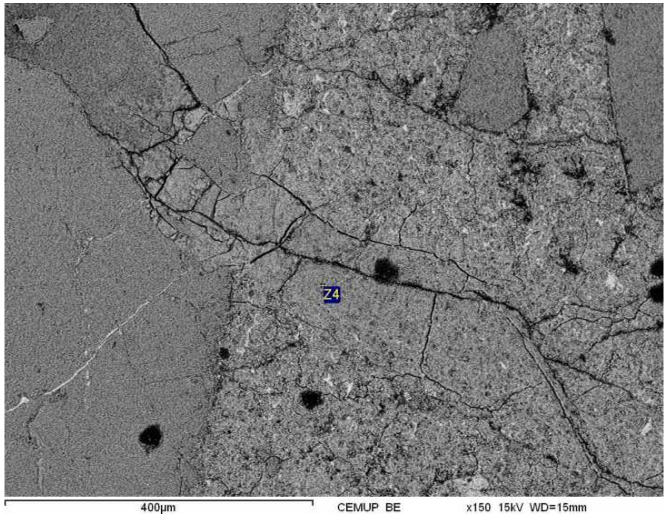


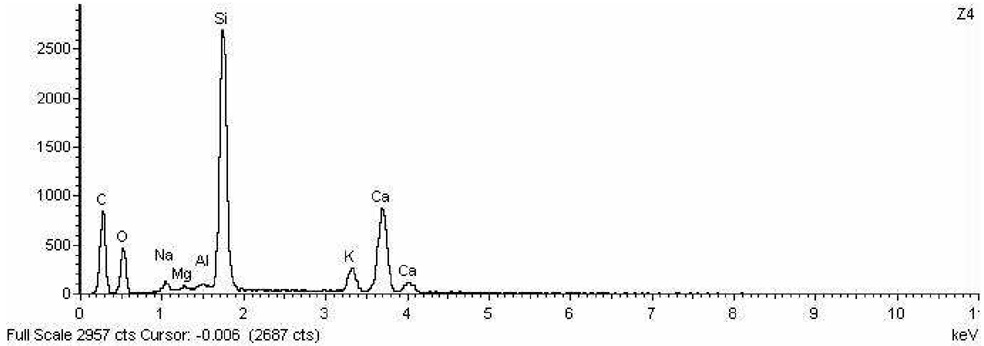


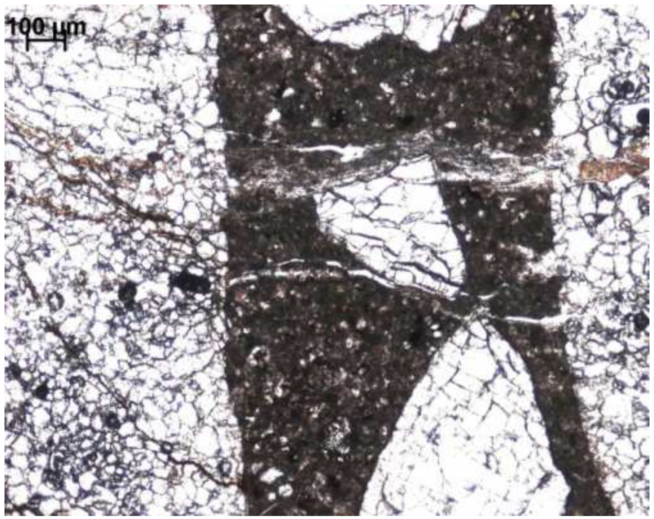


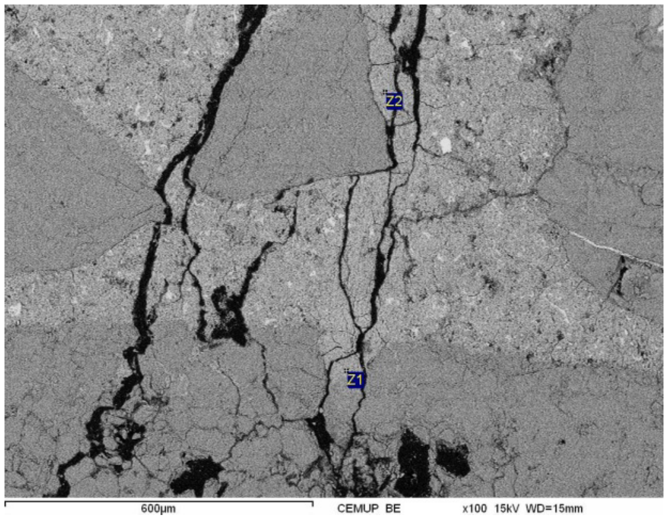
Diagnosis and assessment of damage

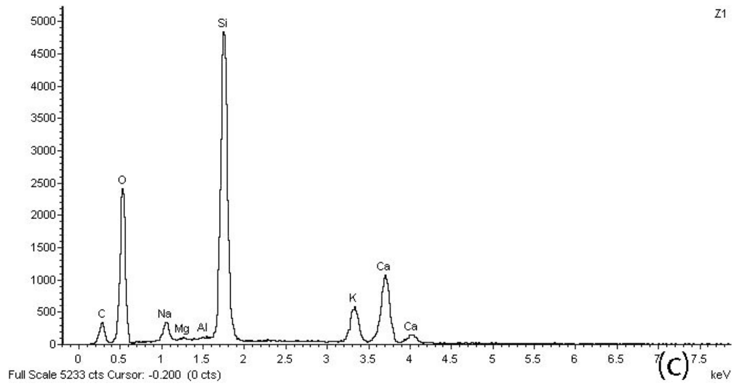
- Microscopic examination by SEM/EDS (thin sections)











