Probabilistic Assessment of Long-Term Vault Durability in a Sulfate-Bearing Waste Environment

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Cementitious Materials for Waste Treatment, Disposal, Remediation, and Decommissioning Workshop
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Presentation Outline

- **Saltstone Waste Disposal**
- **Performance Criteria**
- **Concrete Vault Degradation by Sulfate Attack**
- **Sulfate Delivery Modes**
- **Preliminary Geochemical Batch Analyses**
- **Probabilistic Modeling Approach**
- **Results and Assessment**

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"Saltstone" Waste Disposal

- **36 million gallons of liquid radioactive waste at Savannah River Site (SRS)**
- **Most radioactivity will be vitrified and disposed off-site**
- **Remaining waste comprises a low activity salt solution and most of the original volume**
- **To be mixed with dry cement, fly ash and blast furnace slag mix, and poured into on-site vaults**
- **Entombed, solidified, waste is termed "saltstone"**

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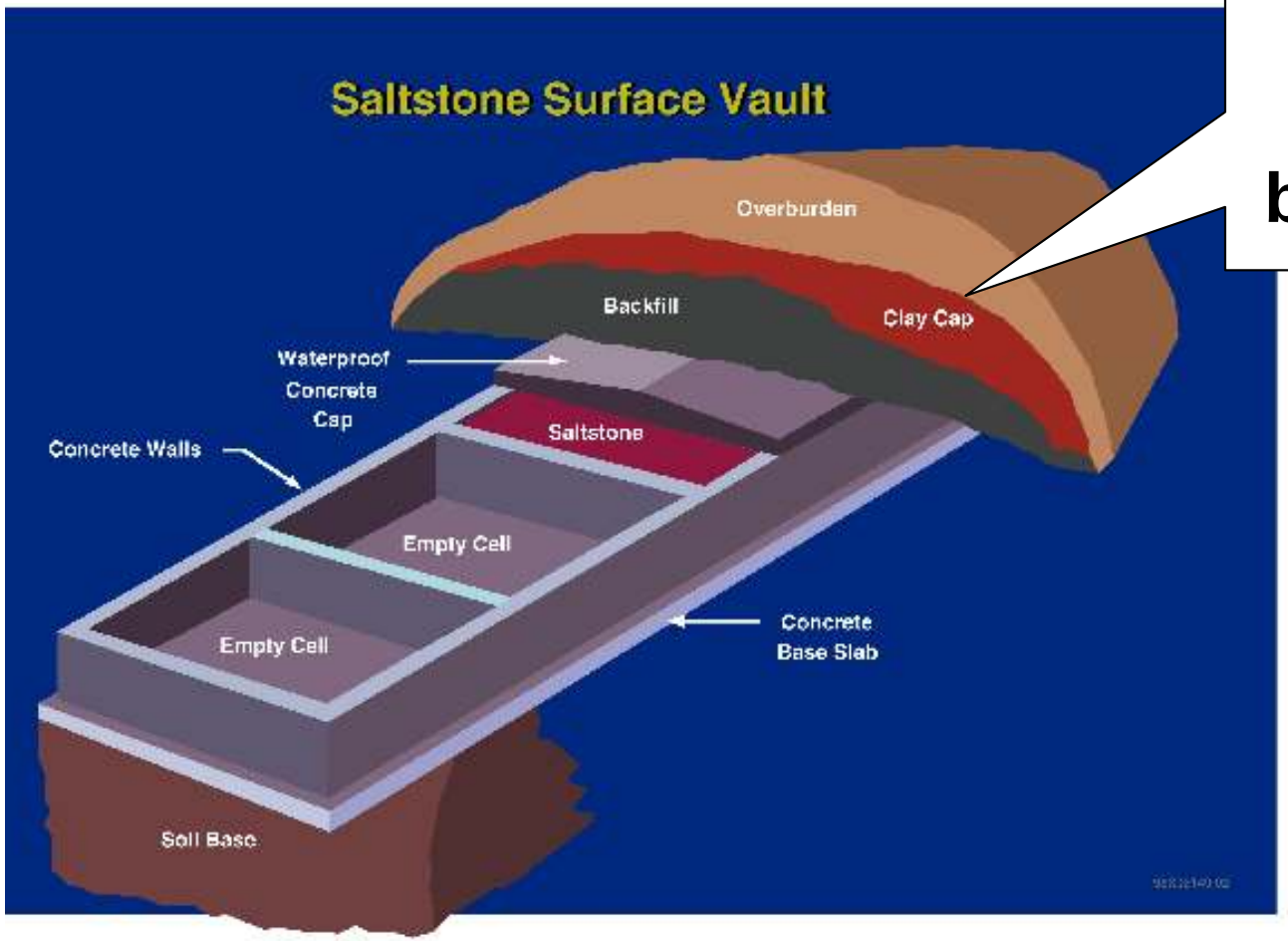
Saltstone Facility Closure

Multi-layer intruder and infiltration barrier system



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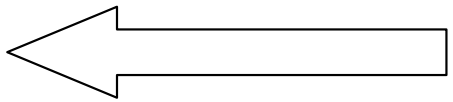
Saltstone Facility Performance Criteria

- **DOE Order 435.1 "Radioactive Waste Management"**
- **10 CFR Part 61 (NRC) "Licensing Requirements for Land Disposal of Radioactive Waste"**
  - **invoked by Section 3116 of NDAA 2005 for non-High Level Waste determinations**
- **Groundwater related criteria**
  - **25 mrem/yr all-pathways dose limit**
  - **groundwater protection (EPA MCLs)**
  - **10,000 year period of performance**



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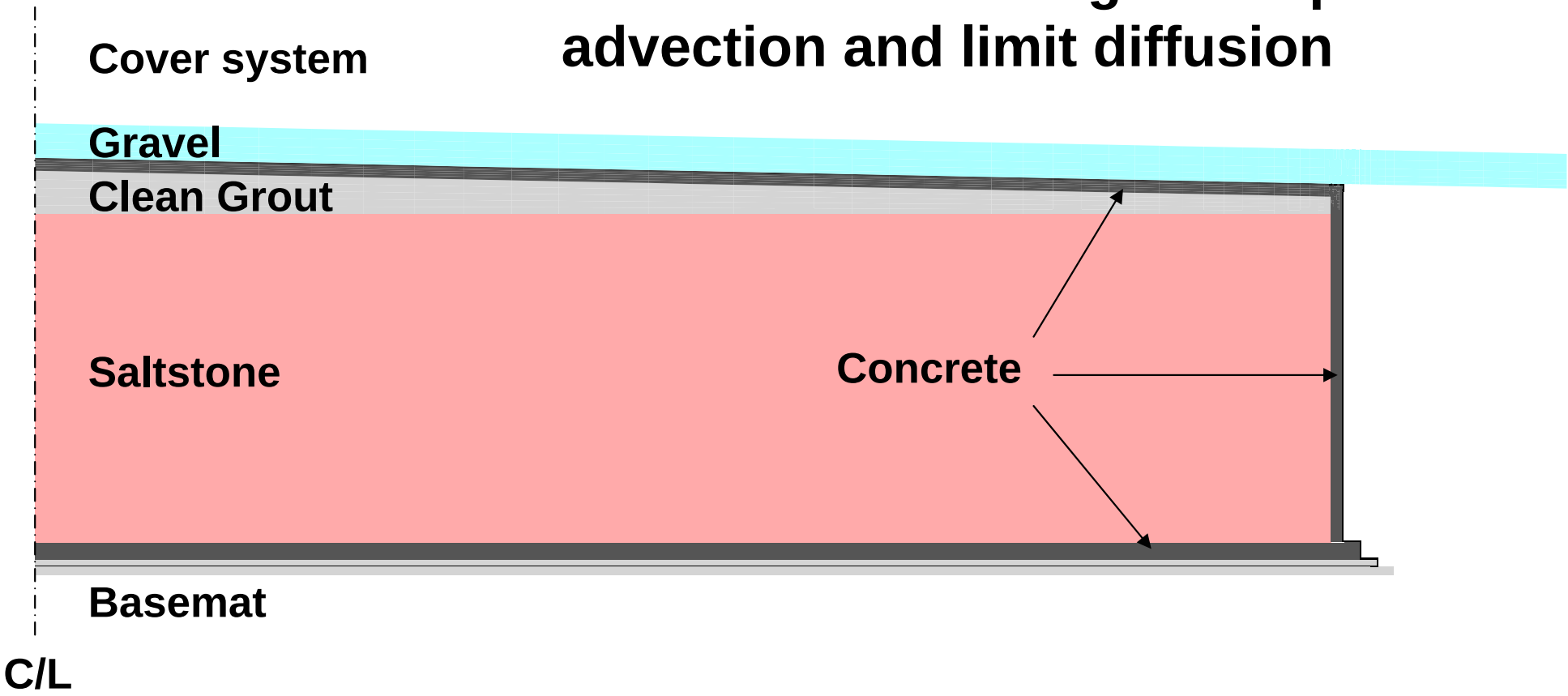
Concrete Containment Barrier

Concrete vault designed to prevent advection and limit diffusion



? How will concrete perform over 10,000 years?

