Physical Causes of Concrete Deterioration

- **1. Deterioration by surface wear.**
- **Abrasion:** dry attrition (wear on pavements and industrial floors by traffic)
- **Erosion:** wear produced by abrasive action of fluids containing solid particles in suspension (canal lining, spillways and pipes).
- **Cavitation:** loss of mass by formation of vapor bubbles and their subsequent collapse.

Abrasion - Erosion

- **Note: the deterioration starts at the surface, therefore special attentions should be given to quality of the concrete surface.**
- **Avoid laitance (layer of fines from cement and aggregate).**

Cavitation

- Good-quality concrete shows excellent resistance to steady high-velocity flow of clear water; however nonlinear flow at velocities exceeding 40 ft/sec. may cause severe erosion of concrete due to cavitation.
- Note: In contrast with erosion or abrasion, a strong concrete may not necessarily be effective in preventing damage due to cavitation. Solution = eliminate the causes of cavitation (review hydraulic design such as surface misalignments or abrupt change of slope).

2. Cracking by crystallization of salts in pores

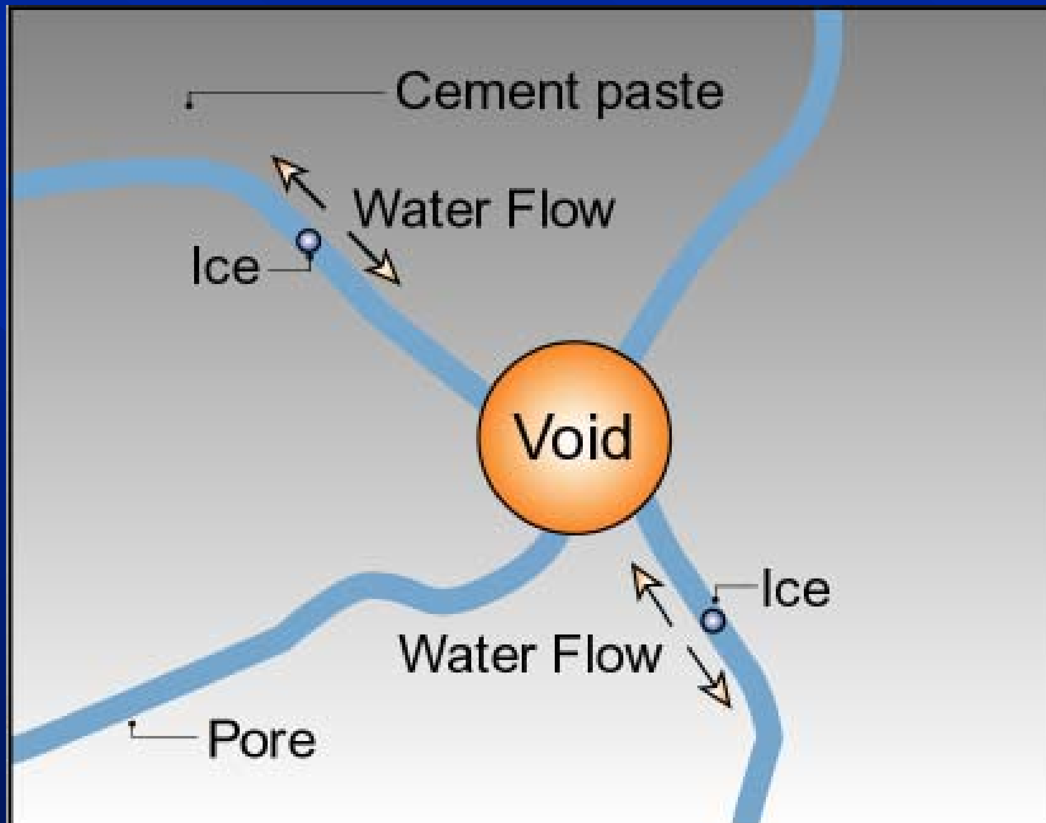
- **The crystallization of salts in the pores of concrete can produce stresses that may damage the concrete structure. This can happen when the concentration of the solute (c) exceeds the saturation concentration (Cs). Higher C/Cs ratio (degree of supersaturation) produces higher crystallization pressure.**

3. Deterioration by Frost Action

- When water freezes, there is an expansion of 9%. However, some of the water may migrate through the boundary, decreasing the hydraulic pressure.
- Hydraulic pressure depends on: (a) rate at which ice is formed. (b) permeability of the material. (c) distance to an "escape boundary."

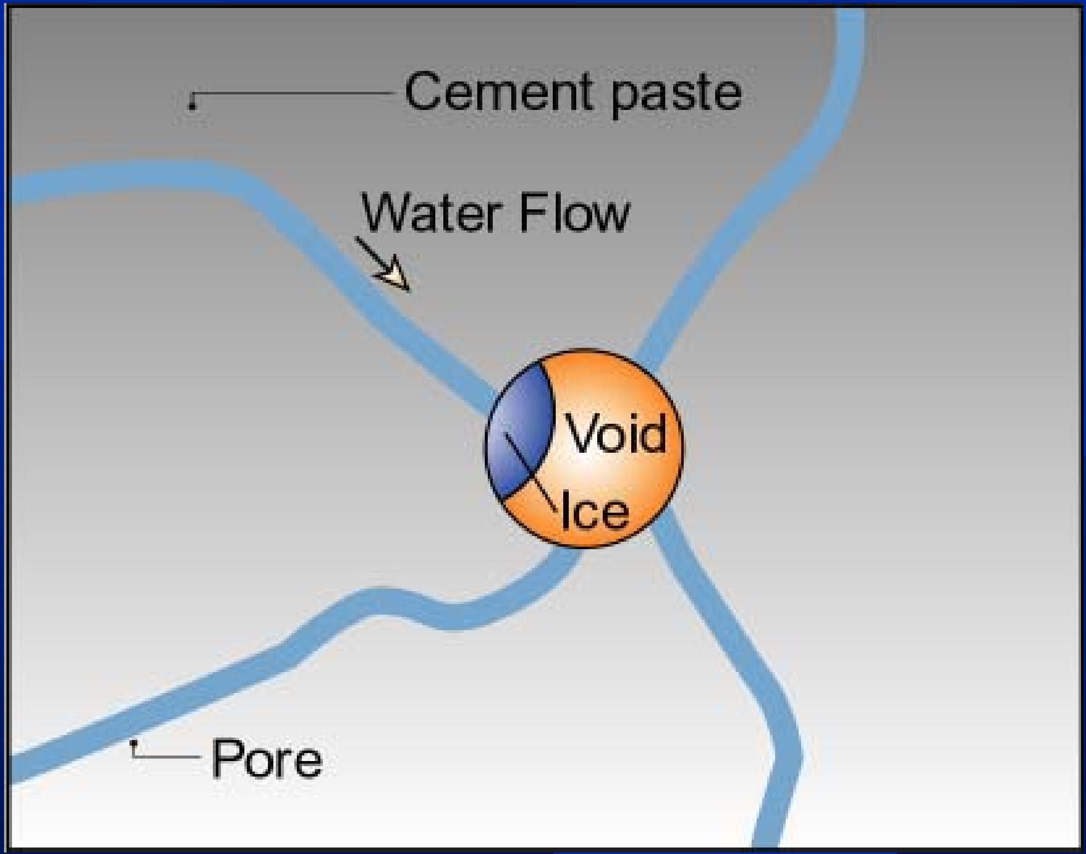
Ice Formation in Concrete

The problem



e transformation of ice from liquid water generates a volumetric ation of 9%. If the transformation occurs in small capillary pores, the crystals can damage the cement paste by pushing the capillary lls and by generating hydraulic pressure.