Diagnosis and assessment of damage

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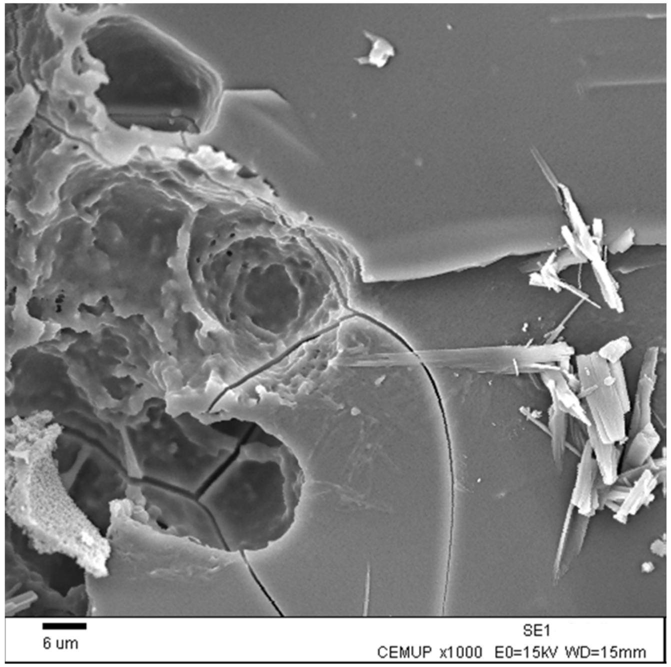
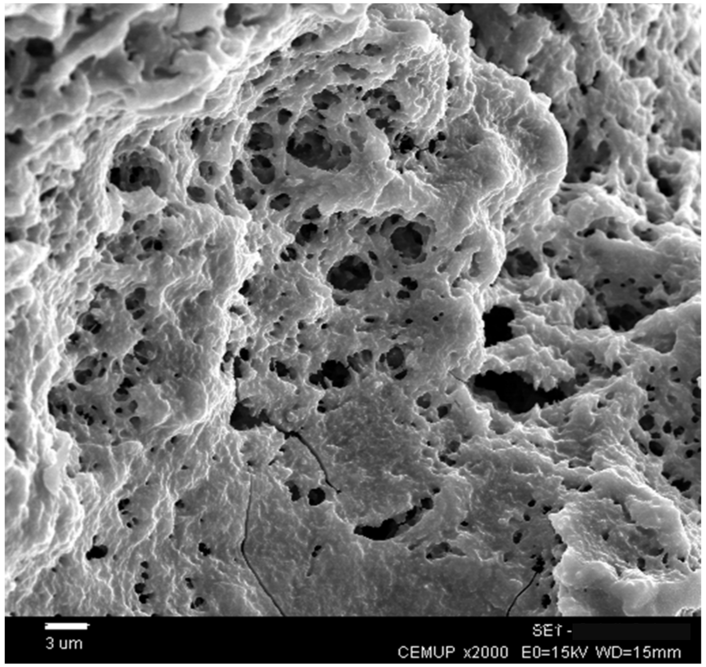
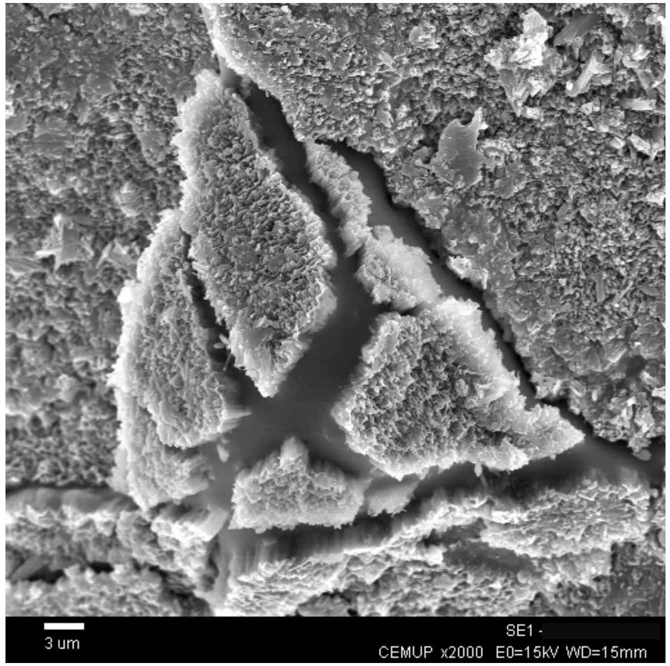
- Microscopic examination by SEM/EDS (exudations)

