

*Deep Saline Aquifers for Geological Storage of CO<sub>2</sub> and Energy*  
*may 27-29 2009* *Rueil Malmaison*

## Decarbonation, mineral sequestration and their localization in a water-assisted CO<sub>2</sub> storage scenario, Dogger reservoirs, Paris Basin

**SHP**CO<sub>2</sub>

*a contribution from  
the ANR supported program SHPCO<sub>2</sub>*

AGENCE NATIONALE DE LA RECHERCHE  
**ANR**

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 Géosciences pour une Terre durable  
**brgm**

# *Deep Saline Aquifers for Geological Storage of CO<sub>2</sub> and Energy*

**Decarbonation,  
mineral sequestration**

**and their localisation  
in a water-assisted CO<sub>2</sub>  
storage scenario,**

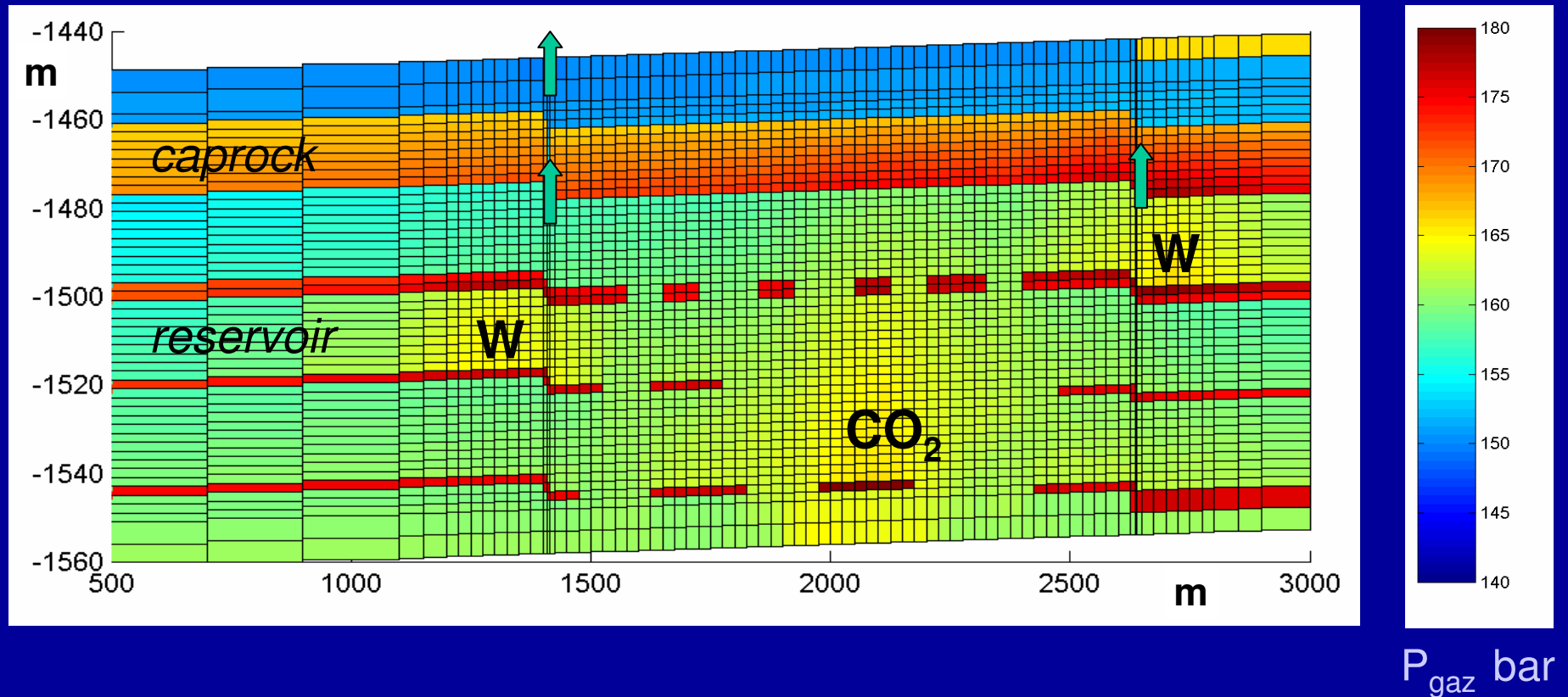
**Dogger reservoirs,  
Paris Basin**

Reactions induced by CO<sub>2</sub>  
storage in deep aquifers  
*reactive transport modeling  
short term to long term*

Impact of injection design  
and later water movements  
*reaction management  
safety issues*

Carbonate-dominated targets  
*data from earlier programs*

# Stage 1: multiple injection CO<sub>2</sub> and brine – 5 years



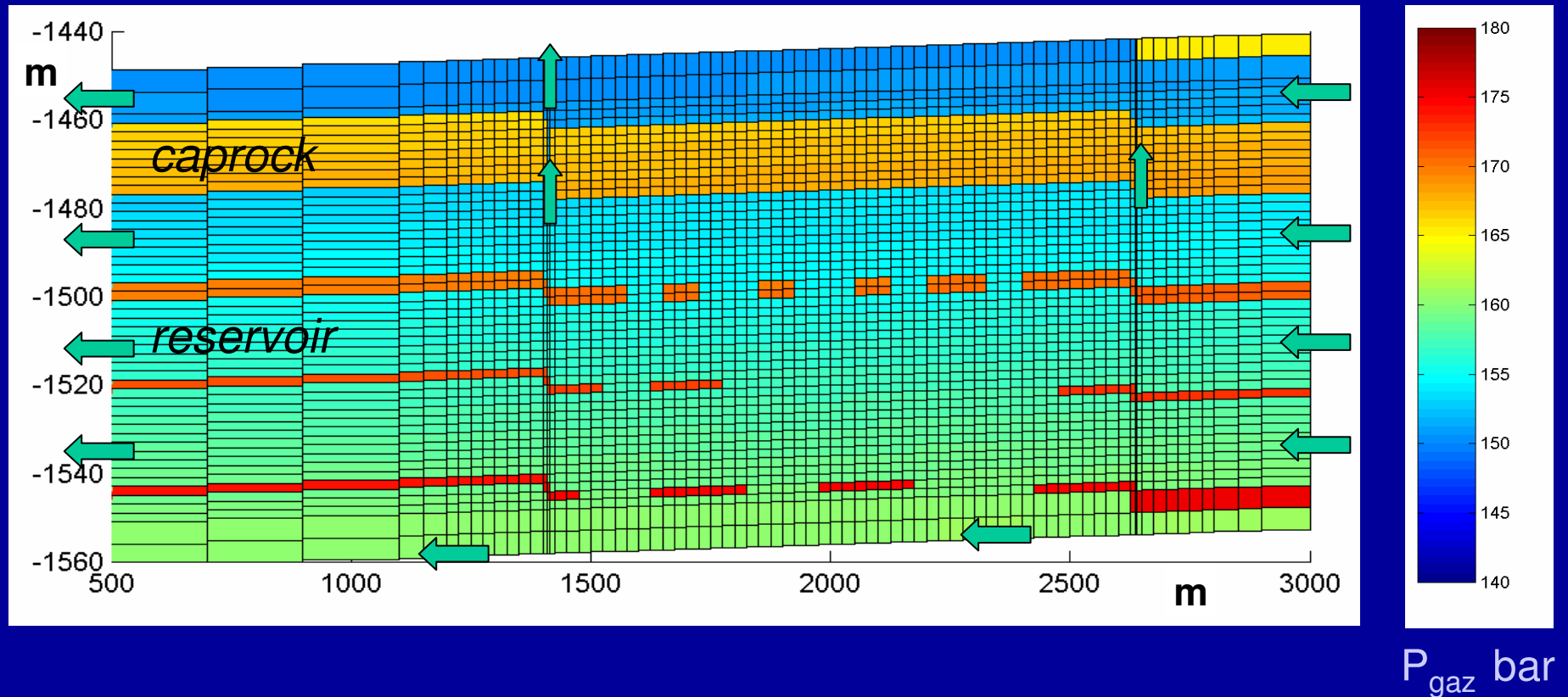
GEOMETRY : 2D monoclinial section (4 km x 100 m)

– depth 1500 m (60°C, 150 bar)

caprock and discontinuous screens (marls), some fractures  
layered reservoir (impure carbonate), upper (control) aquifer

BOUNDS : CO<sub>2</sub> injector, Water injectors, one leak point, aquifers ( $v \sim 1\text{m/y}$ )<sup>3</sup>

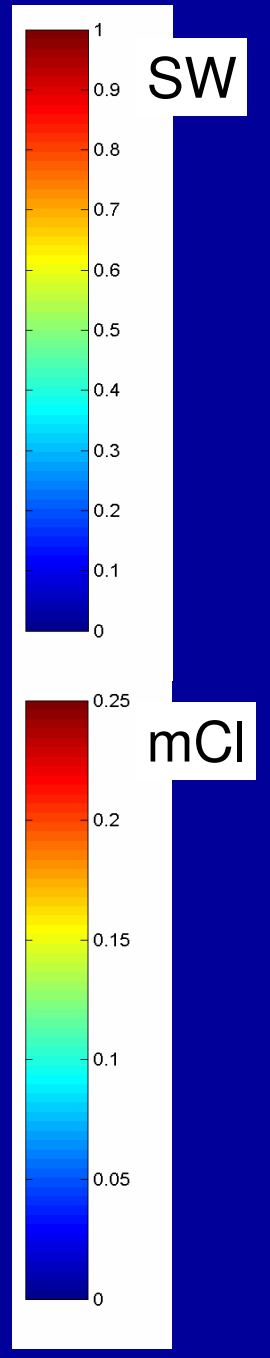
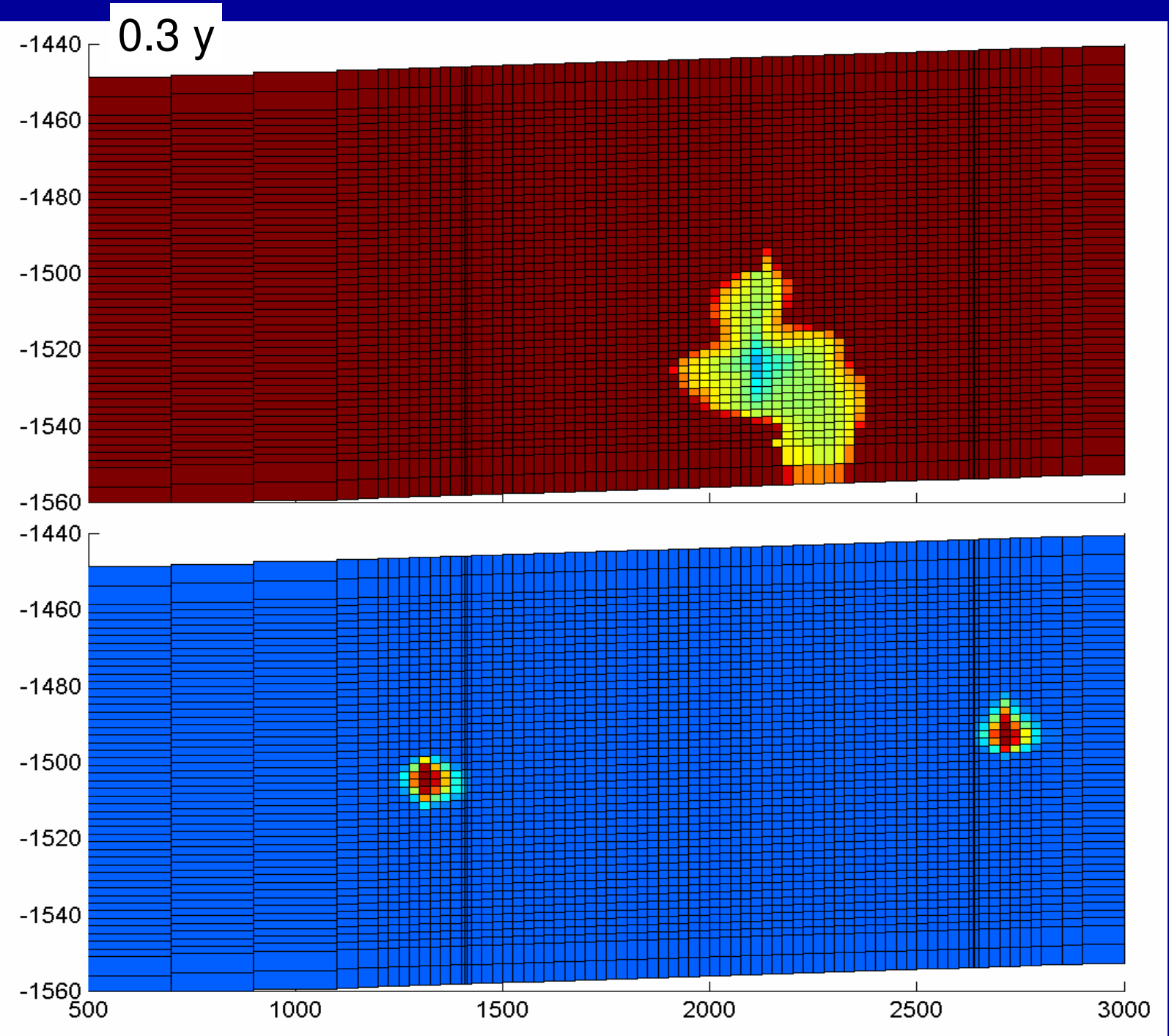
## Stage 2 aquifer sweep – 2500 years



