Mineralogical Aspects of Expansion Phenomena of Concrete in Japanese Dams

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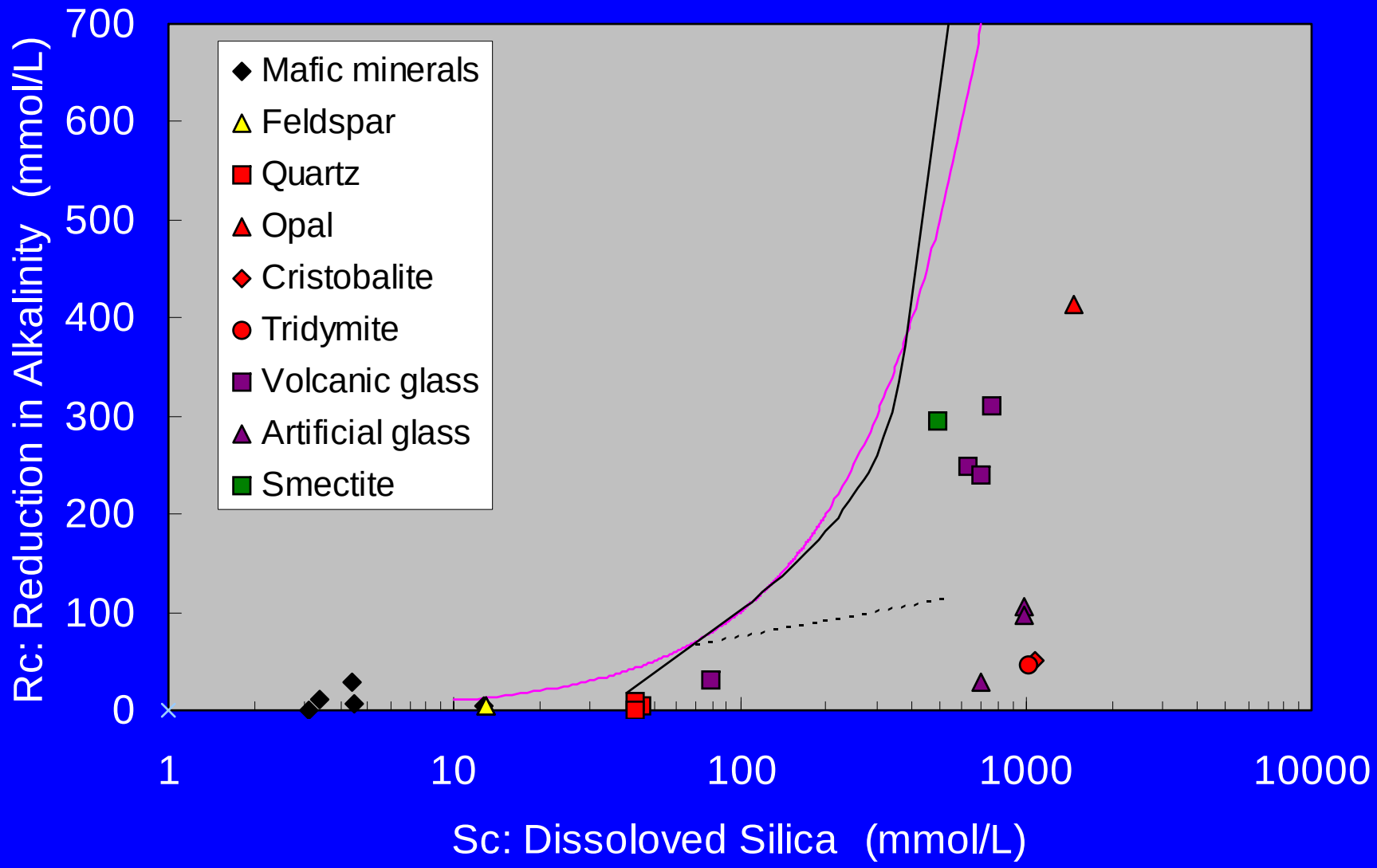
1. Harmful minerals which cause expansion to concrete

- *Silica minerals (Alkali-silica reaction)*
- Oxide (MgO)
- Iron sulphide
- Pyrite
- Marcasite
- Pyrrotite
- Gypsum
- Alunite
- Jarosite
- *Smectite*
- Serpentinite
- *Laumontite*

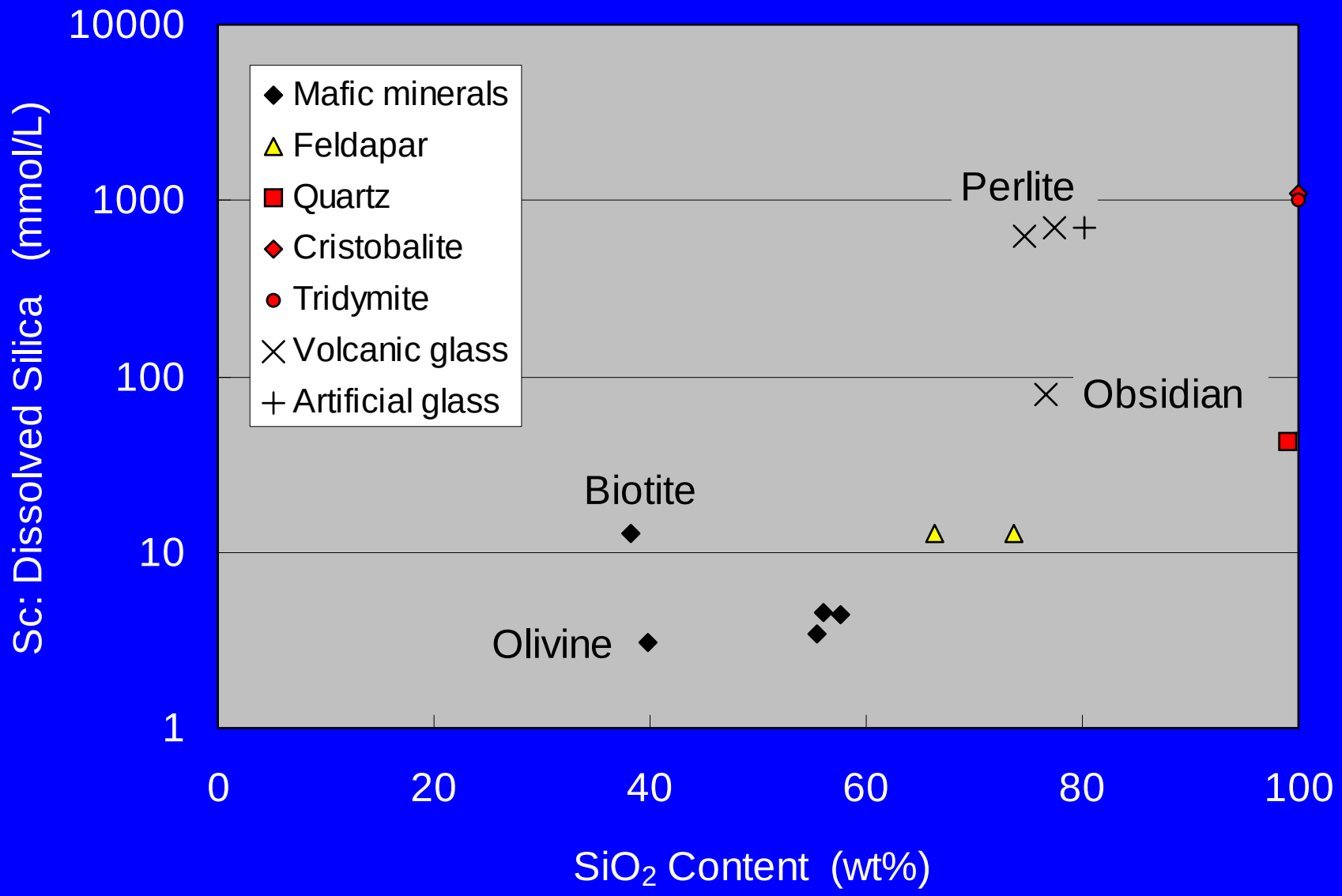
2. Alkali-silica reactivity of minerals

- Alkali-silica reaction in Japan
  - Since 1980's, many deteriorated structures due to alkali-silica reaction have been recognized in Japan.
  - Reactive minerals and rocks were not confirmed in 1980's. We investigated reactivity of minerals and rocks, especially factors which control reactivity of minerals.
  - However, no deteriorated dams have been recognized in Japan.
  - Because the unit cement paste weight have been little in dam construction in Japan.