The solution



Air voids can provide an effective escape boundary to reduce this pr

Air-Entraining

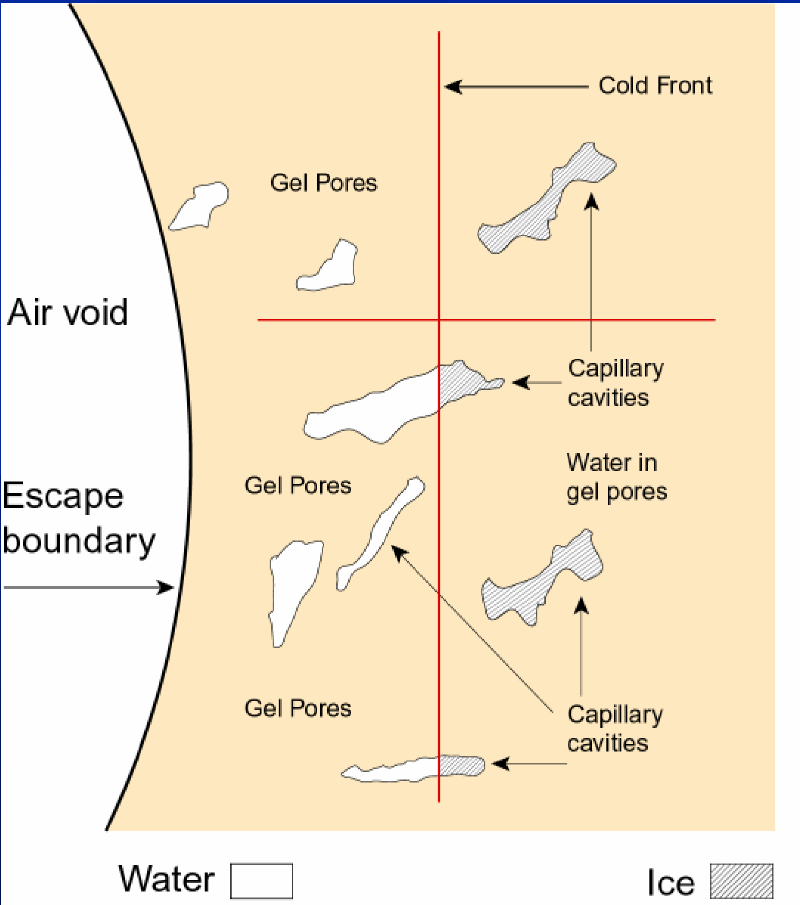
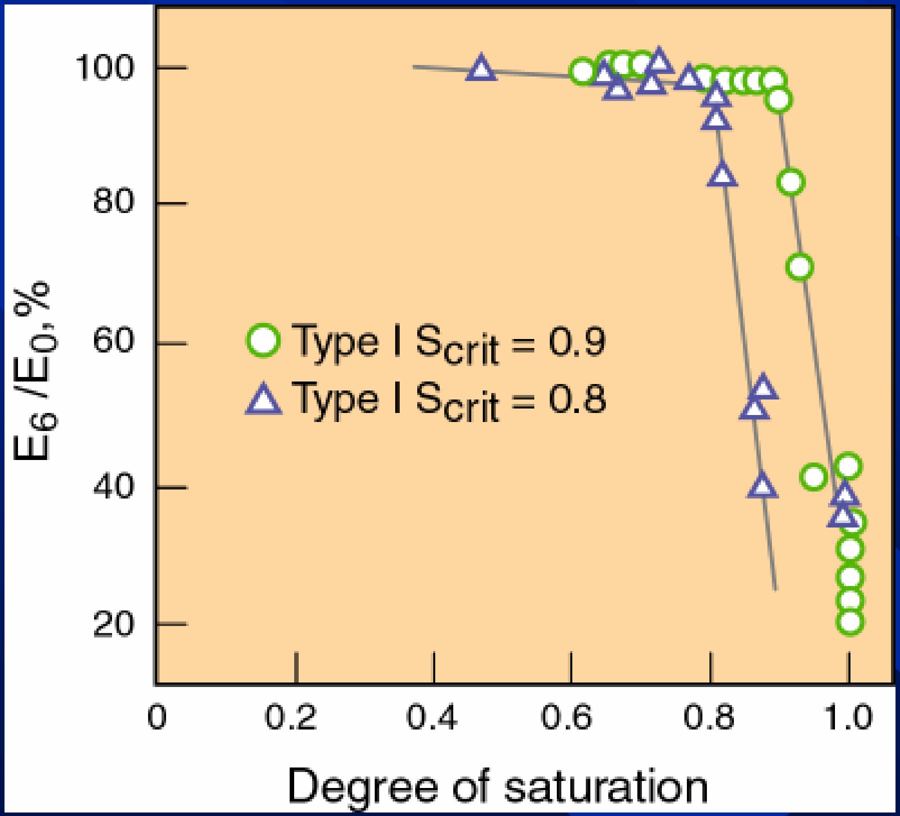
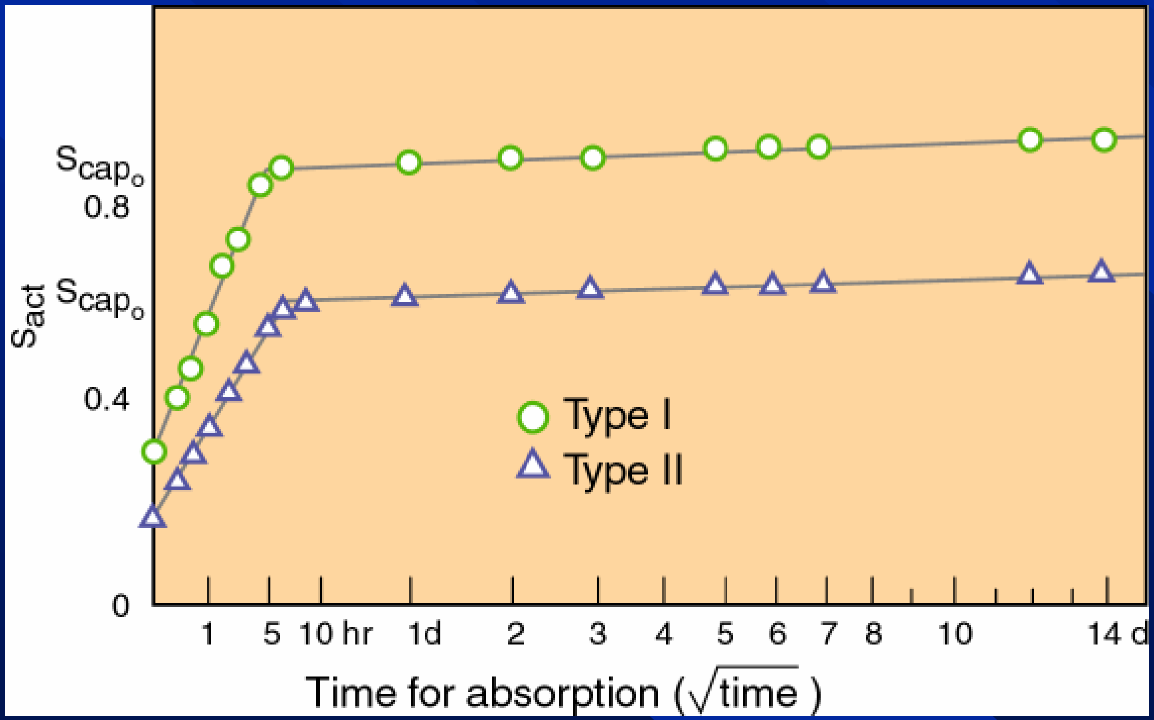


Figure 5-6 Response of saturated cement paste to freezing and thawing both without entrained air.