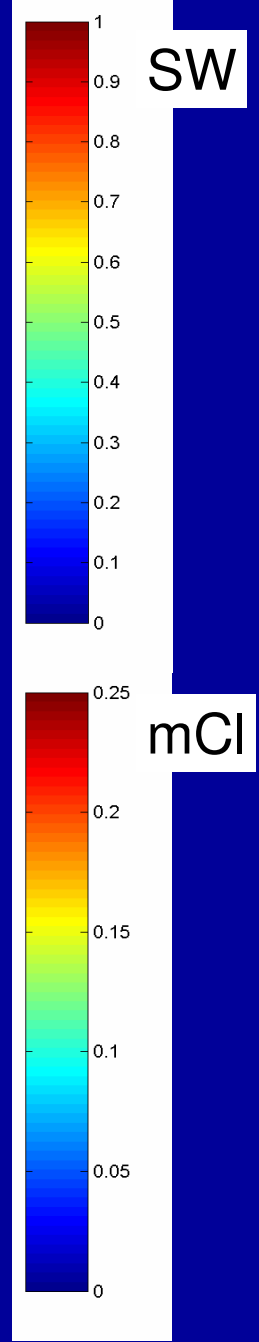
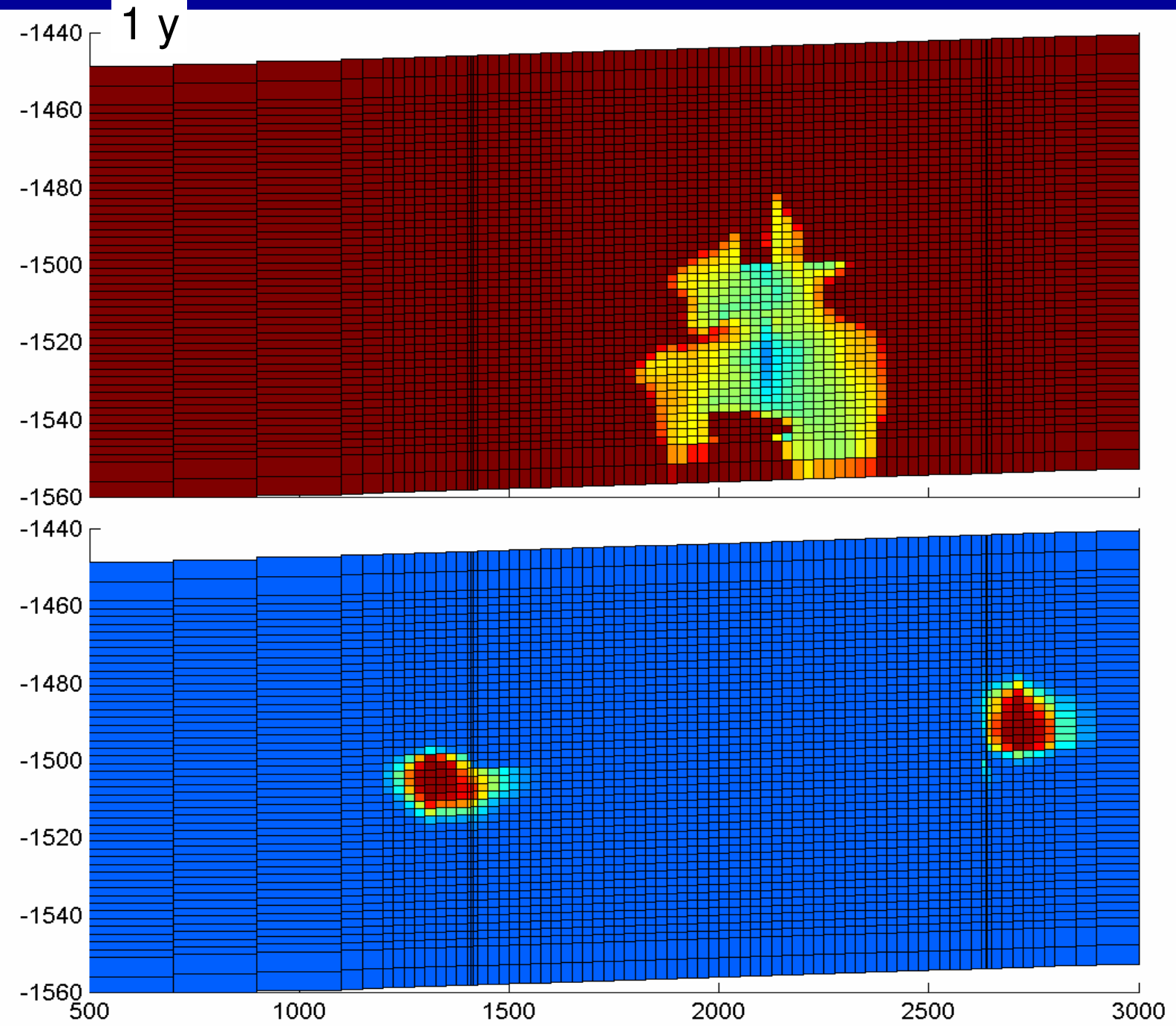
**PETROPHYSICS :** reservoirs SWI = 0.2 SGC = 0.1 (optional hysteresis)  
heterogeneous reservoir permeability (av KX 80 mD, KZ 8 mD)  
capillary entry pressure in marls 15 bar

**CHEMISTRY :** system Na-K-Ca-Mg-Si-Al-C-Cl-S (simplified Dogger)<sub>4</sub>  
2 carbonates, 1 sulfate, 4 silicates – PCO<sub>2</sub> buffer