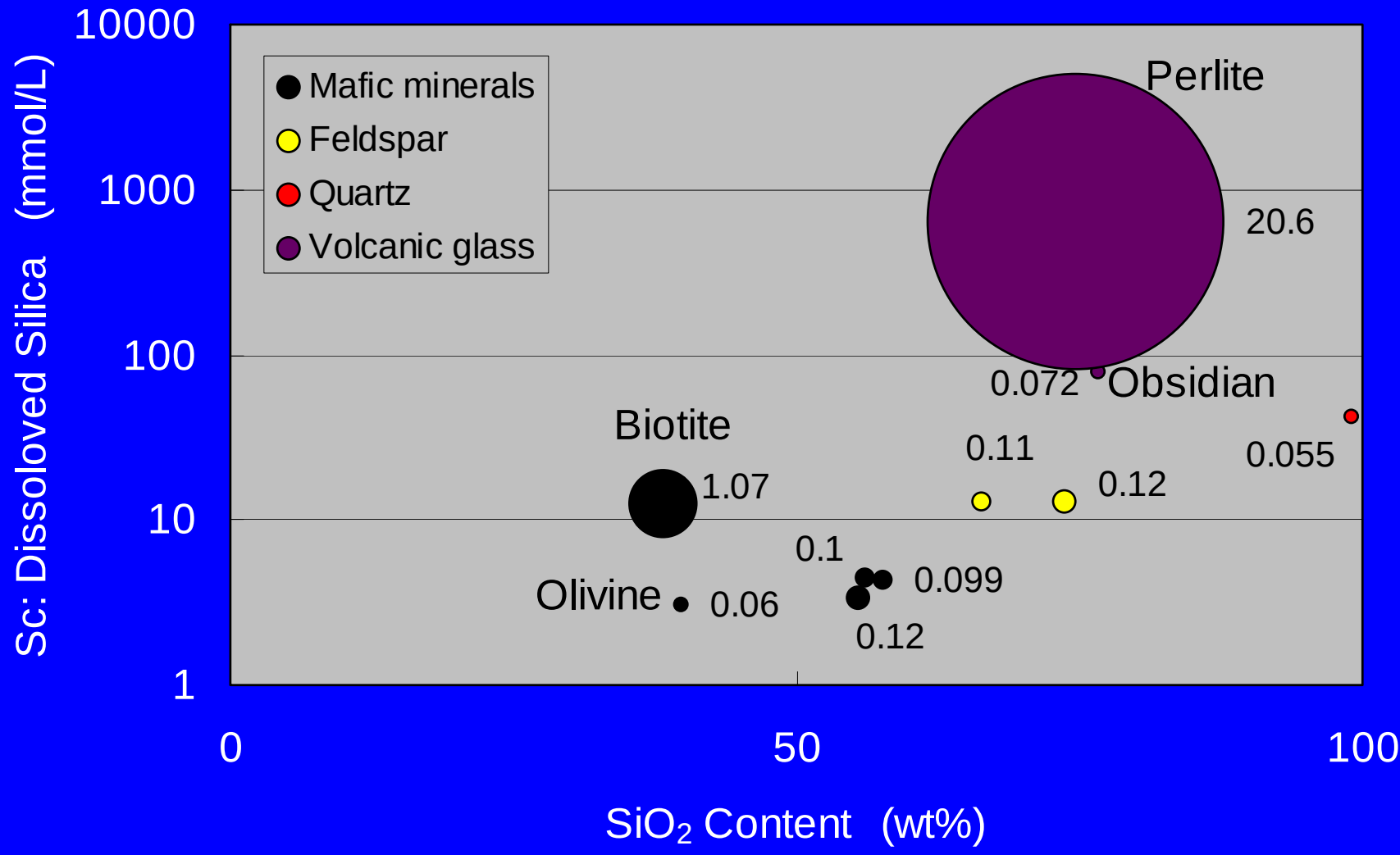
Results of the chemical method for minerals



Main factors controlling Sc

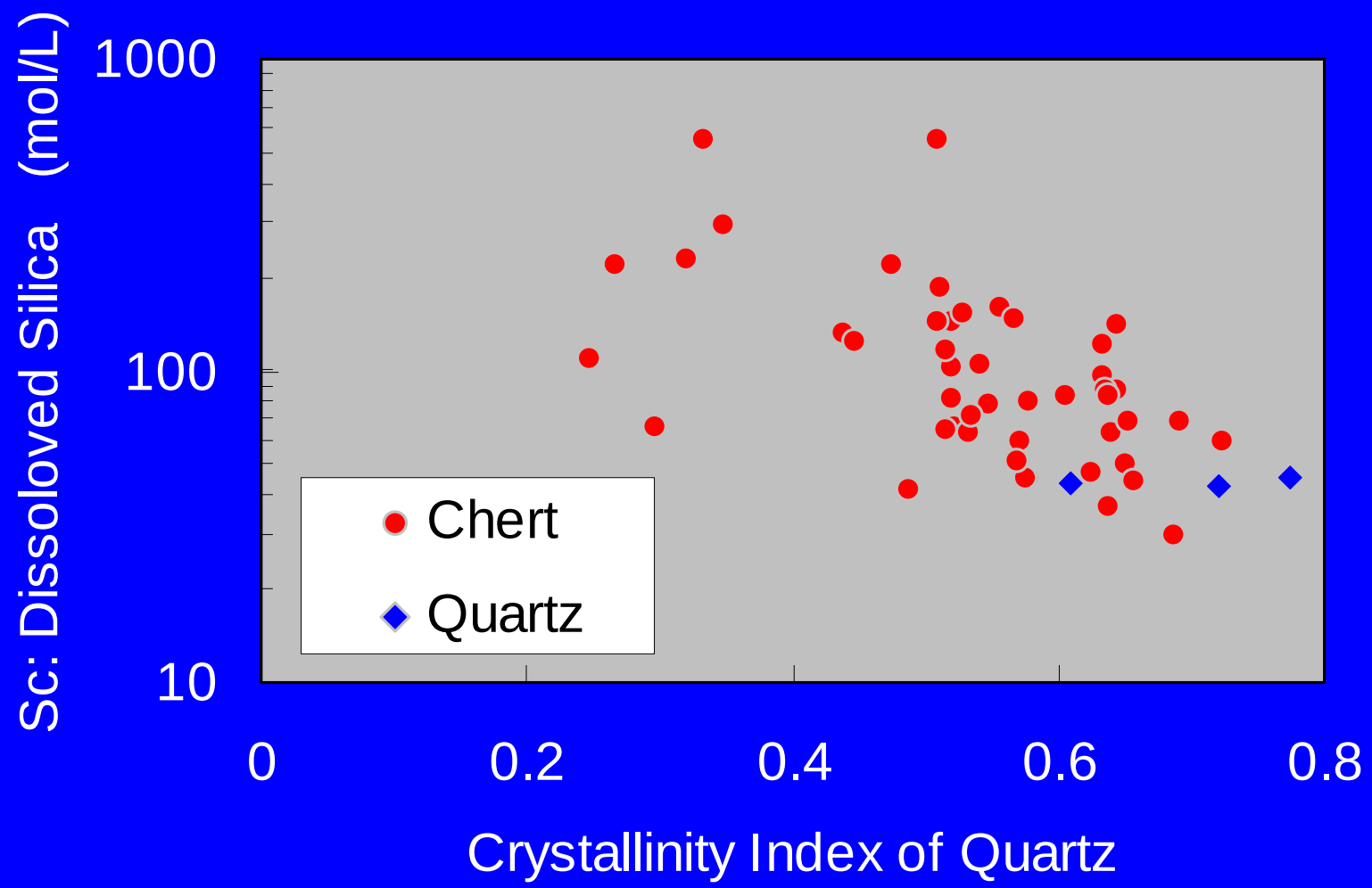


Main factors controlling Sc



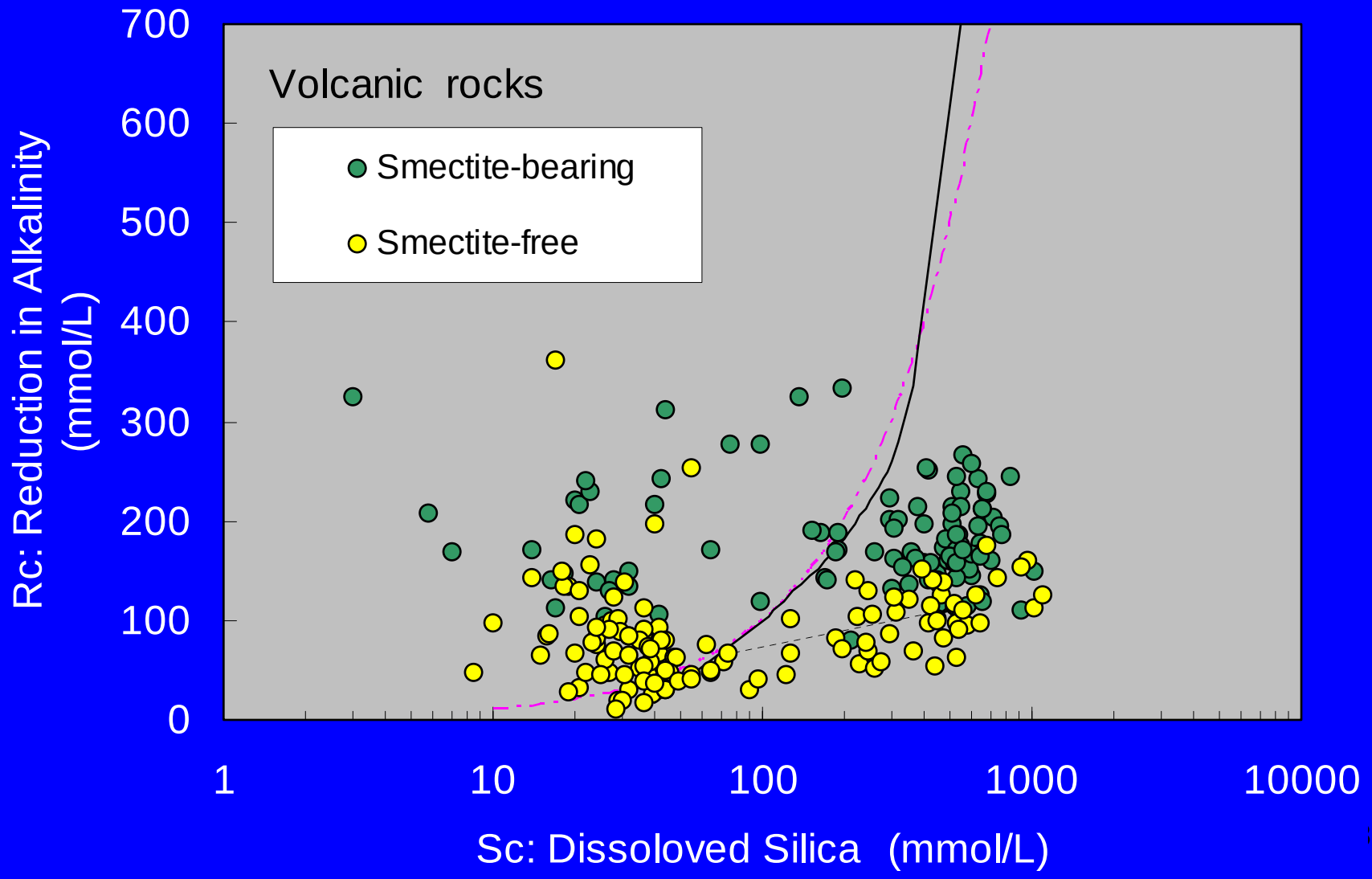
Size of the circles indicates specific surface area