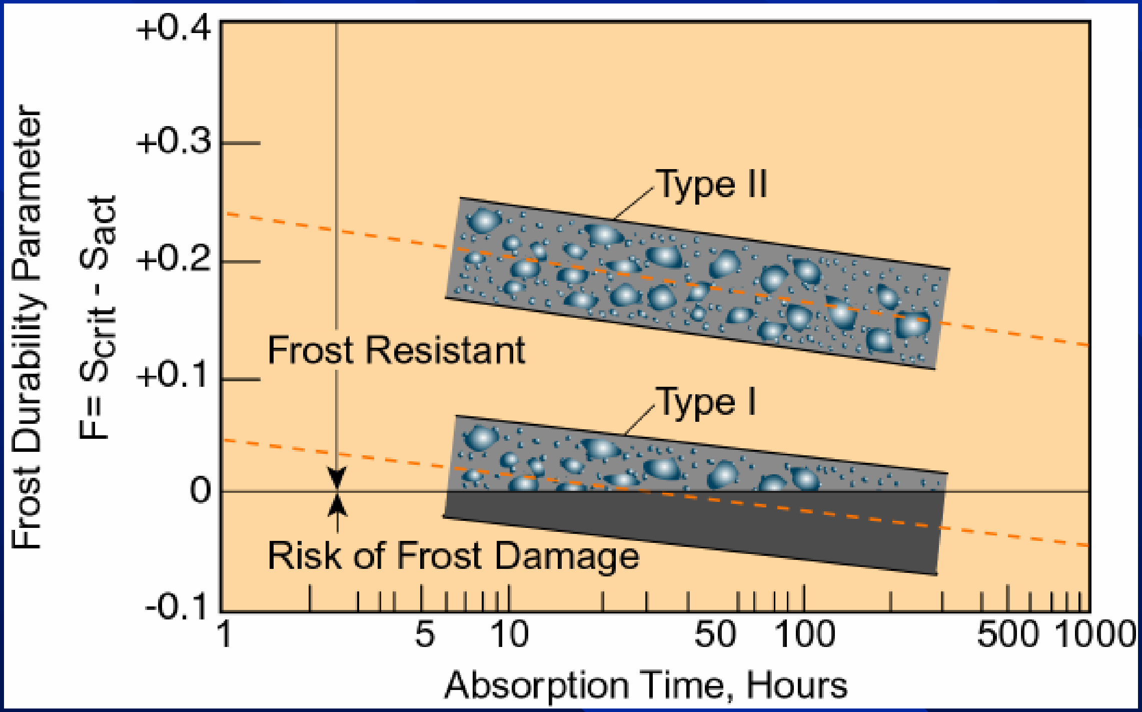
Degree of Saturation



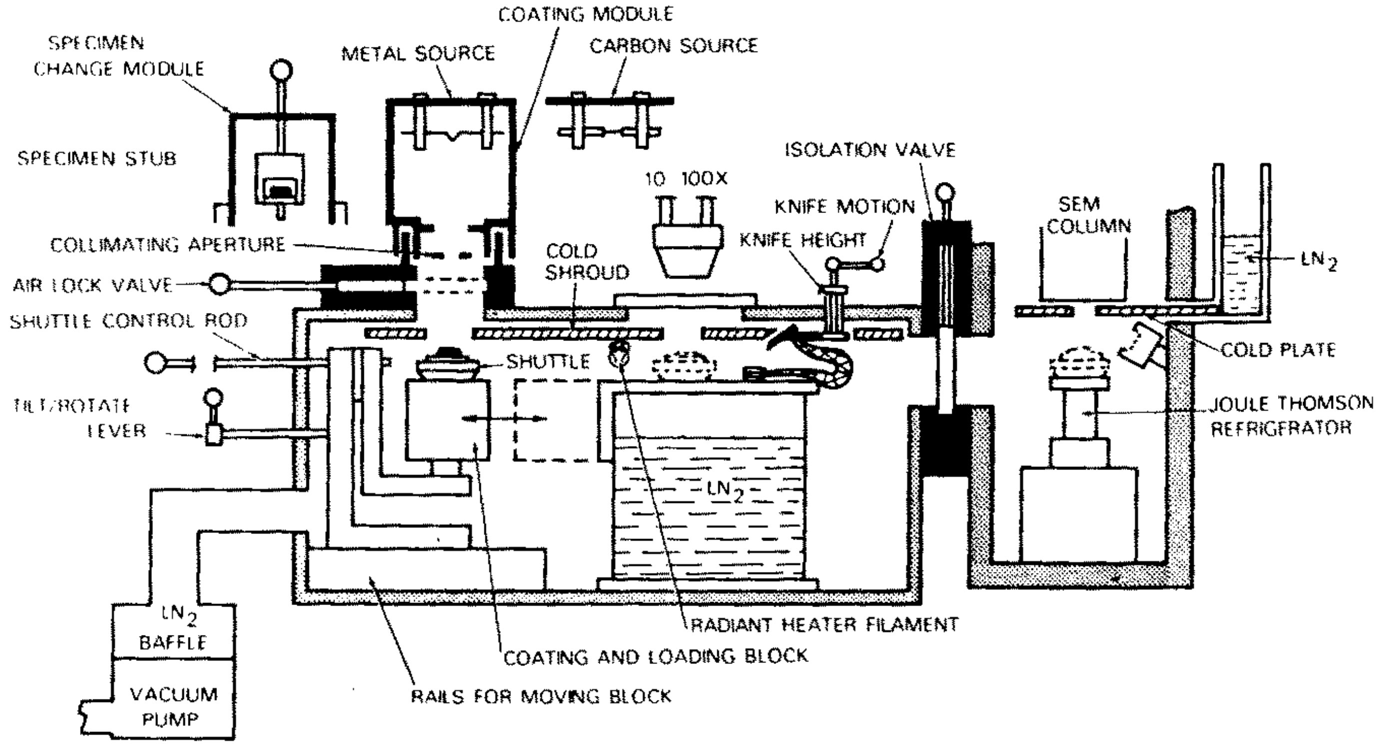
Degree of Saturation