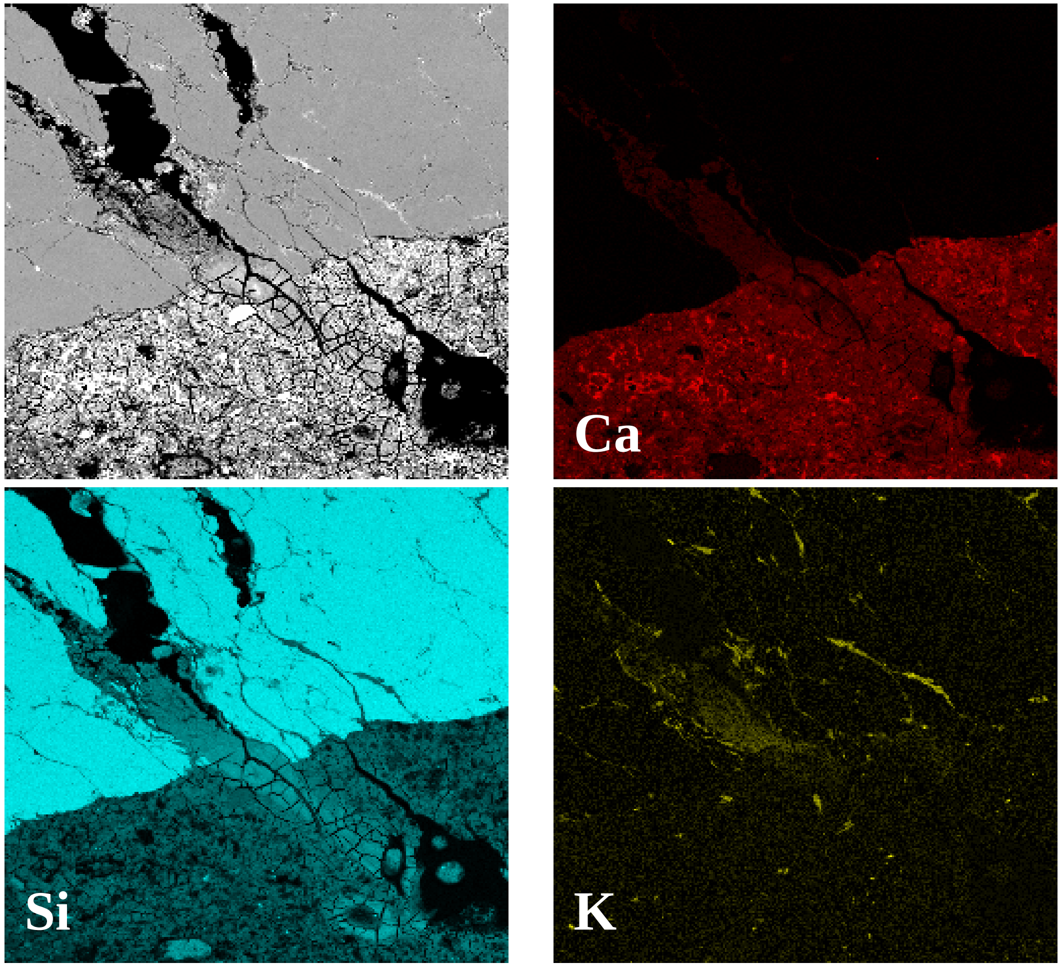






Diagnosis and assessment of damage

- Composition of alkali-silica gel
  - SEM/EDS and EPMA (for quantitative composition)
  - Maps of elements



Diagnosis and assessment of damage

- Expansion tests on cores

- Expansion tests on cores
  - at 100% R.H.
  - (in alkaline solutions – NaOH or KOH)

Diagnosis and assessment of damage

- Expansion tests on cores

Interpretation of results:

The values obtained can be compared with some criteria, e.g., < 100 mm/m/year – negligible, 100 to 500 mm/m/year – moderate
> 500 mm/m/year - important [LCPC nº 44].

or

< 0.005% per year – low expansion

> 0.005% per year – significant expansion [Bérubé et al., 1993].

Residual alkali-silica expansion.			
Saturated environment conditions	*Location of the core*	*Residual expansion (μm/m)*	
		Max.	*Min.*
Over water at 38º C	**A**	**183**	**110**
	B	**146**	**110**
	C	**183**	**146**
Over 1M KOH solution at 38º C	**A**	**73**	**73**
	B	**146**	**0**
	C	**26**	**22**

Diagnosis and assessment of damage

- Alkali measurement

Diagnosis and assessment of damage

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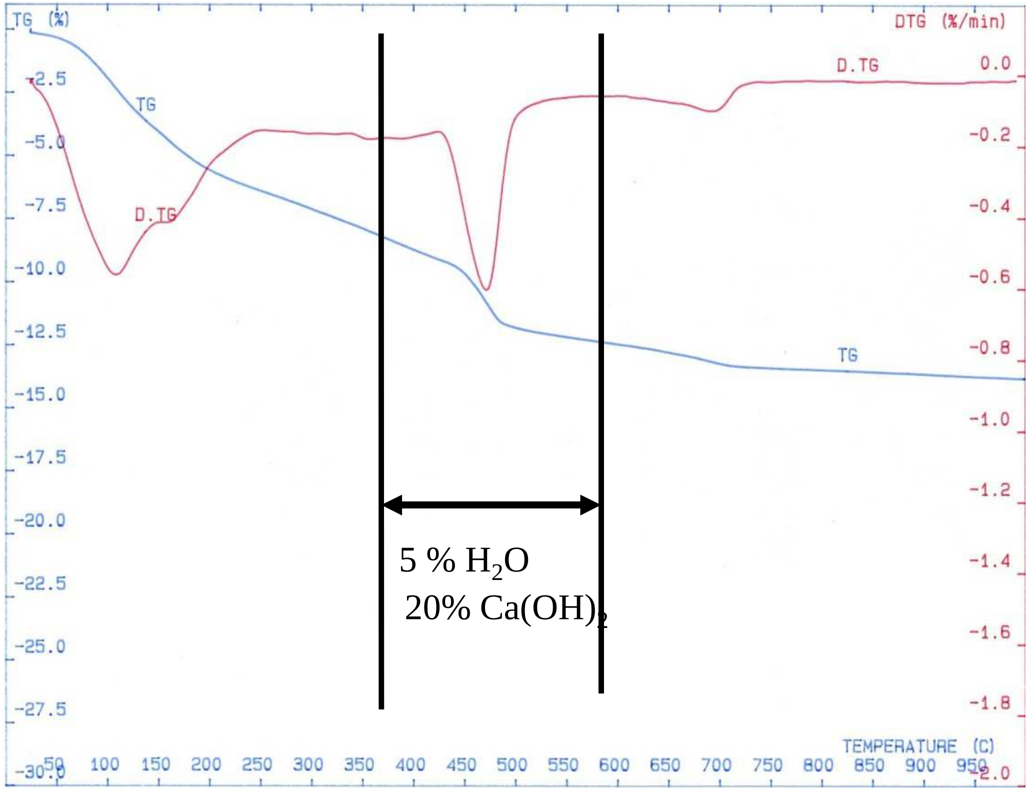
- Portlandite content of concrete