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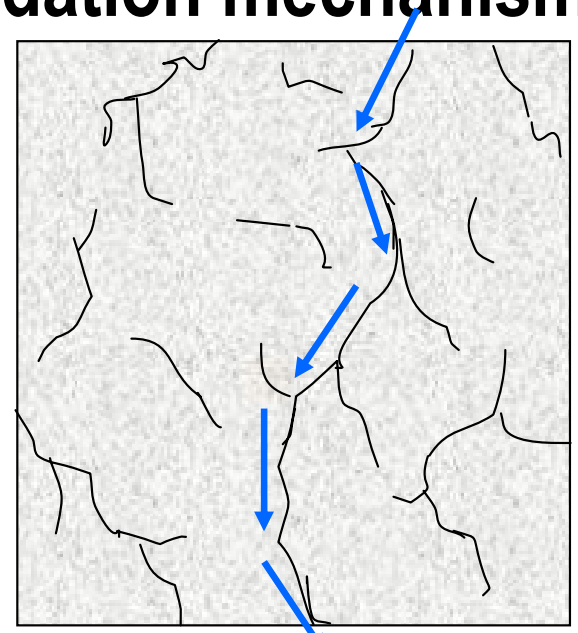
Concrete Degradation

- **Saltstone feed water**
  - approximately 0.1 M or 10,000 mg/L sulfate
  - enables formation of ettringite (expansive mineral phase)
- **Sulfate attack identified as main degradation mechanism**
  - attack occurs from inside of vault
  - soil sulfate level is low
- **Potential impact on vault performance**
  - cracking and advective release



A. Garrabrants

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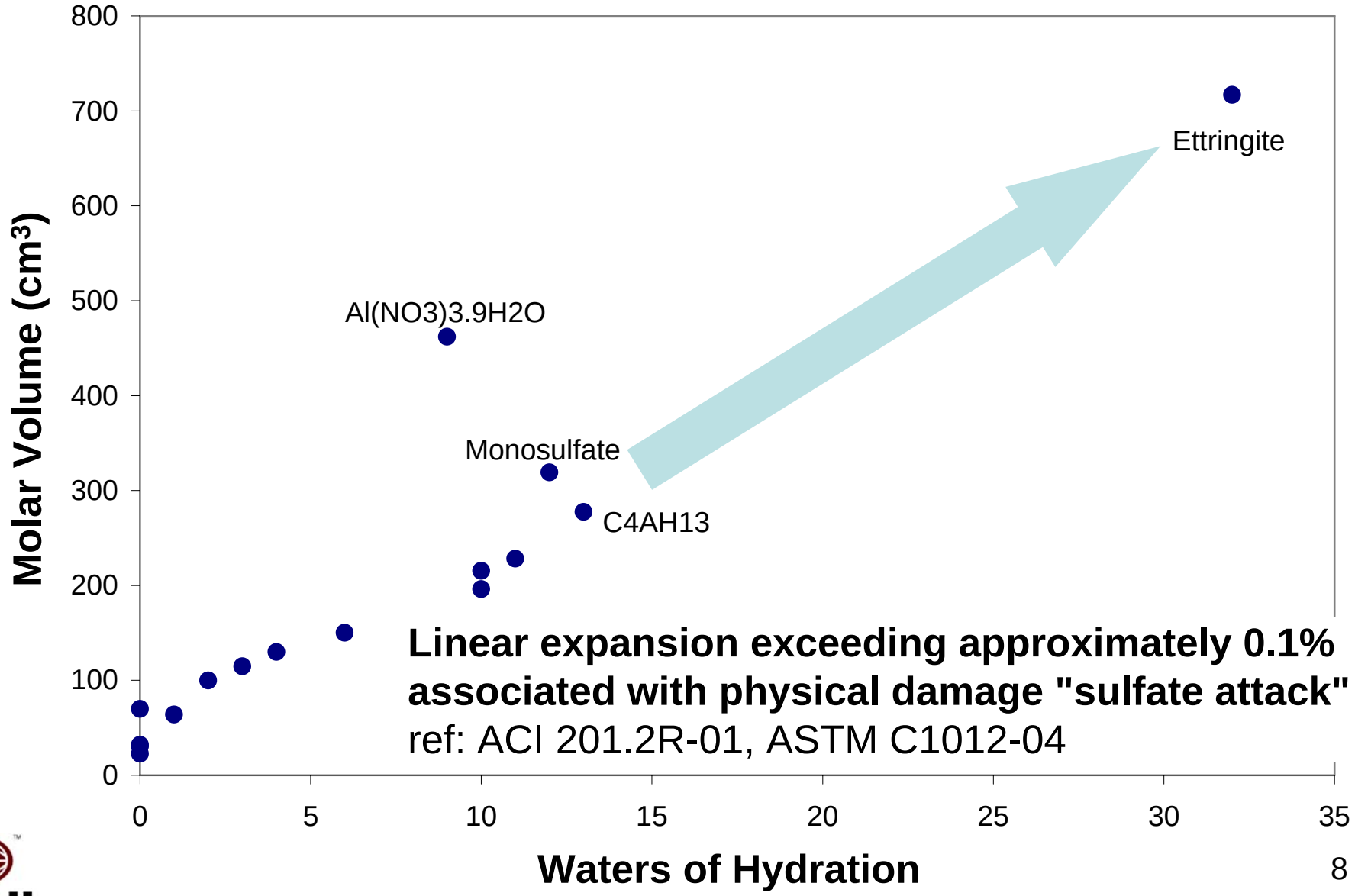
Ettringite as an Expansive Mineral Phase



Linear expansion exceeding approximately 0.1% associated with physical damage "sulfate attack"