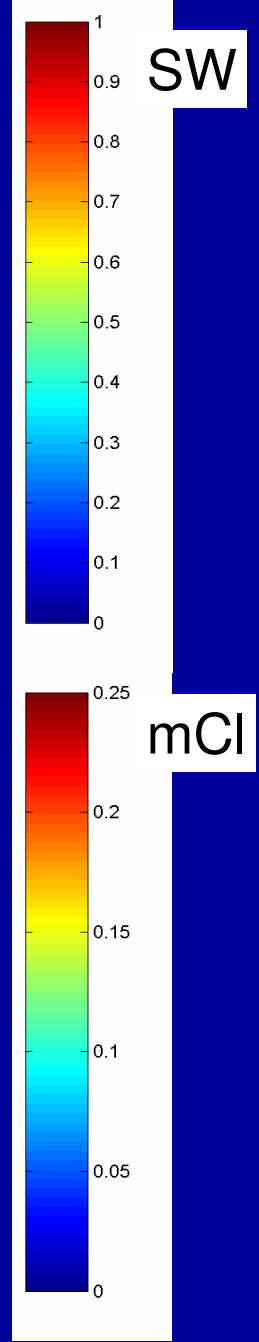
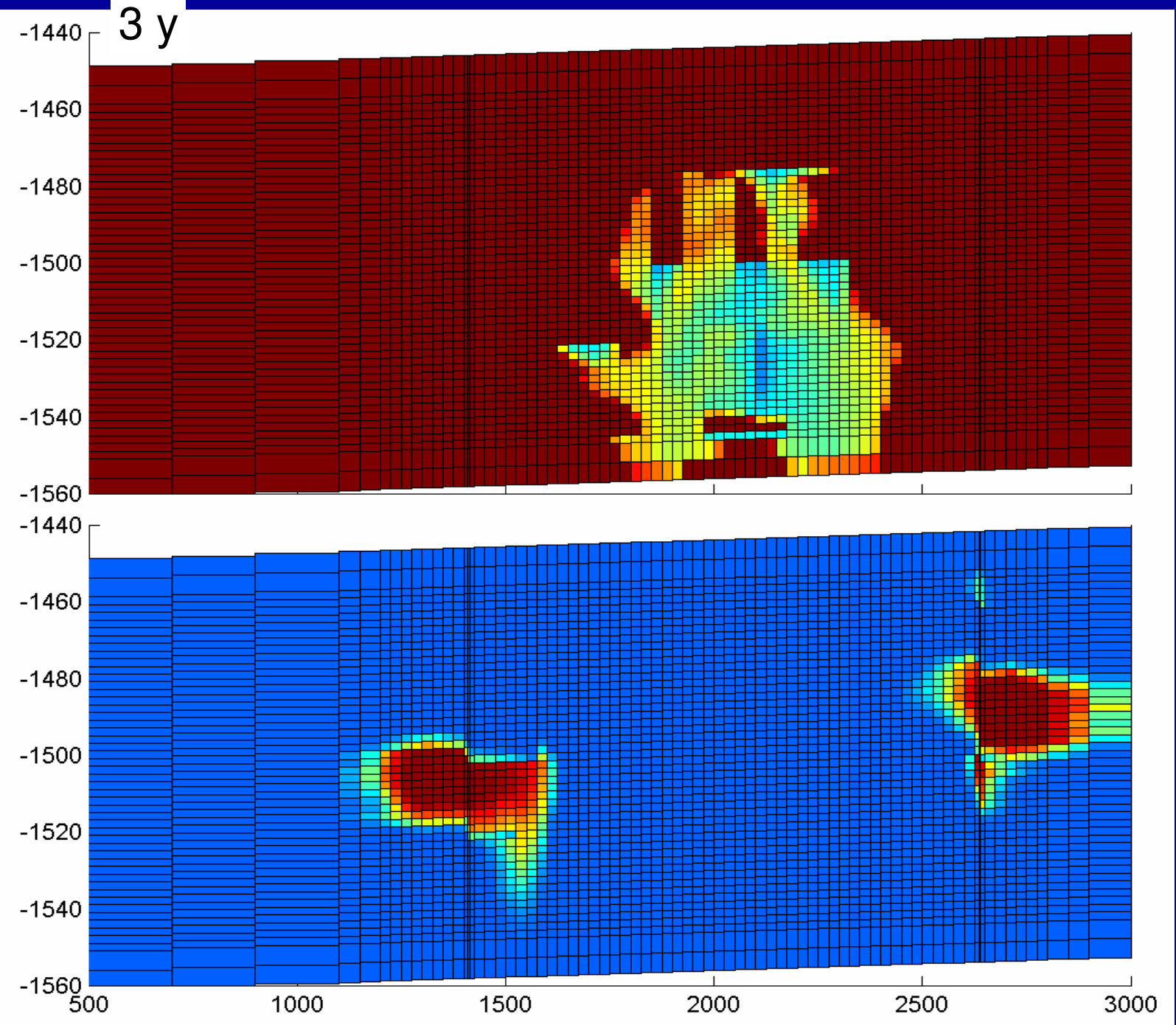
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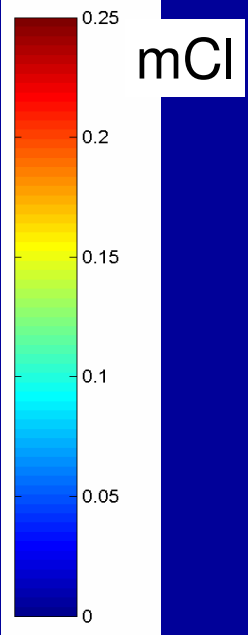
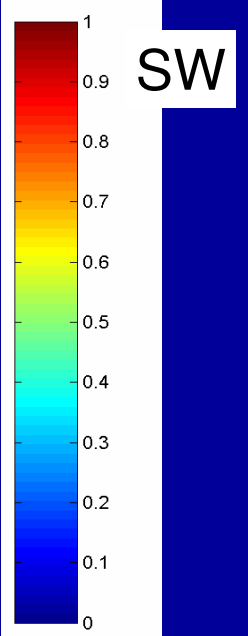
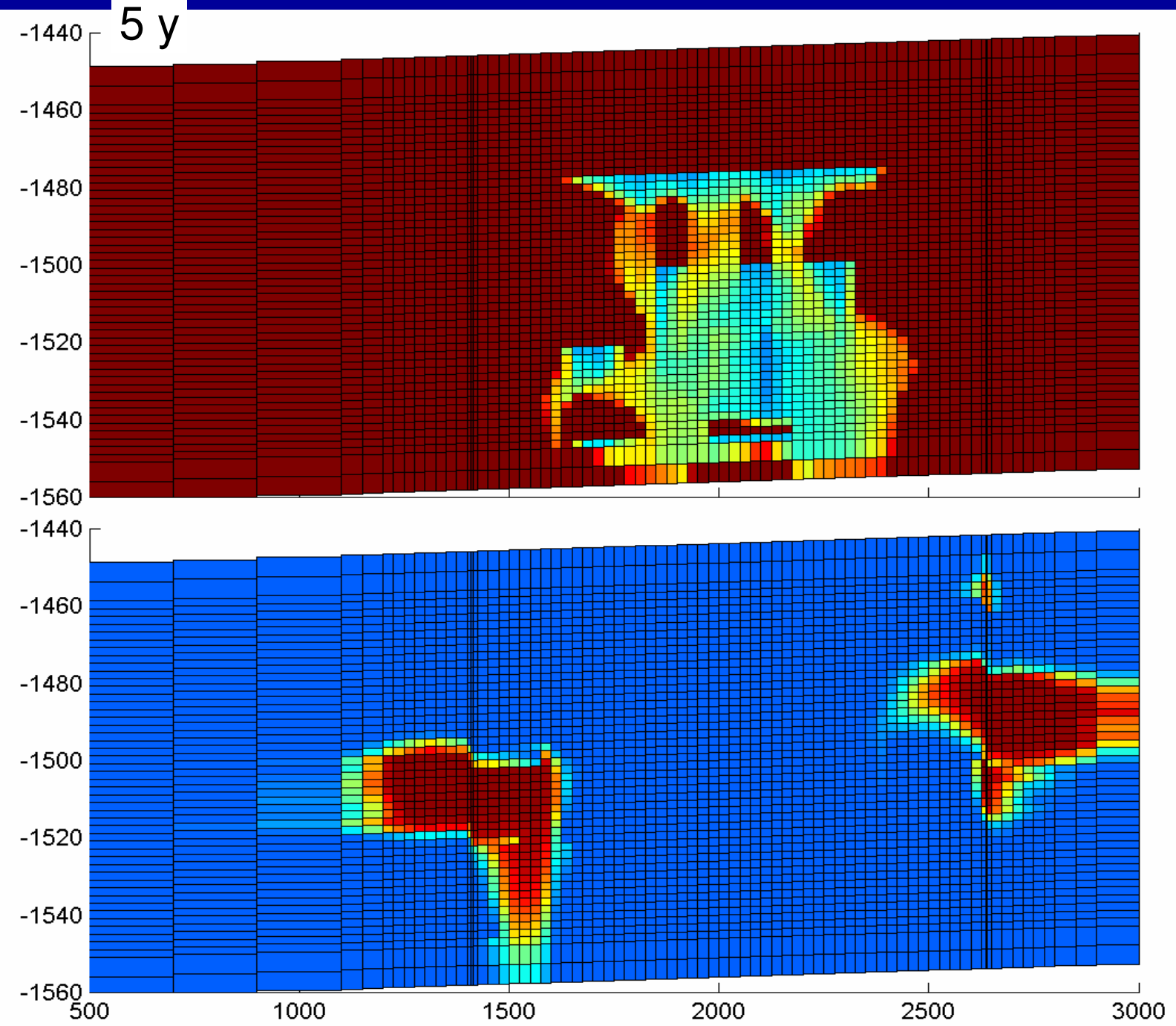
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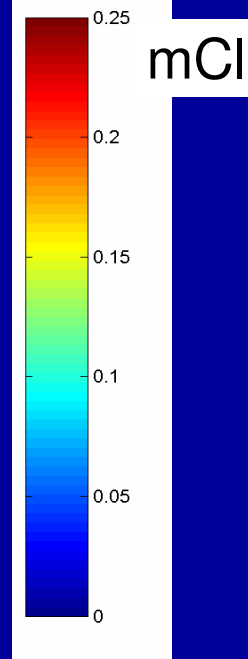
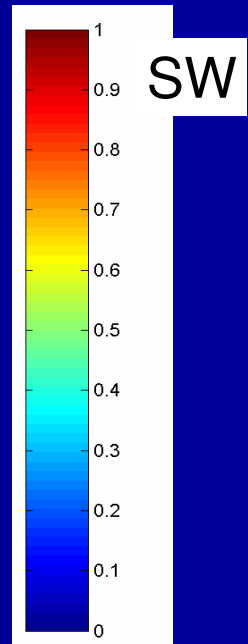
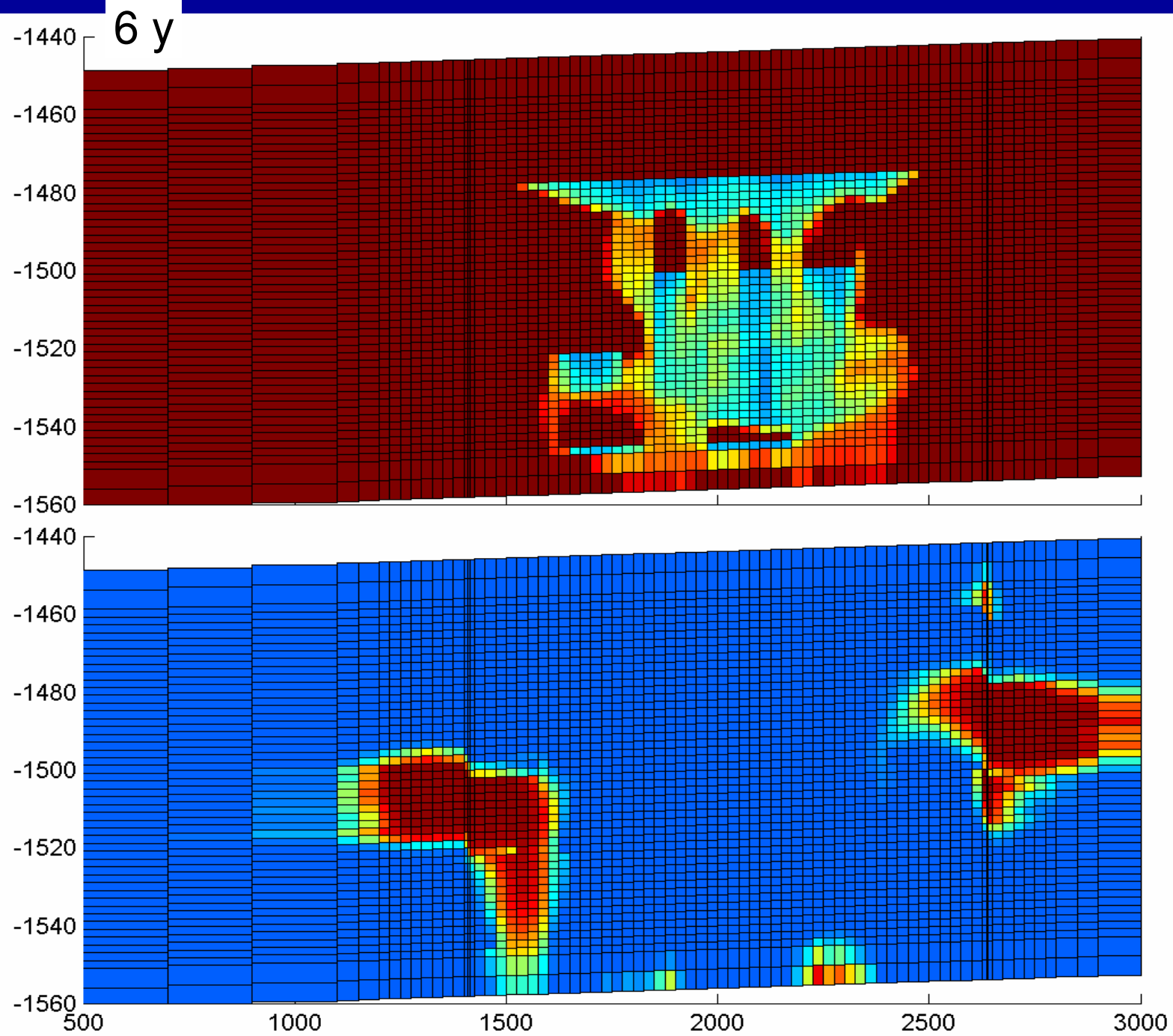
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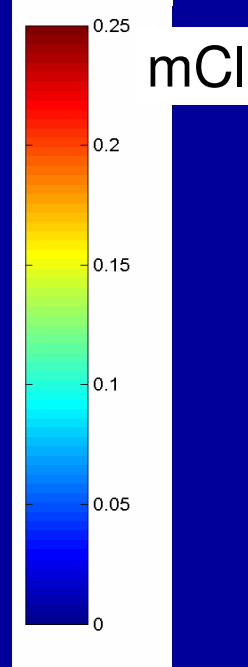
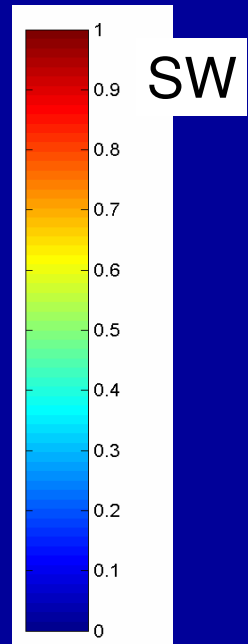
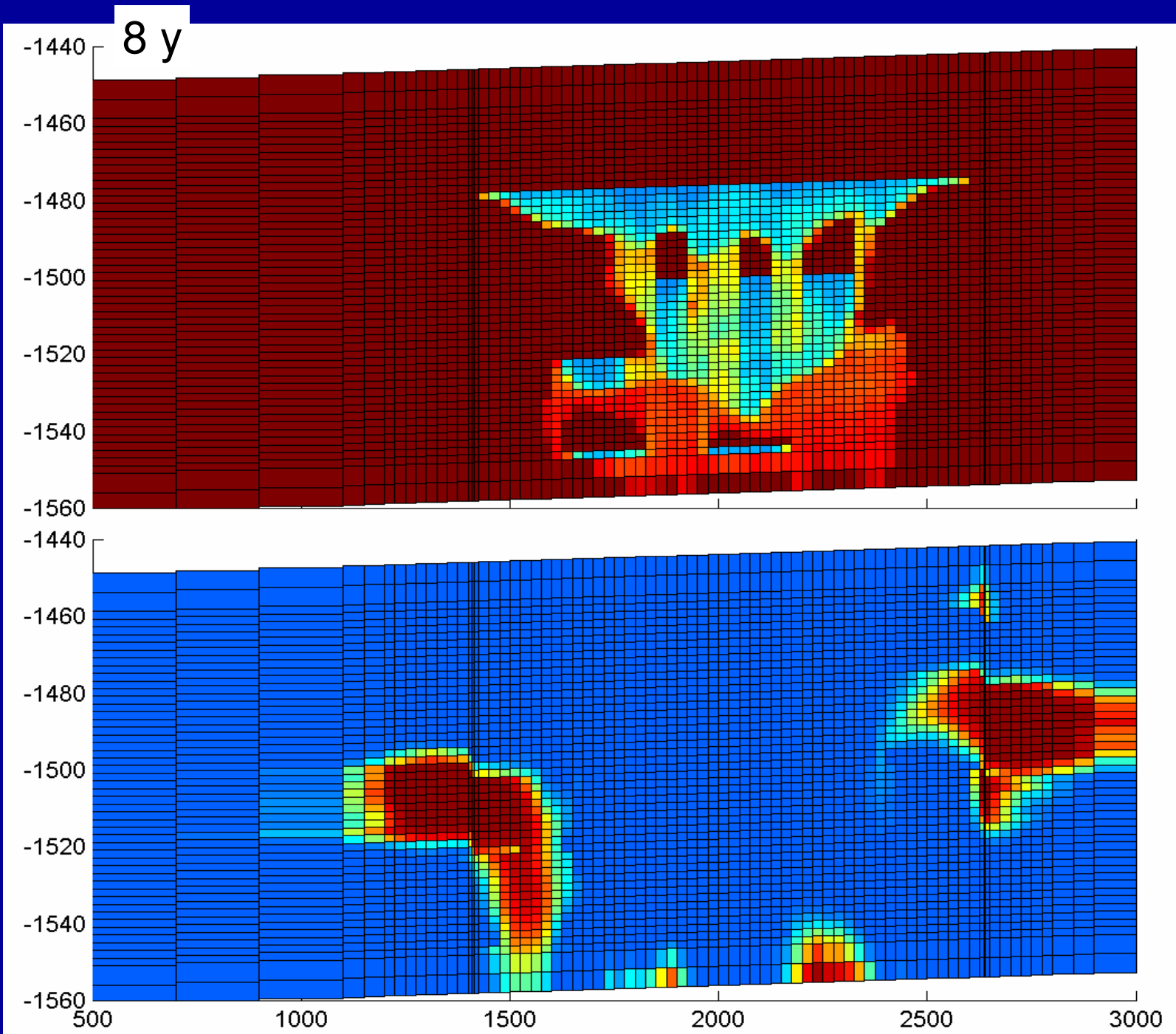
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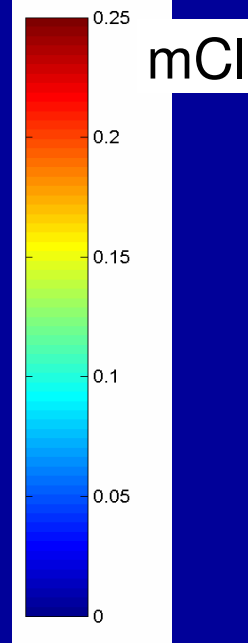
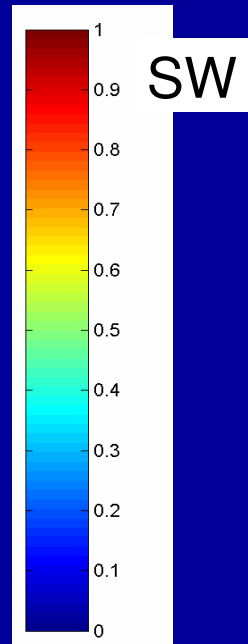
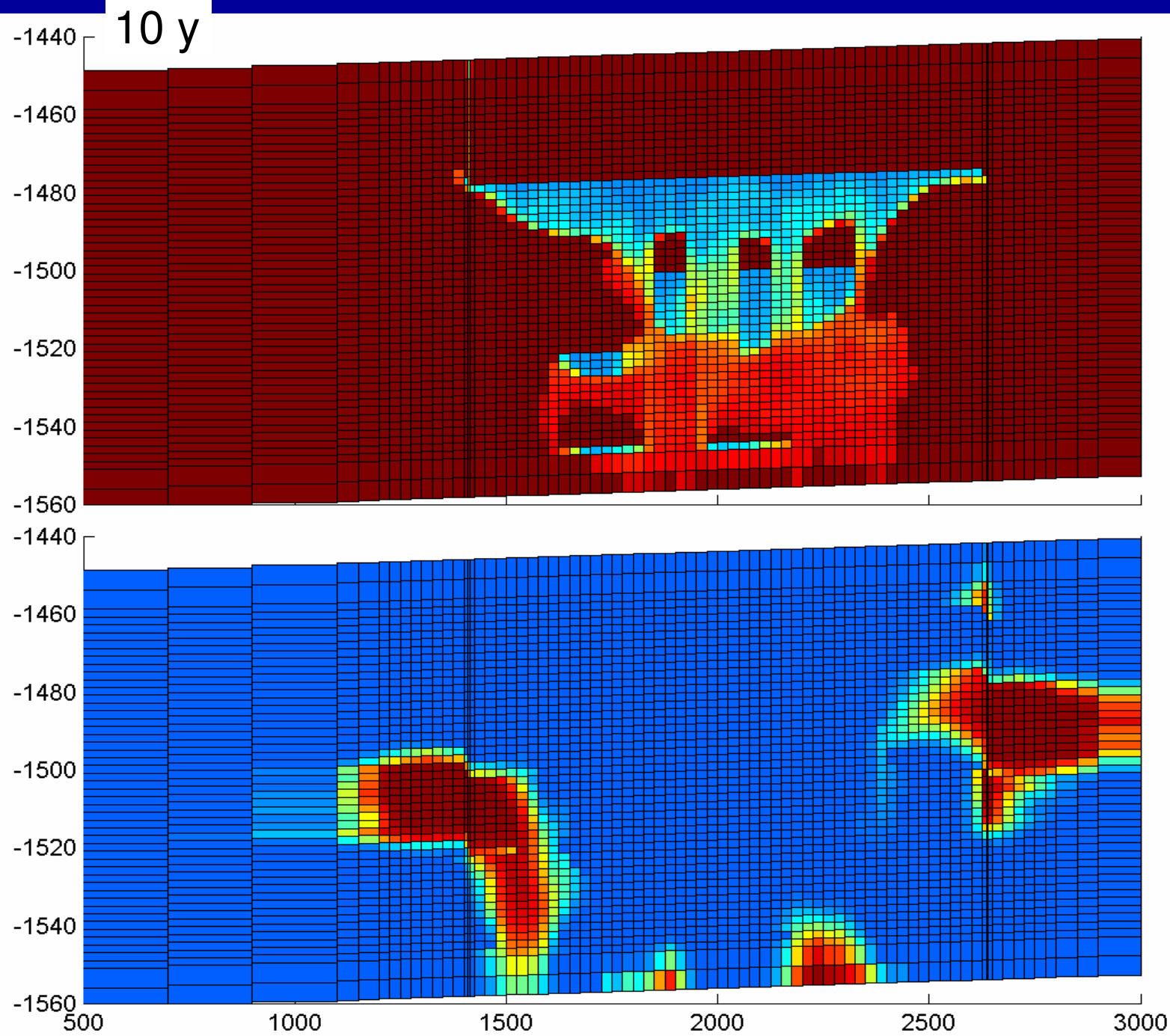