Factors controlling Sc



Crystallinity indices of quartz are determined by the method of Murata & Norman (1976)

Main factors controlling Rc



Conclusion of alkali-silica reactivity of minerals

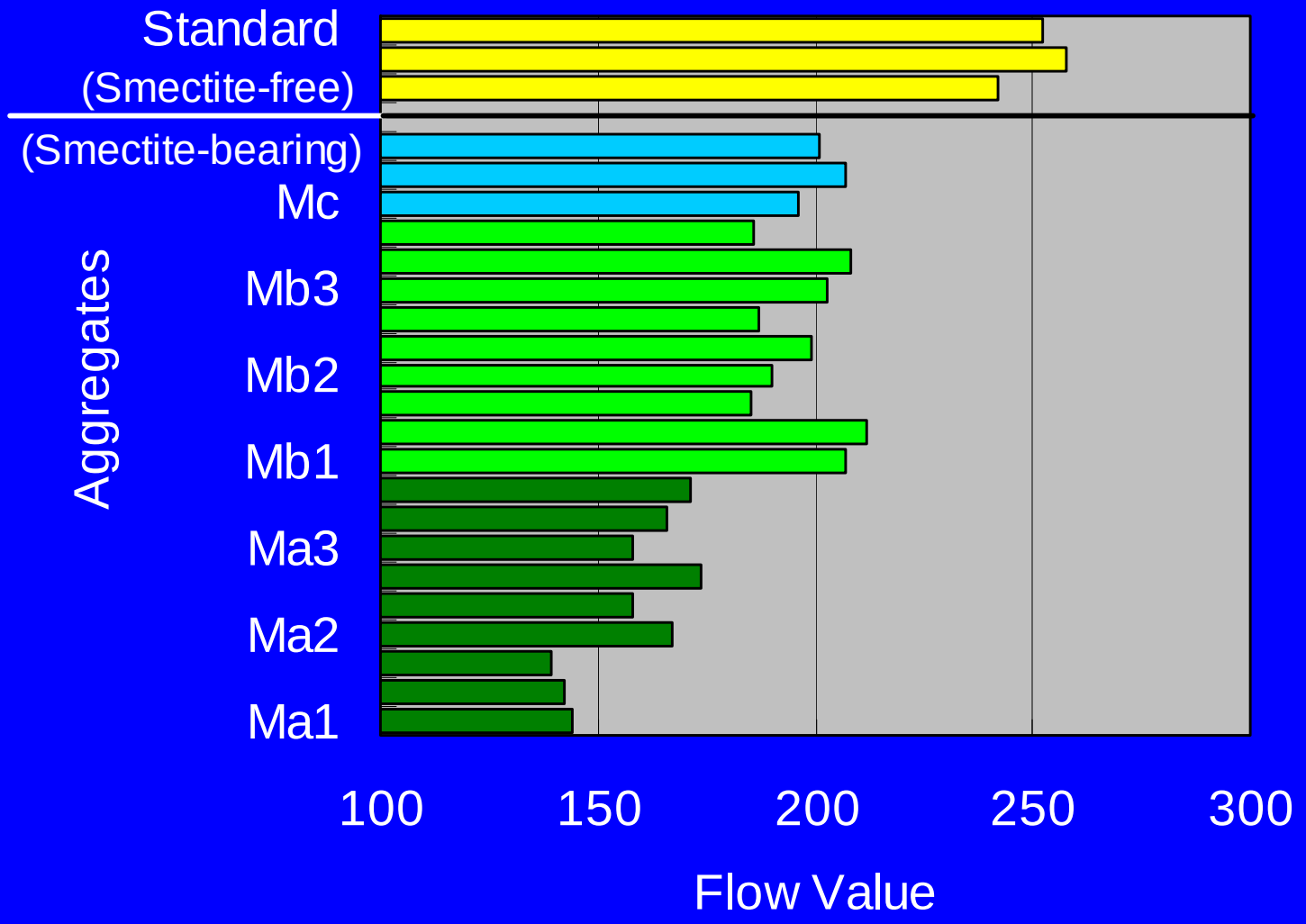
- Dissoloved silica of minerals is controlled by SiO_2 content, grain size, specific surface area, crystallinity index and X-ray crystallographical grain size.
- Reduction in alkalinity of minerals is controlled by grain size and ion exchangeability.

3. Smectite

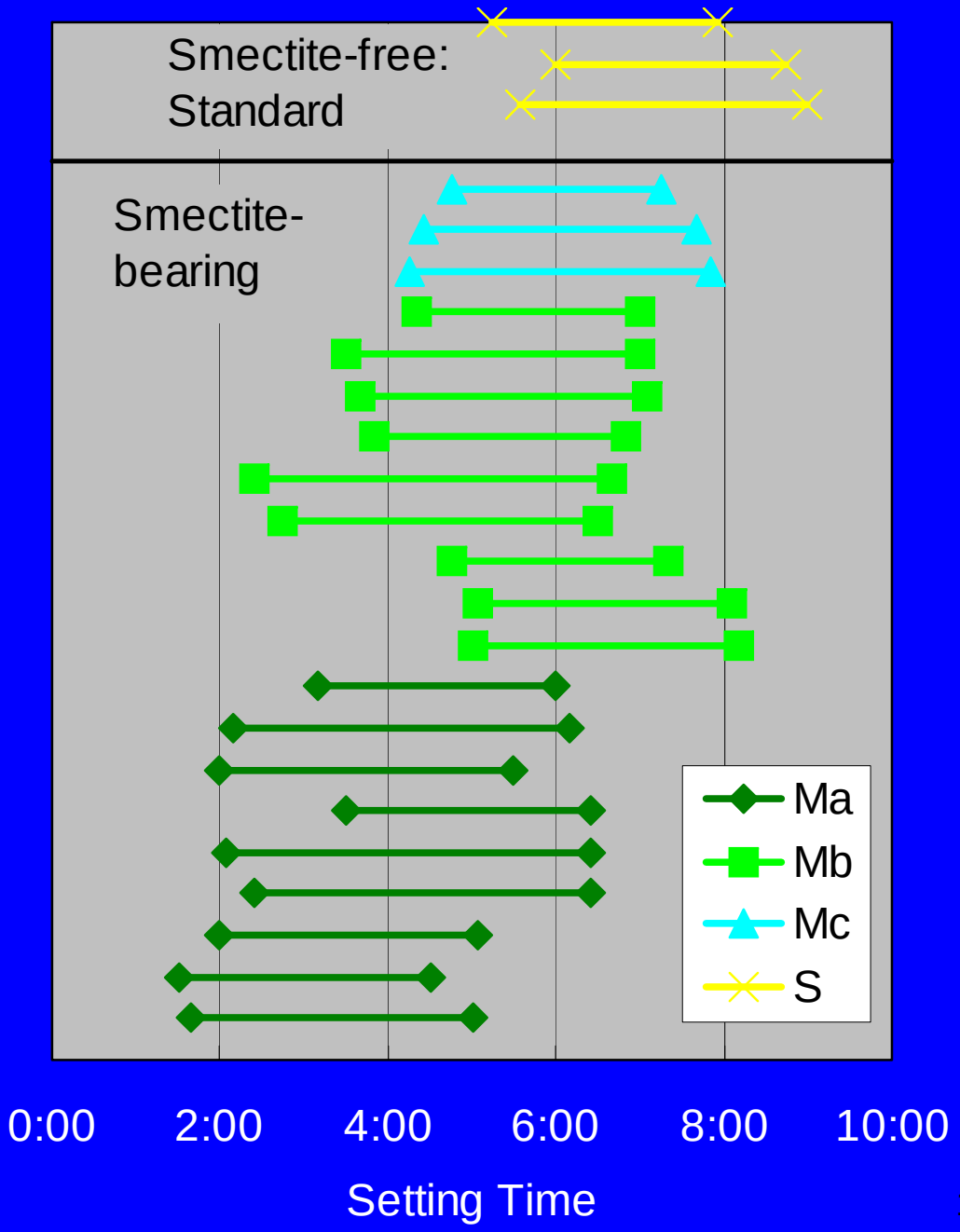
- Mineralogy of smectite
  - Expand by absorption of water in interlayer
  - High water absorption
  - Cation exchangeable
  - Occurrence: weathered parts, hydrothermally altered parts
- Quality drop of concrete due to smectite
  - Expansion, cracking
  - Shrinkage
  - Accelerated setting was reported since 1985 in Japanese dams