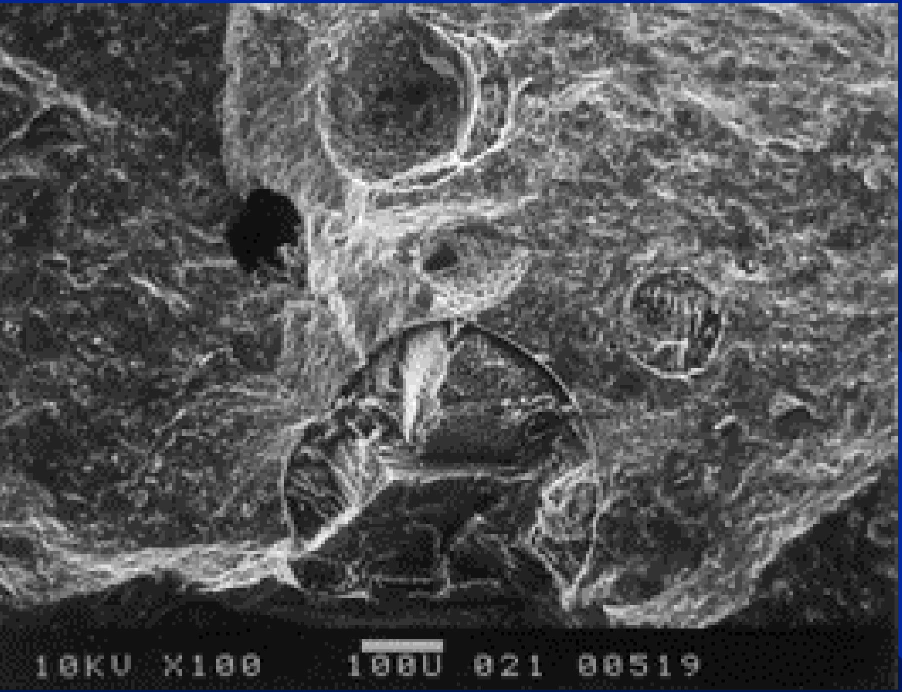
Degree of Saturation

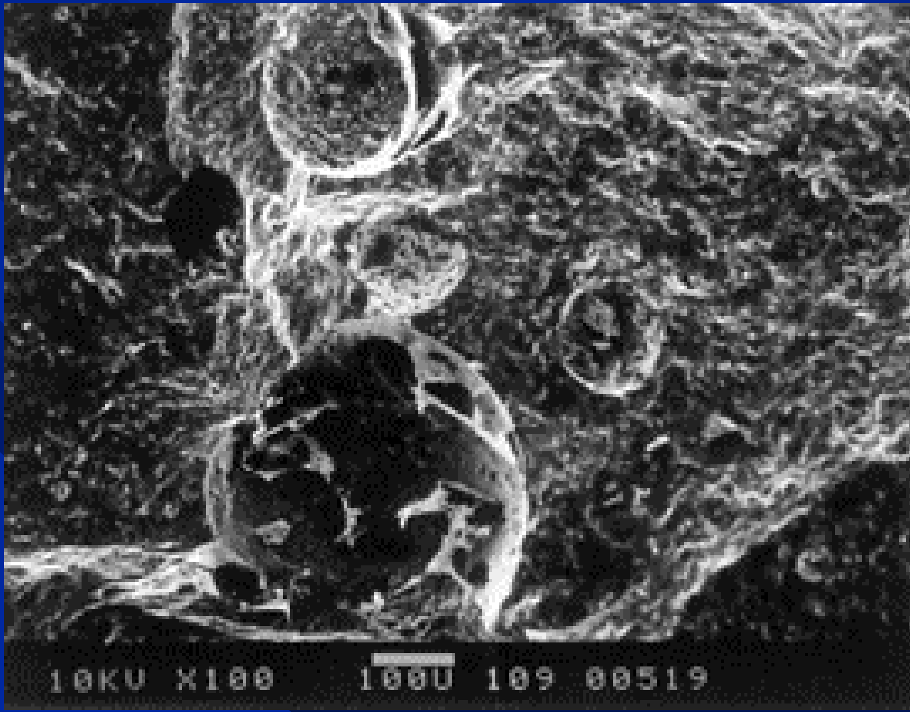


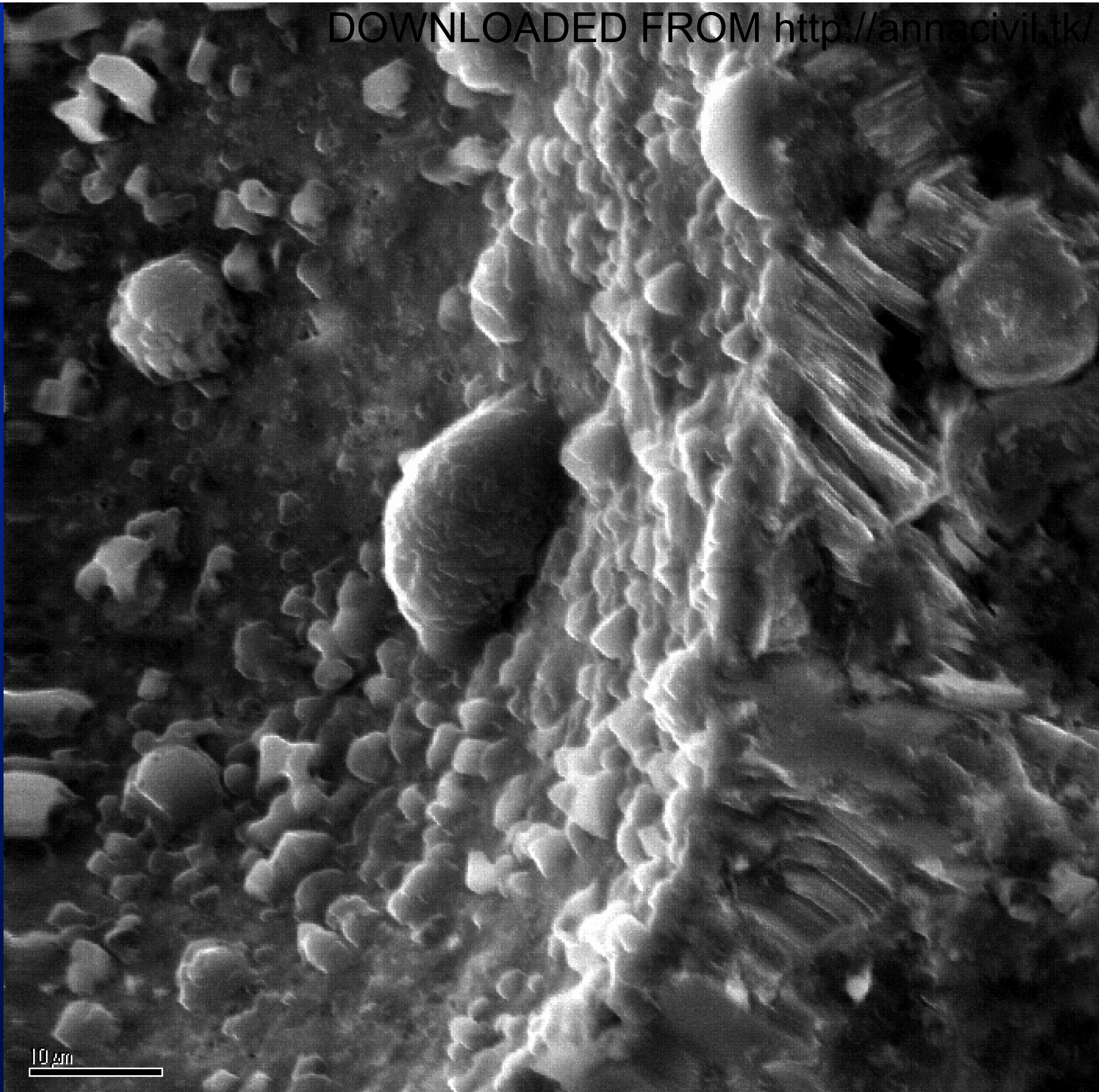
Low-temperature SEM