ref: ACI 201.2R-01, ASTM C1012-04

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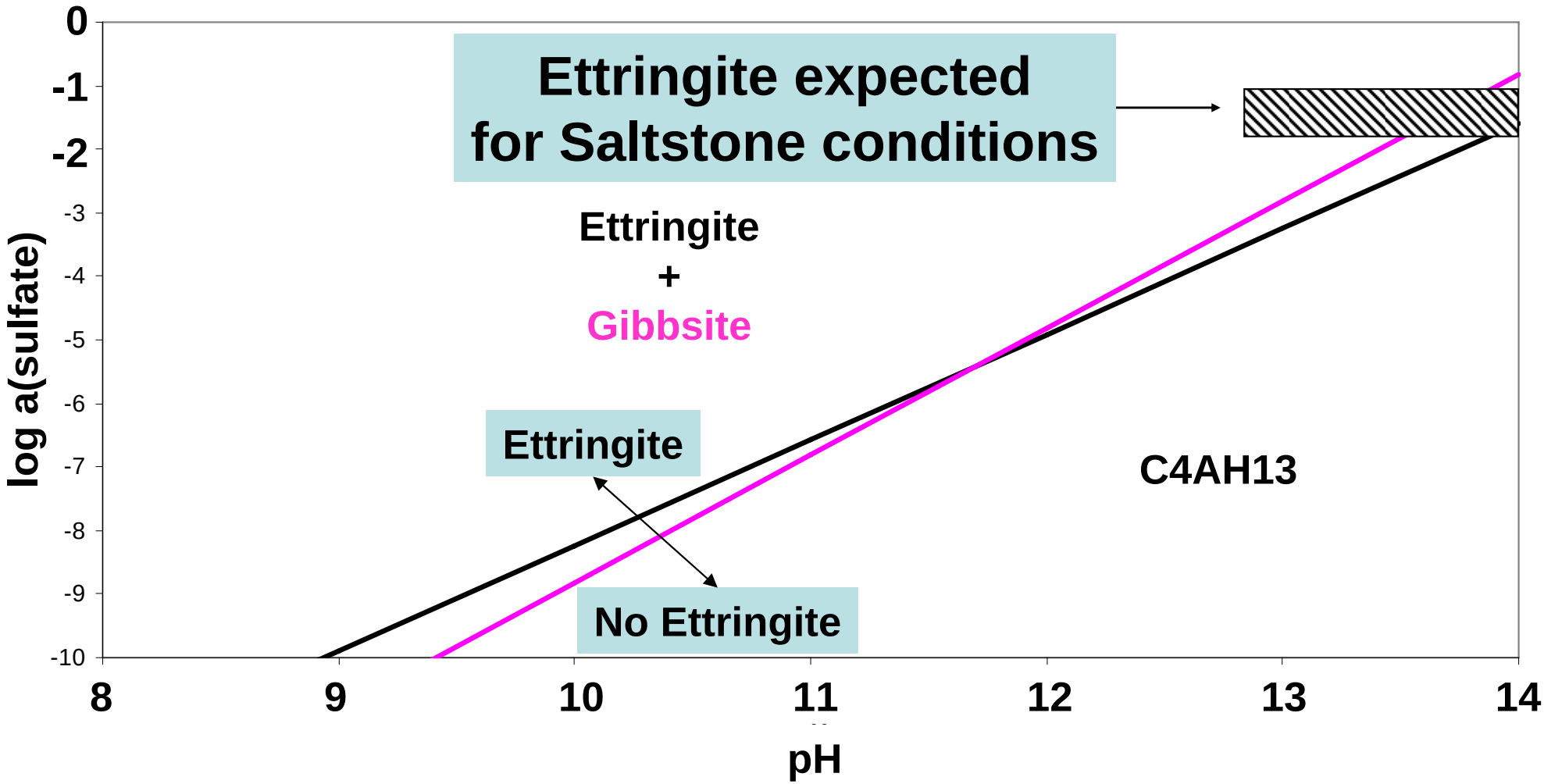
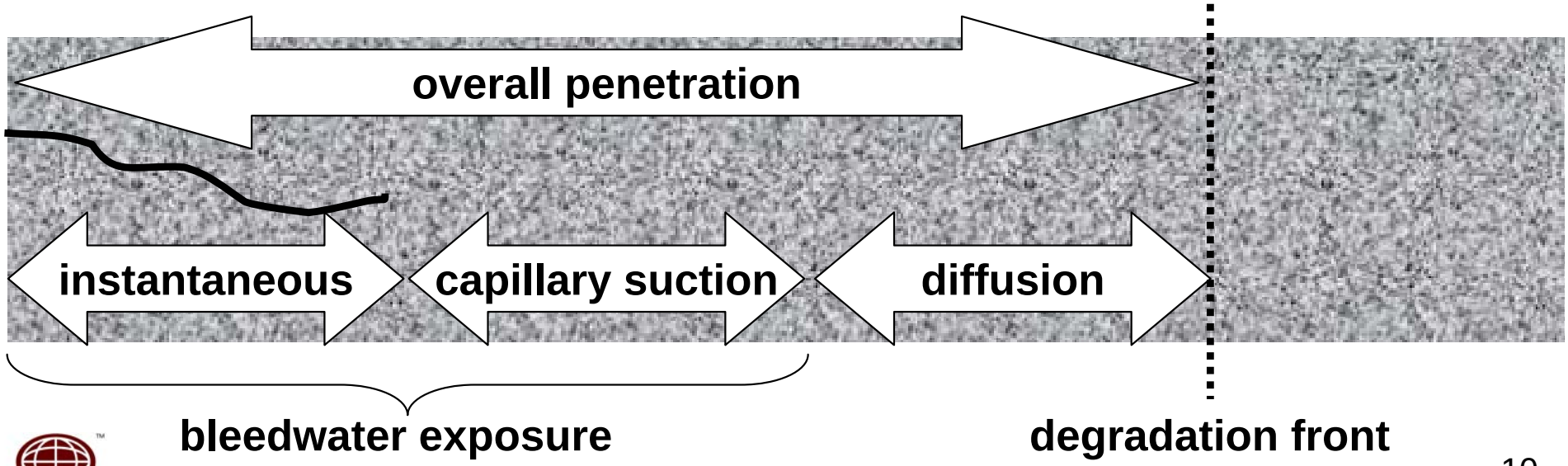
Ettringite Presence vs. pH and SO_4



Sulfate Delivery Modes

- **Bleedwater penetration**
  - **through 0 to 0.5" / 1.3 cm surface cracks (instantaneous)**
  - **by capillary suction into "dry" vault**
- **Sulfate diffusion from pore water in cured saltstone**
  - **long-term sulfate delivery mechanism**



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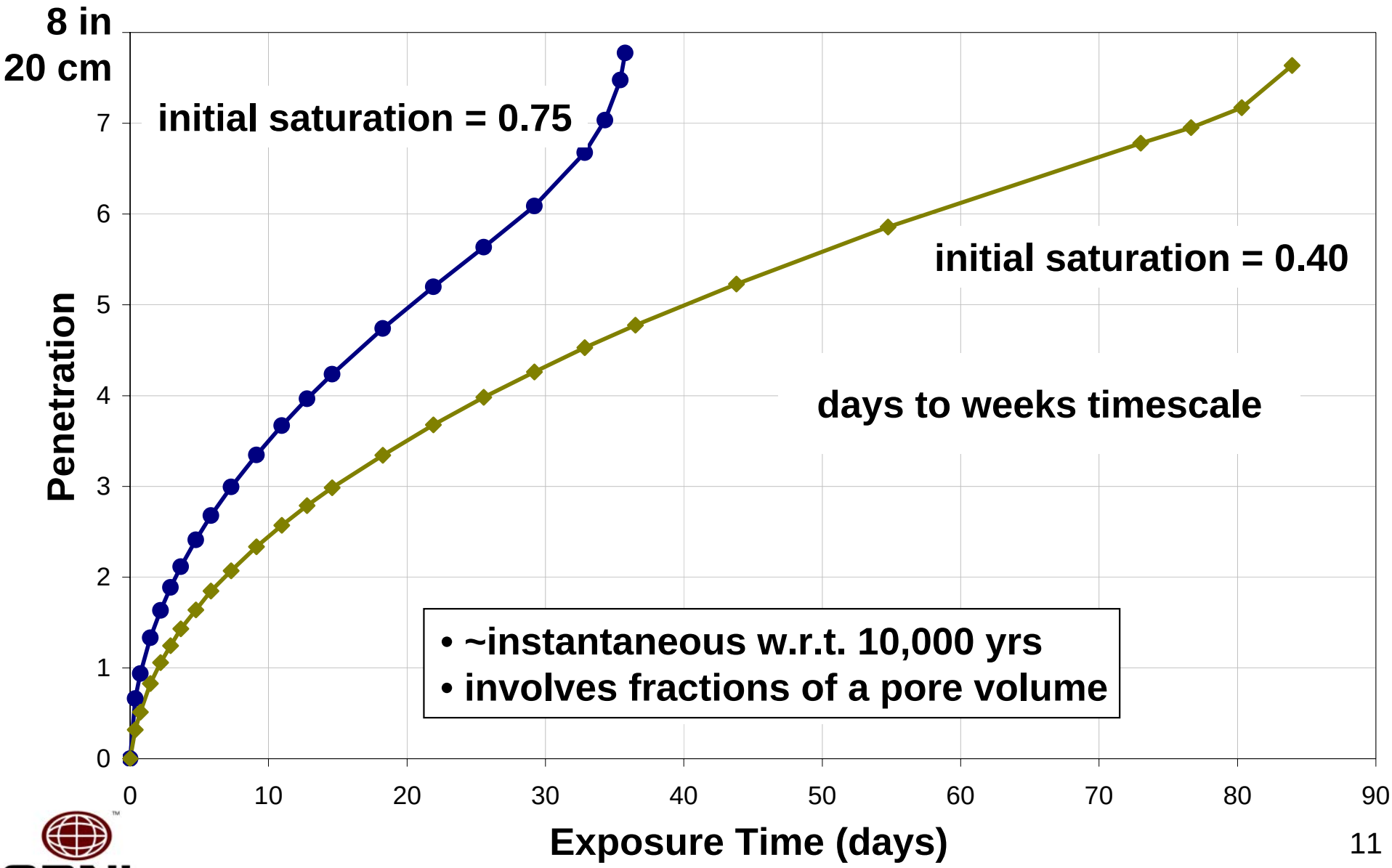
Bleedwater Penetration