Flow of the mortar which contain
smectite-bearing aggregate

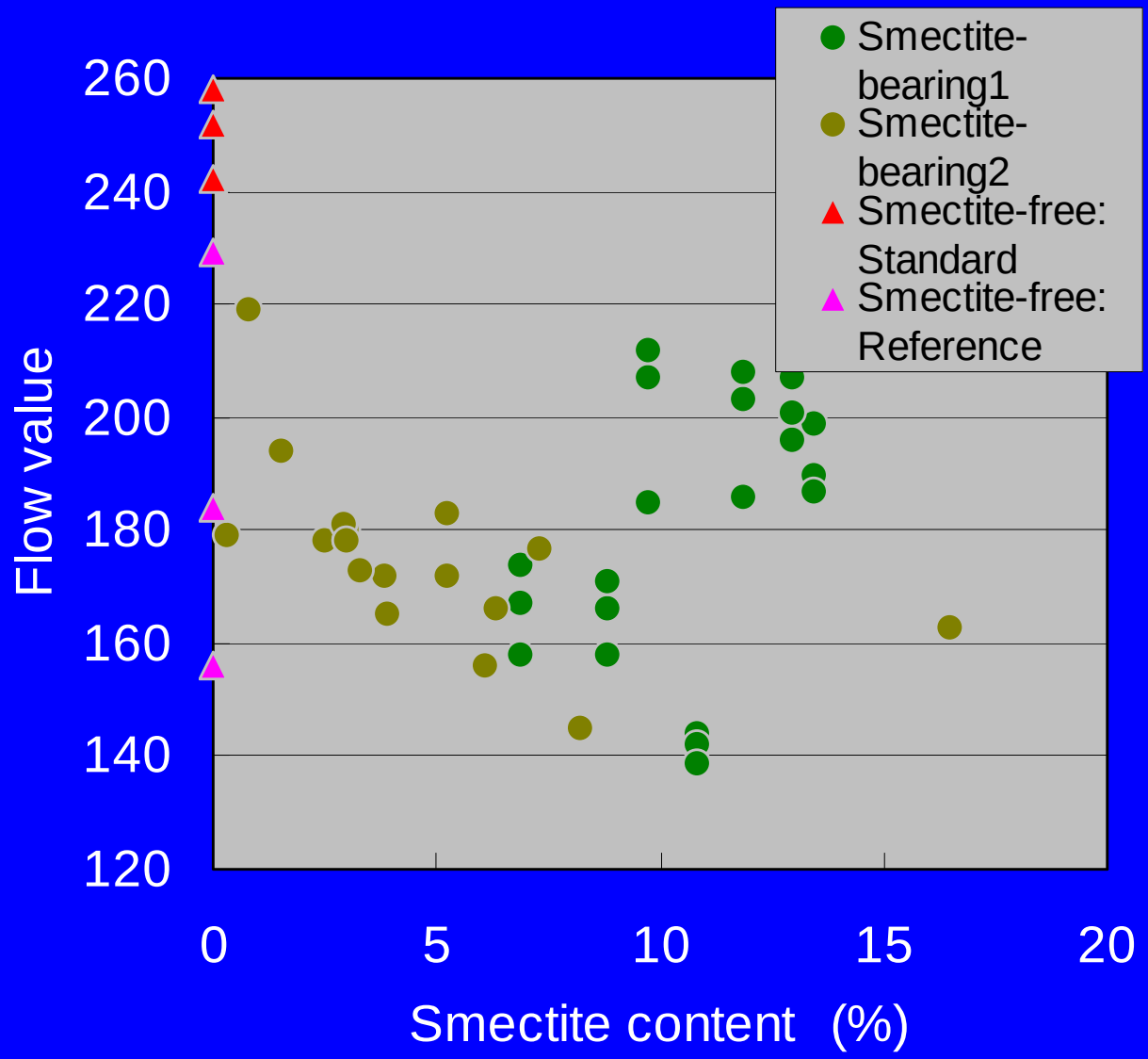
Flow value of mortar which contain smectite-bearing aggregates



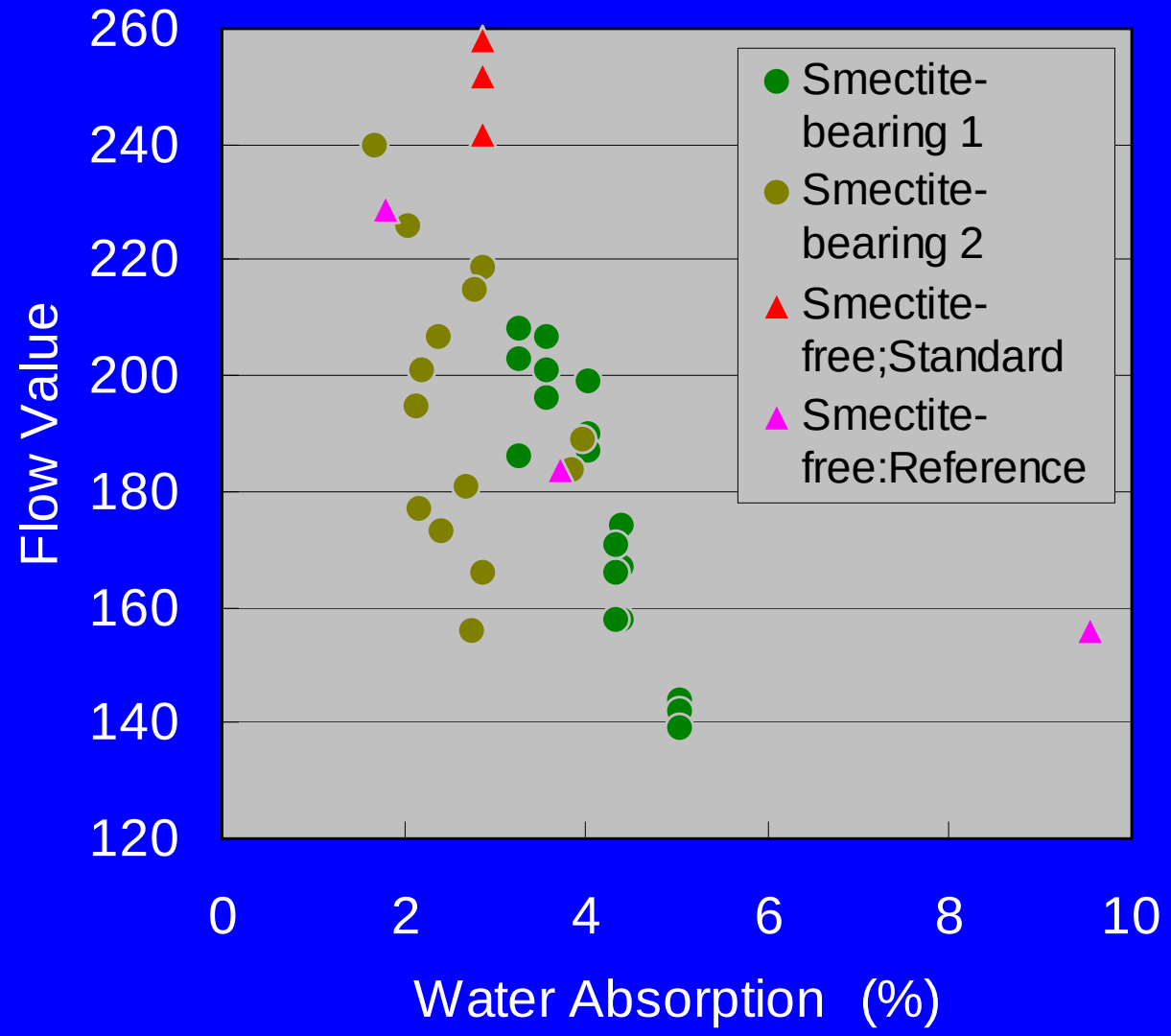
Setting time of mortar which contain smectite-bearing aggregates