$$Ca(OH)_2 \longrightarrow CaO + H_2O$$

$$\% \ Ca(OH)_2 = \% \ H_2O_{\text{weight loss}} \times (74/18)$$

Diagnosis and assessment of damage

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- Examples of application – Fagilde Dam

- Built in the 1980s
- First impoundment: 1985-87
- 2 arch dams, 3 buttresses,
- 2 spillways
- Height: 26.6 m
- Ready mixed concrete
- CEM I (360 kg/m^3)
- Coarse aggregate: limestone (micritic)
- Fine aggregate: alluvial siliceous sand

Diagnosis and assessment of damage

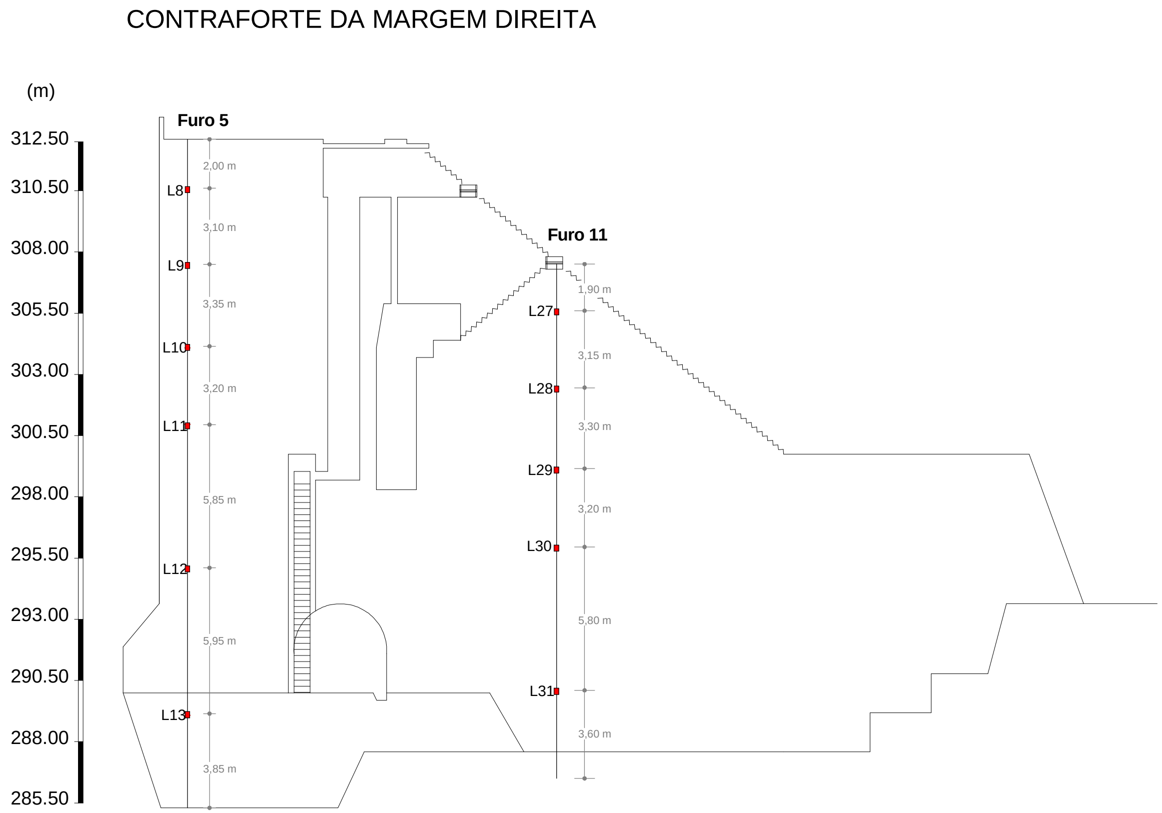
- Examples of application – Fagilde Dam

Cracking, discoloration, dissolution, exudations

Diagnosis and assessment of damage

- Examples of application – Fagilde Dam

✓ Drill coring
✓ Mechanical tests
✓ Residual alkali-silica reactivity of concrete
✓ Residual internal sulfate reactivity of concrete
✓ Soluble alkali content
✓ Petrographic observation:
  - ✓ Petrographic microscope
  - ✓ SEM/EDX
    - ✓ Thin-sections
    - ✓ Exudations
    - ✓ Concrete pieces