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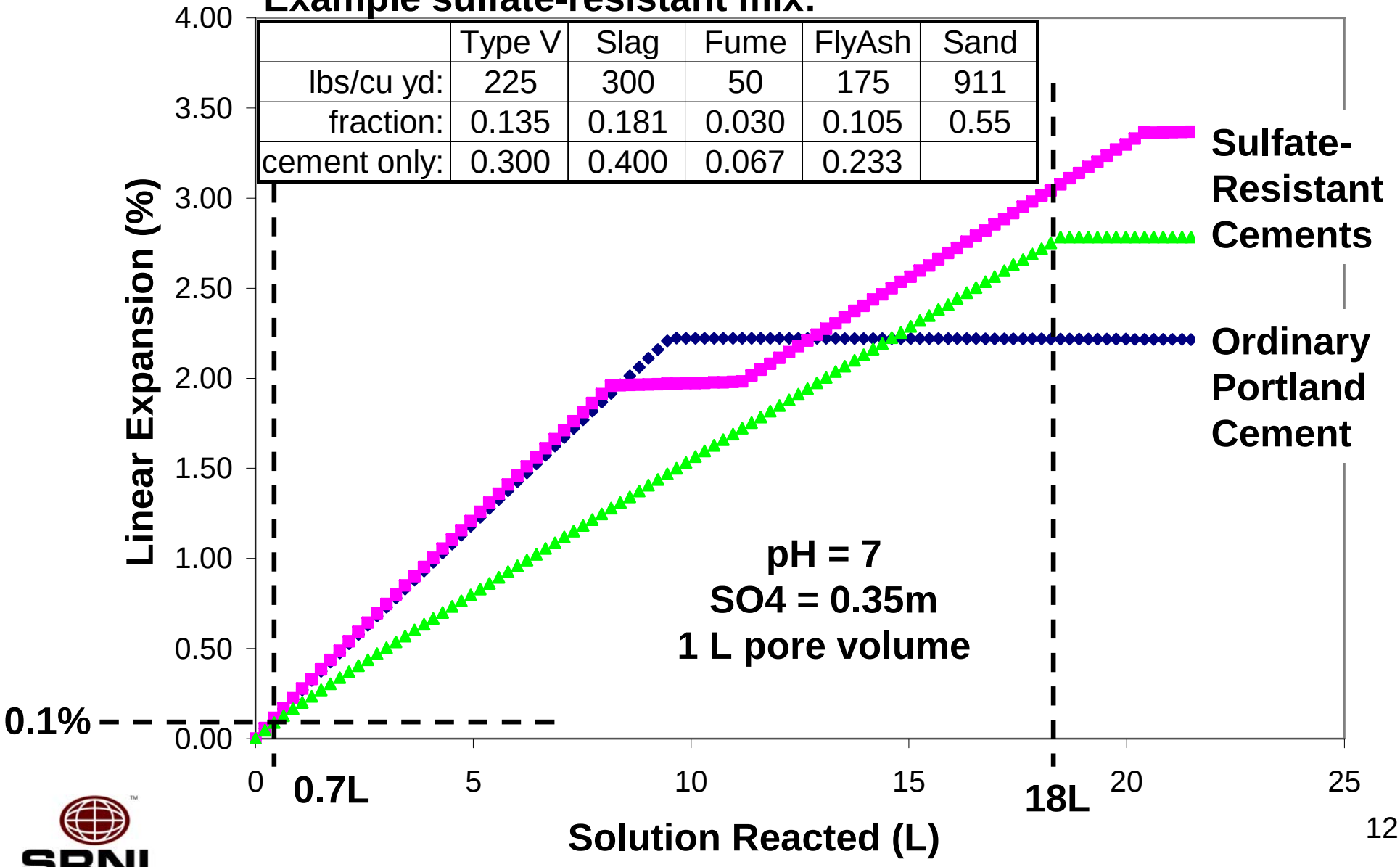
Batch Analysis Expansion Calculation

Example sulfate-resistant mix:

	Type V	Slag	Fume	FlyAsh	Sand
lbs/cu yd:	225	300	50	175	911
fraction:	0.135	0.181	0.030	0.105	0.55
cement only:	0.300	0.400	0.067	0.233	



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Batch Analysis Findings

- **Chemical composition of concrete does not appear to significantly affect expansion at equilibrium**
- **Sulfate resistant mixes SLOW the rate of sulfate attack**
  - **lower permeability and diffusion coefficient**
  - **possibly slower chemical reaction rates**
- **Pore volumes at 0.35 mol/L sulfate**
  - **0.7 needed for 0.1% expansion**
  - **~18 needed for full reaction**
- **Bleedwater effect limited by sulfate delivery**
  - **fraction of a pore volume imbibed**

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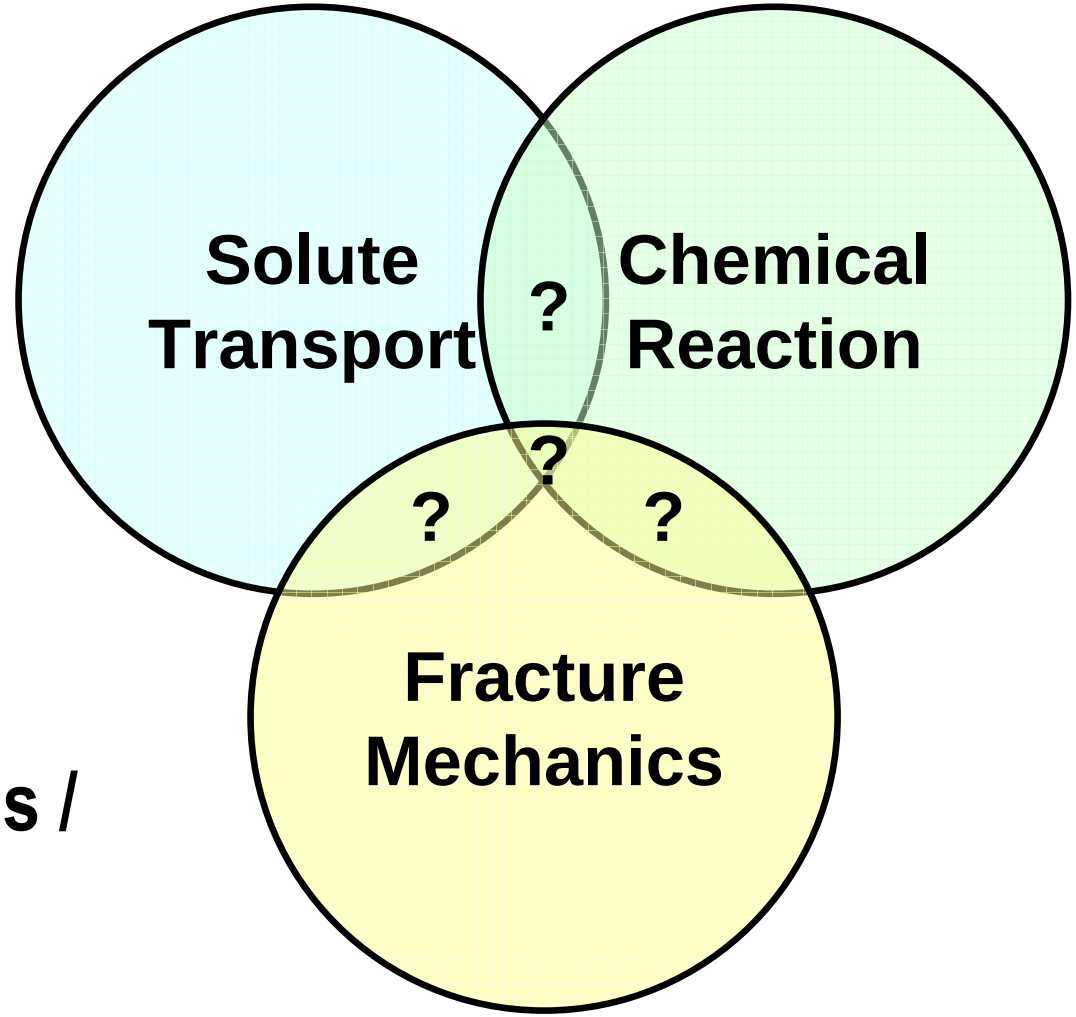
Sulfate Attack Phenomena

- **Coupled**
- **Bi-directional feedback**
- **Incompletely understood**
- **Modeling limitations / uncertainty**



Probabilistic forecasting approach

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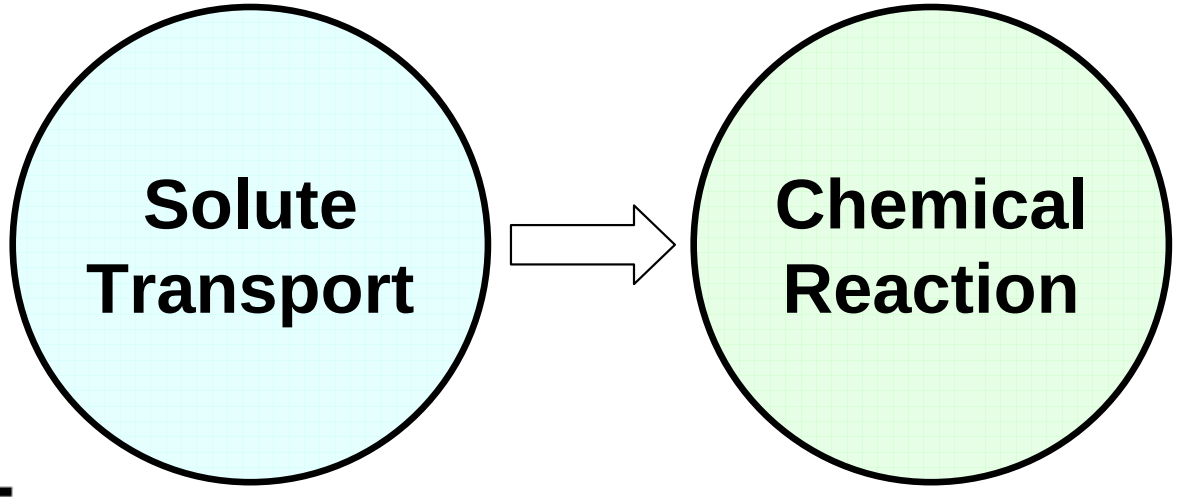
Key Simplifying Assumptions