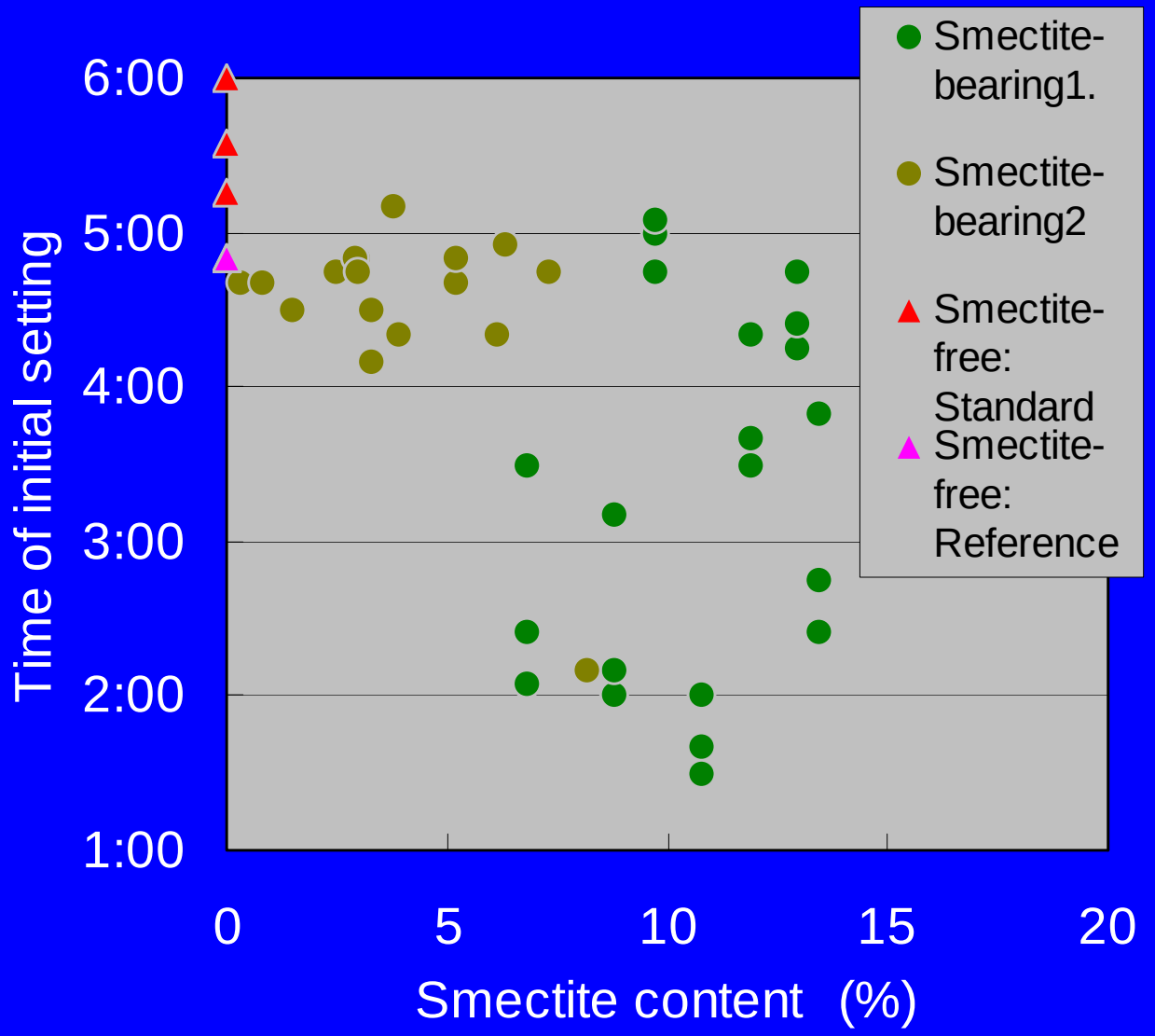
Smectite content and flow value



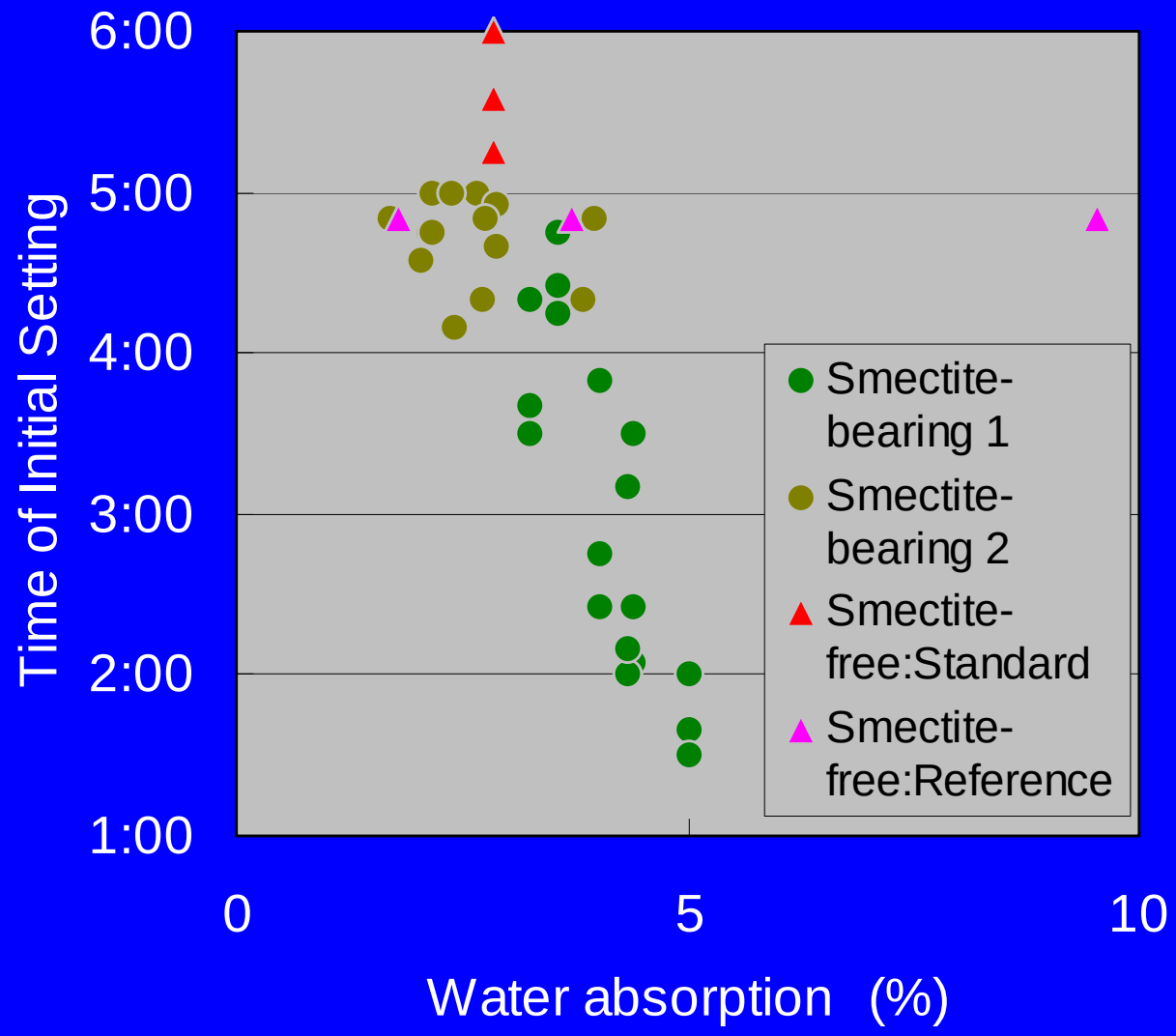
Water absorption and flow value



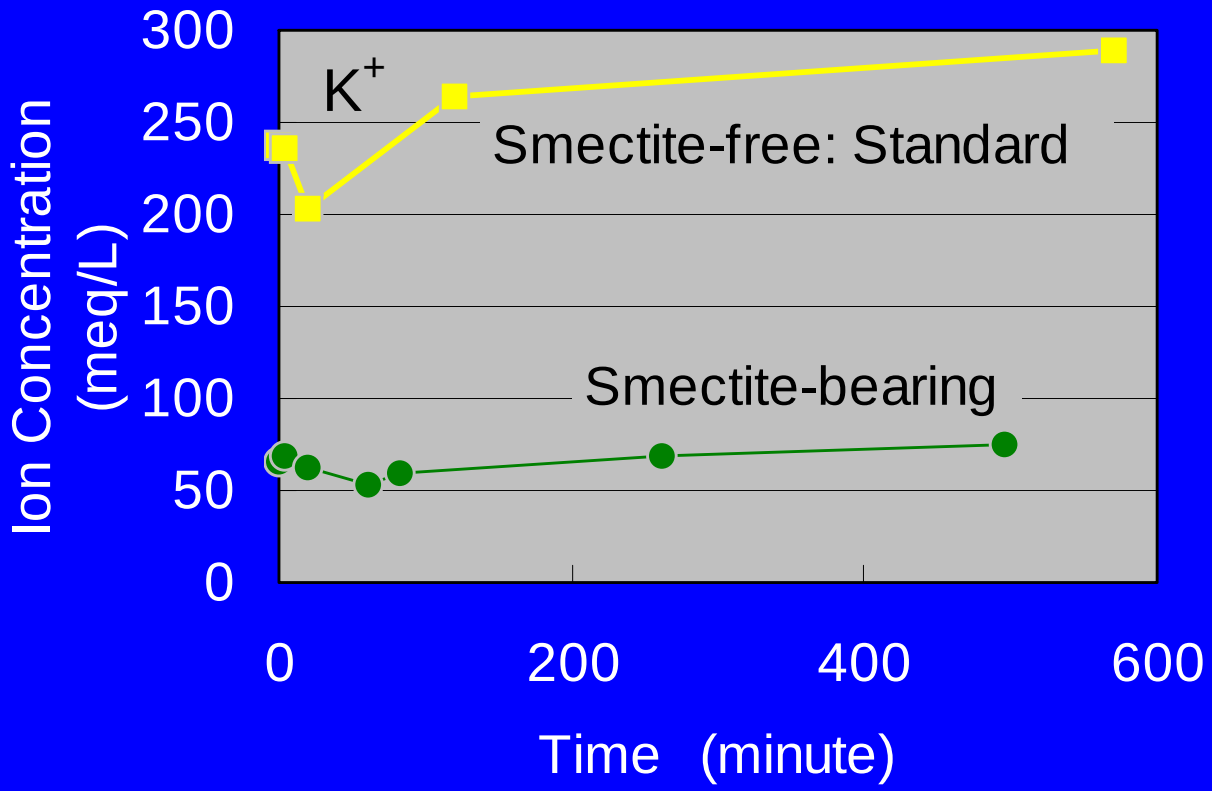
Smectite content and time of initial setting



Water absorption and time of initial setting



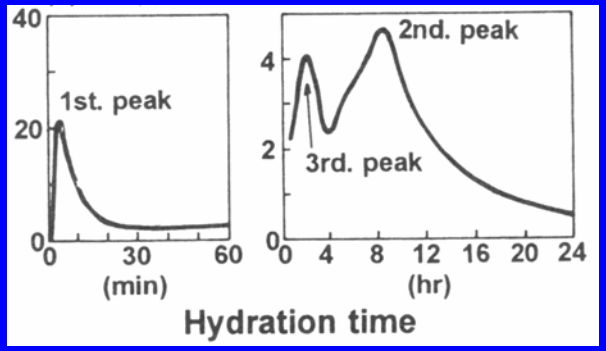
Chemical composition of mortar pore solution