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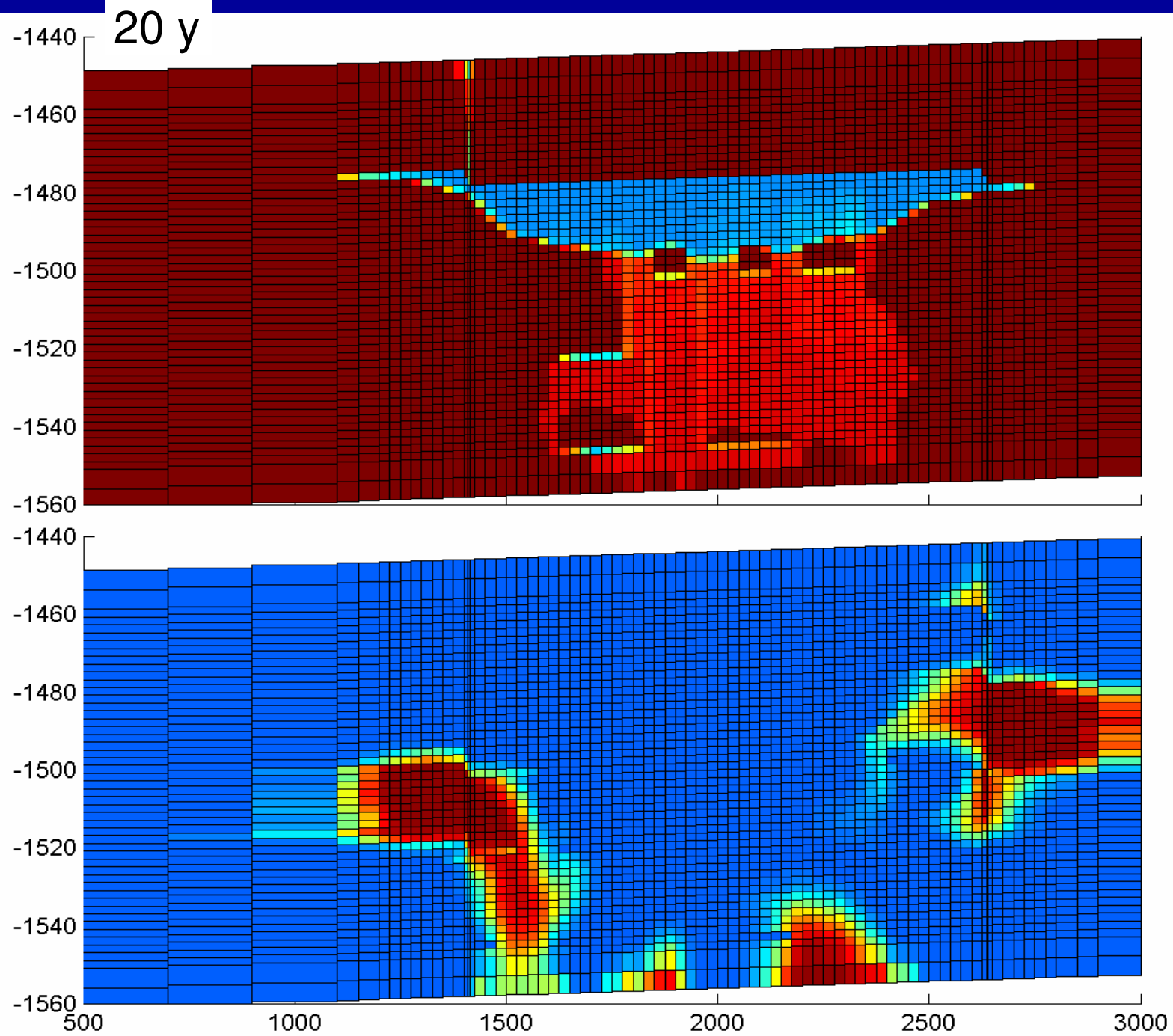
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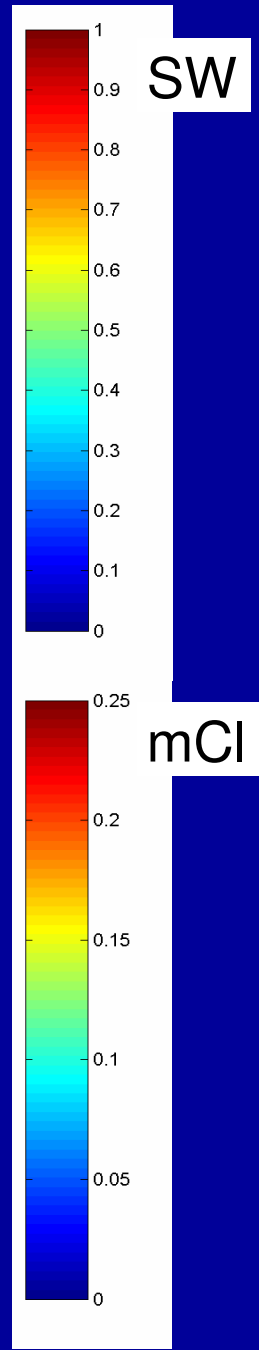
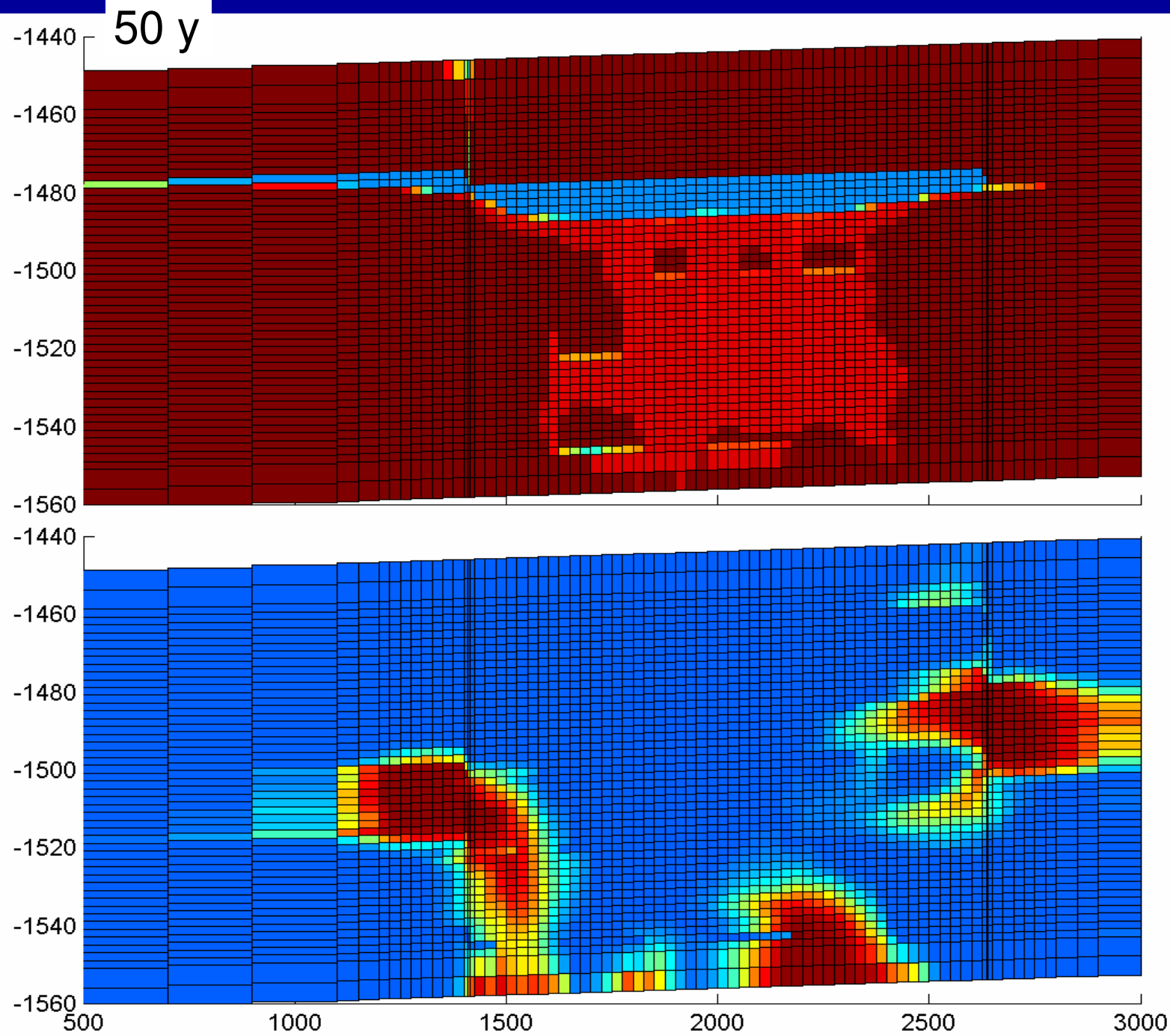
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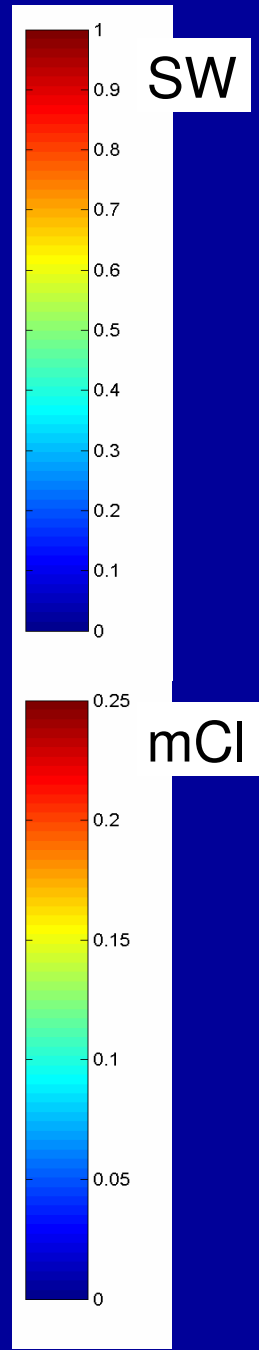
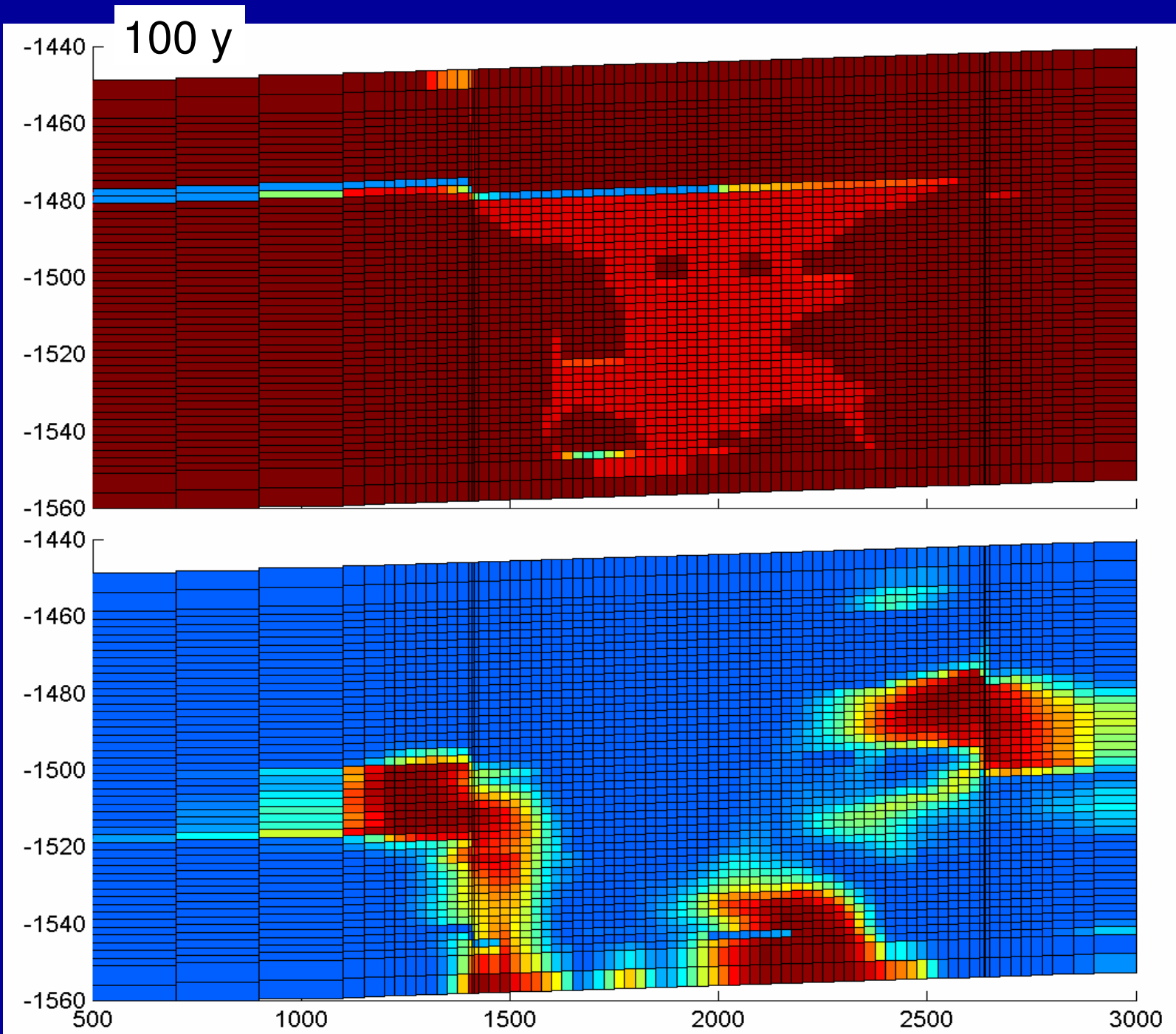
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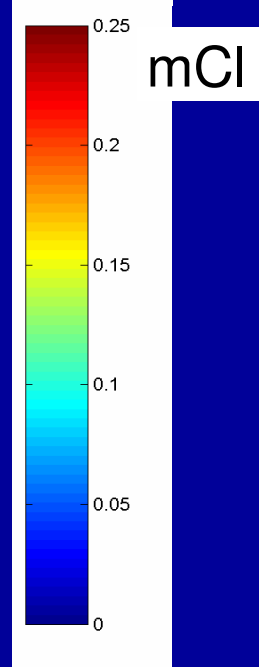
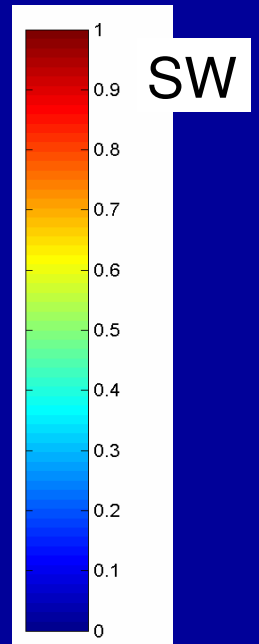
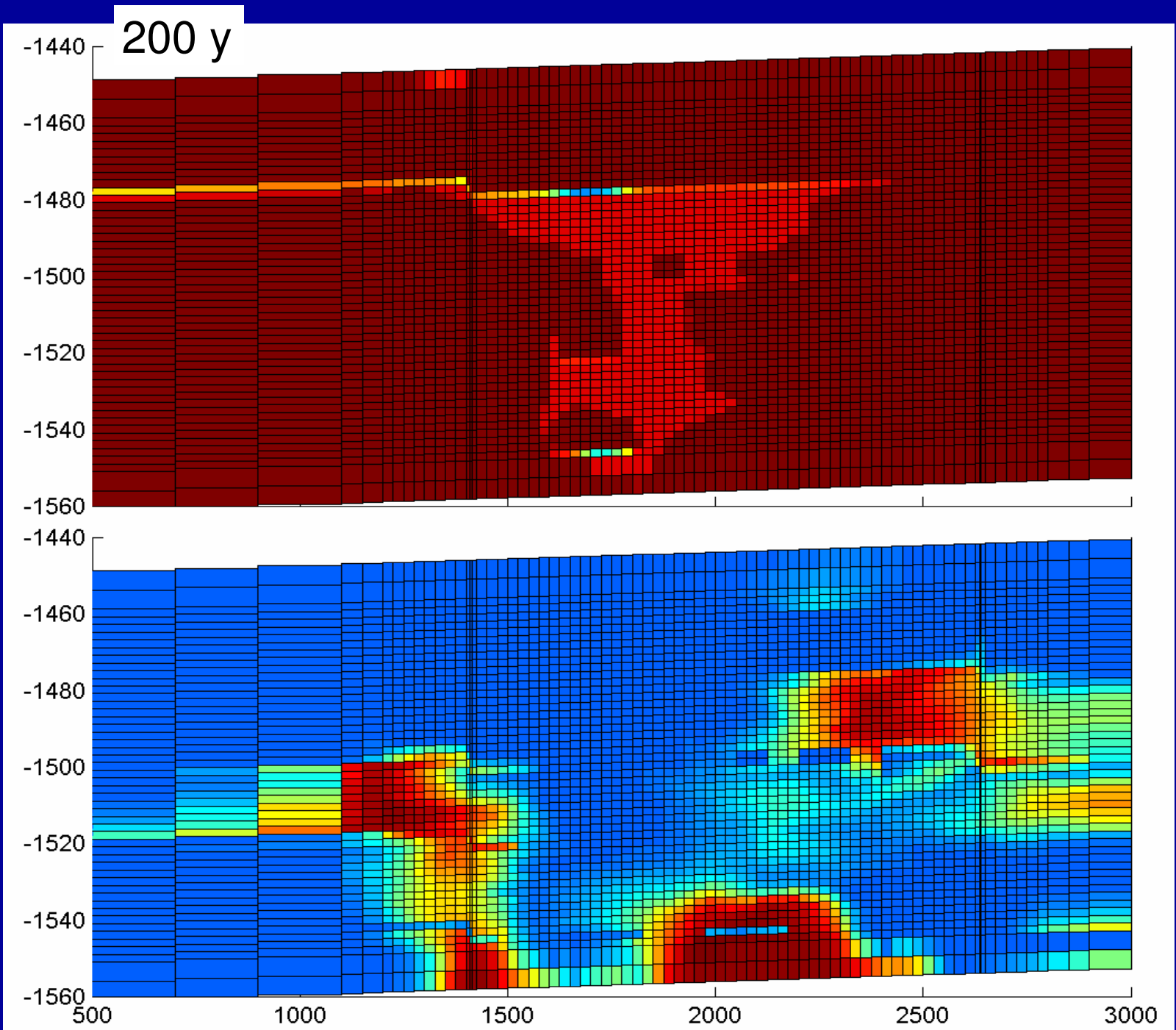
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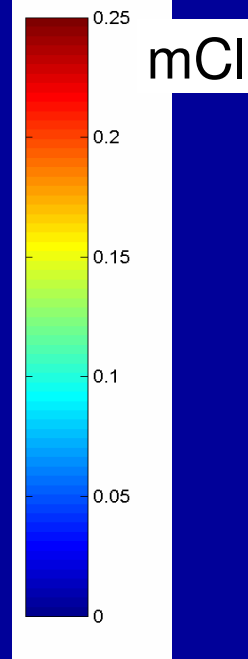
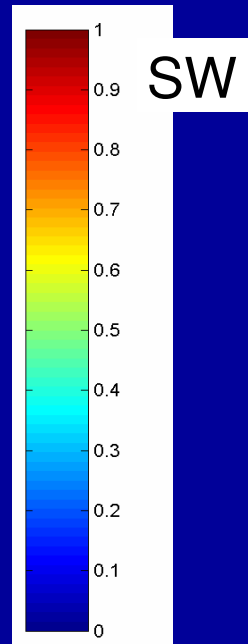
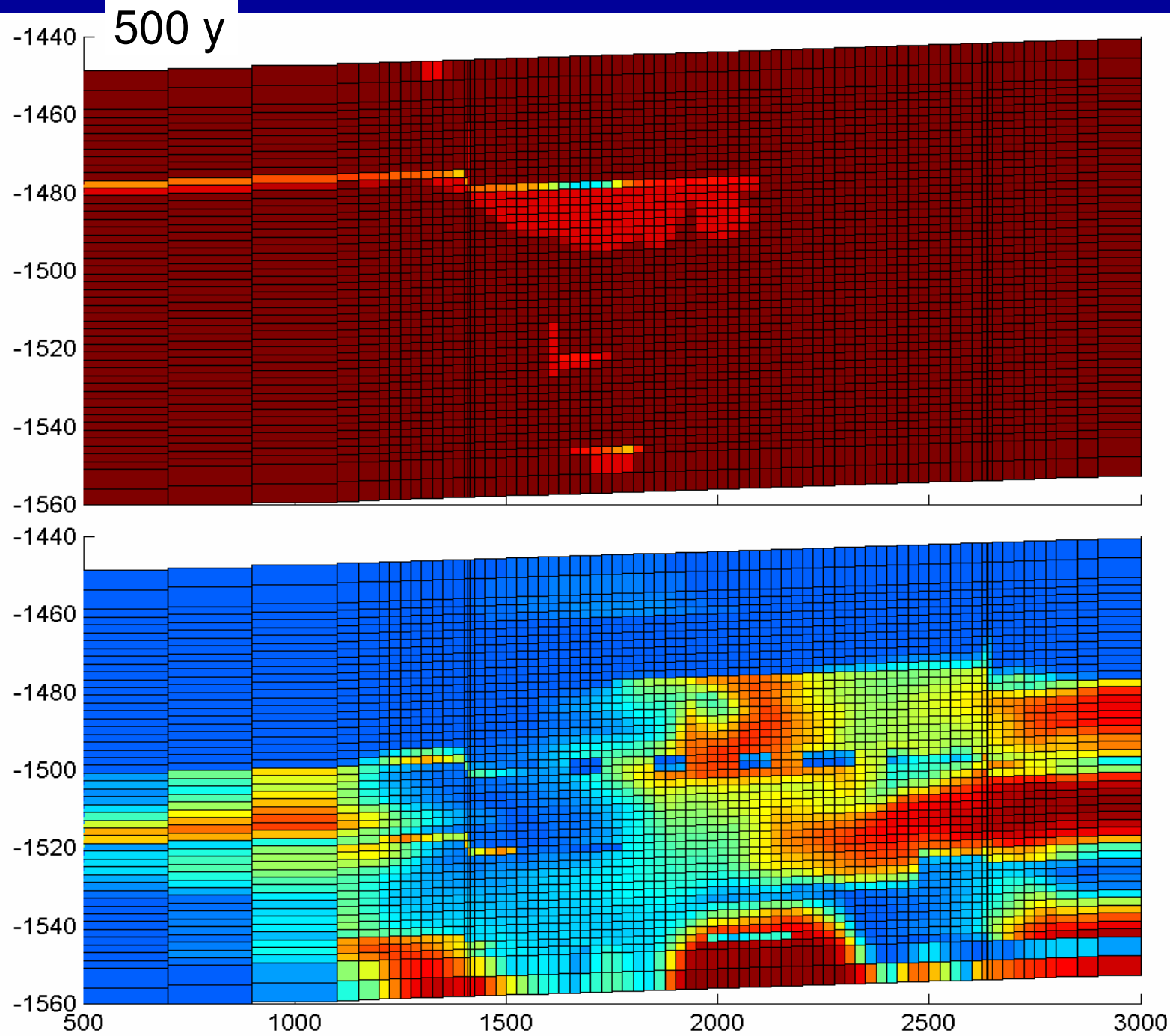
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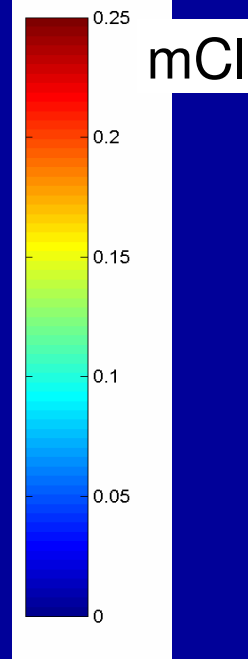