- **Ettringite formation = sulfate attack (physical damage)**
  - **omit fracture mechanics analysis**
- **Sulfate attack does not alter diffusion coefficient**
  - **? confining pressure suppresses crack formation**
  - **? cracks desaturate under negative pressure head conditions**
  - **∴ chemical reactions do not influence solute transport**



(The Geochemist's Workbench software)

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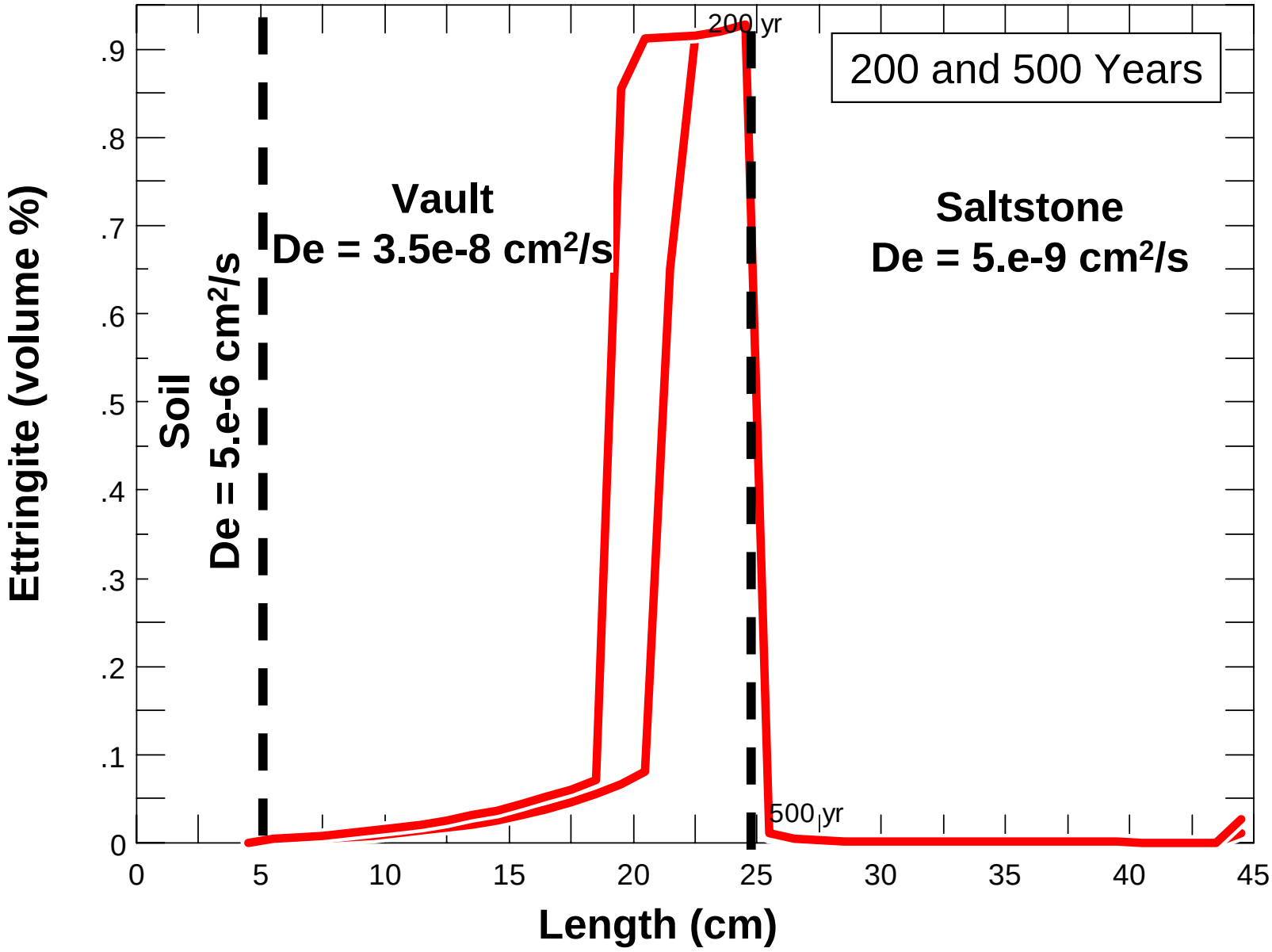
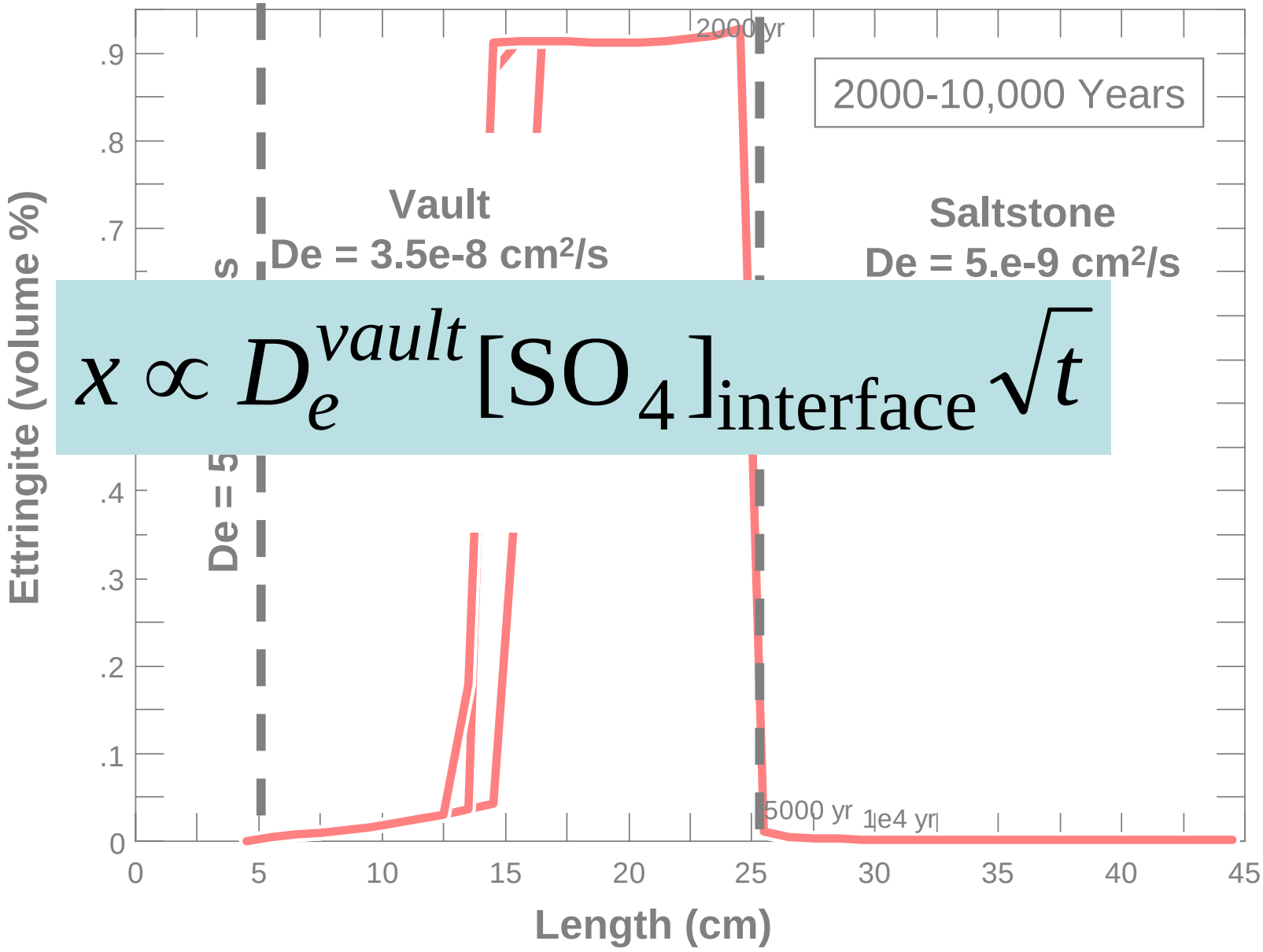
Nominal Geochemical Simulation