Diagnosis and assessment of damage

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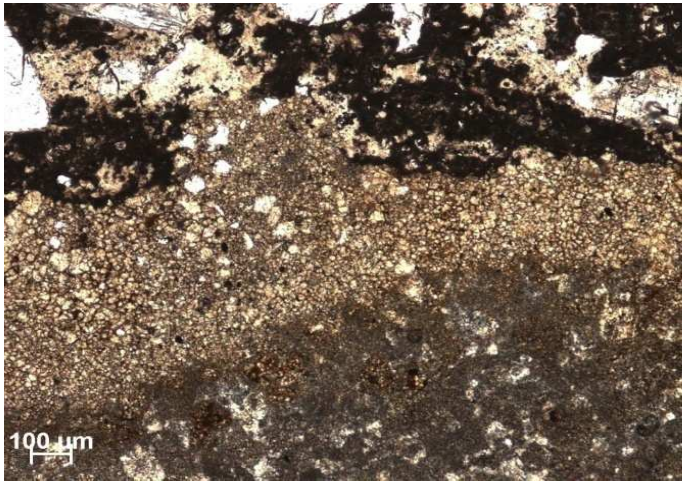
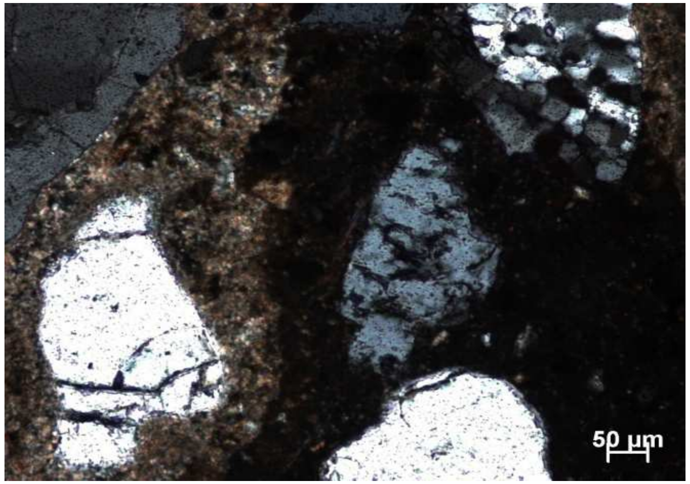
- Examples of application – Fagilde Dam
  - Potential reactivity of aggregates
  - Coarse aggregates
    - Micritic limestone (carbonate mudstone)
    - Interstices of calcite crystals with finely dispersed microsilica and silicate minerals
    - Limestone contains remains of fossils with chalcedony

and

- some well rounded siliceous particles of polycrystalline quartz, including microcrystalline quartz