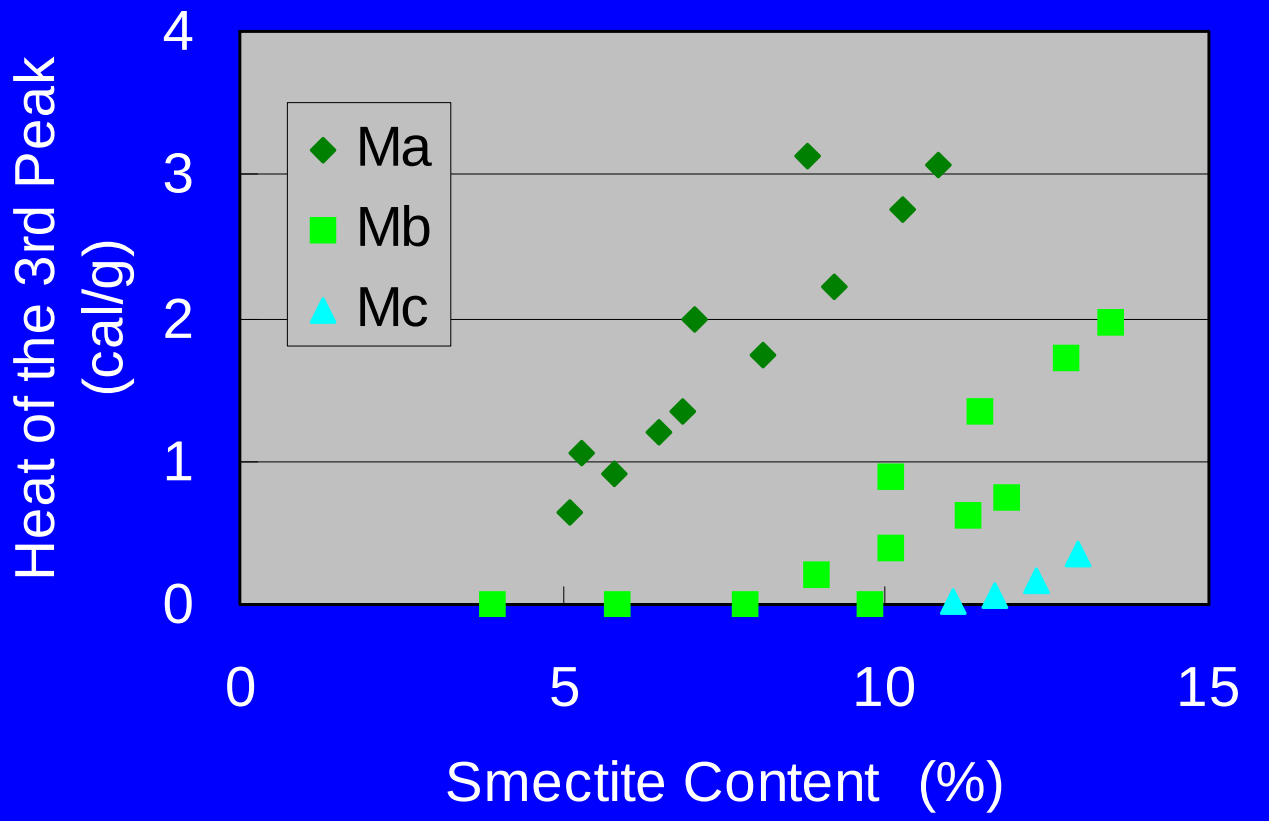
Smectite absorbs K^+ ions in mortar pore solution

Ca^{2+} ions in smectite are released into mortar pore solution

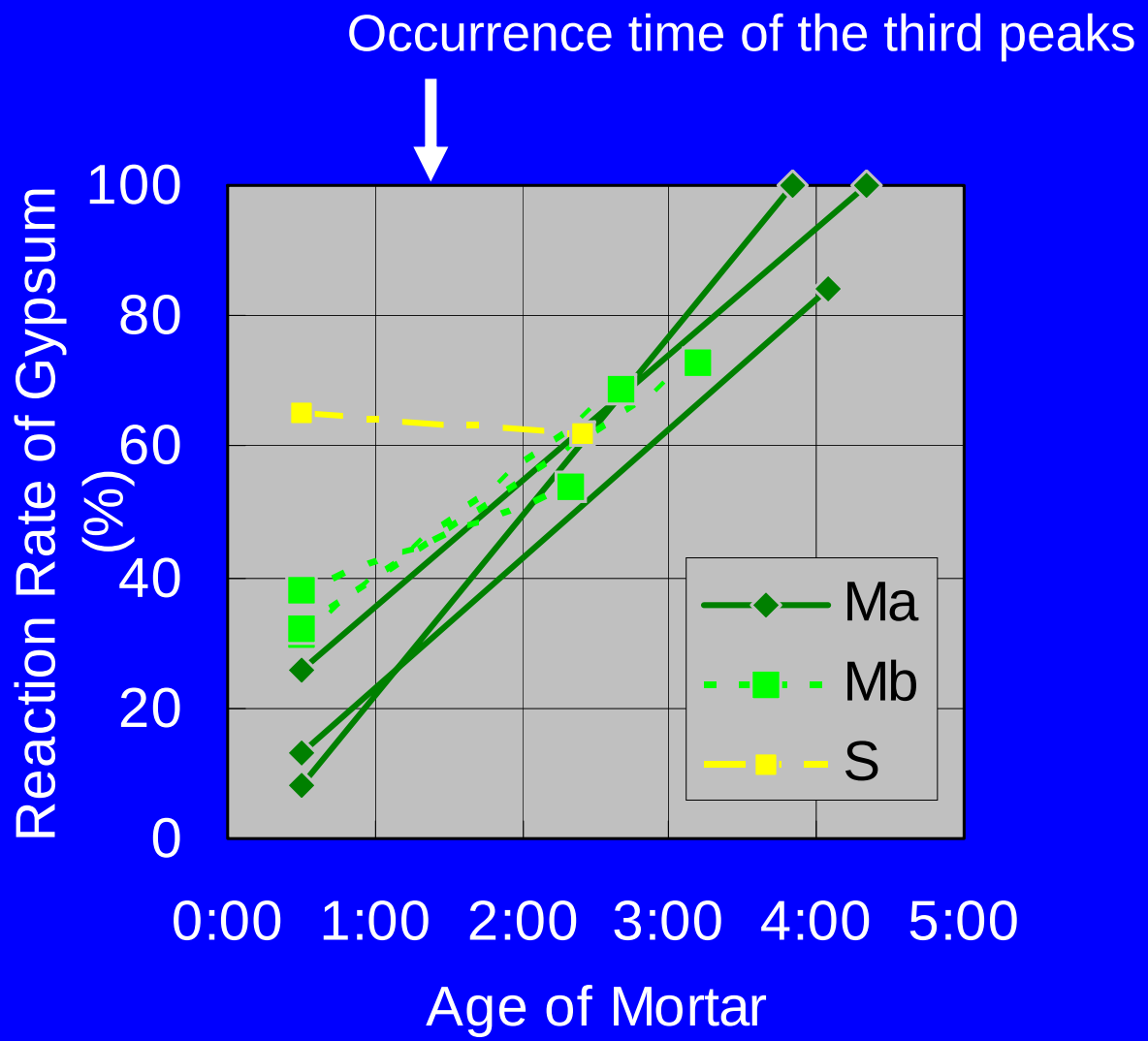
Hydration process



In general, 3rd peak appears when C_3A content is higher than normal cement, or gypsum content is lower than normal cement.



Reaction rate of gypsum



Hydration of alminate phase

1. In the case of sufficient gypsum is added

- Hydration of C_3A is slow, because ettringite cover surface of C_3A particles.

$$C_3A + 3CSH_2 + 26H = C_6AS_3H_{32}$$

Alminate Gypsum Water Ettringite

2. In the case of gypsum is not added

- Fast setting occurs due to the following reaction.

$$2C_3A + 21H = C_4AH_{13} + C_2AH_{18}$$

$$C_4AH_{13} + C_2AH_{18} = 2C_3AH_6 + 9H$$

Hydro-garnet

Mechanism of accelerated setting by smectite

1. Ion exchange occurs between Ca^{2+} in smectite and K^{+} in mortar pore solution.
2. Then, Ca^{2+} ions release into mortar pore solution.
3. Decomposition of gypsum is controlled, because Ca^{2+} ions are already existed in the mortar pore solution.
4. Ettringite do not cover the surface of C_3A particles.
5. Consequently, fast setting of C_3A occurs.

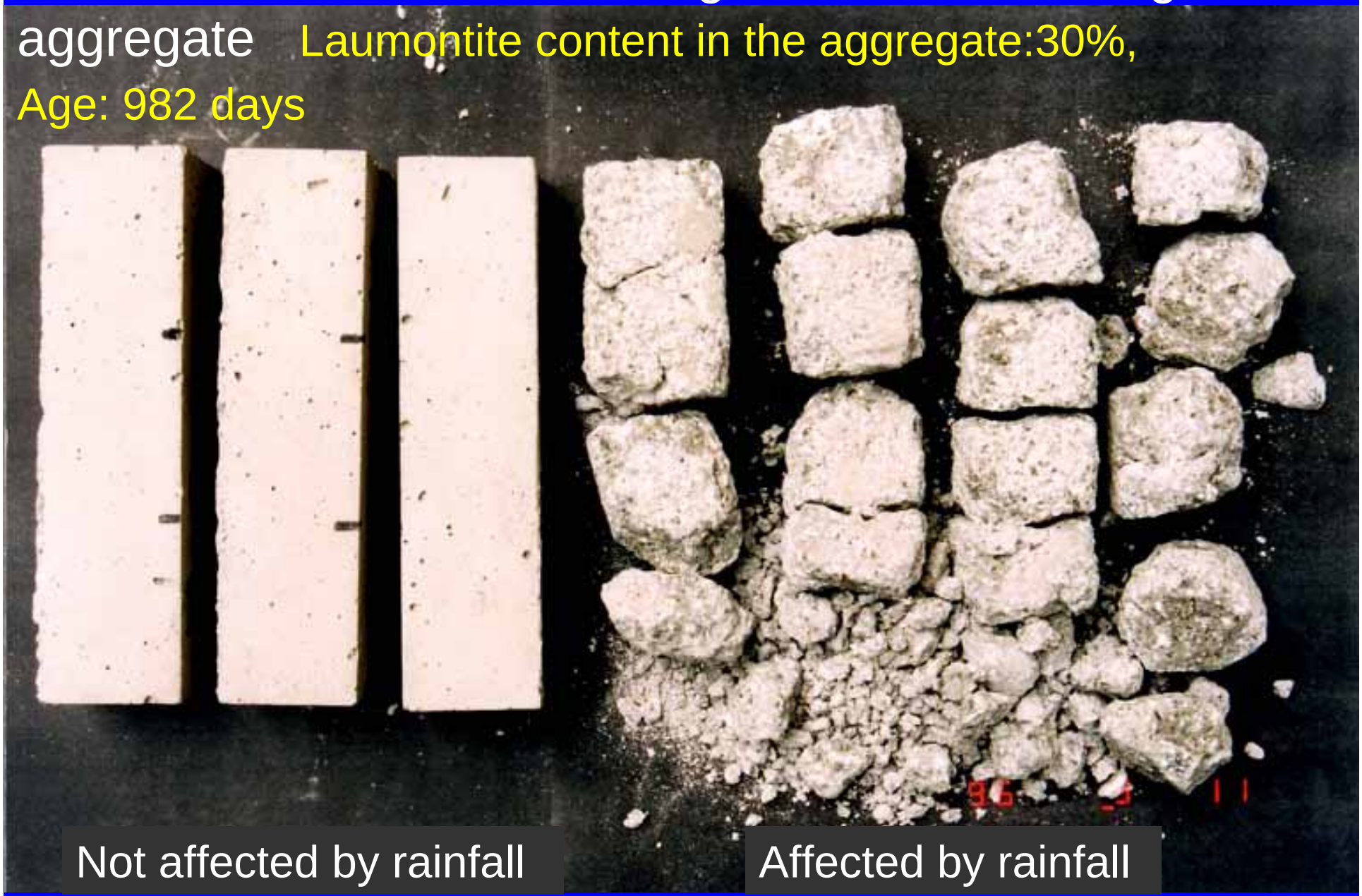
Effective utilization of smectite-bearing aggregates

- Super retarder which is composed of oxycarboxylic acid is effective to control the accelerated setting.
- In Japanese dams such as Jozankei-dam, Asesigawa-dam, Miyagase-dam, Takou-dam, super retarder was used to control the accelerated setting.
- Use of super retarder do not affect physical properties of concrete.