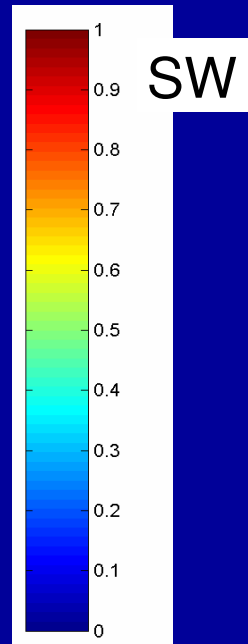
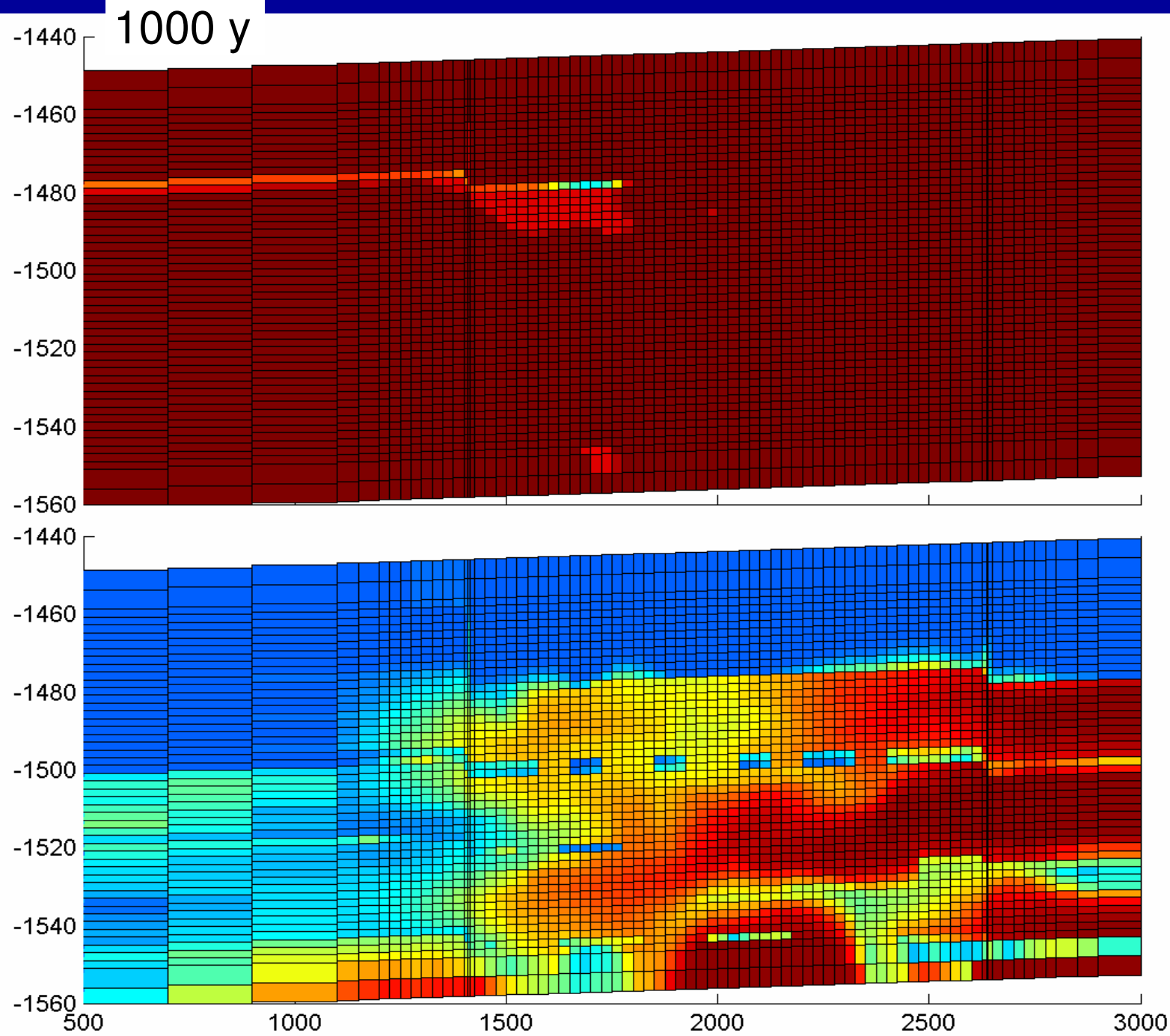
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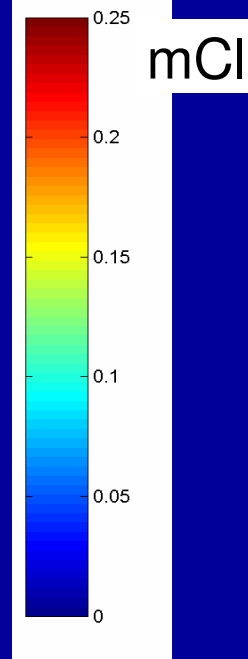
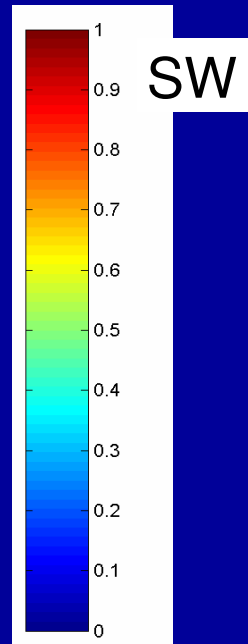
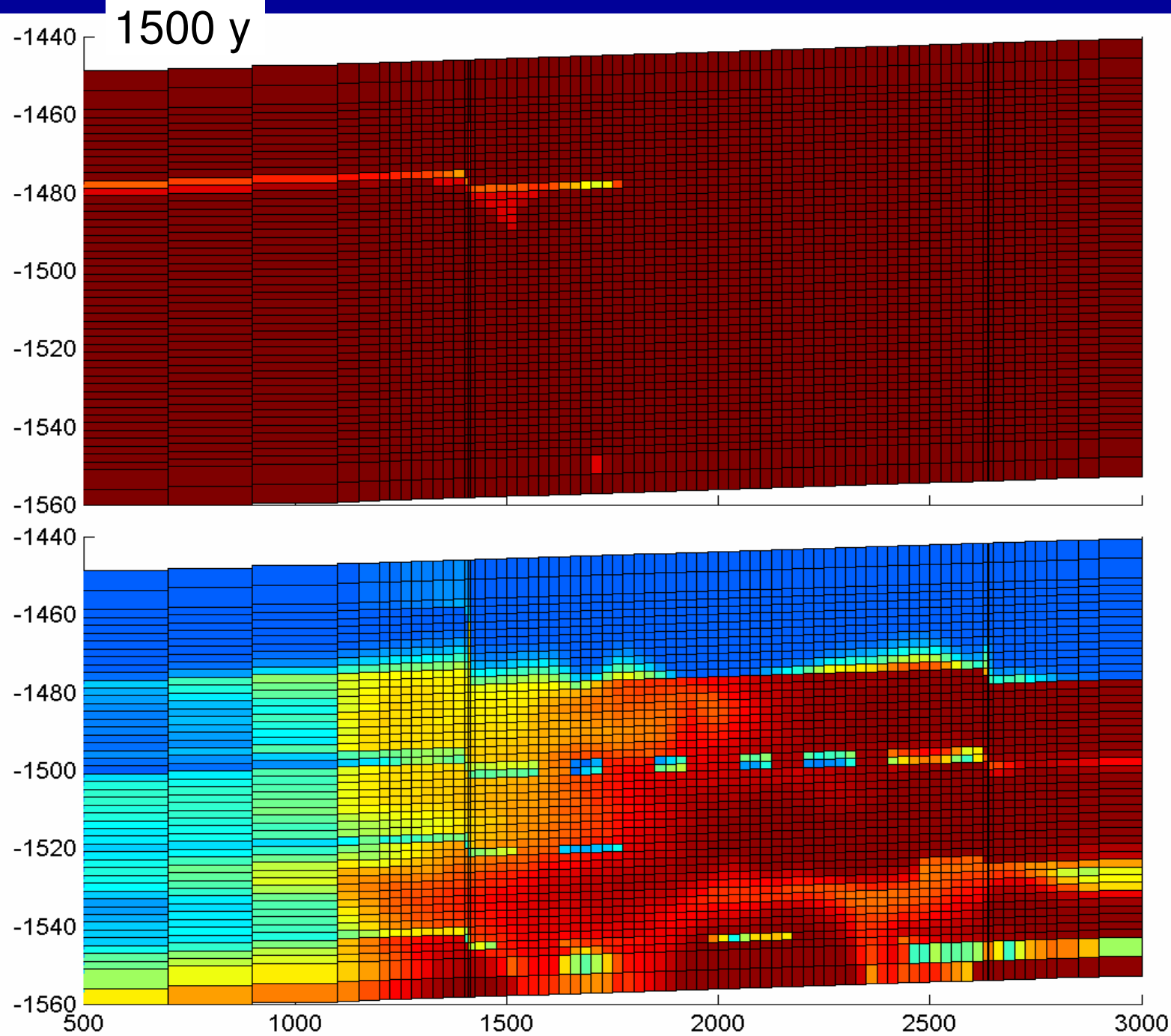
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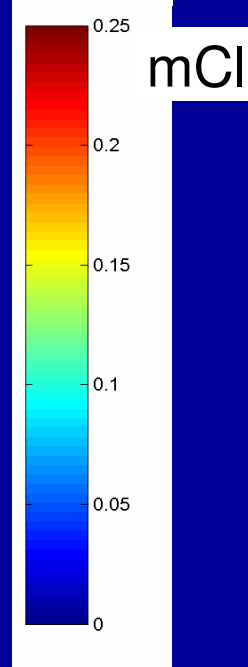
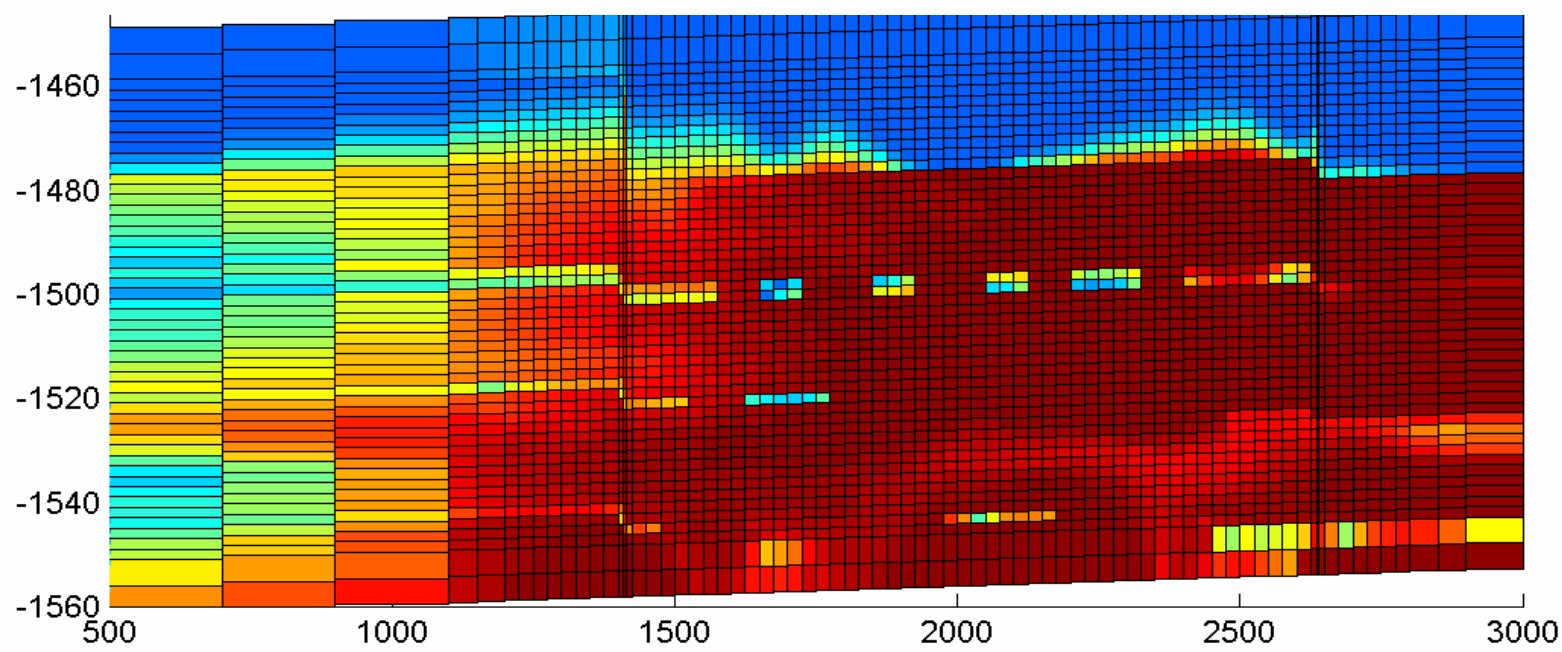
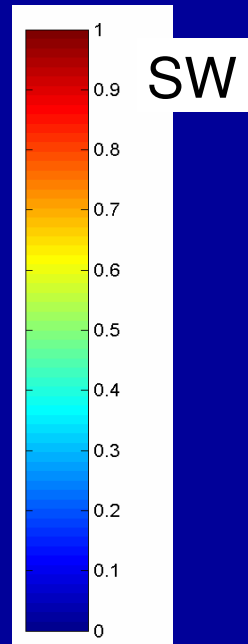
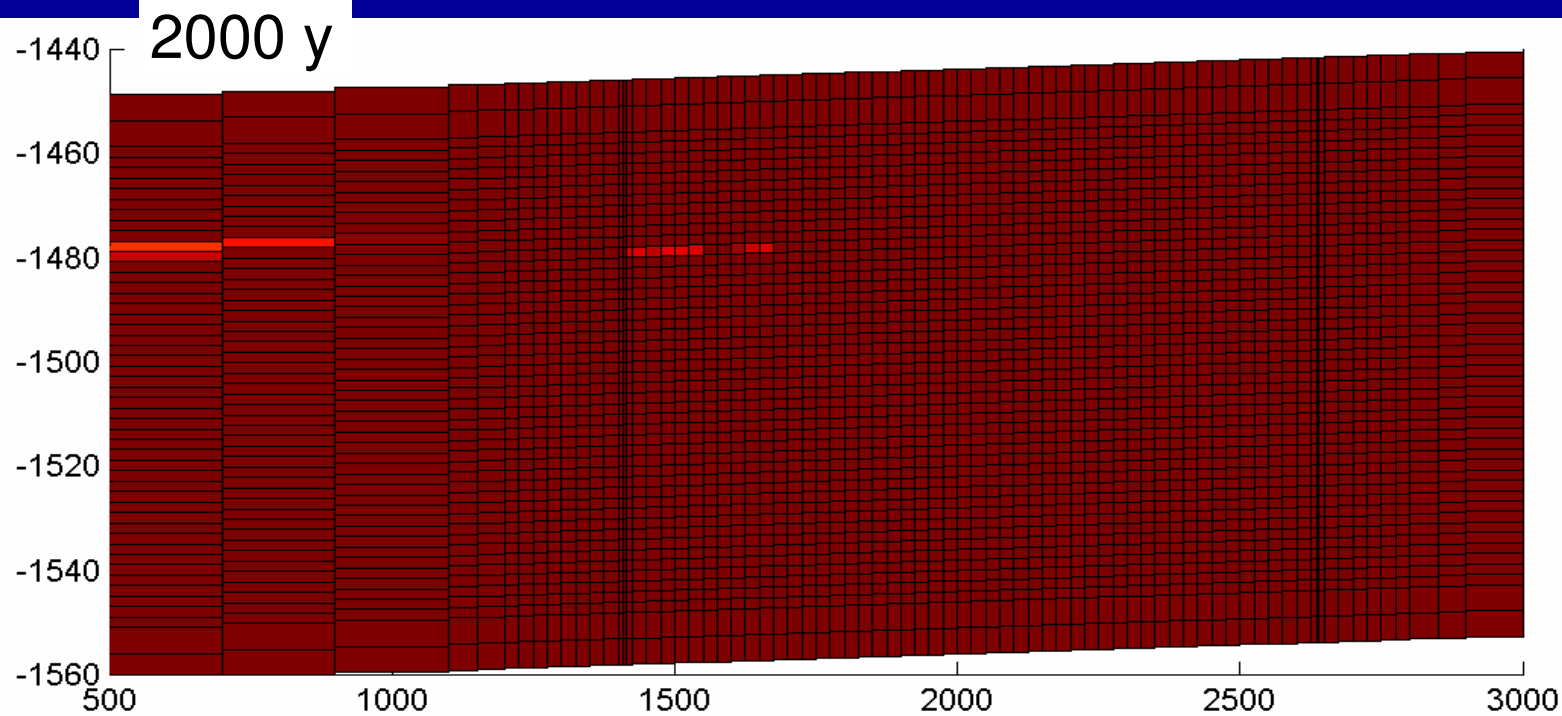
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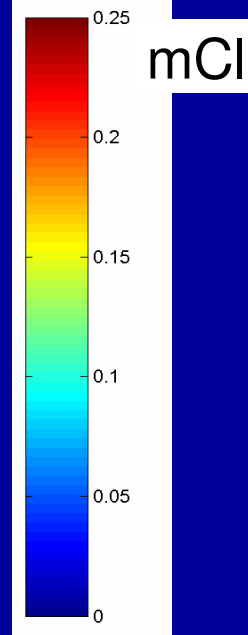
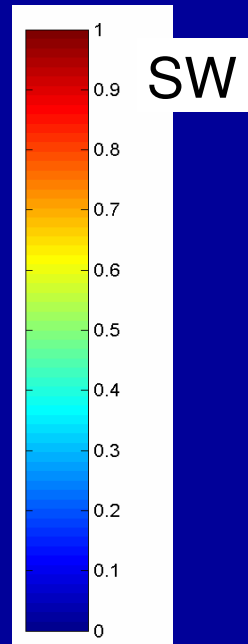
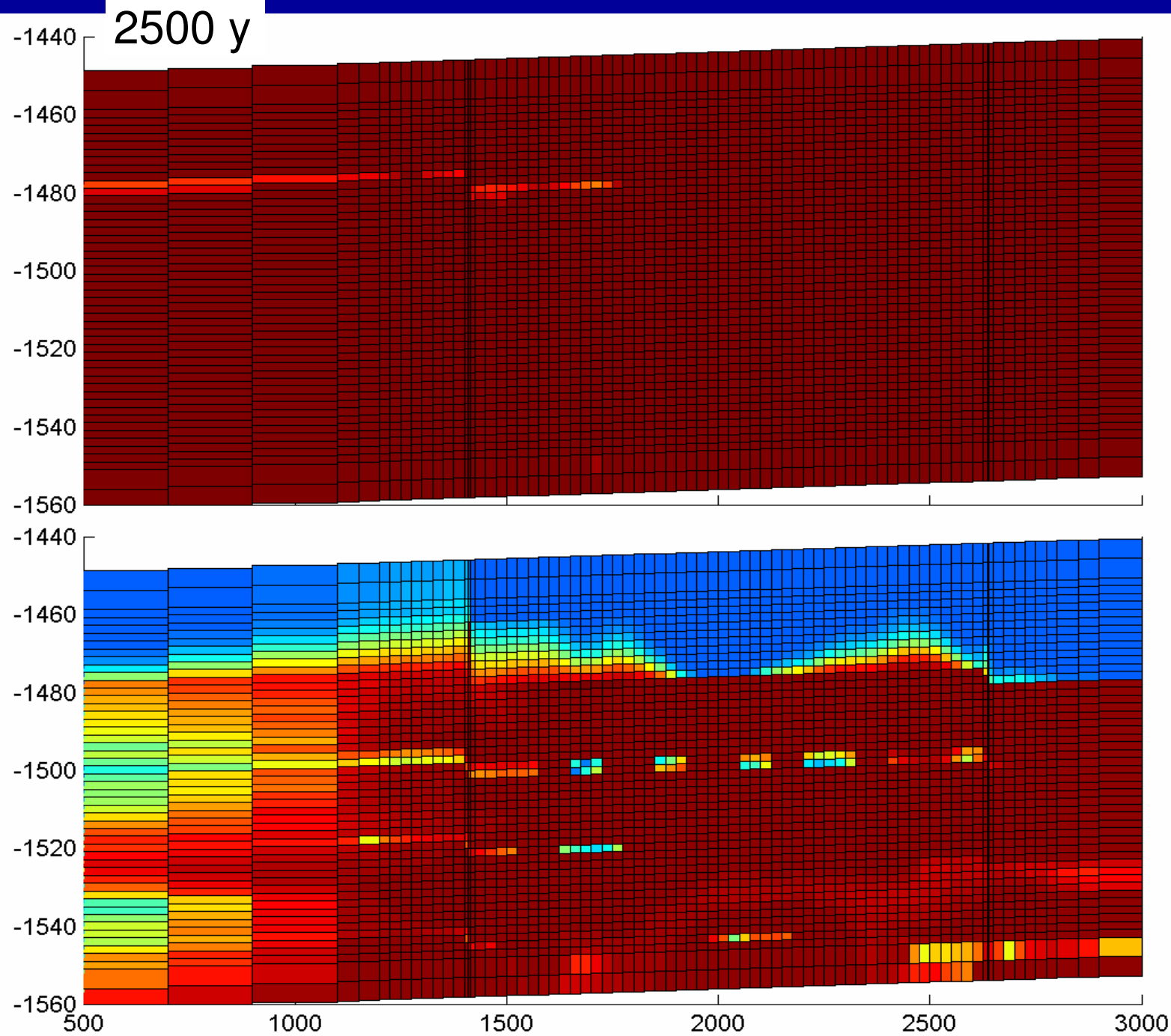
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# Expected chemical reactions (*0D kinetic model*)

