Migration of Solutes in Unsaturated Fractured Rock at Yucca Mountain: Mechanisms, Measurements, and Models

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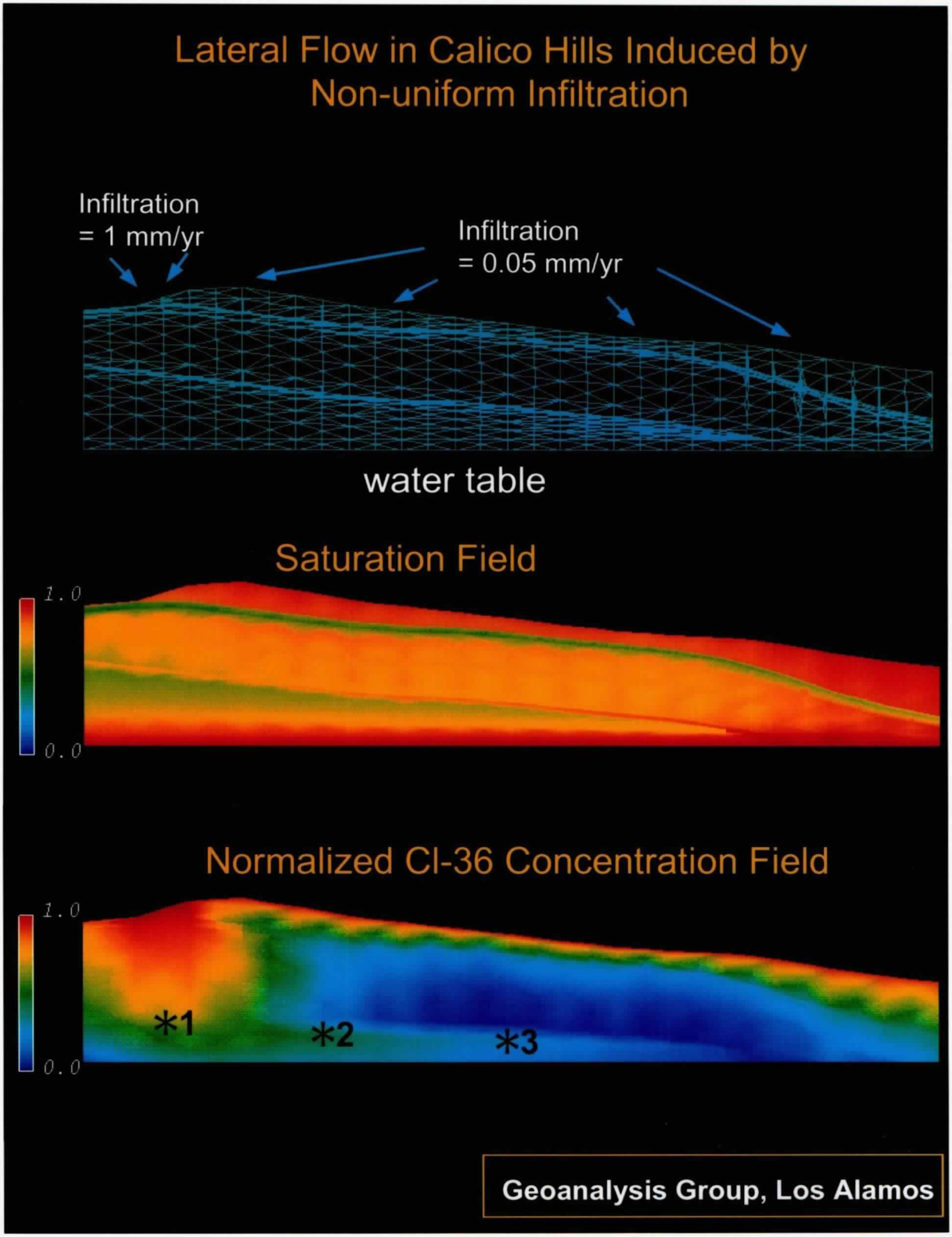
EES-5

Mechanisms

- **Driving Forces**
  - Aqueous phase solutes
    - » Infiltration
  - Gas phase solutes
    - » Temperature gradients
    - » Pressure gradients
- **Barries to Solute Migration**
  - Aqueous phase solutes
    - » Molecular diffusion
    - » Sorption
  - Gas phase solutes
    - » Diffusion into rock matrix from fractures
    - » Reactions: Partitioning and fractionation with aqueous phases

Measurements

- Infiltration - Flint et al. , USGS
- Cl-36 - Fabryka-Martin et al., LANL
- C-14 - Yang, USGS
- Kd - Triay et al., LANL


Lateral Flow in Calico Hills Induced by
Non-uniform Infiltration
Infiltration
= 1 mm/yr
Infiltration
= 0.05 mm/yr
water table
Saturation Field
1.0
0.0
Normalized Cl-36 Concentration Field
1.0
0.0
*1
*2
*3
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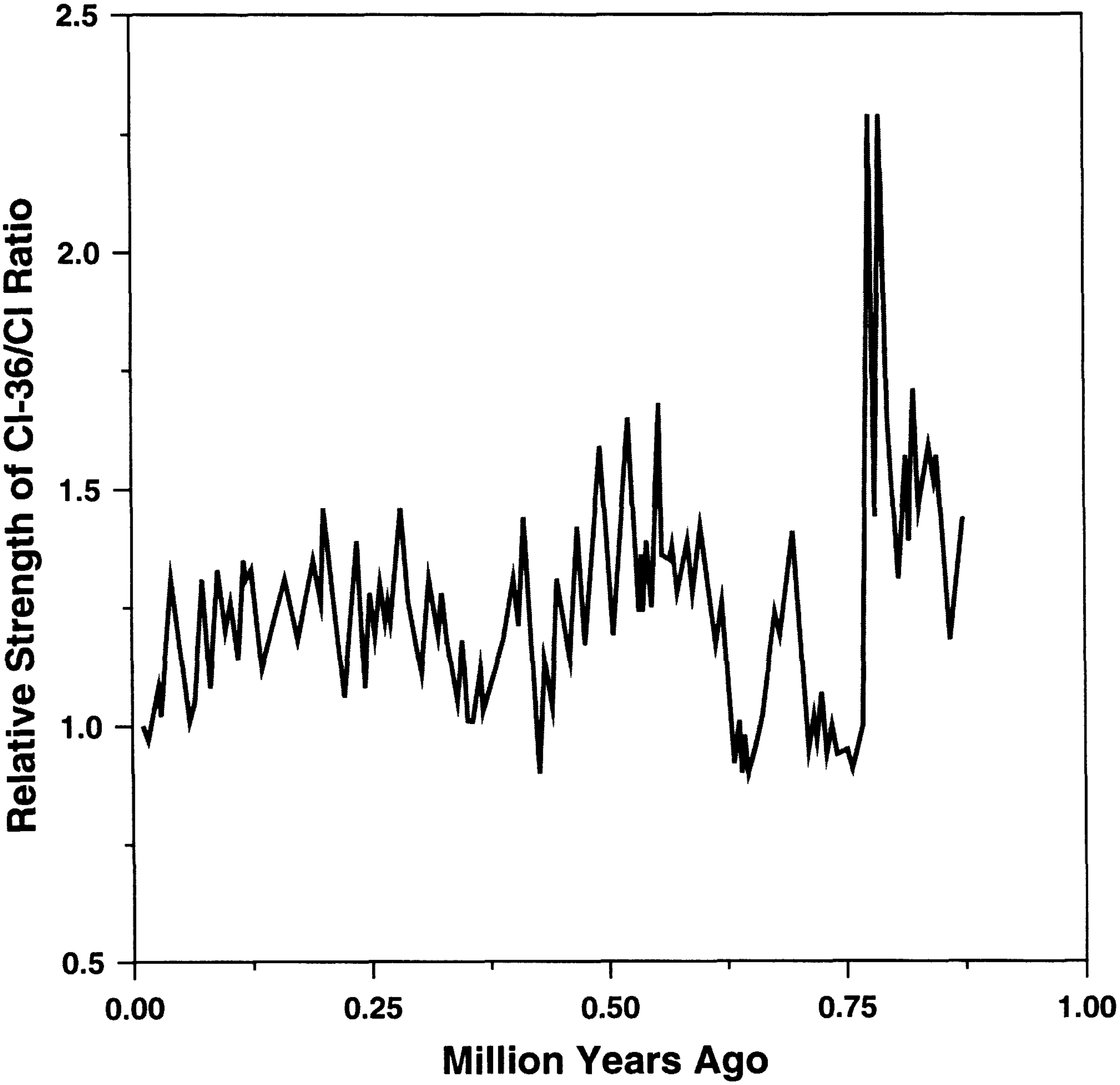
Estimated Variations in Cl-36/Cl Ratio Over Last One-Million Years