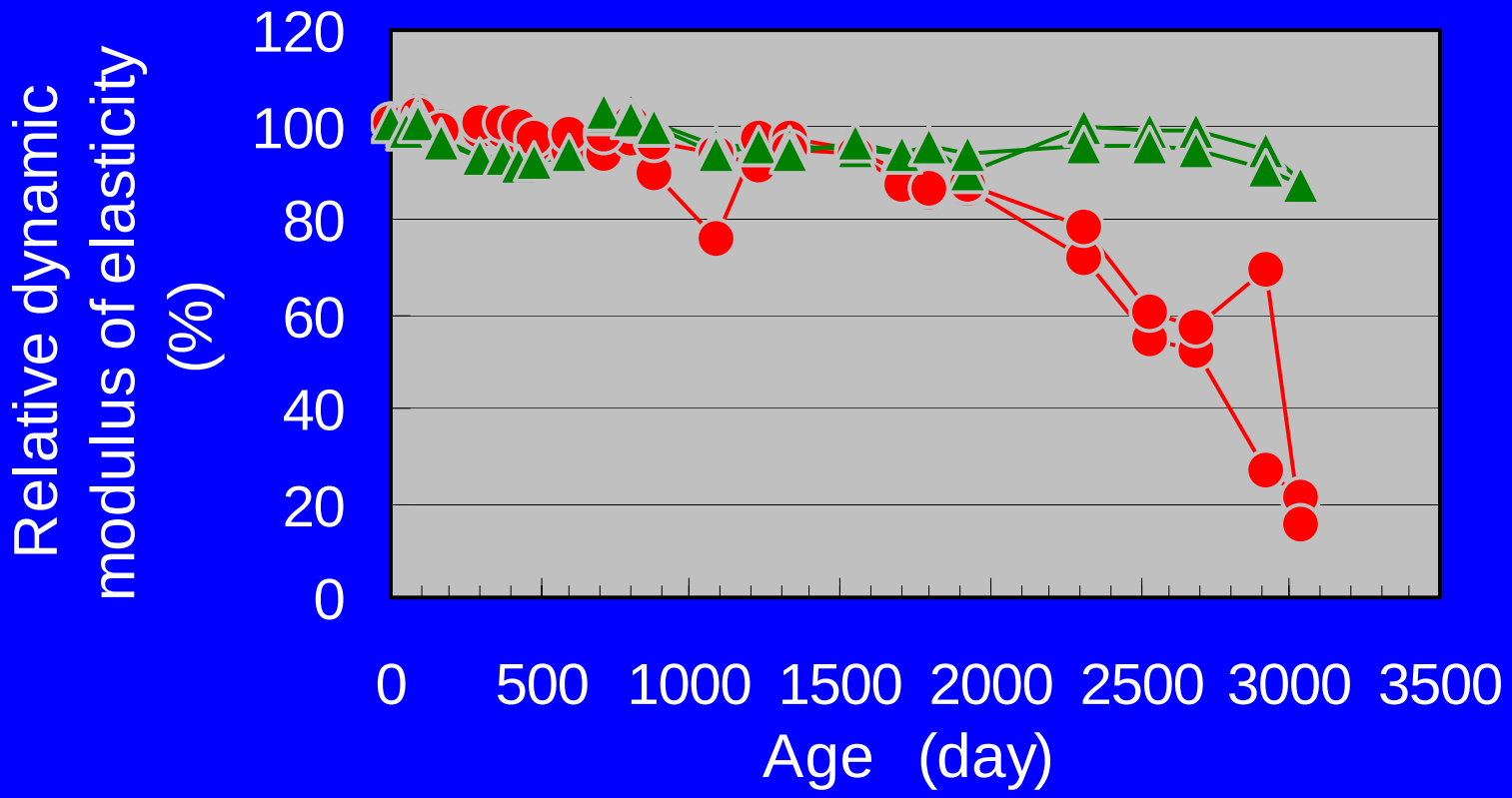
4. Laumontite

- Mineralogy of laumontite
  - Laumontite is converted to leonhardite by dehydration.
  - This conversion accompanied with volume change.
  - Occurrence: Hydrothermally altered parts, as cement material in sedimentary and volcano-clastic rocks
- Quality drops of concrete due to laumontite
  - Deterioration
  - Deleterious effect by seawater
  - Pop-outs of concrete surface in Japanese dams

● Deterioration of mortar using laumontite-bearing aggregate Laumontite content in the aggregate:30%, Age: 982 days