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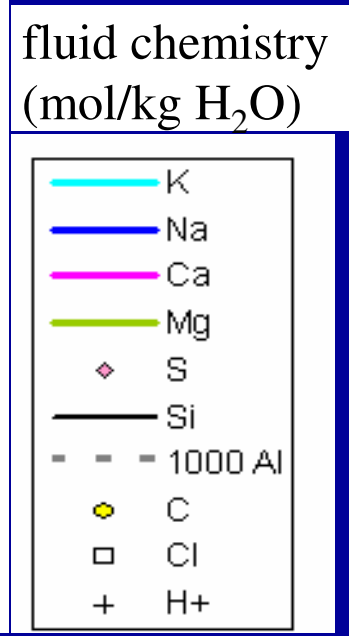
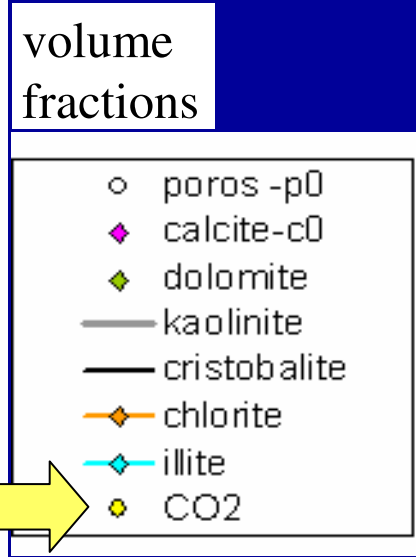
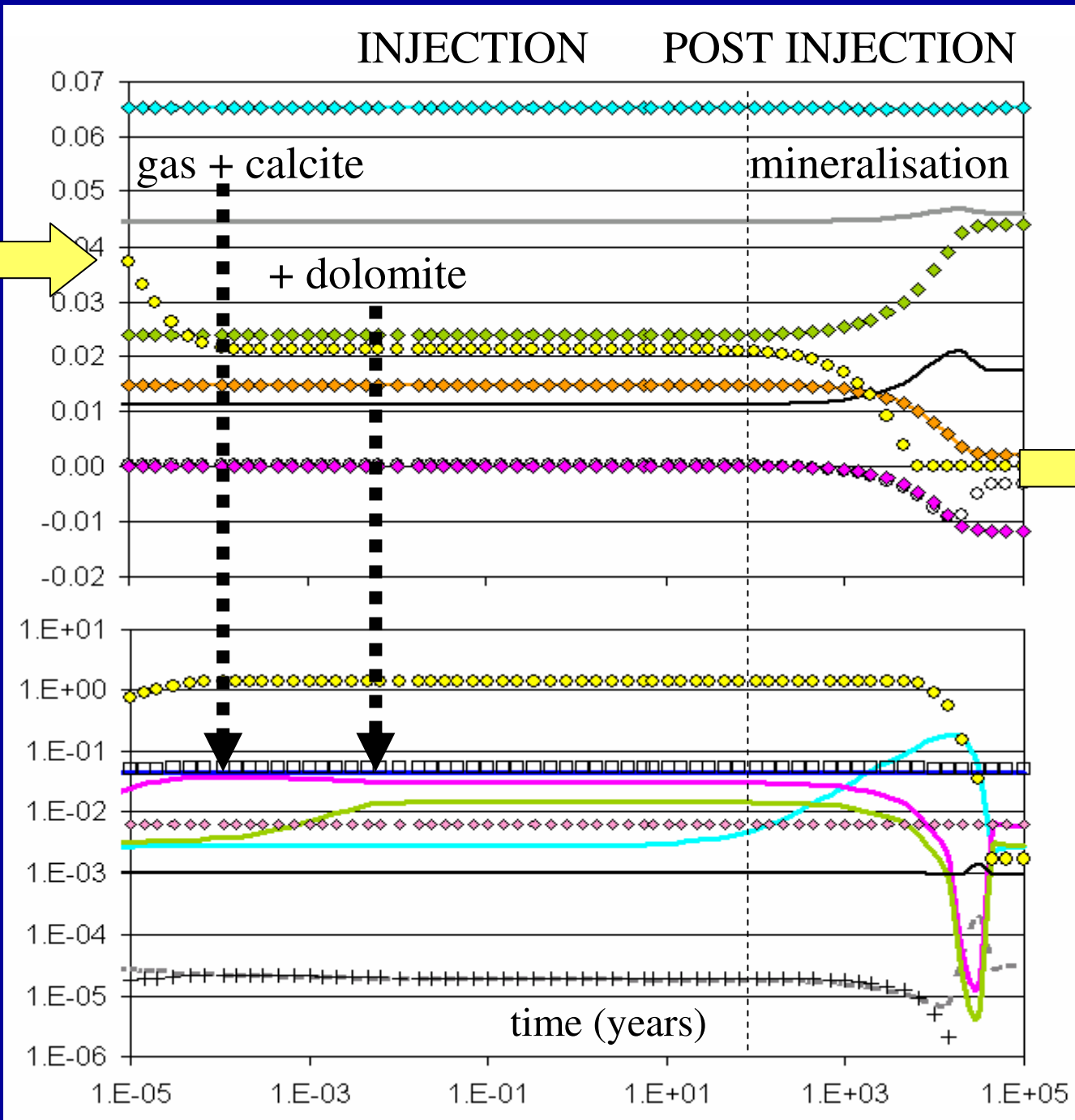
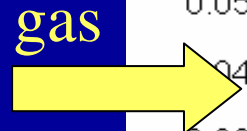
## SHORT TERM