Images






10 µm

Dynamics of Ice Propagation

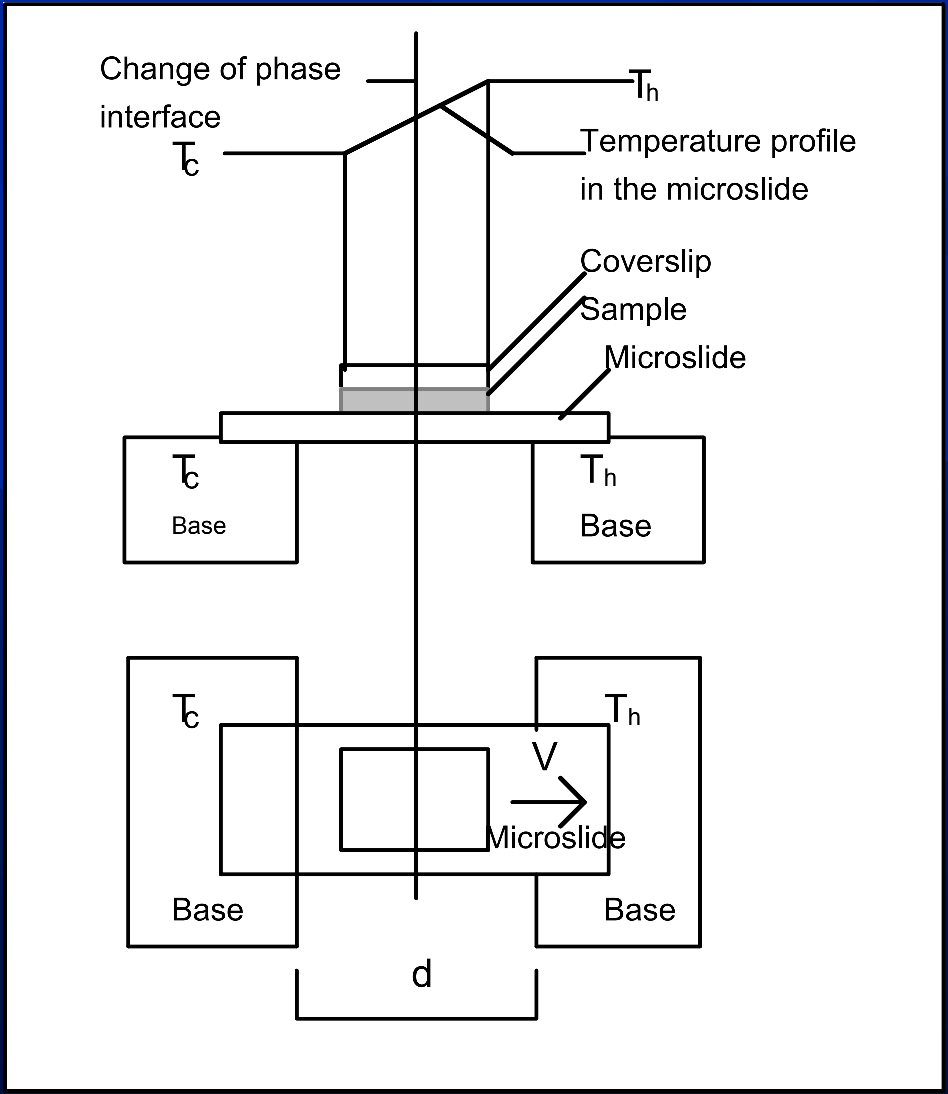
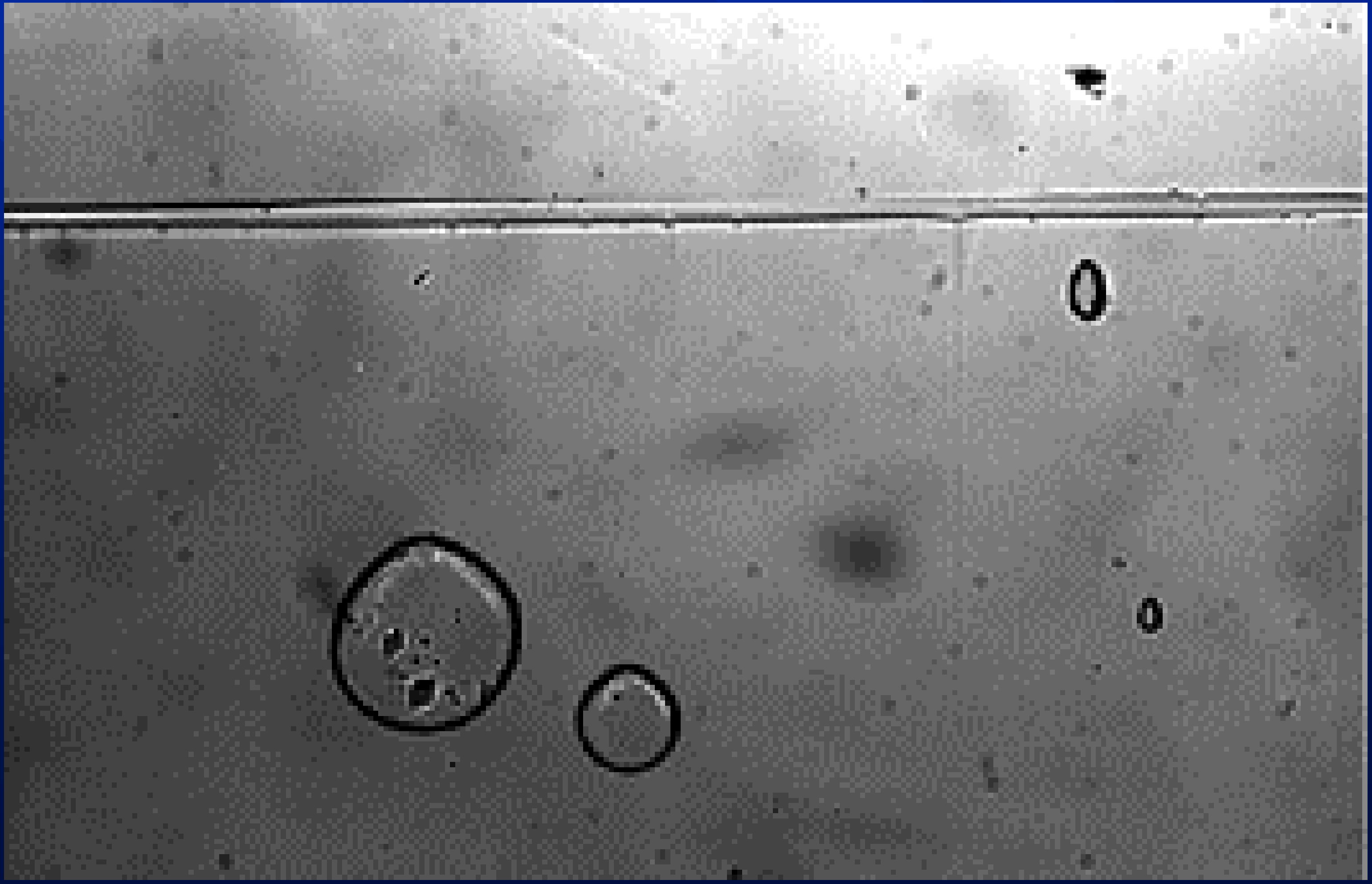