Based on Estimates of Variations in Geomagnetic Field Intensity



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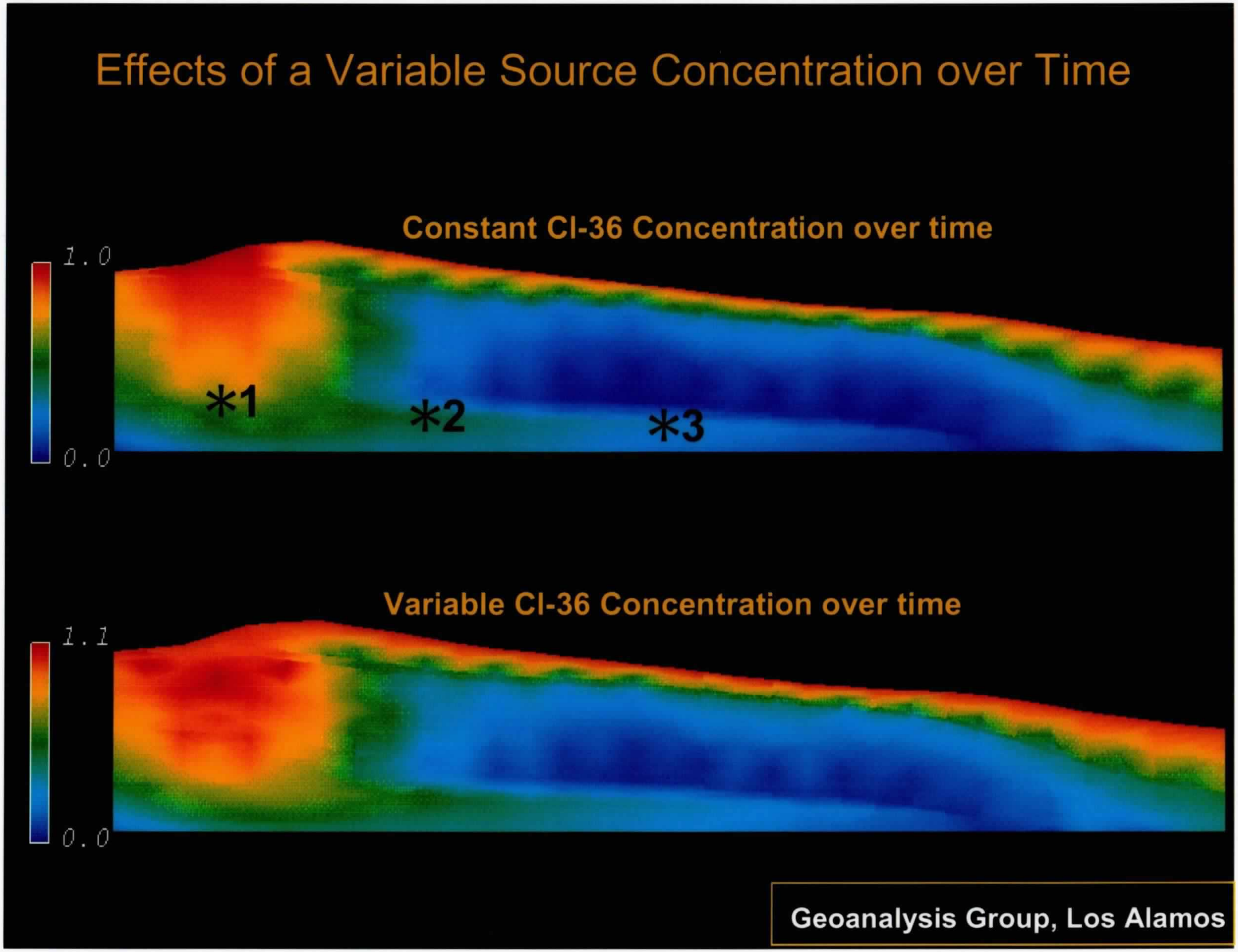
Effects of a Variable Source Concentration over Time
Constant Cl-36 Concentration over time
1.0
0.0
*1
*2
*3
Variable Cl-36 Concentration over time
1.1
0.0
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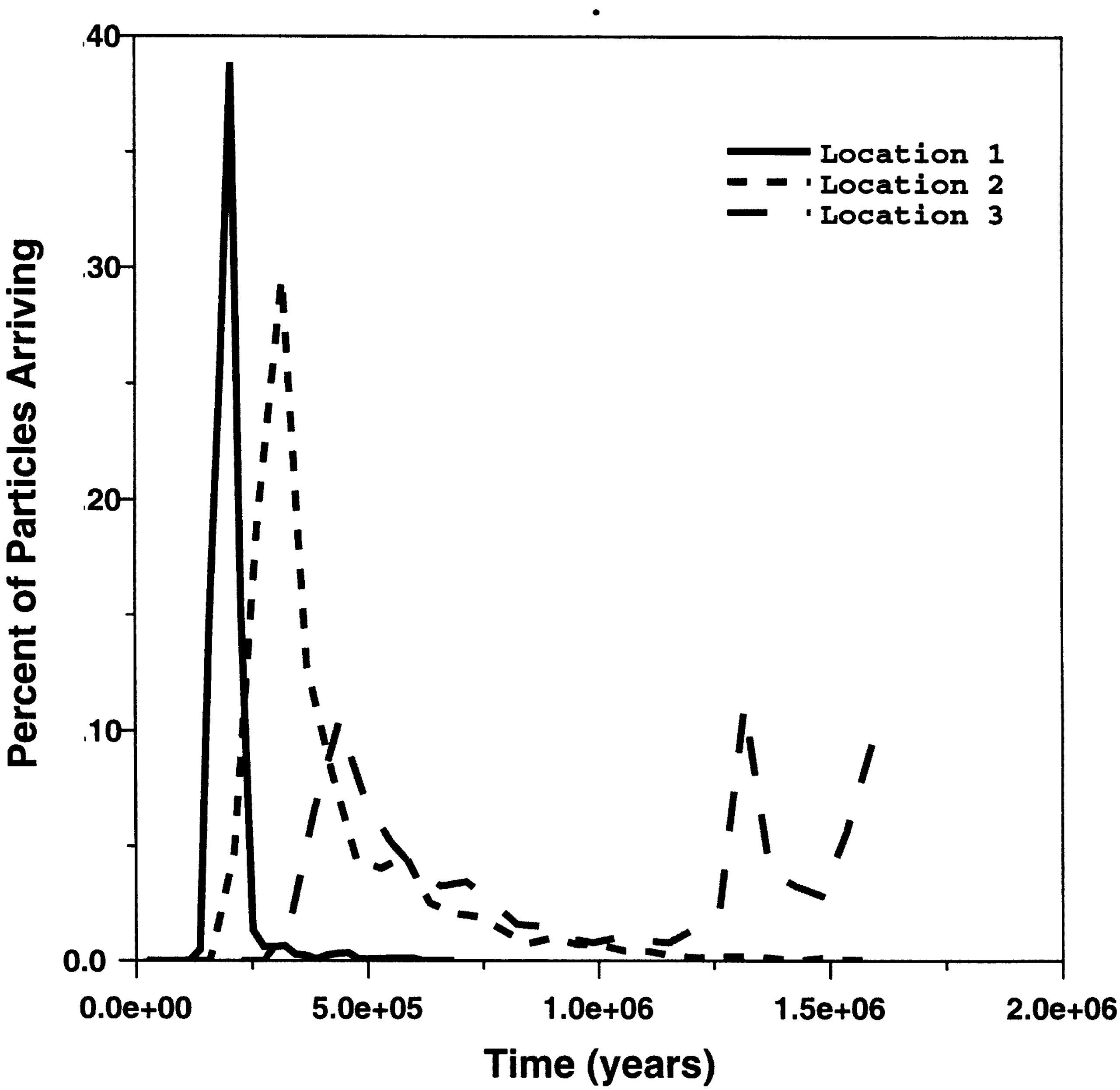
Particle Arrival Times at Three Locations in Calico Hills Unit