water equilibrates with free CO<sub>2</sub> and carbonates  
mC, mCa, mMg increases, solid carbonates dissolve  
porosity increases

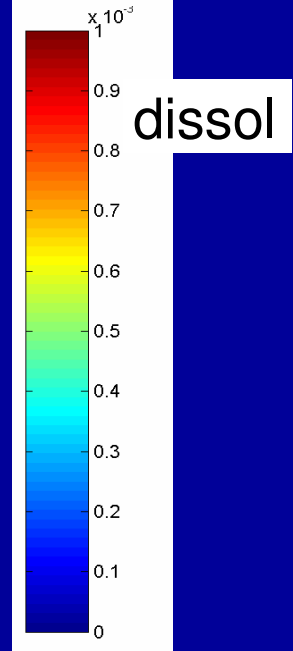
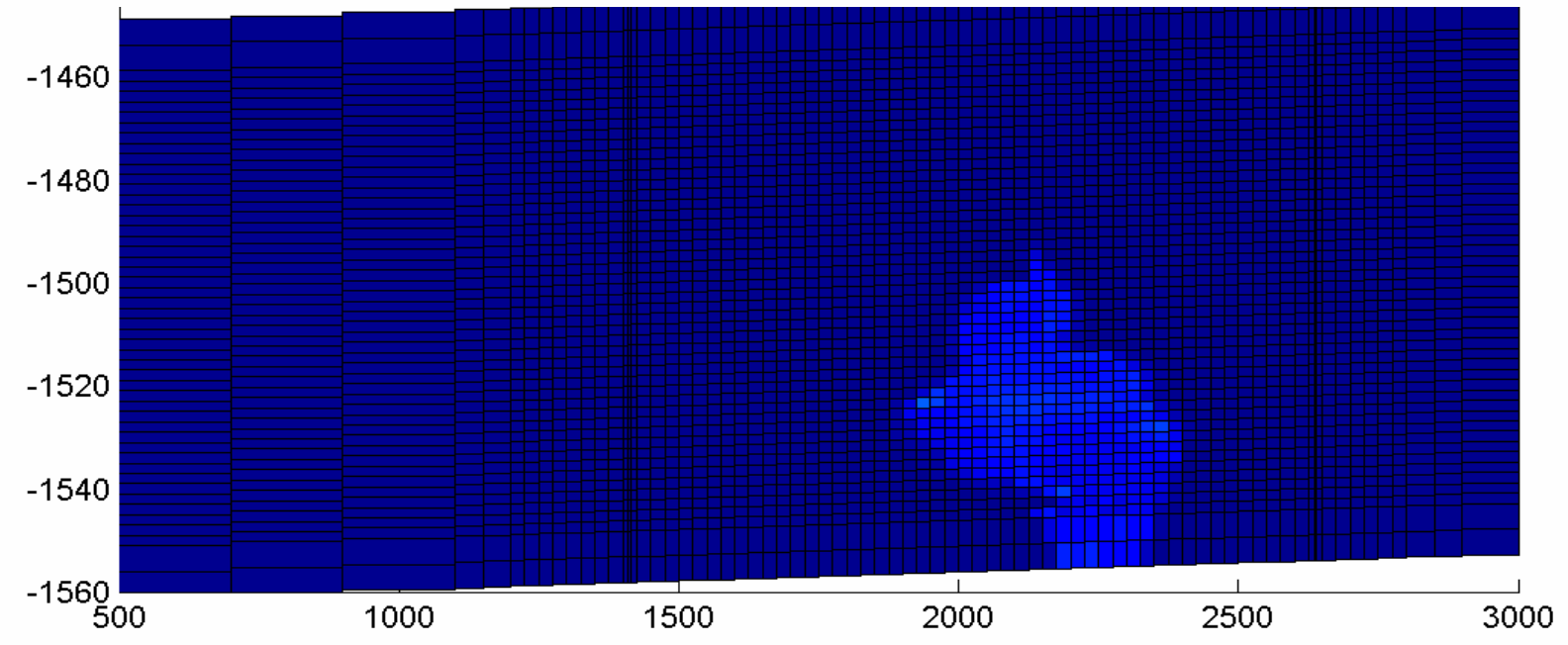
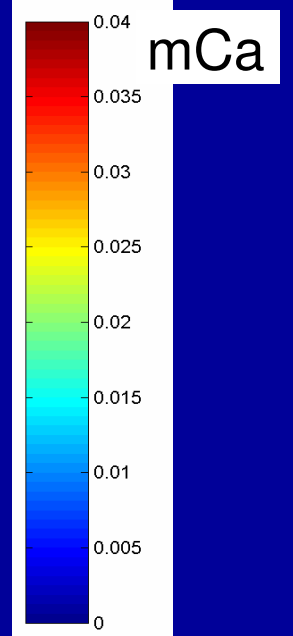
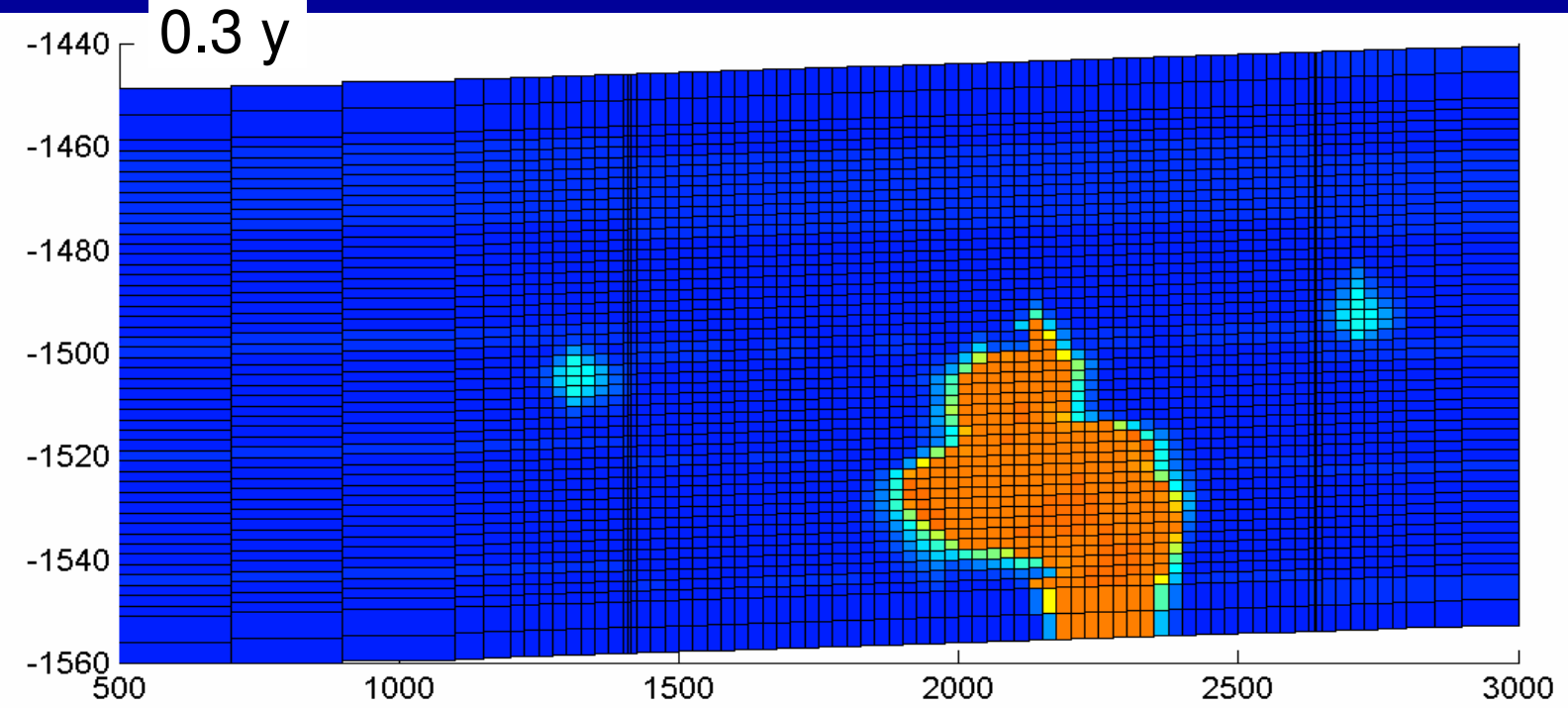
## LONG TERM (*ky*)