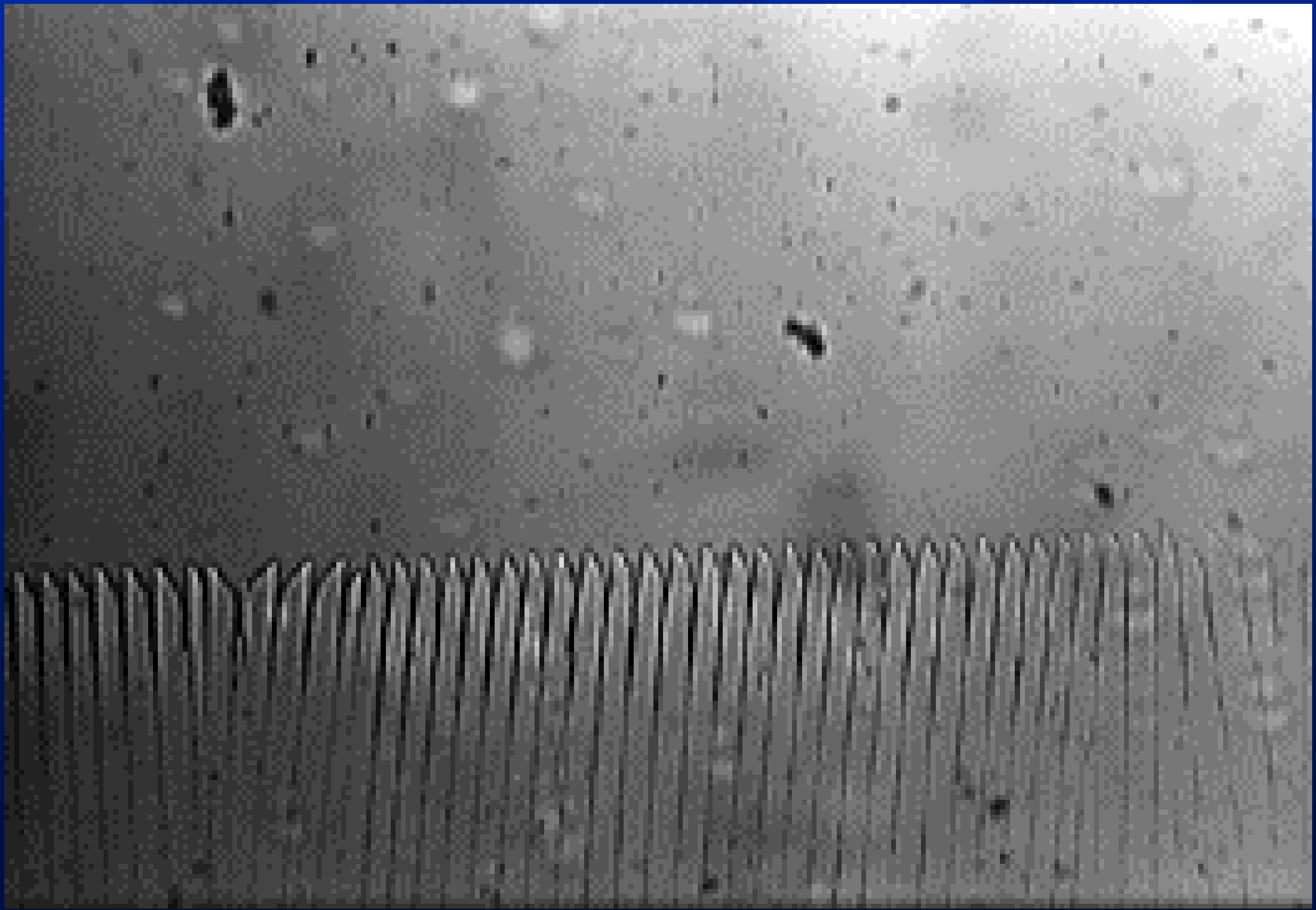
Fig. 6

Imagens

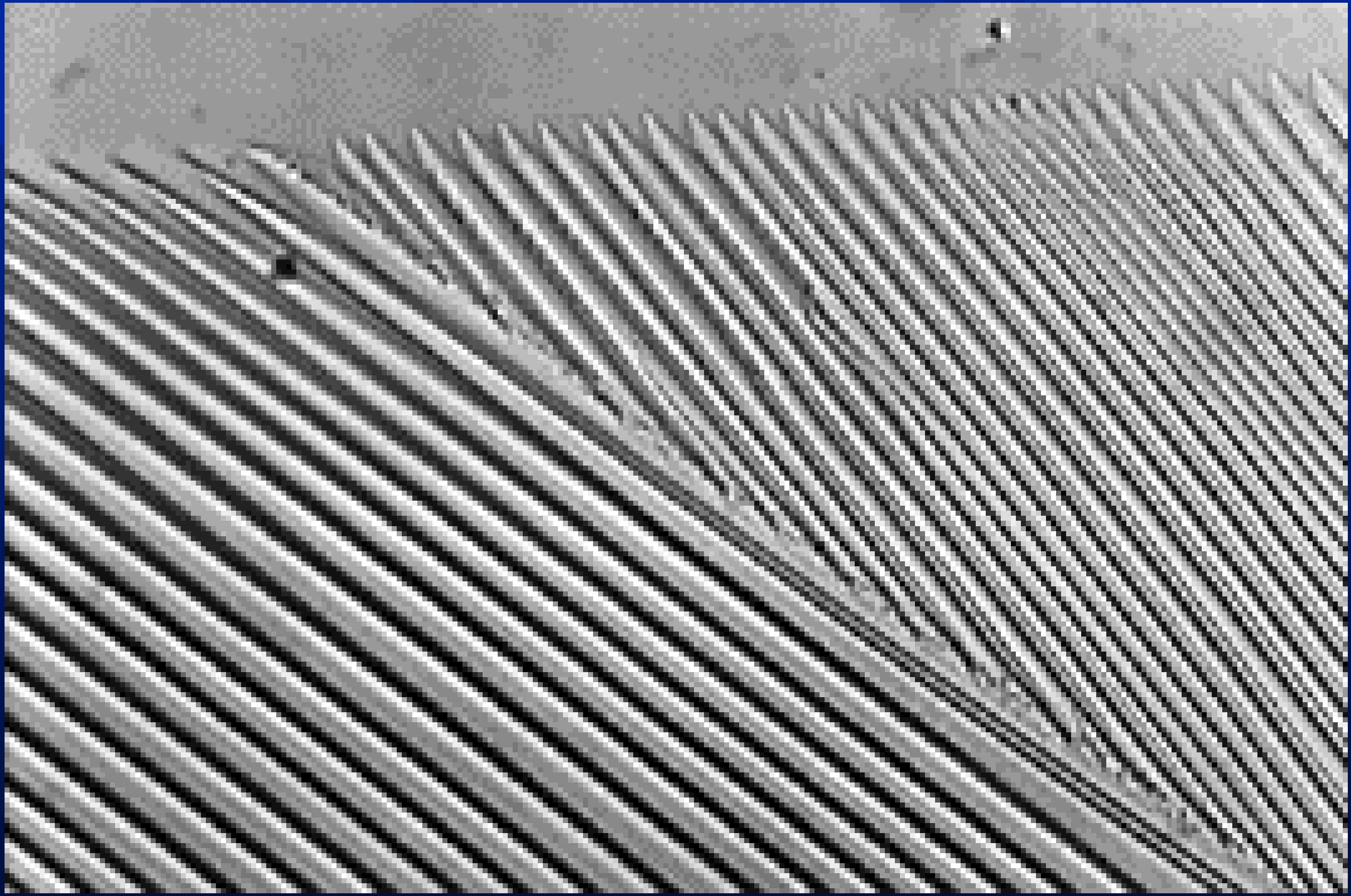
Interface gelo-líquido em água pura



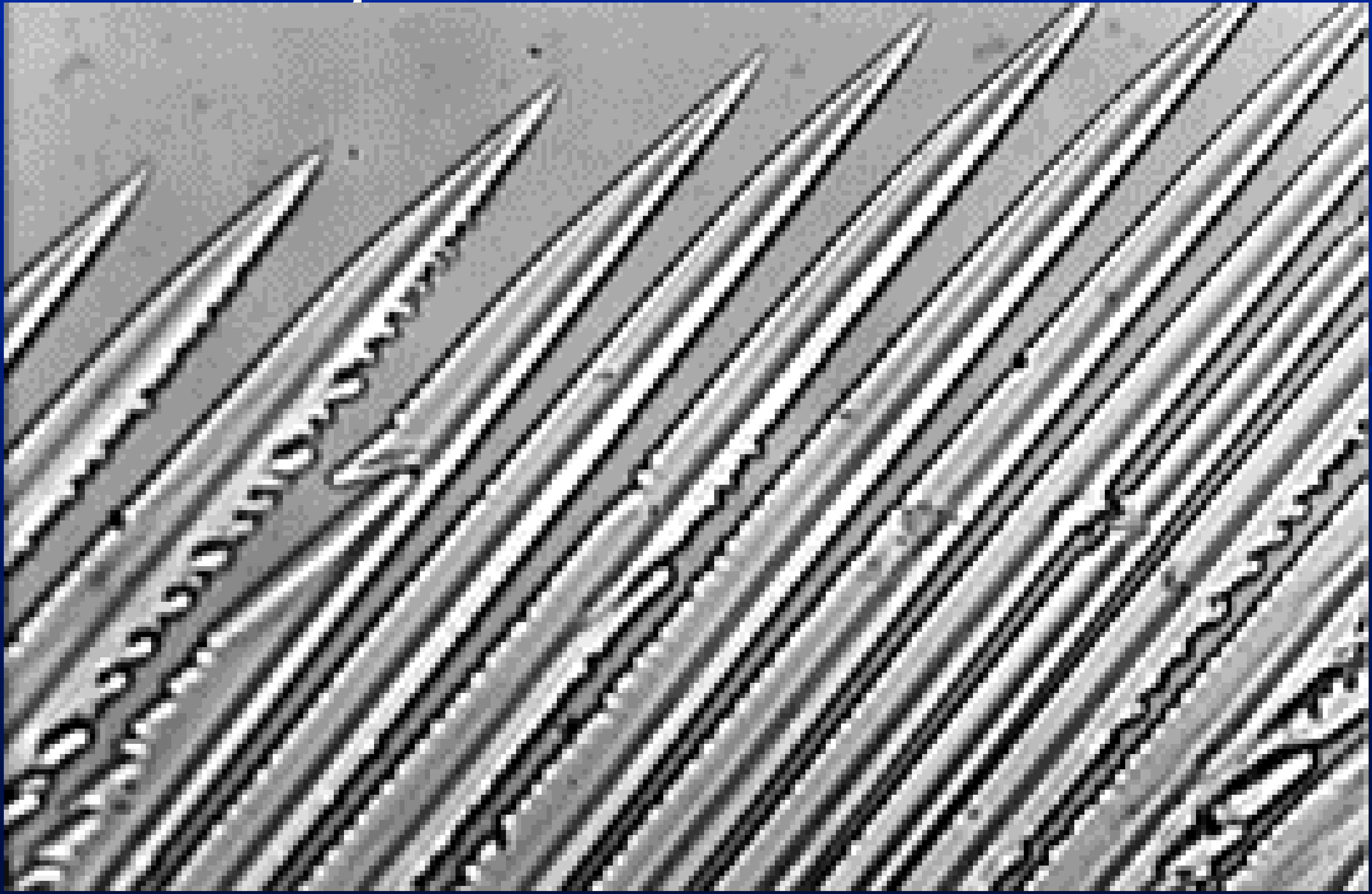