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Carbon-14 Migration Studies

Initial Conditions
(figures)

Saturation Profile

Temperature Profile

Gas Velocity Vectors

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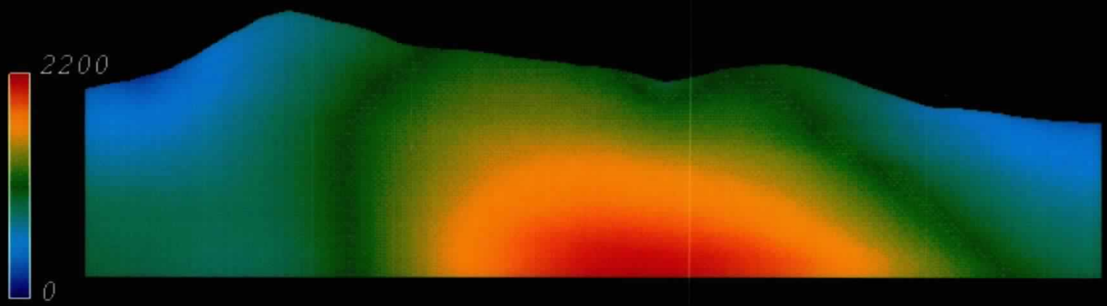
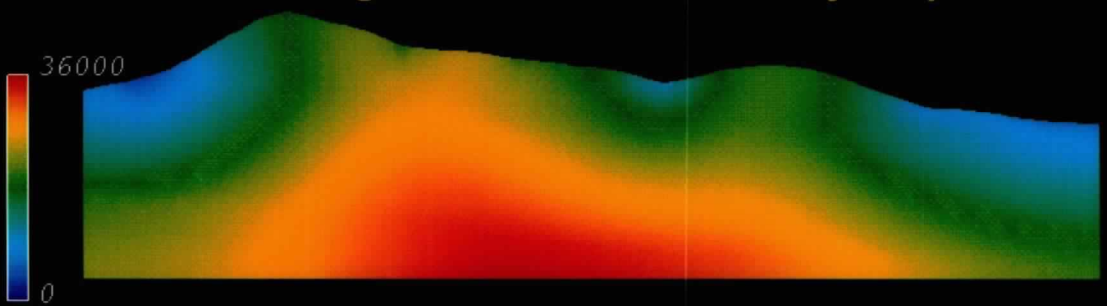
Carbon-14 Migration Studies

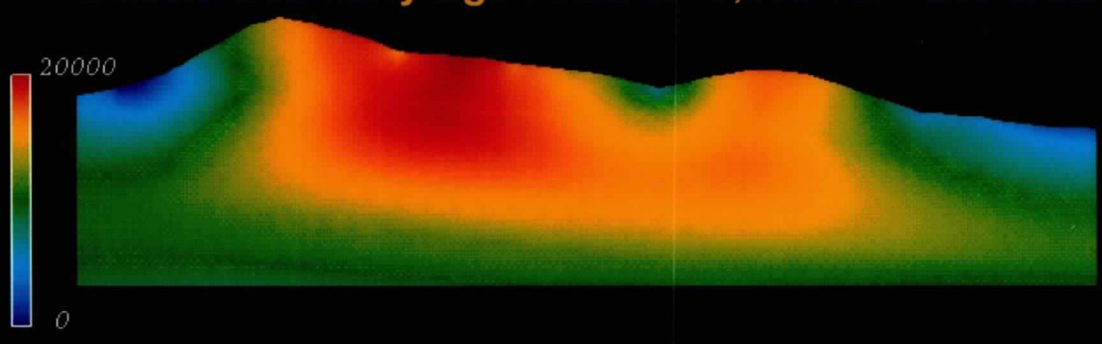
Radiometric Age - No Chemistry



Radiometric Age - Carbonate Chemistry for pH = 8.4



Radiometric Age - Carbonate Chemistry for pH = 8.4 Bottom Boundary Age Fixed at 10,000 Year Old Water



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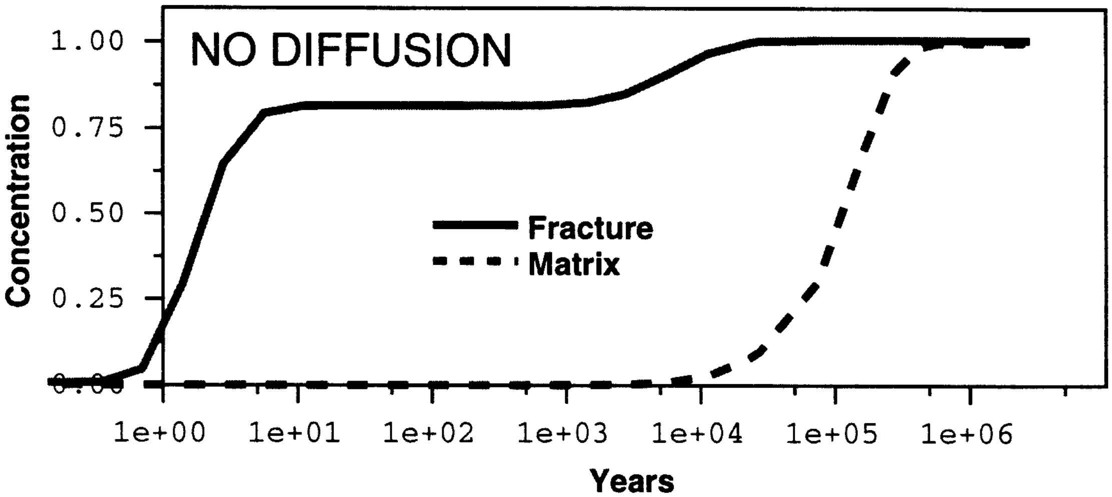
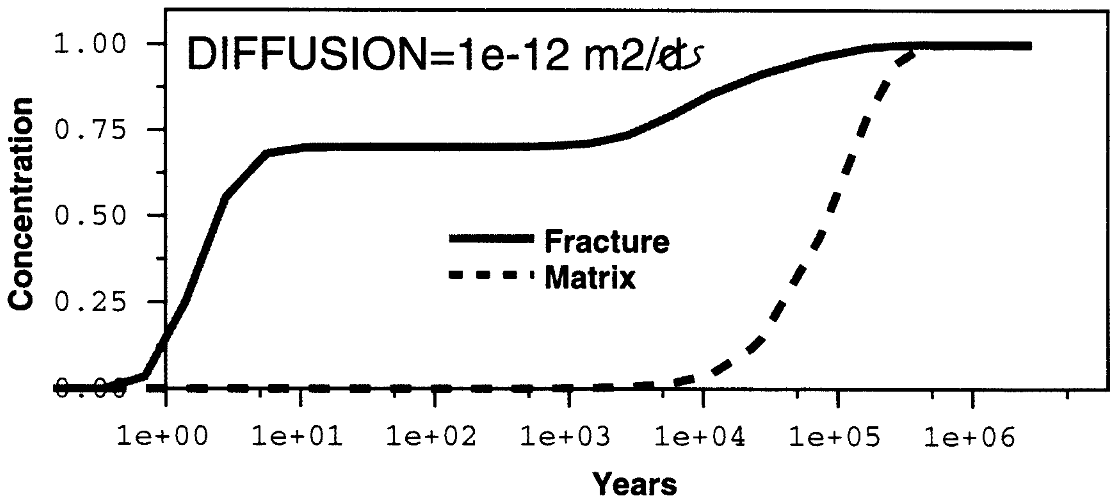
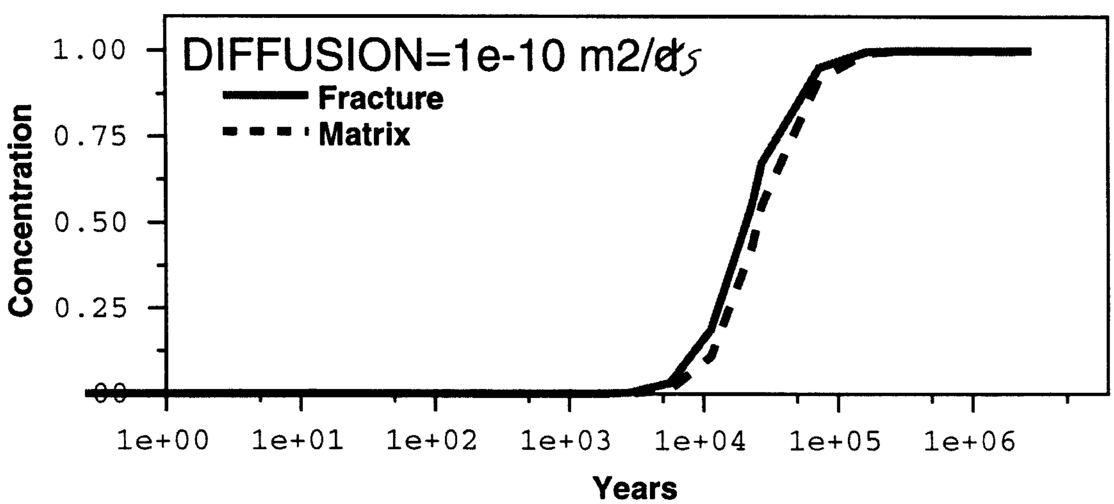
Reduced Matrix/Fracture Connectivity