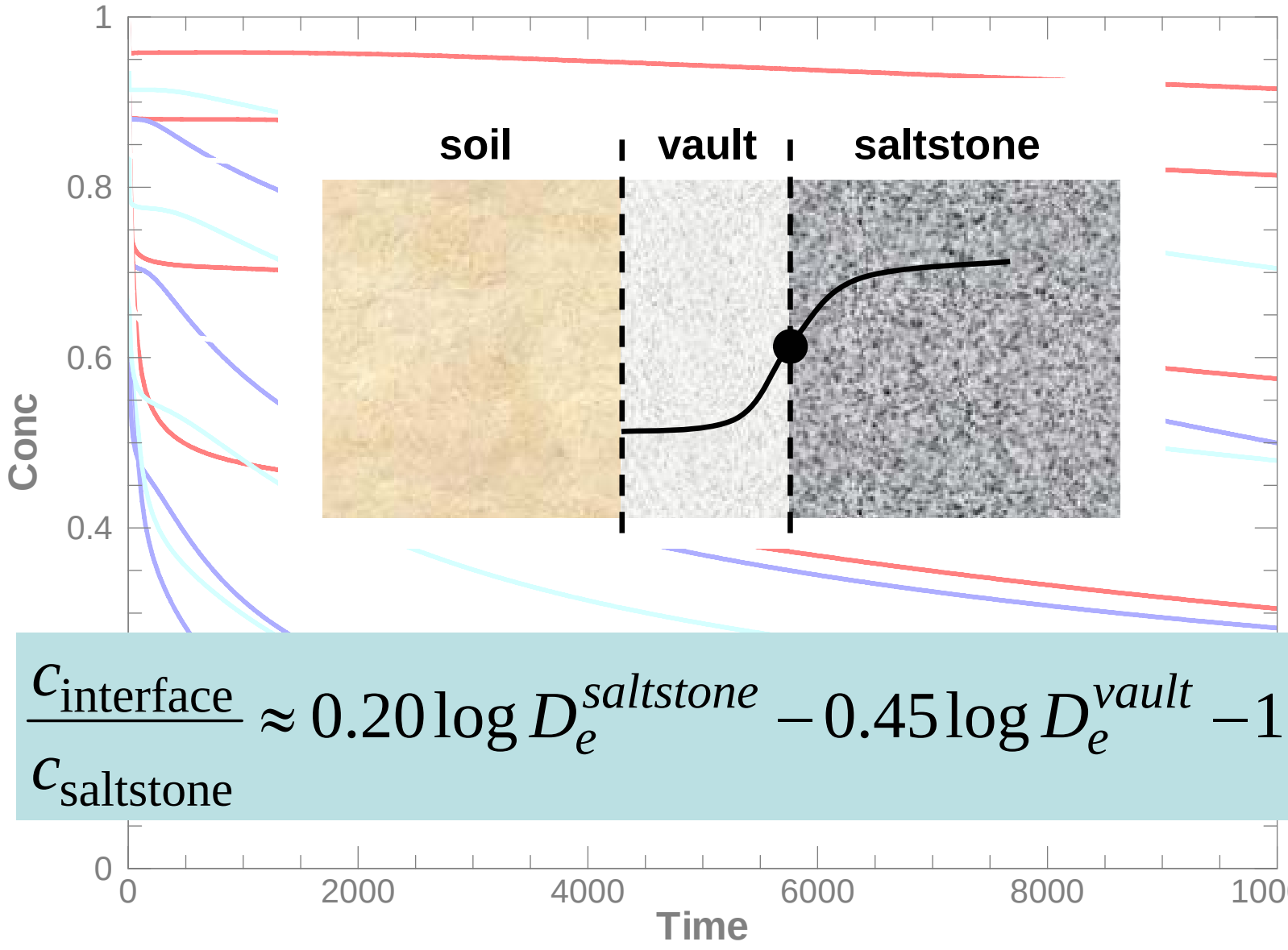


Nominal Geochemical Simulation (cont'd)



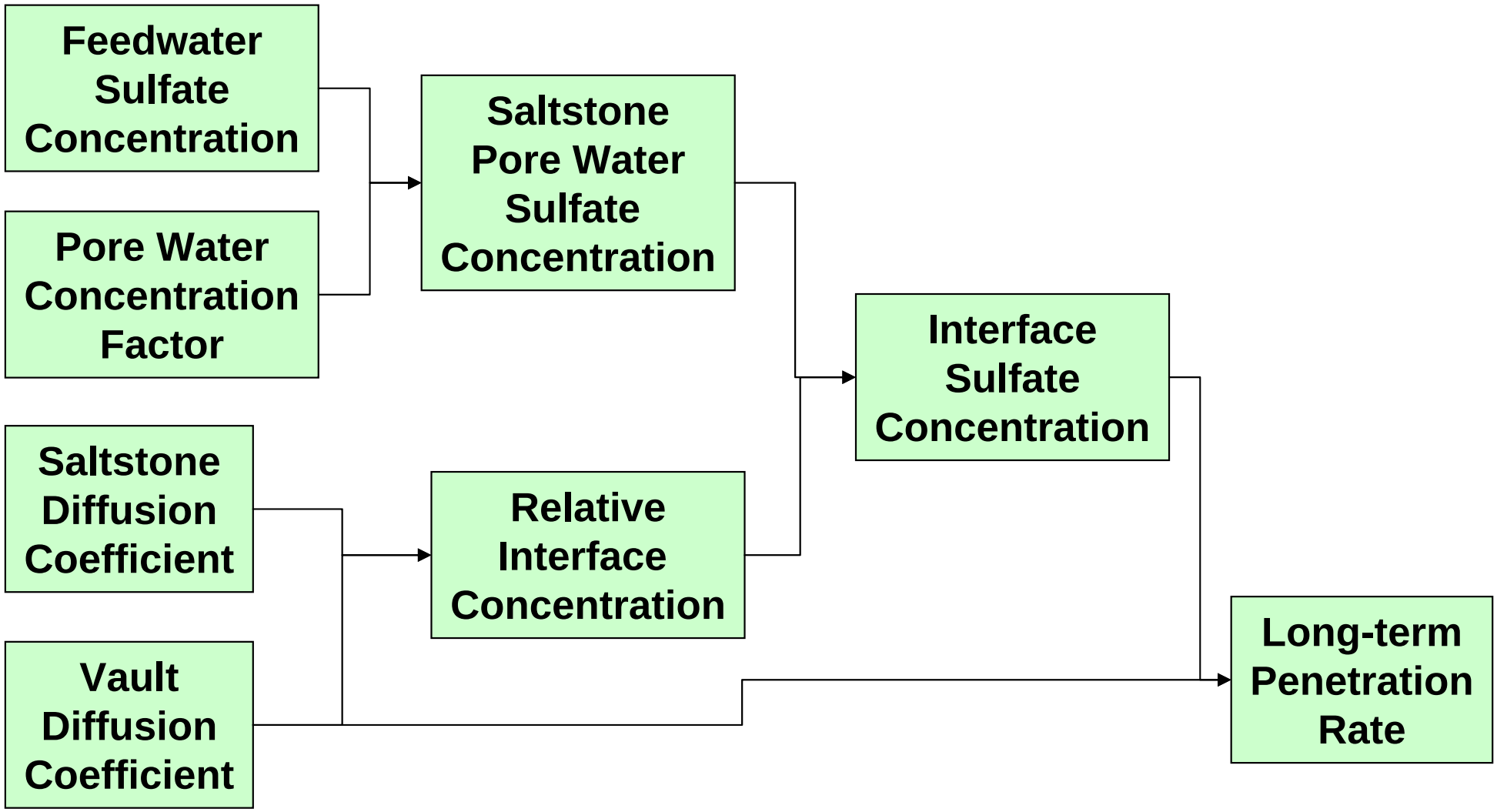
$$x \propto D_e^{vault} [SO_4]_{interface} \sqrt{t}$$

Relative Interface Concentration



$$\frac{c_{\text{interface}}}{c_{\text{saltstone}}} \approx 0.20 \log D_e^{saltstone} - 0.45 \log D_e^{vault} - 1.44$$