Interface gelo-líquido em solução de 0.7M $Ca(OH)_2$



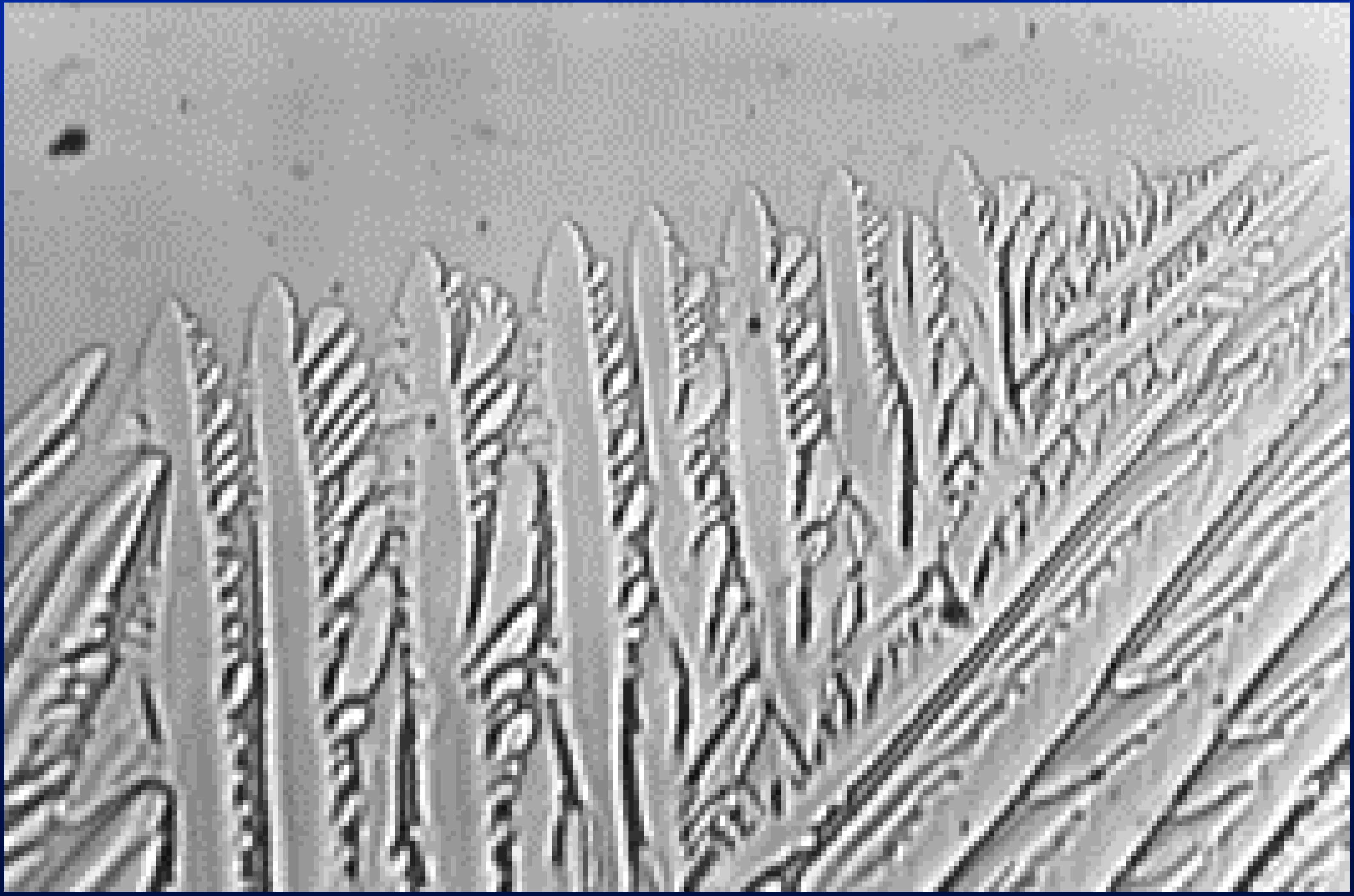
Interface gelo-líquido em solução de 0.085M $CaCl_2$