Breakthrough Curves for Infiltration = 4 mm/yr







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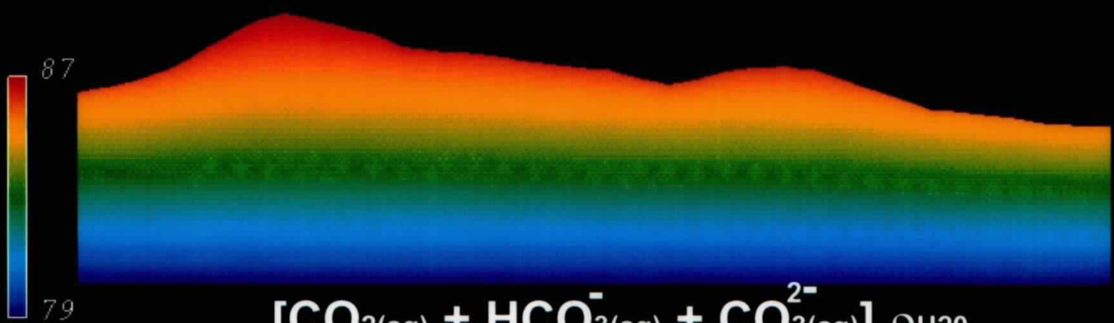
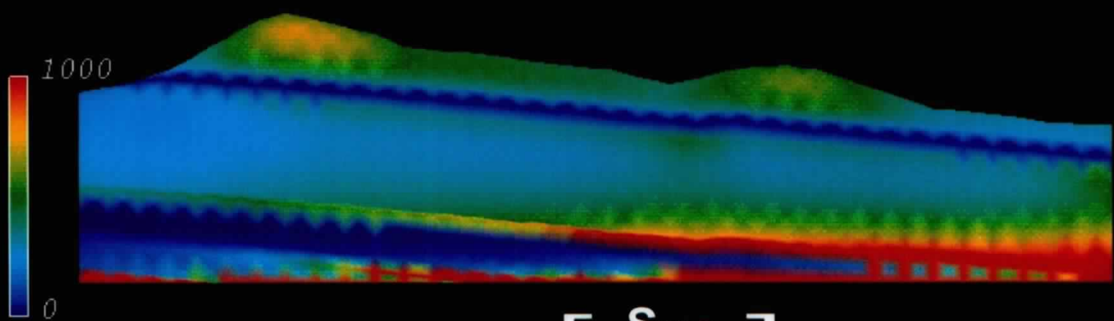
Carbon-14 Migration Studies

Computed Kd map for pH = 8.4



$$Kd = \frac{[CO_{2(aq)} + HCO^{-}_{3(aq)} + CO^{2-}_{3(aq)}]\ \rho_{H20}}{[CO_{2(g)}]\ \rho_{vapor}}$$

Computed map of Retardation Factors



$$R = 1 + Kd \left[\frac{S_{H2O}}{1 - S_{H2O}} \right]$$

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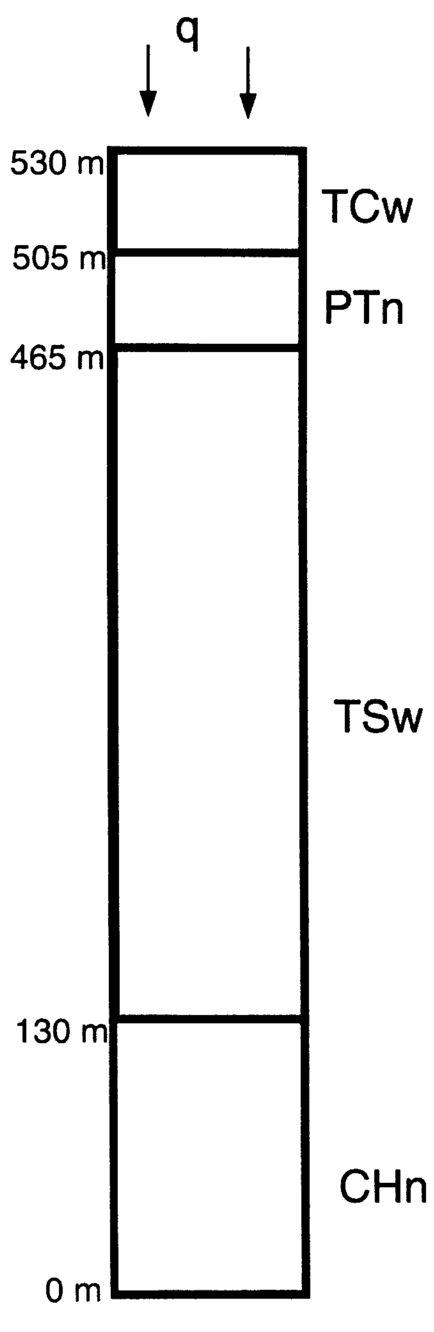
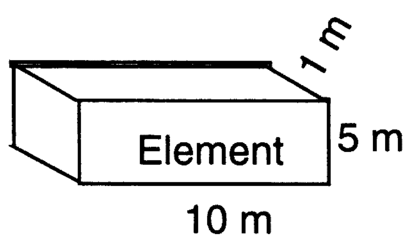
Dual Permeability Flow and Transport Model Evaluation