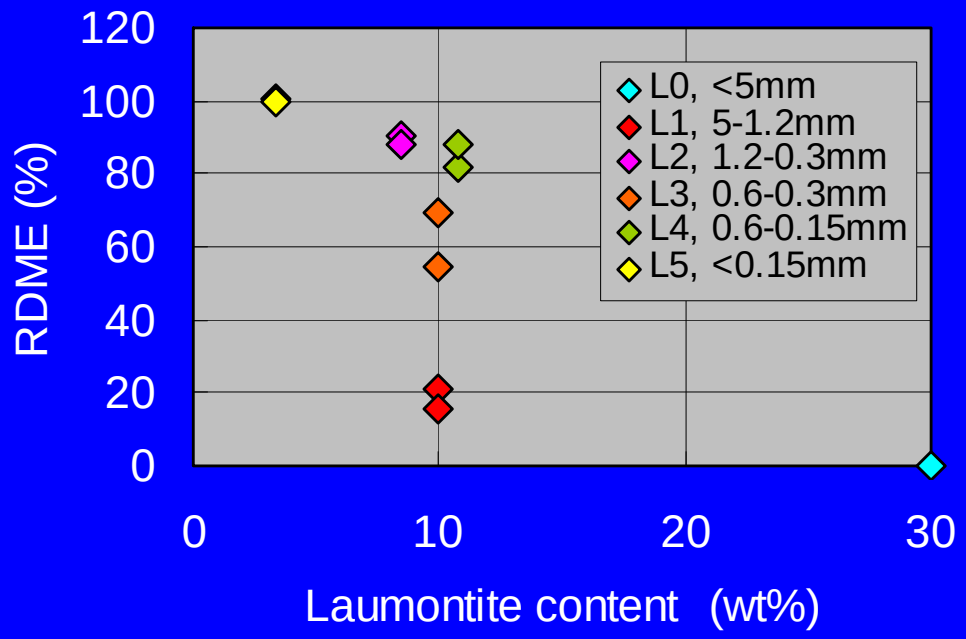
Results of exposure tests

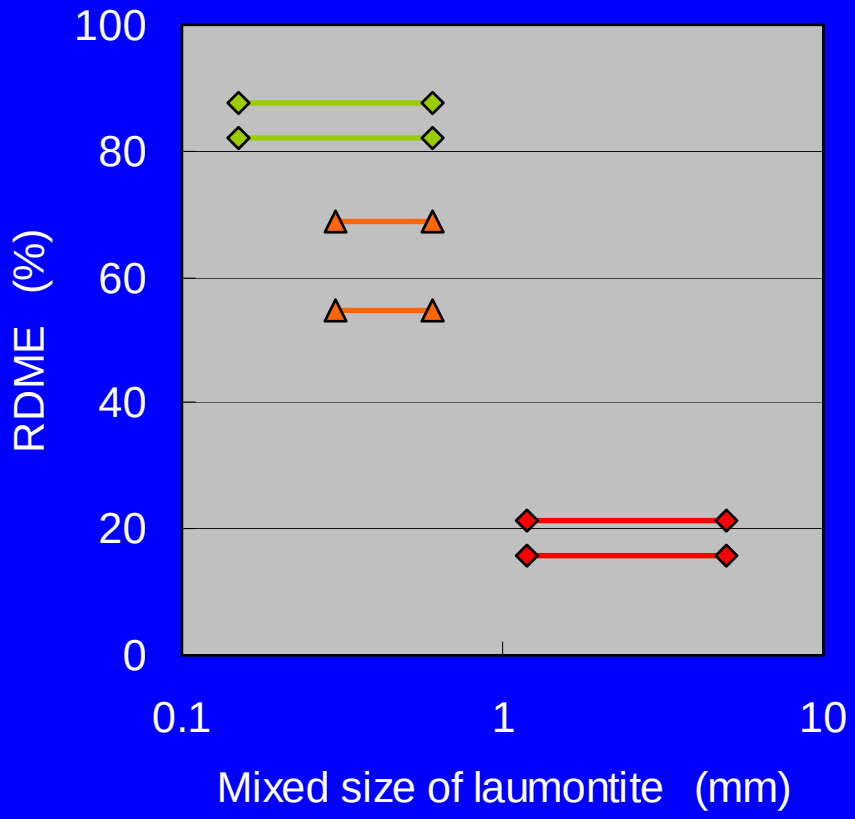


Laumontite content in the aggregate: 10%

Grain size of the laumontite-bearing aggregate: 5 mm

Influence of content and grain size of laumontite

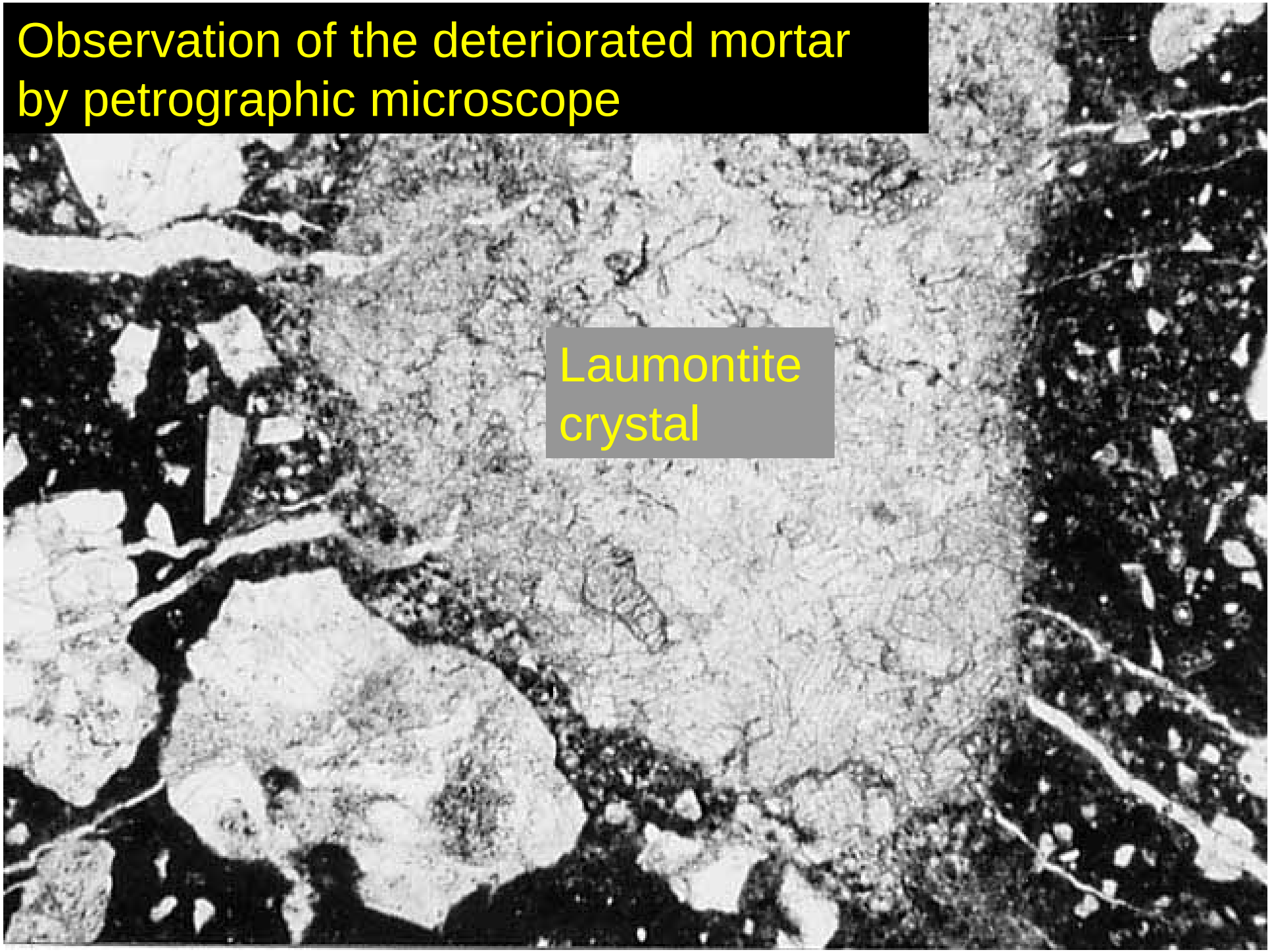




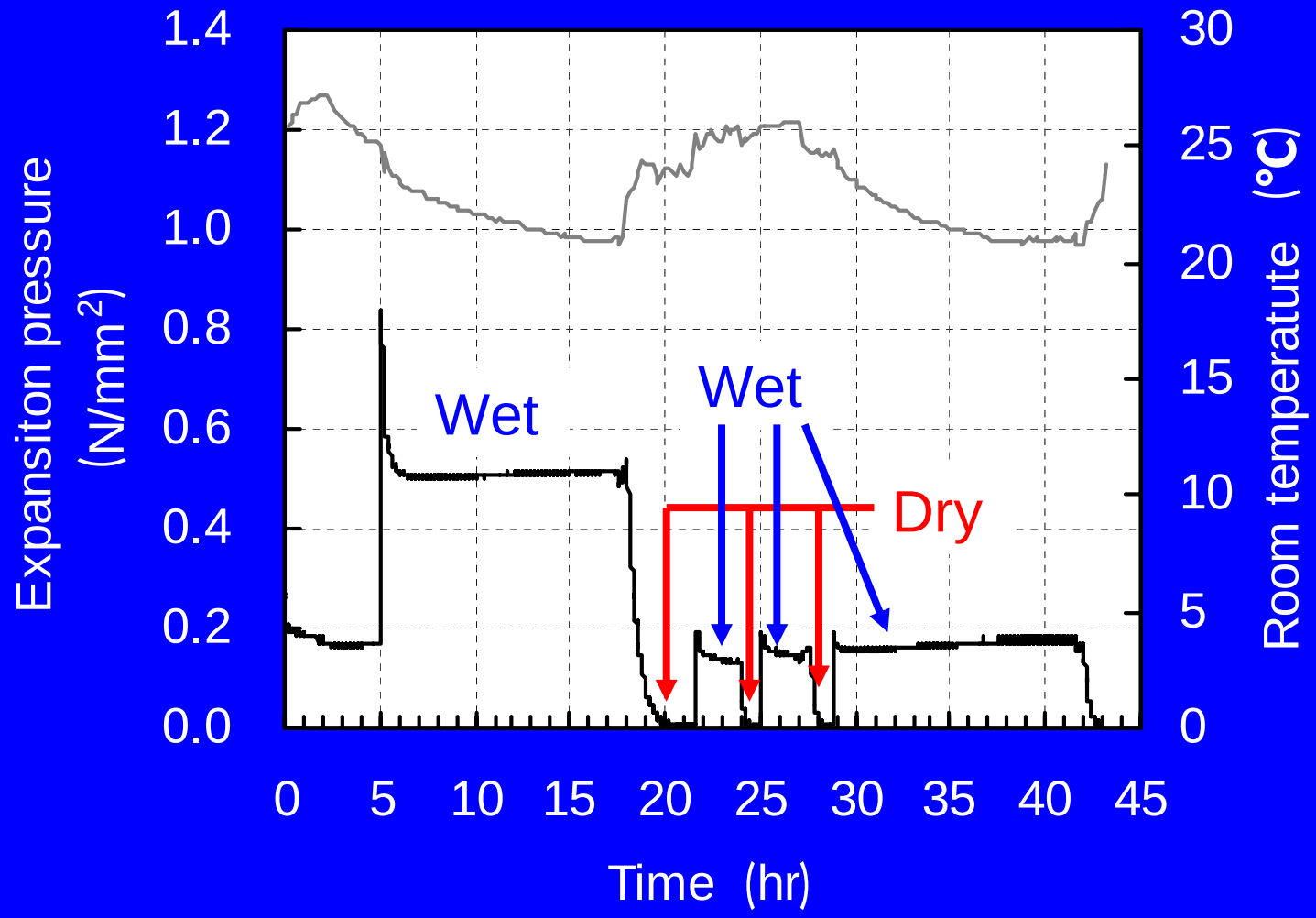
(REMD: relative dynamic modulus of elasticity)

Laumontite content in the aggregate: approx. 10%

Observation of the deteriorated mortar by petrographic microscope



A result of expansion pressure measurements



Conclusion of laumontite

- Deterioration of concrete due to laumontite is cracking, exholiation.
- Relative dynamic modulus of elasticity of mortar which contaion laumontite bearing aggregates is correlated with laumontite content and size of laumontite.
- Expansive pressure is produced when leonhardite-laumontite converision occurs. Expansive pressure is repeatedly occurs.
- Deterioration of concrete is caused by repeat of expansion pressure.

5. Conclusion

- Some of abnormal phenomena of concrete are caused by harmful minerals.
- Therefore, mineralogical studies are important to understand the abnormal phenomena and its mechanism.

Mineralogical indicators for quality drop of concrete

Mineralogical indicators	Minerals	Quality drop of concrete
Content in aggregate	All minerals	
Chemical composition	Pyrite	Deteriorartion
SiO_2 content	Silica mimerals, volcanic glass	Alkali-silica reaction
$CaCO_3$ content	Carbonate	Thaumasite formation
Thermodynamic stability	Cristobalite, tridymite, volocanic glass	Alkali-silica reaction
Grain size, specific surface area	Quartz	Alkali-silica reaction
	Mica	Decreasing flow value, decreasing strength, decreasing resistance for freezing & thawing
	Laumontite	Deterioration (pop-out)
Ion exchange	Smectite	Accelerated setting
Expansion (shrinkage)	Smectite	decreasing strength, decreasing durability, dry shrinkage
	Smectite-mixed layer min.	
	Vermiculite	
	Laumontite	Deterioration (pop-out)
	Brucite/coalingite	Pop-out
Water absorption	Smectite	Decreasing flow value
	Smectite-mixed layer min.	
	Vermiculite	
Form	Mica	Decreasing flow value, decreasing strength, decreasing resistance for freezing & thawing