Diagnosis and assessment of damage

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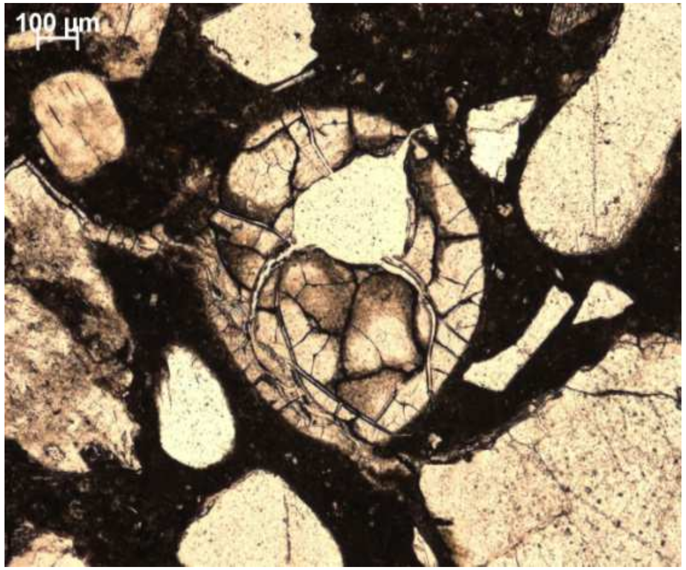
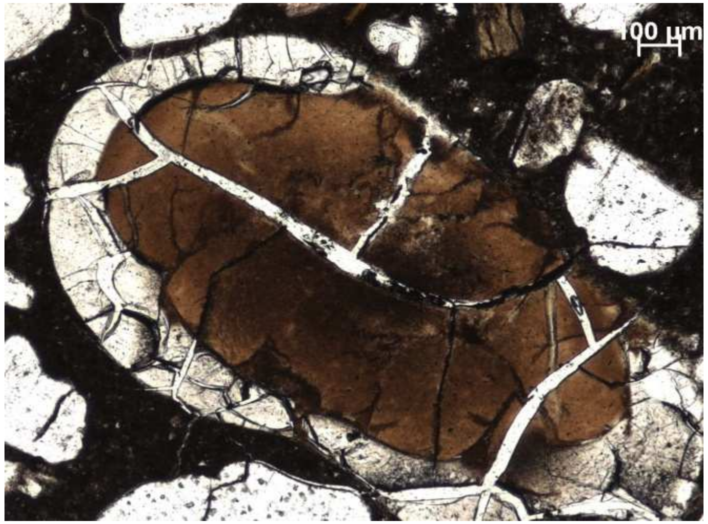
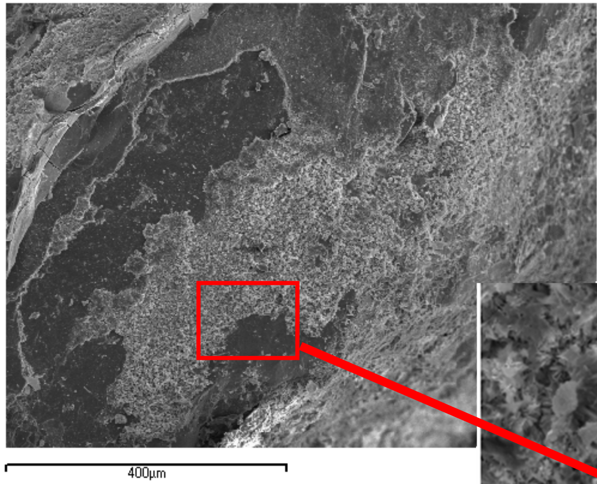
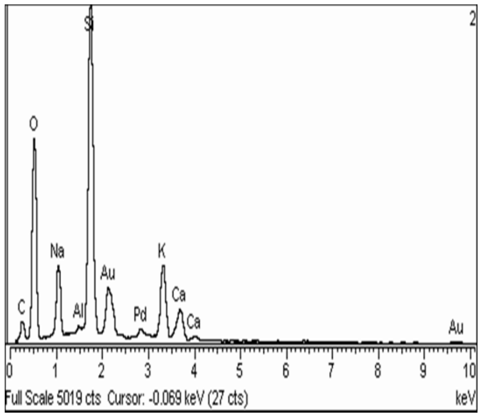
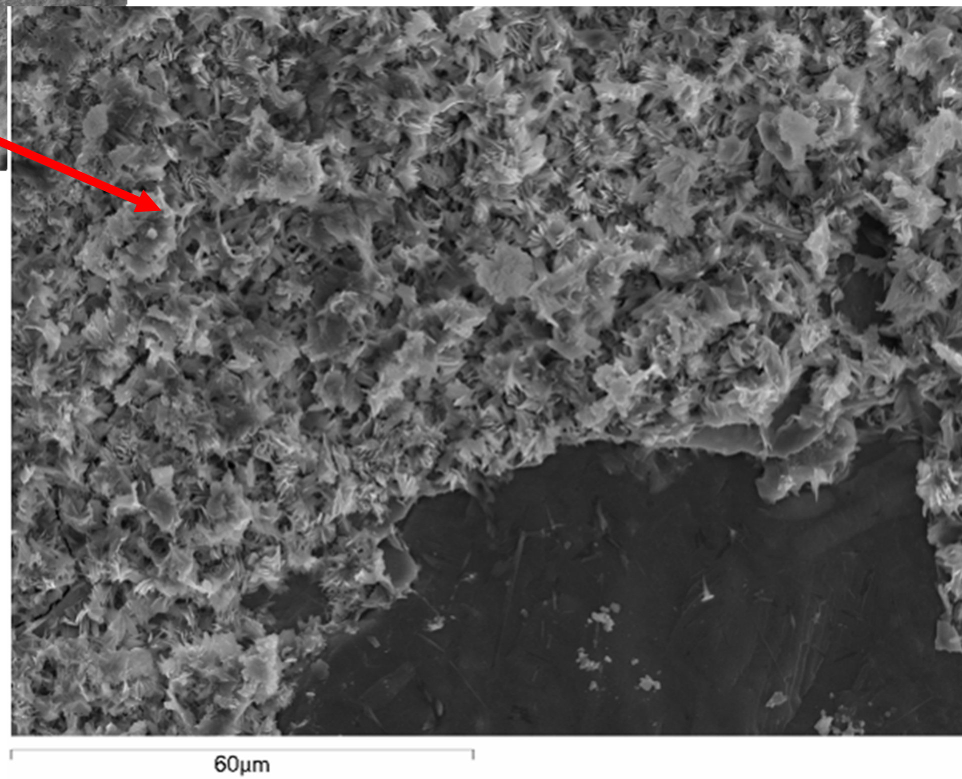
- Examples of application – Fagilde Dam
  - ✓ Manifestations of internal reactions
    - ➢ Gel in cracks and in siliceous particles of sand fraction











Diagnosis and assessment of damage

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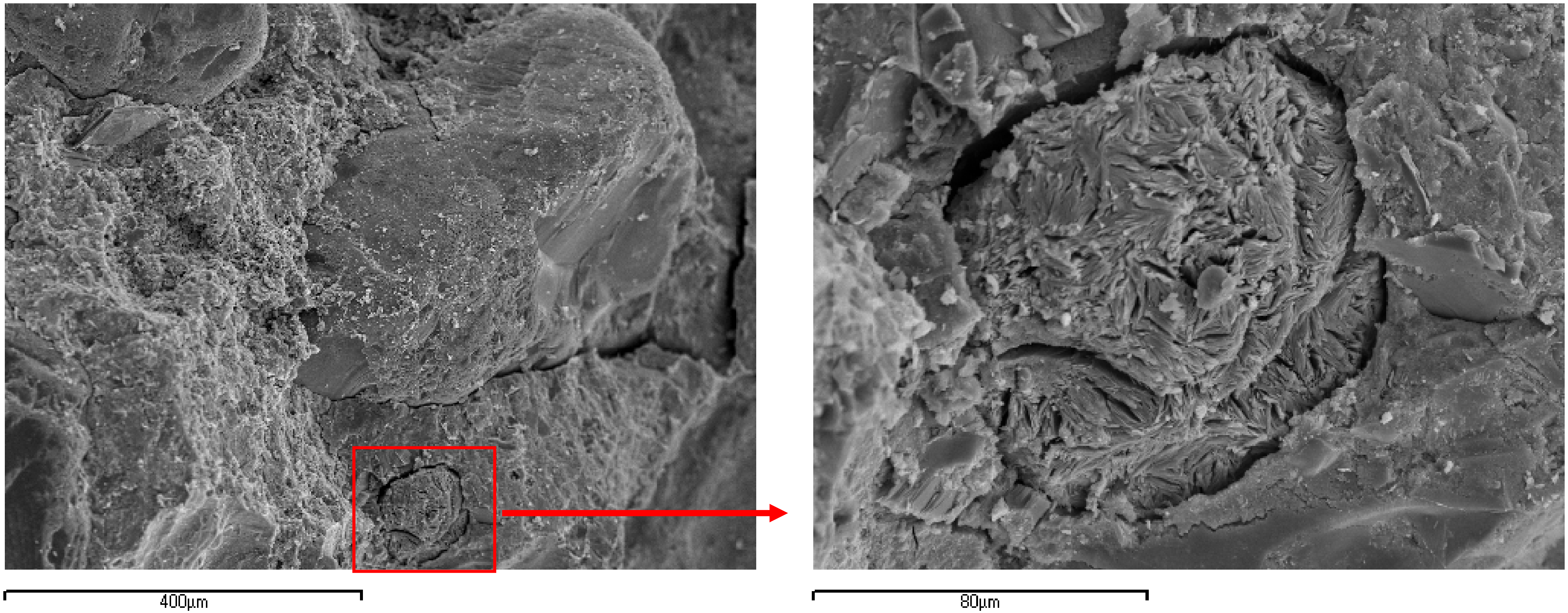
- Examples of application – Fagilde Dam