Evaluate Sensitivity to:
- Infiltration Rate
- Diffusion
- Fracture/Matrix Connectivity



water table boundary



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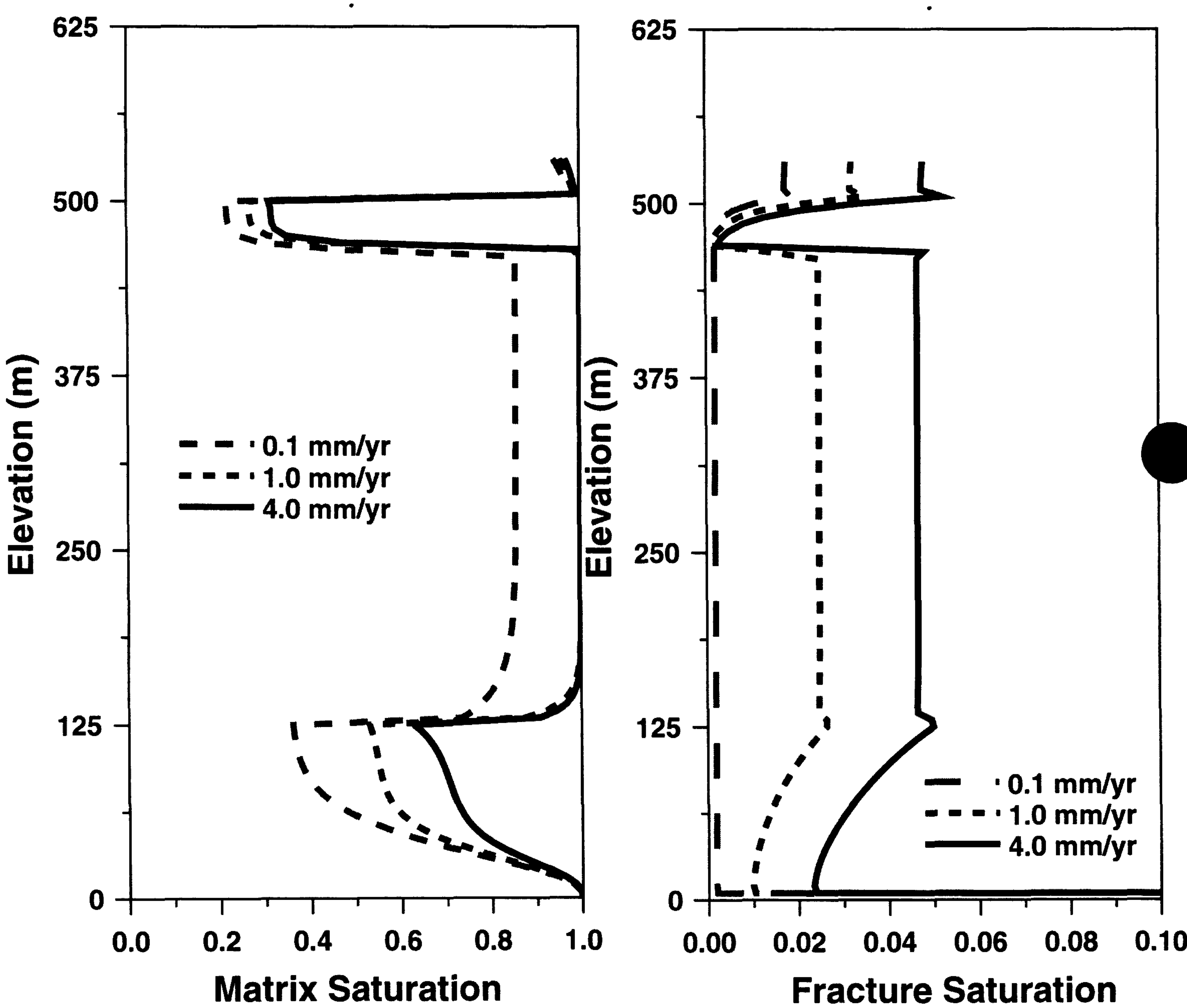
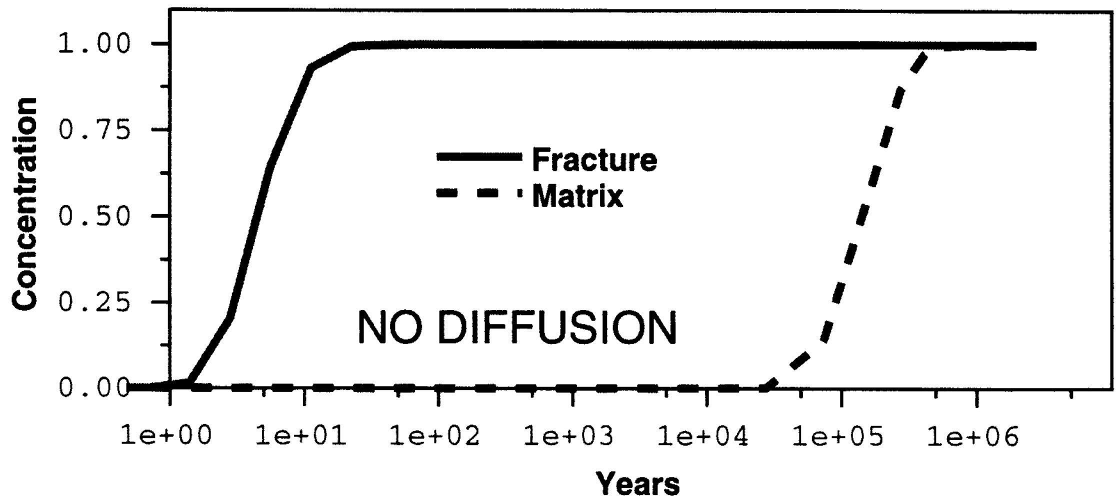
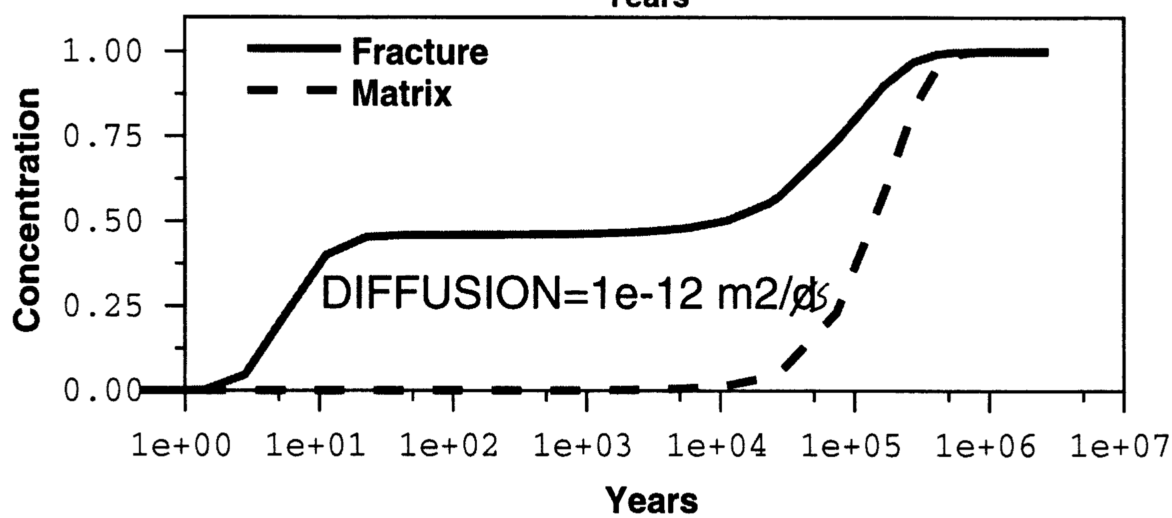
Matrix and Fracture Saturations For Three Different Infiltration Rates