Probabilistic Model, Long-Term Effects



Probabilistic Model, Short-Term Effects

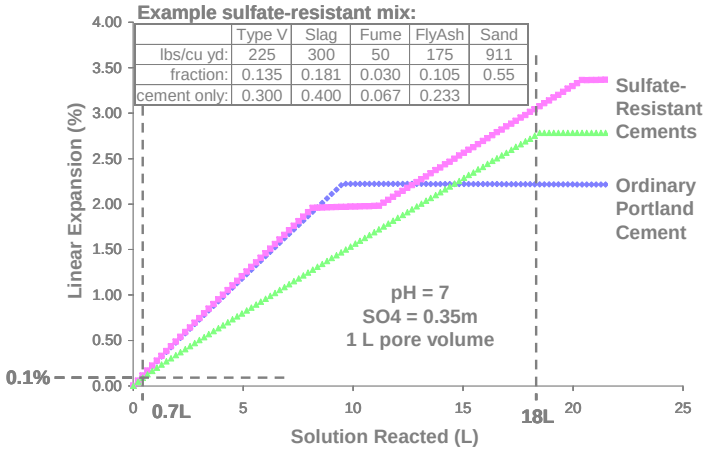
Failure Depth

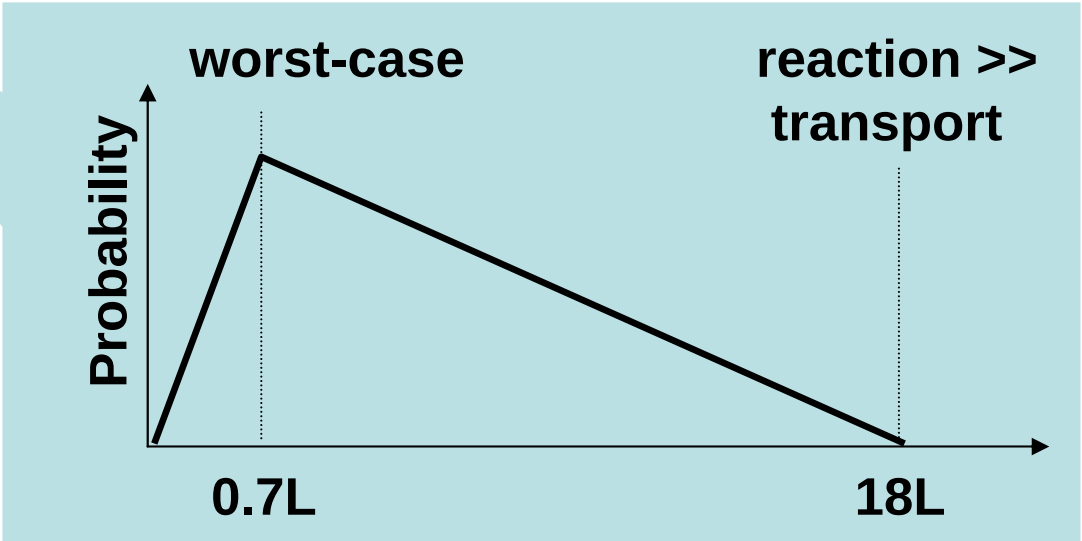
Initial Crack Depth

Bleedwater Intrusion

Short-term Penetration Depth

Net Intact Thickness





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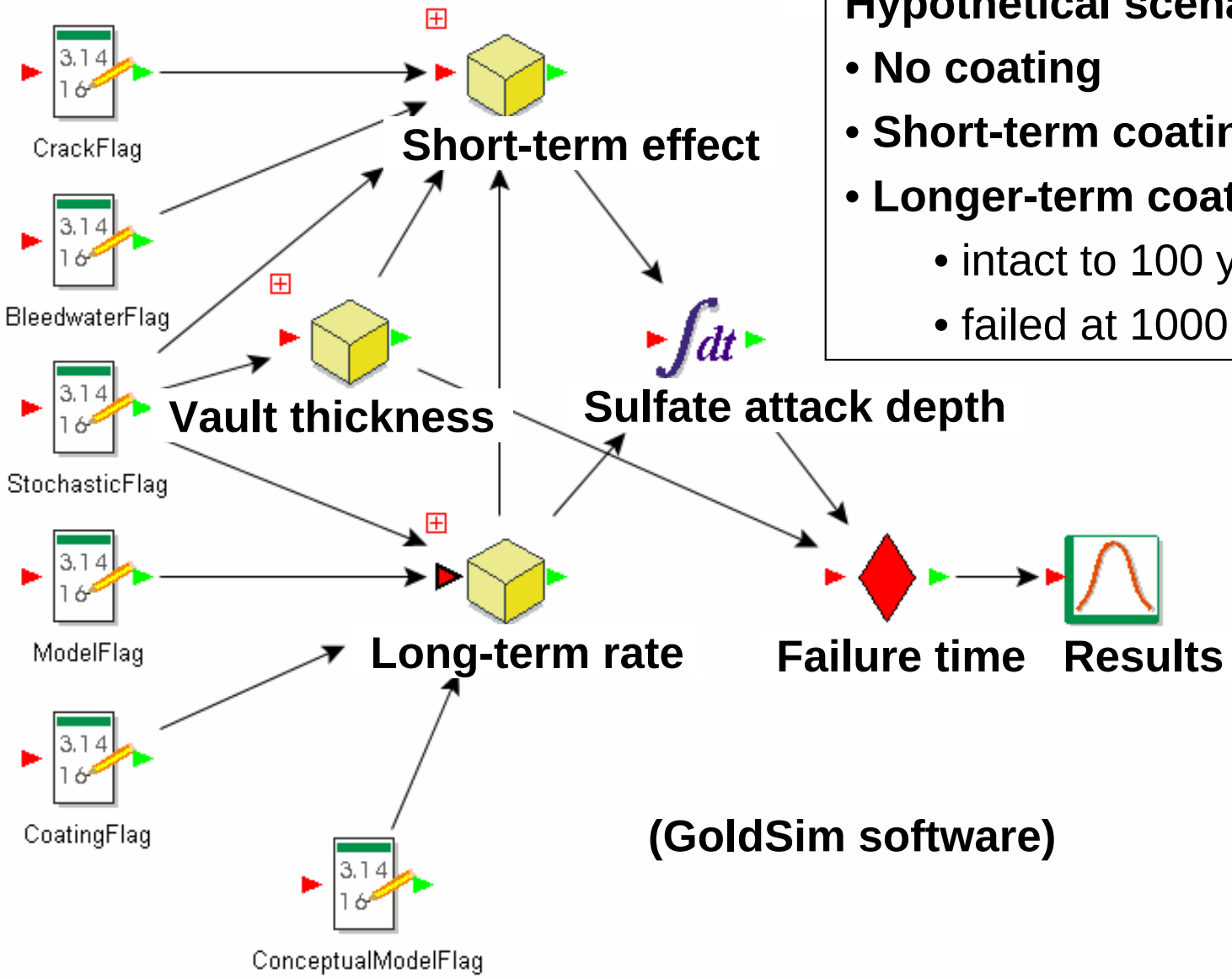
Probabilistic Forecast



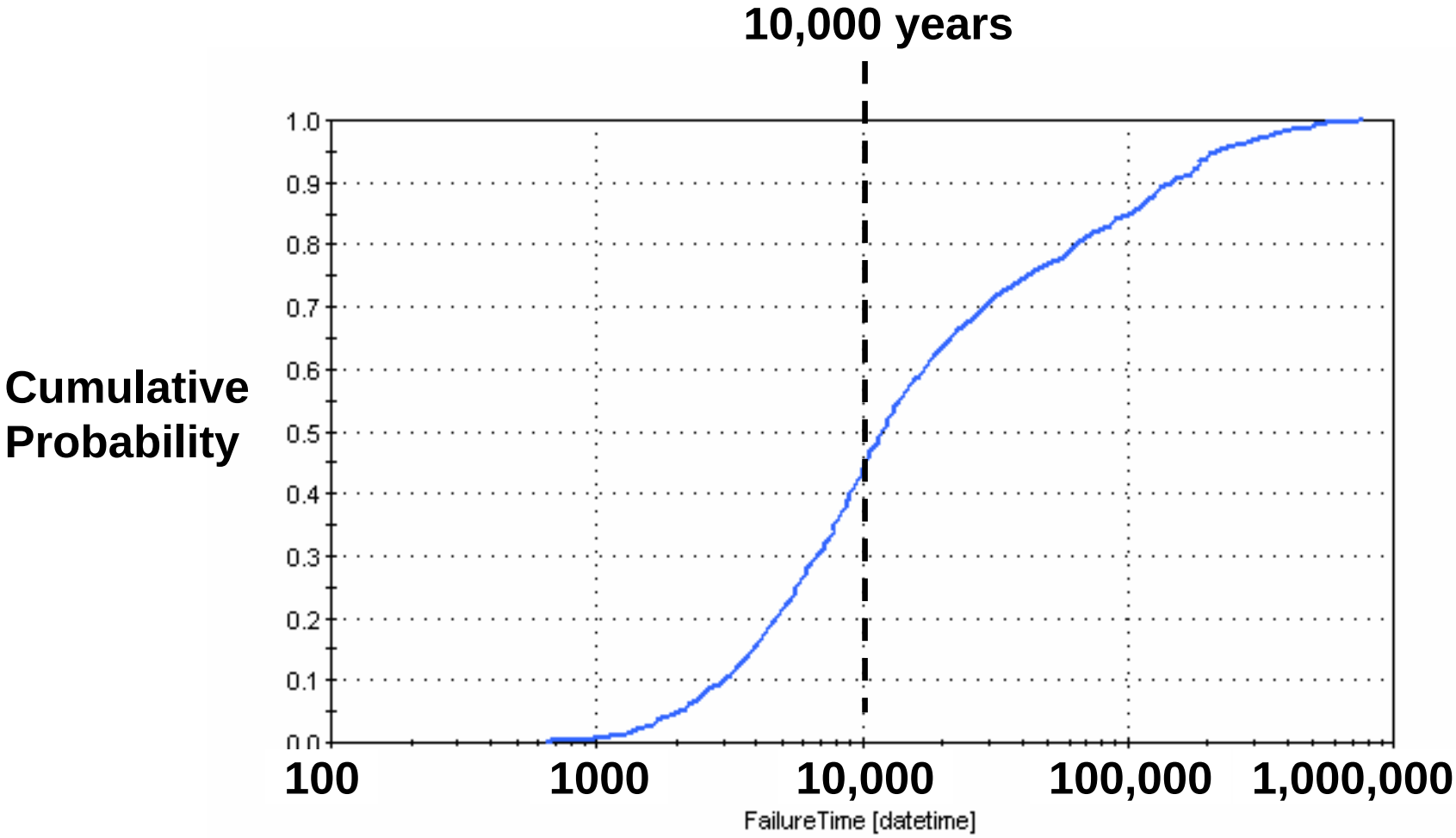
Hypothetical scenarios: 20 cm vault

- **No coating**
- **Short-term coating**
- **Longer-term coating**
  - intact to 100 years
  - failed at 1000 years