Interface gelo-líquido em solução de 0.7M NaOH

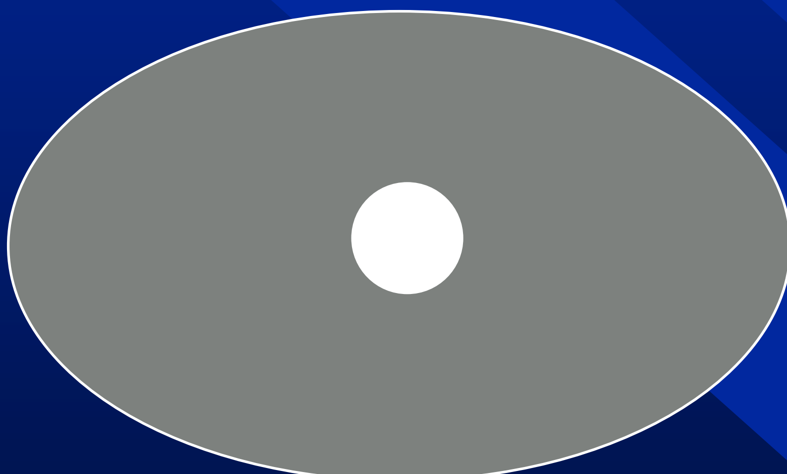


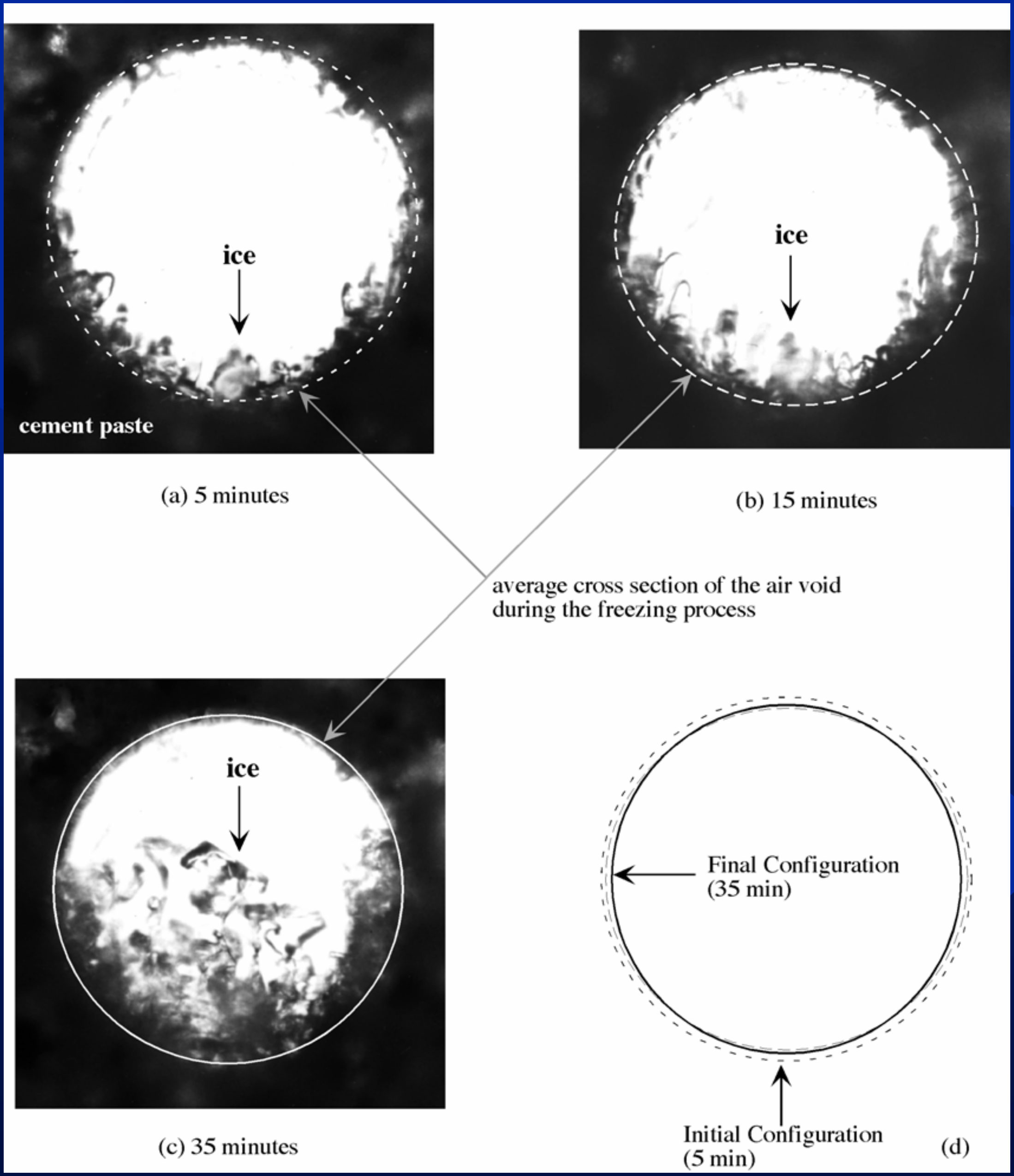
Interface gelo-líquido em solução de 0.7M KOH



Freezing of concrete

Does the air void increases or decreases when ice forms?




ice
cement paste
(a) 5 minutes
ice
(b) 15 minutes
average cross section of the air void
during the freezing process
ice
(c) 35 minutes
Final Configuration
(35 min)
Initial Configuration
(5 min)
(d)

3.1 Frost Action on Aggregate

- Aggregates are also porous bodies: (a) size of the pores. (b) number of pores. (c) continuity of pores.
- There are three classes of aggregate
- (1) Low permeability and high strength: No problem! The rock is strong enough to support the hydraulic pressure.
- (2) Intermediate permeability: Potential depending on (a) rate of temperature drop. (b) distance the water must travel to find an escape boundary -- Critical Aggregate Size (a large aggregate may cause damage but smaller particles won't).
- (3) high permeability: May cause problem with the transition zone.

3.2 Factors Controlling Frost Resistance of Concrete

- (A) Air entrainment = void spacing of order of 0.1 to 0.2 mm

MSA (in)	air content (%)
3/8	7.5
1/2	7
3/4	6
1	6
2	5
3	4.5

B) Water / Cement ratio and curing.

- **Figure

C) Strength. No direct relationship between strength and durability.

- **Example: air-entrained concrete durability (increase) strength (decrease)**

4. Types of frost action damage in concrete:

- 4.1) **Scaling: breaking away a small flat flake from the surface**

4.2) D-Cracking

- Aggregate problem! Appearance of fine parallel cracks along transverse and longitudinal joints and free edges of pavements.

5. Deterioration by fire

- Concrete is able to retain sufficient strength for a reasonably long time.

5.1) Effect of High Temperature on Cement Paste

- (a) degree of hydration
- (b) moisture state
- de-hydration:
- ettringite > 1000C
- Ca(OH)2 500-6000C
- CSH ~ 9000C

5.2) Effect of High Temperature on Aggregate

- **Siliceous quartz: 573 C --sudden volume change ($\alpha - \beta$ quartz)**
- **Carbonate: $MgCO_3$ > 700 C, $CaCO_3$ > 900 C**

5.3) Effect of High Temperature on Concrete

- **Note: unstressed concrete**