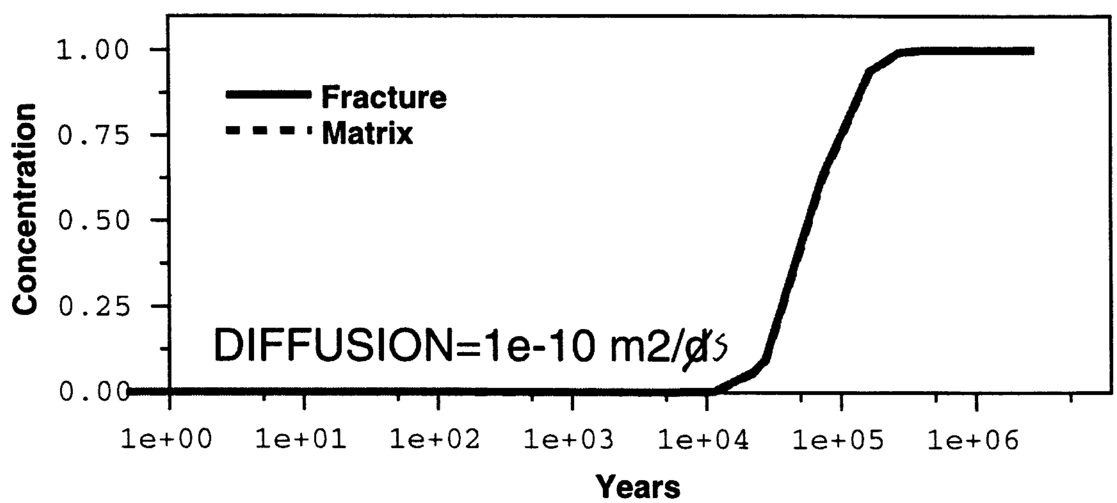


Reduced Matrix/Fracture Connectivity

Breakthrough Curves for Infiltration = 1 mm/yr







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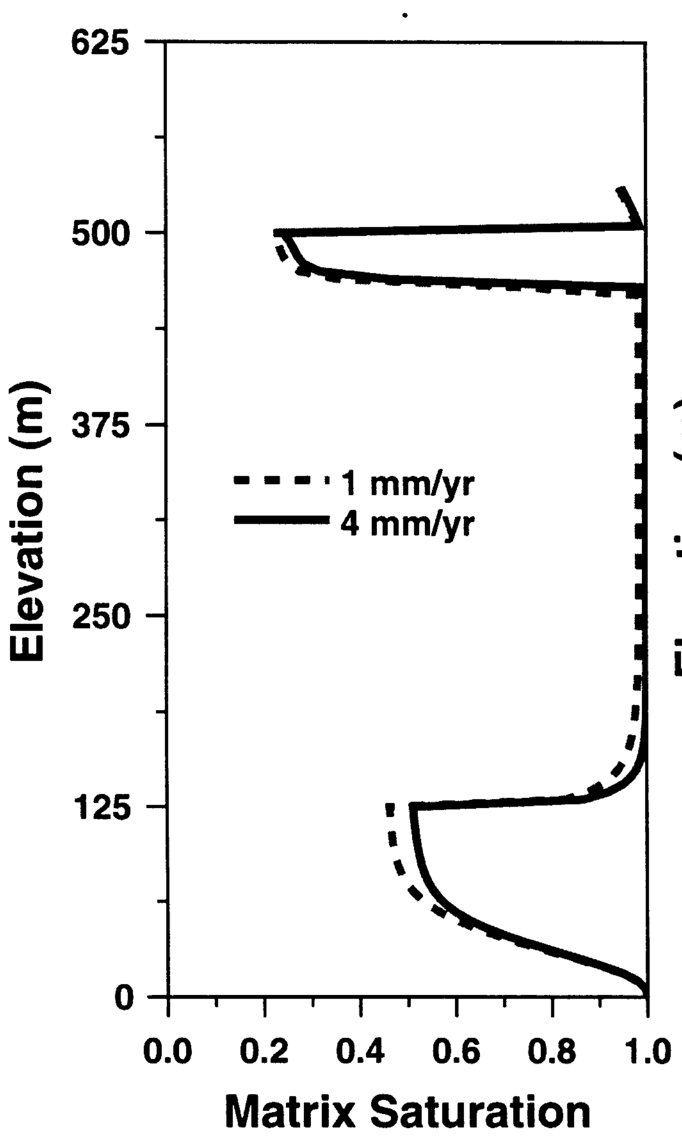
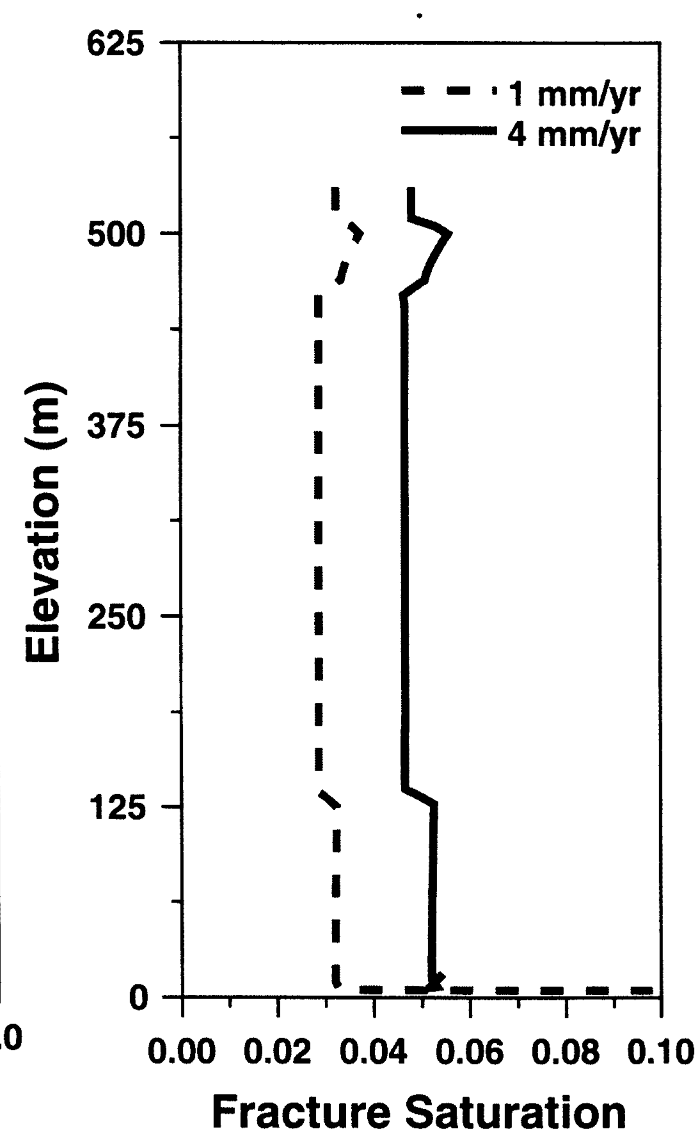
Decreased Matrix/Fracture Connectivity