  - ✓ Manifestations of internal reactions
    - ✓ Ettringite in cracks, voids and in cement paste



Diagnosis and assessment of damage

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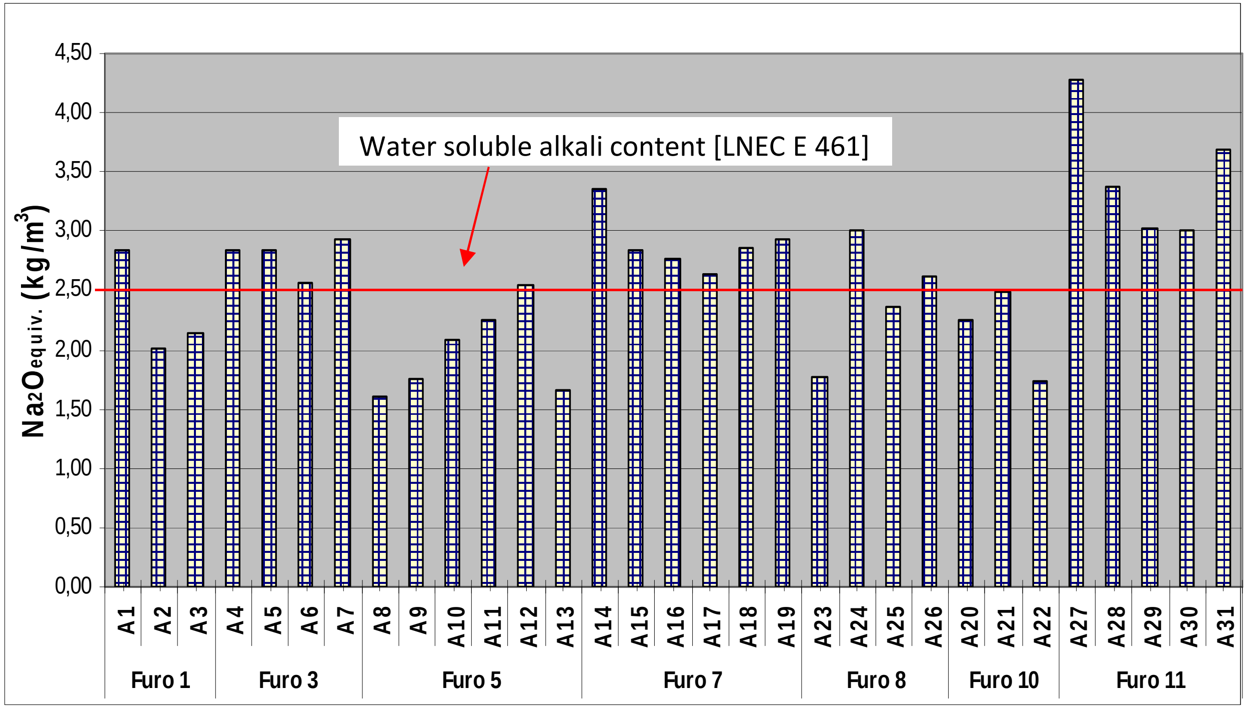
- Examples of application – Fagilde Dam



According some authors (Thomas, 1992) a water-soluble alkali content (excluding the contribution from aggregates) > 2.0 kg/m^3 $Na_2O_{eq.}$, is interpreted as a high risk of future expansion due to ASR