(GoldSim software)

Failure Time for No Coating

- **median 11,800 years**
- **mean 48,700 years**



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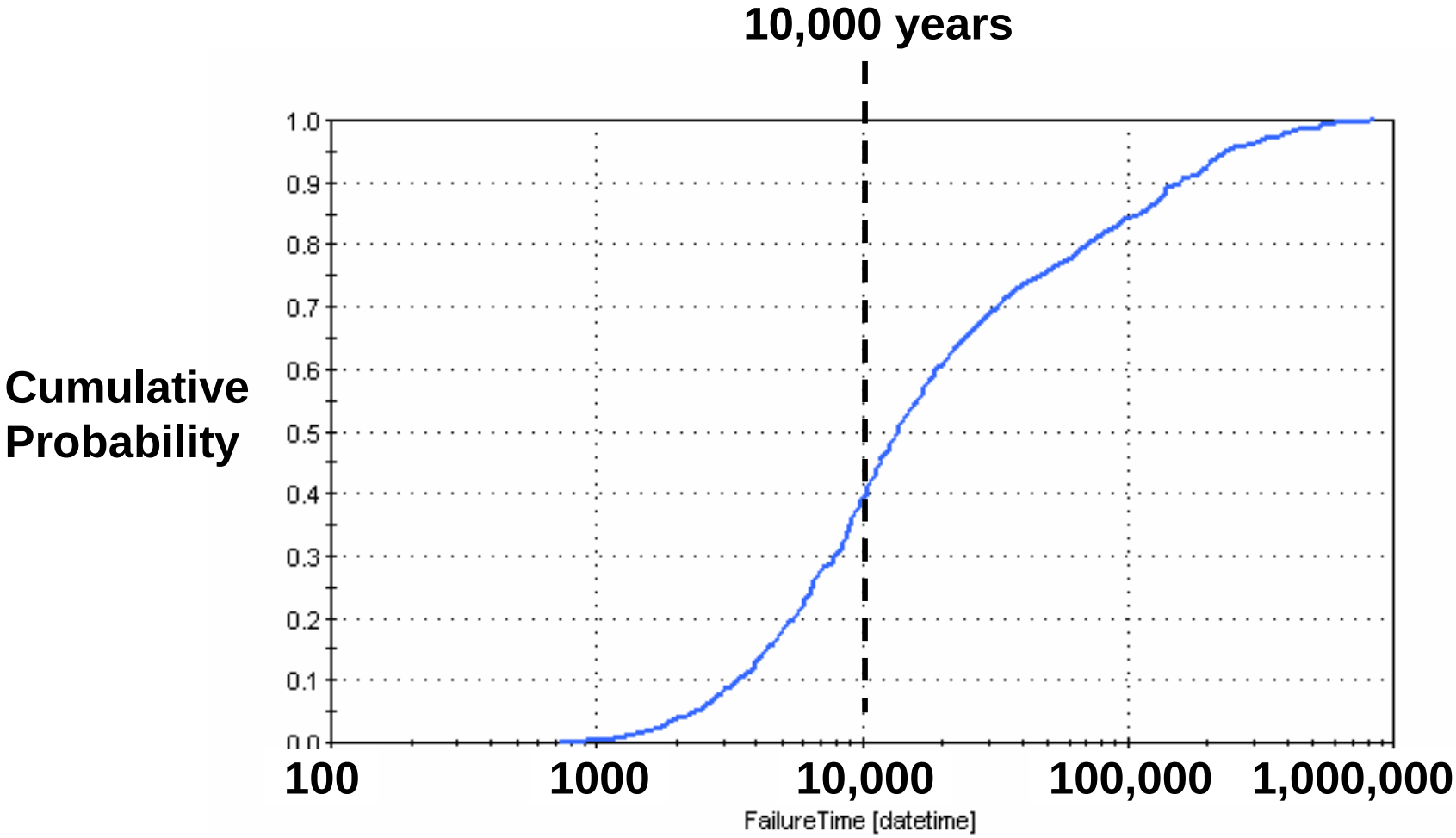
Failure Time for Short-Term Coating

- **median 13,500 years**
- **mean 53,200 years**



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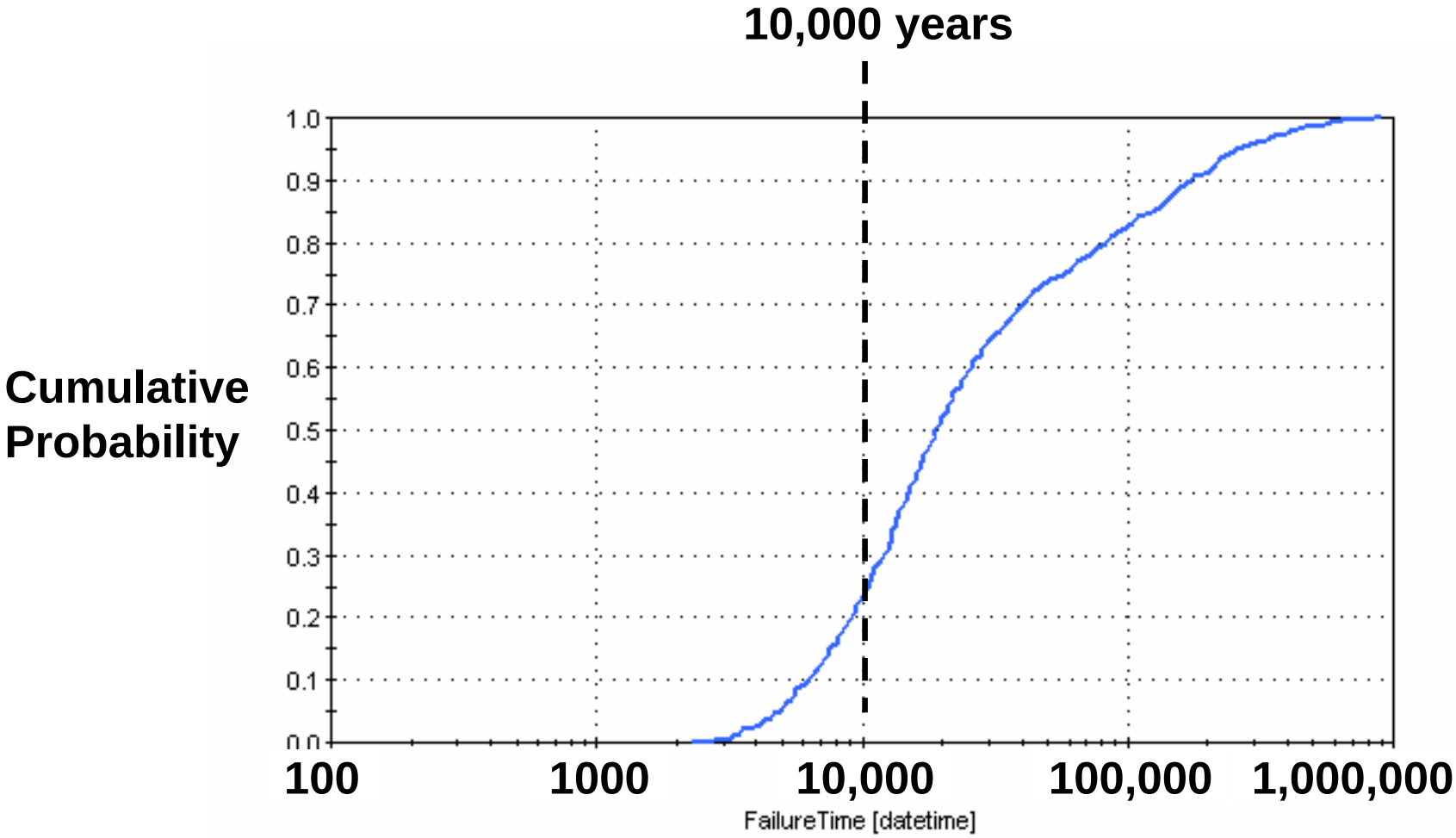
Failure Time for Long-Term Coating

- **median 19,000 years**
- **mean 61,000 years**



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Conclusions

- **Vault durability forecasts contain significant uncertainty**
  - **model uncertainty and process variability**
- **Opportunity to improve underlying models**
  - **$\sqrt{t}$ or t dependence?**
- **Probabilistic results are effective in conveying uncertainty to stakeholders (facility, regulators, public)**
- **Detrimental effects of bleedwater lower than anticipated**
- **Waterproof sulfate barrier could significantly extend lifespan of concrete**

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Q&A Contact Information

- **Questions?**

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