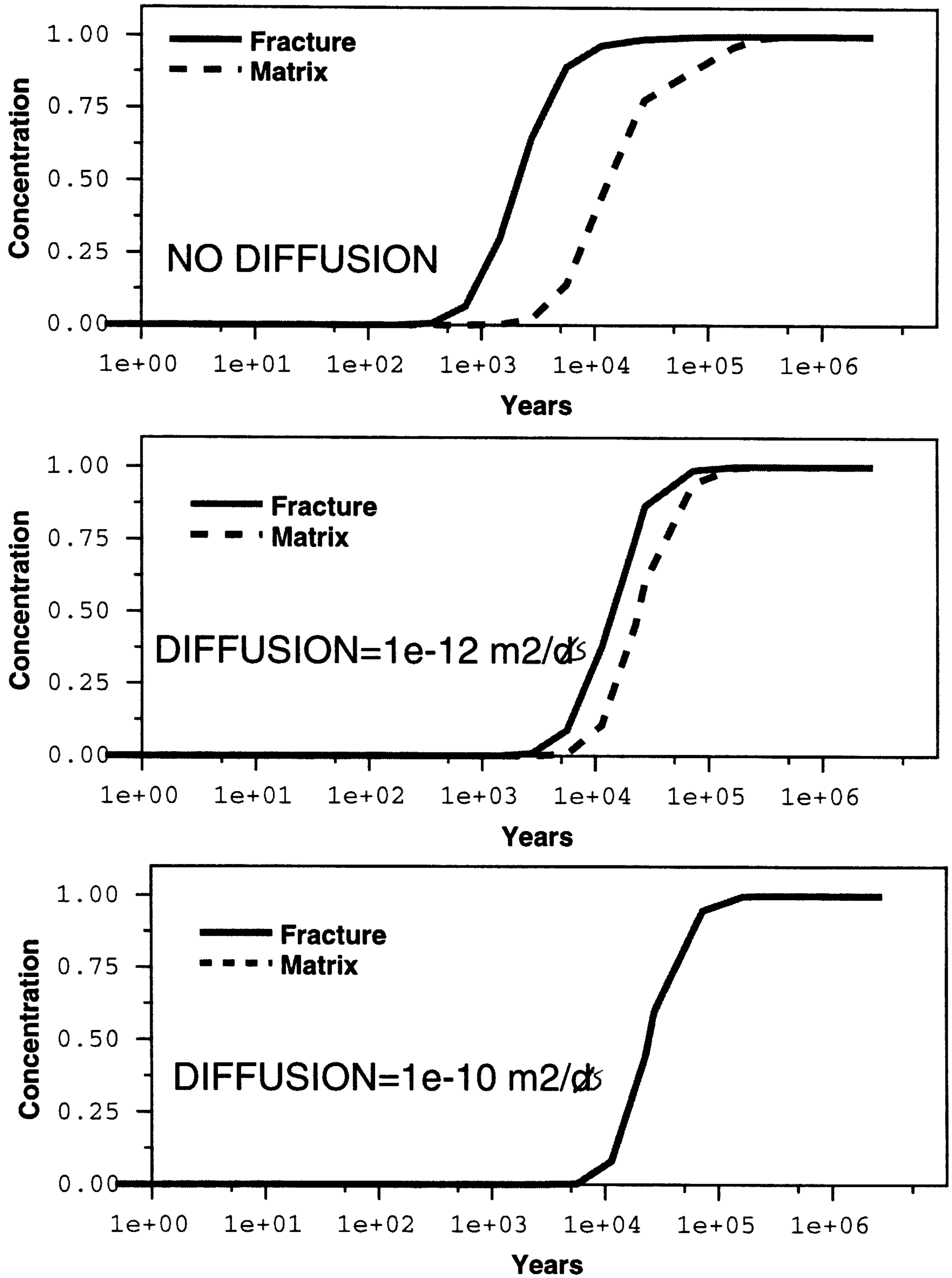
Matrix and Fracture Saturations For Two Different Infiltration Rates





Predecisional Data - Not to be cited or used for license application

Breakthrough Curves for Infiltration = 4 mm/yr



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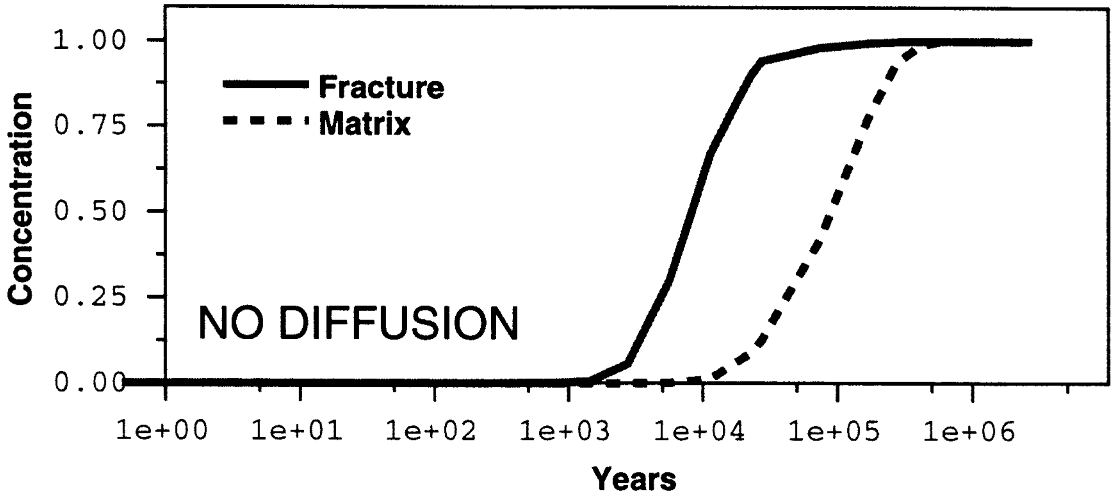
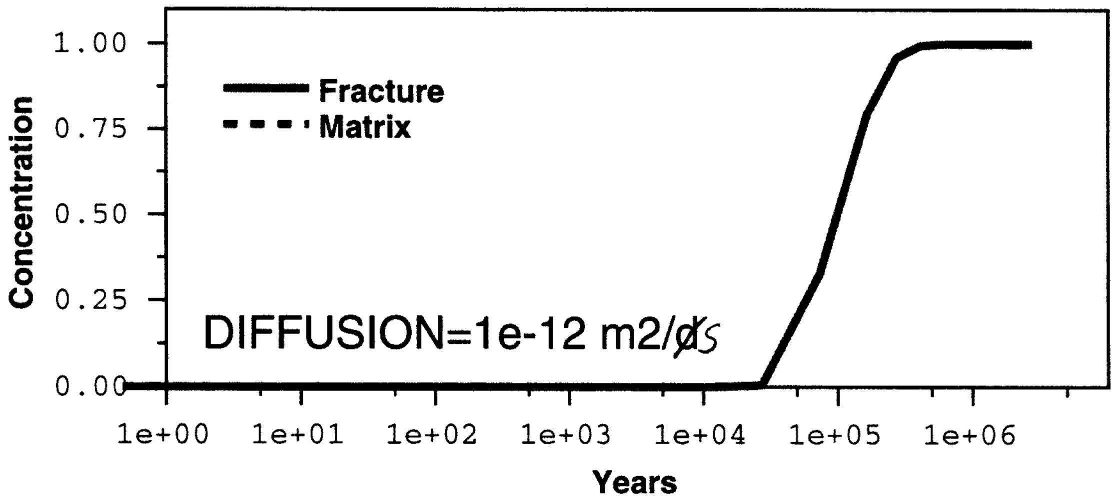
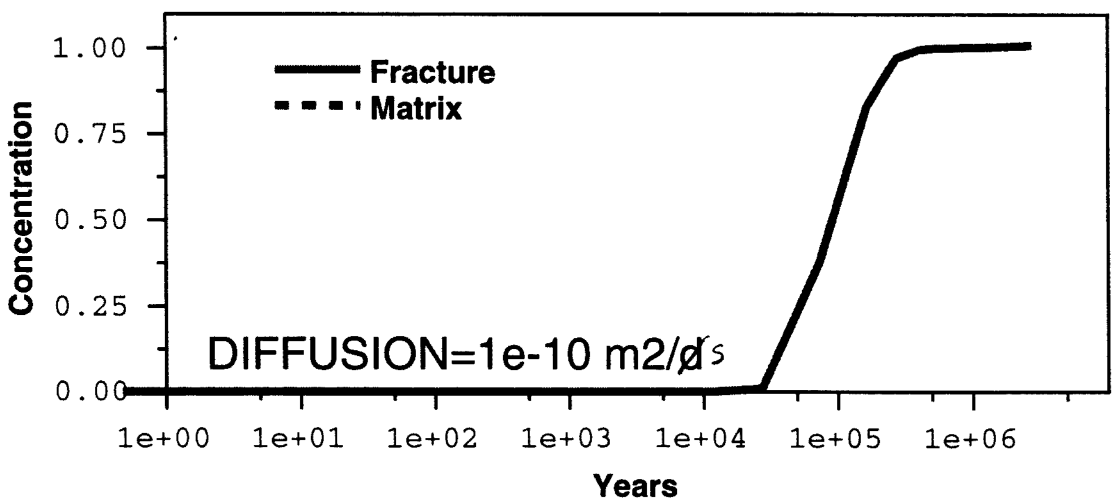
Breakthrough Curves for Infiltration = 1 mm/yr