Diagnosis and assessment of damage

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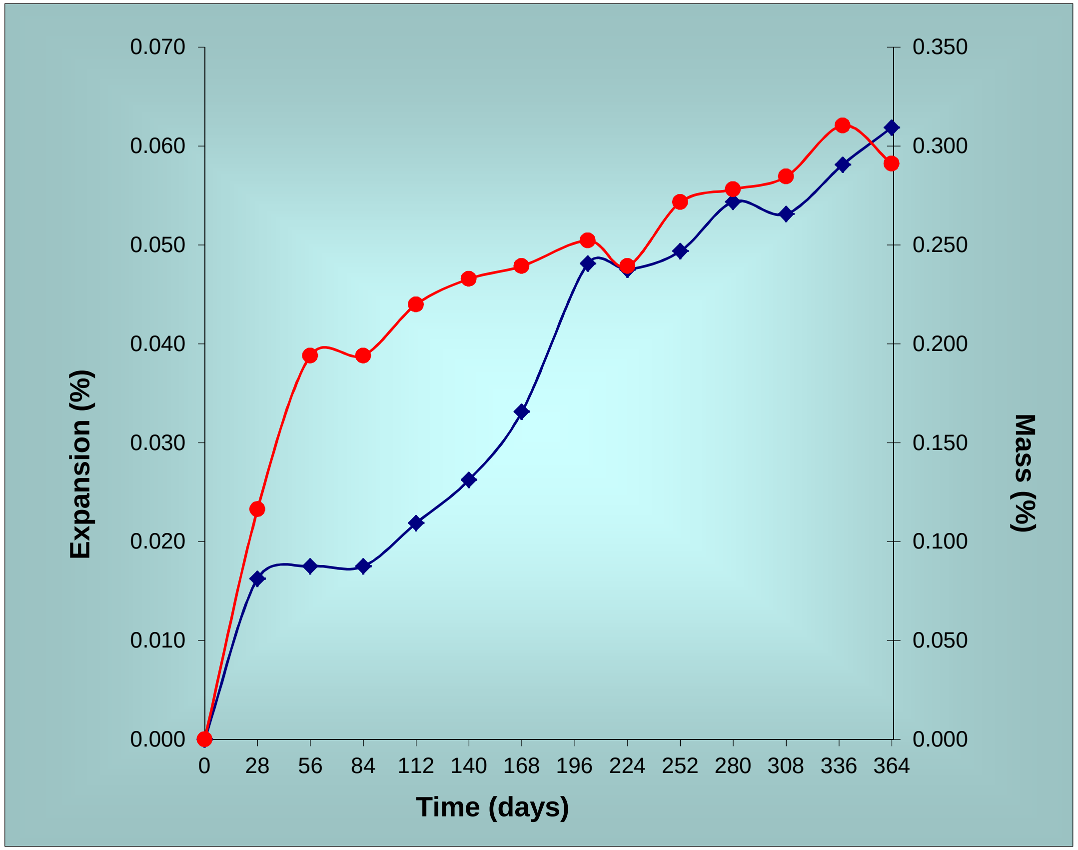
- Examples of application – Fagilde Dam

Residual ASR



Sample	Residual expansion (μm/m/year)	Mass variation (%)
P1C	577	0,29
P2C	40	0,33
P3C	108	0,49
P4C	-15	0,51
P5C	29	0,36
P6C	-69	0,46
P8A	91	0,52
P9A	128	0,34
P10A	-7	0,15
P10B	190	0,43
P11A	-4	0,28
P11B	-11	0,3
P12A	120	0,29
P13A	66	0,41
P14C	47	0,36
P15C	77	0,35
P16C	99	0,25
P17C	-248	0,29
P23A	-4	0,74
P24A	-37	0,76
P25A	117	0,44
P25B	66	0,58

Máx	577	0,76
Min	-248	0,15

Diagnosis and assessment of damage

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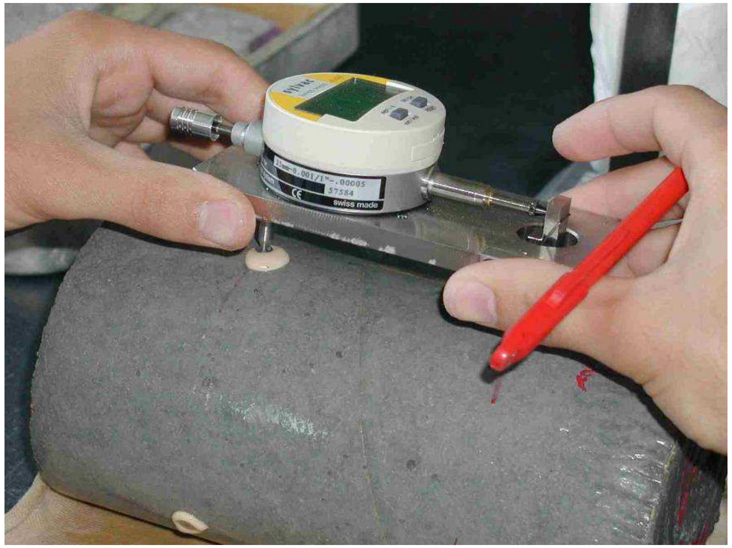
❑ Examples of application – Fagilde Dam

▪ Residual sulfate reactivity of concrete - Test method LPC nº 67, immersion in water at 20º C



Sample	Residual Expansion		Mass variation (%)
	µm/m/year	%	
P7C	106	0,01	0,12
P11C	69	0,01	0,05
P12C	91	0,01	0,15
P18C	-22	-0,01	0,13
P19C	562	0,05	0,12
P24C	113	0,01	0,10
P25C	106	0,02	0,12
P20C	47	0,01	0,14
P22C	164	0,02	0,09
P27C	117	0,02	0,19
P31C	113	0,02	0,12

Diagnosis and assessment of damage

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- Examples of application – Fagilde Dam

  - Irreversible upward vertical displacement
  - Cracks and dissolution features
  - Aggregates potentially reactive. Limestone with dispersed microsilica and silicates
  - Cracks frequent in interfaces
  - ASR gel inside the concrete and in exudations
  - Secondary ettringite widely distributed
  - Alkalis content sufficient to maintain ASR and ISR
  - Residual expansion due to ASR and ISR

RISK of future expansion due to internal expansive reactions (ASR + ISR)

Thank you

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