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Summary

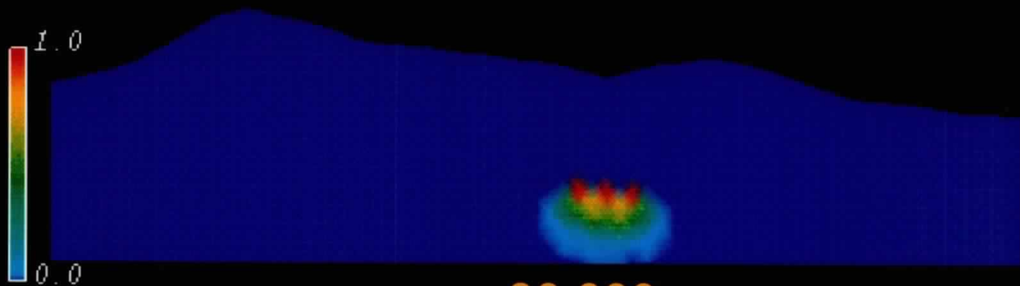
- Dipping stratigraphic beds may provide a reasonable pathway for Cl-36 to travel from regions of high infiltration to measurement locations
- New infiltration data from Flint and three-dimensional solute transport simulations should enhance our understanding of this process
- Gas phase C-14 transport simulations yield maximum and minimum bounds for the measurements taken in Yucca Mountain
- High Tritium signal still not explainable
- Model simulations indicate extreme conditions/parameters required to get rapid movement of solutes to depth with Dual Permeability Formulation

Transport Barriers

Uniform Infiltration = 0.36 mm/yr

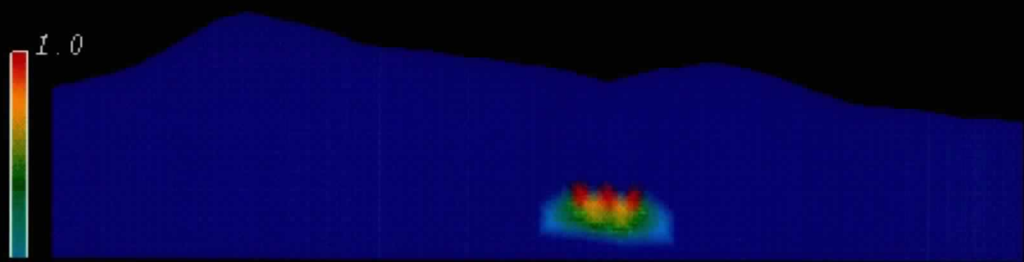
Source Above Thinner Section of Calico Hills

Case 1: No Retardation

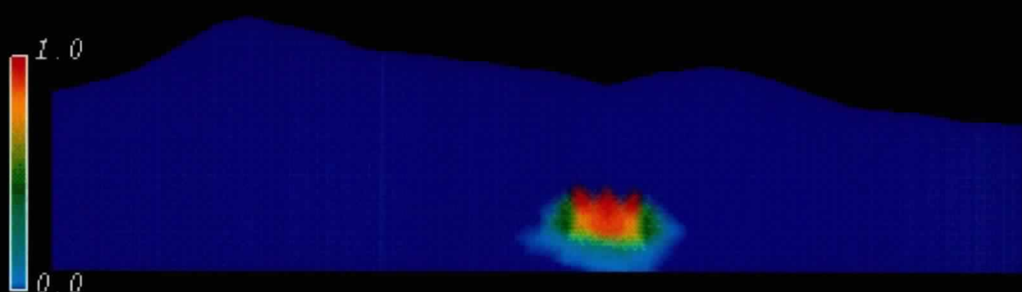


30,000 years

Case 2: With Retardation in Calico Hills (Kd = 3)



30,000 years



400,000 years

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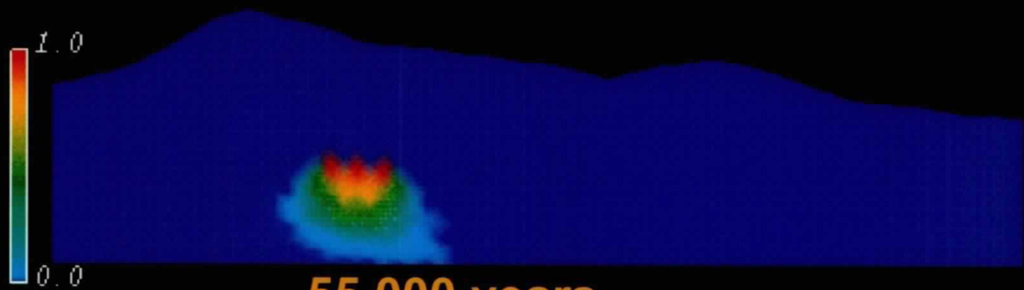
Transport Barriers

Uniform Infiltration = 0.36 mm/yr

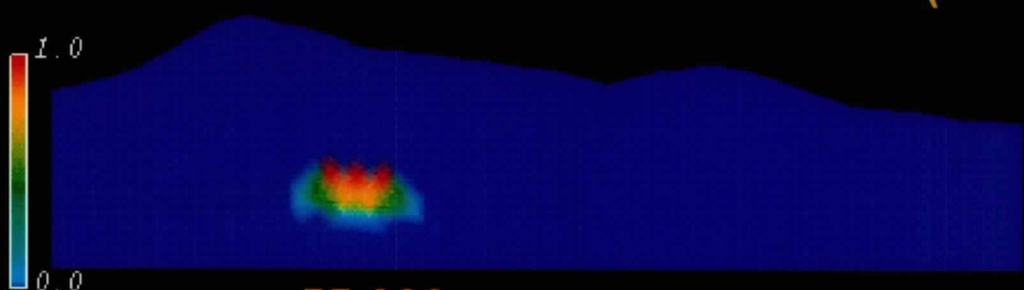
Source Above Thicker Section of Calico Hills

Case 1: No Retardation

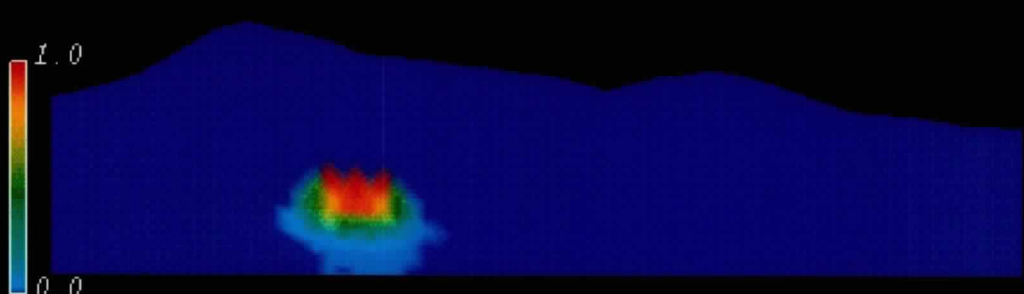


55,000 years

Case 2: With Retardation in Calico Hills (Kd = 3)



55,000 years



820,000 years

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