free gas >>> dissolved C  
primary silicates dissolve (illite, chlorite)  
Si, Al, K, Mg released  
secondary silicates precipitate (cristobalite, kaolinite)  
dissolved C is used in Mg-carbonate precipitation  
porosity decreases

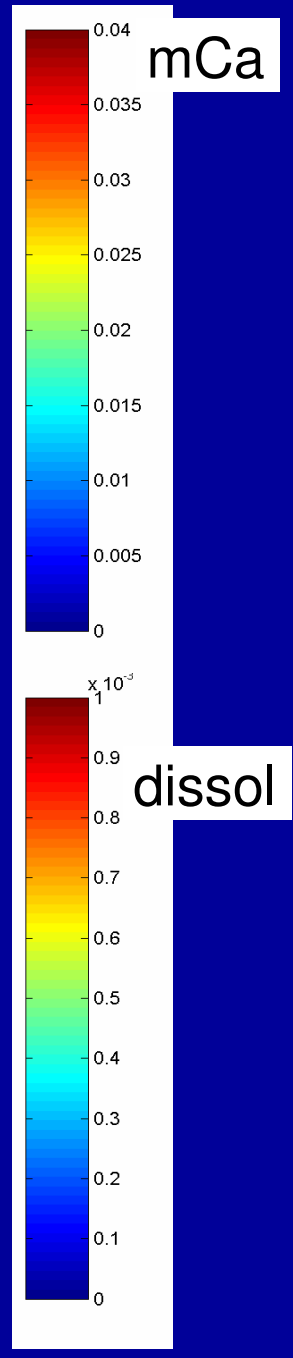
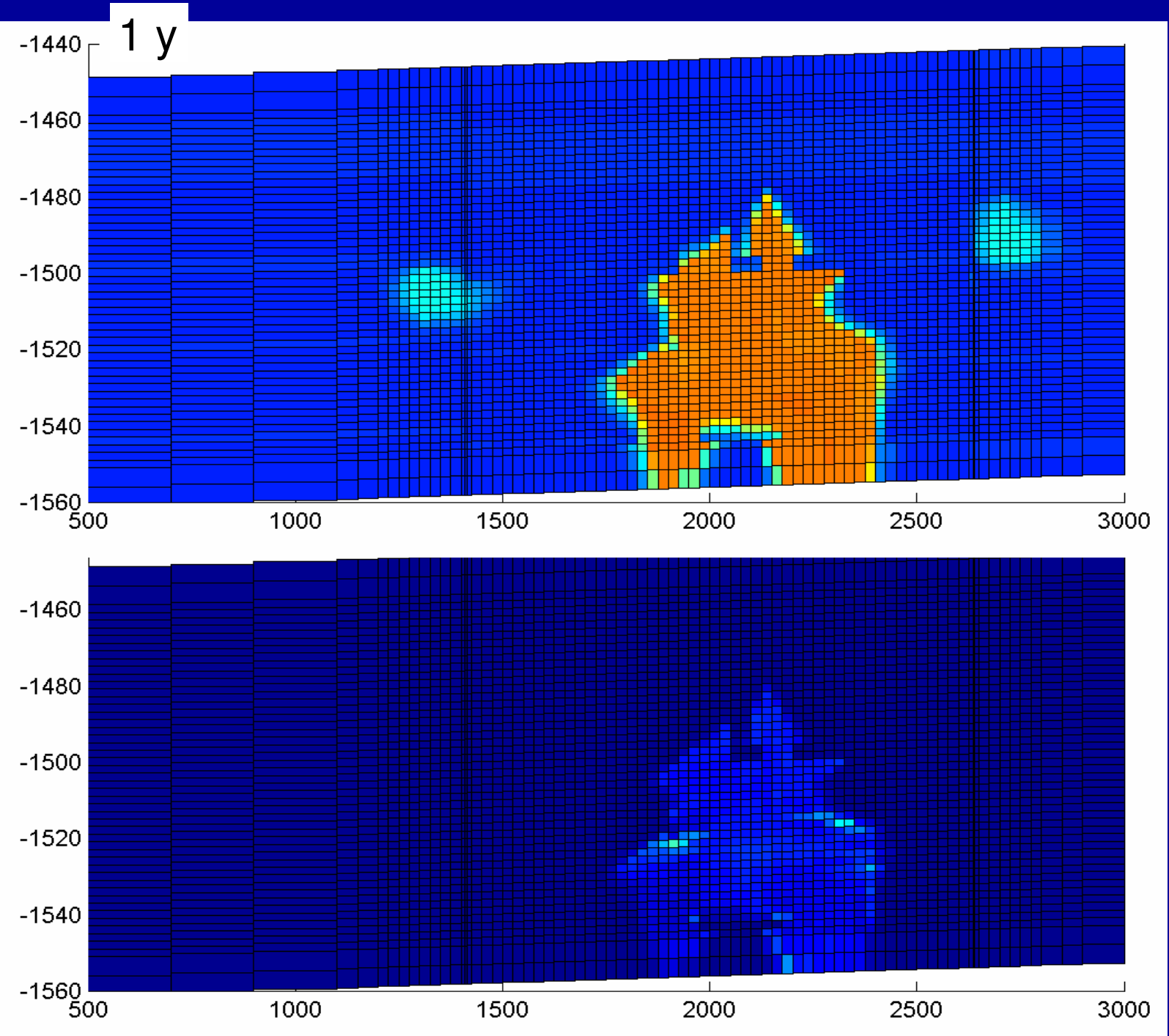
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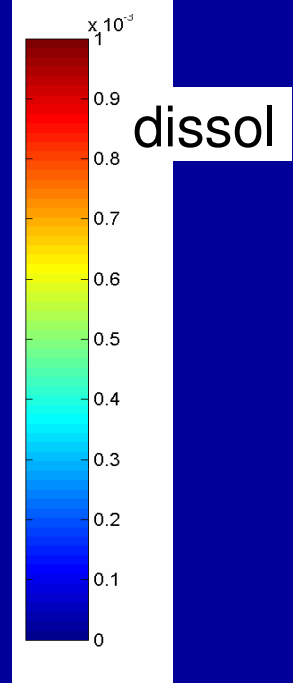
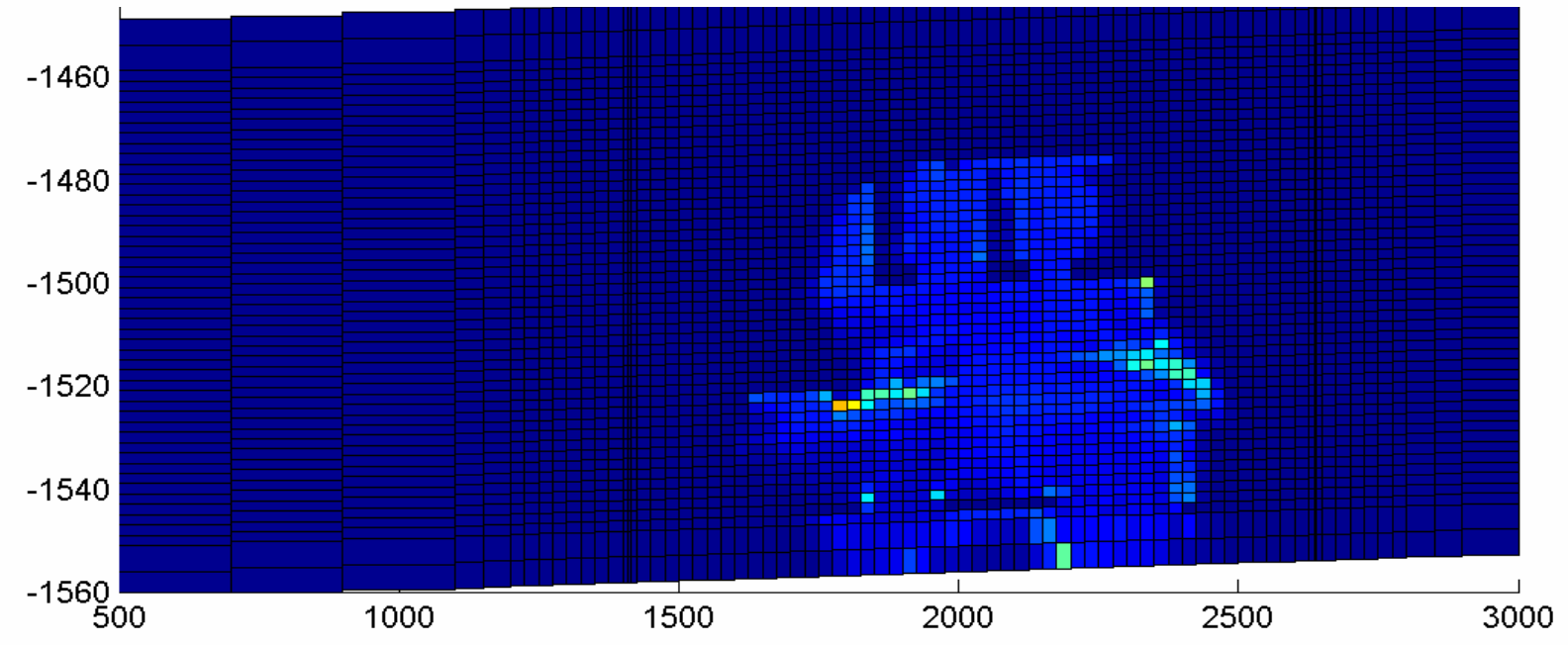
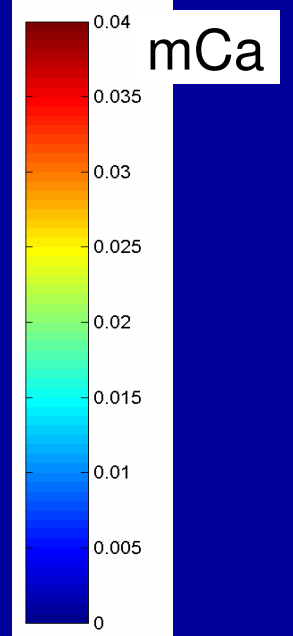
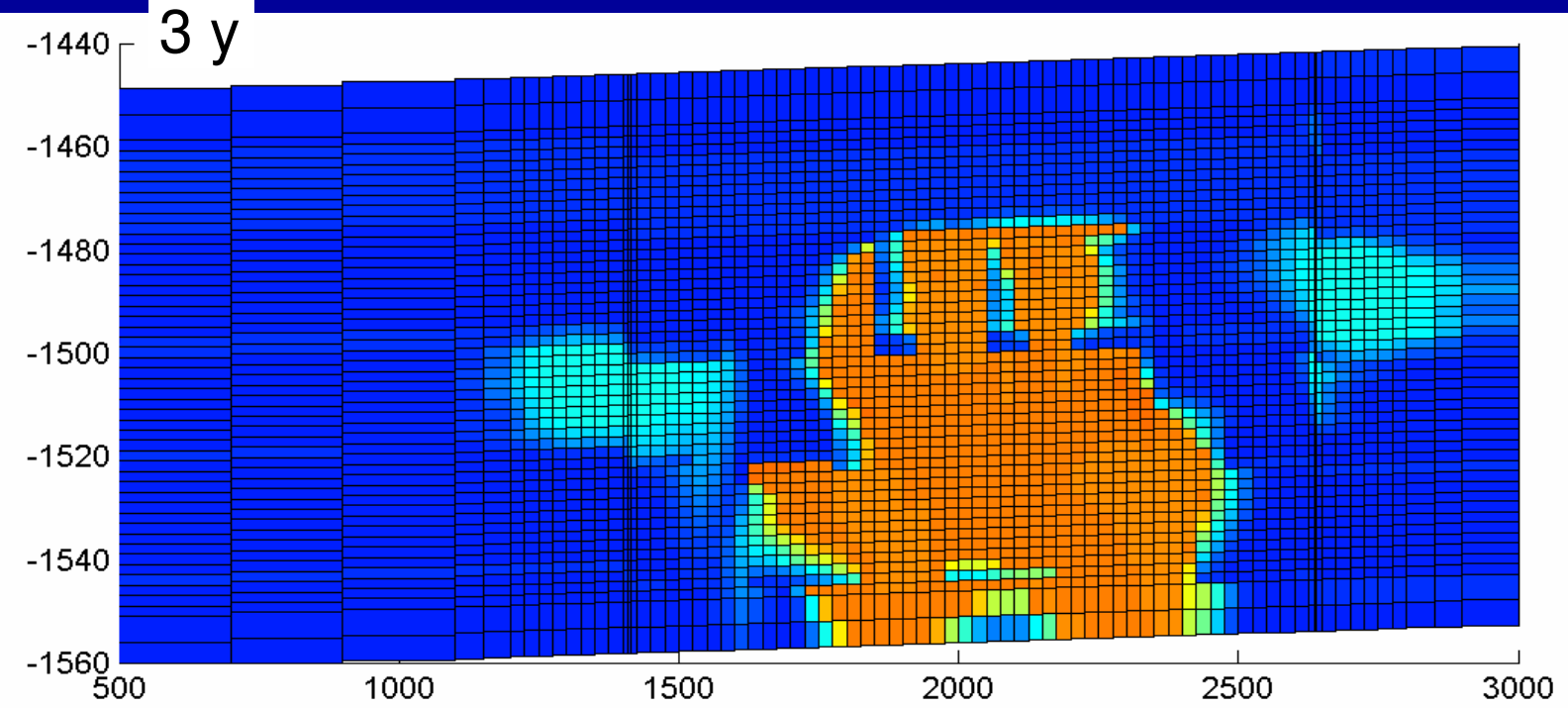
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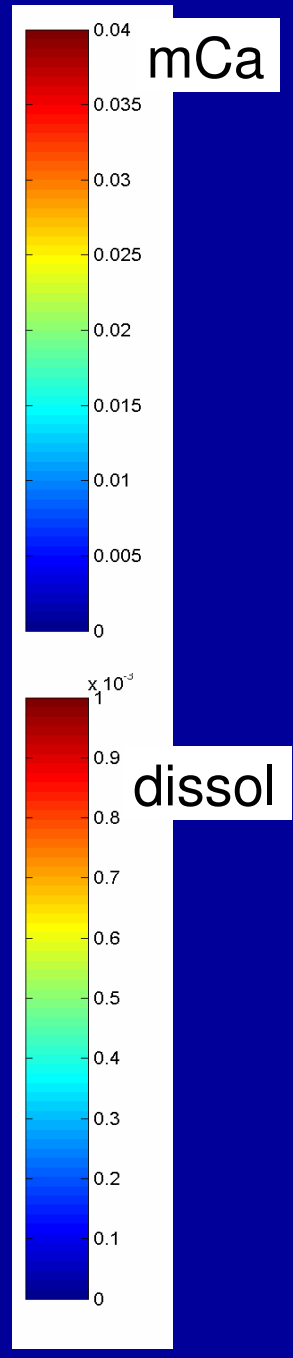
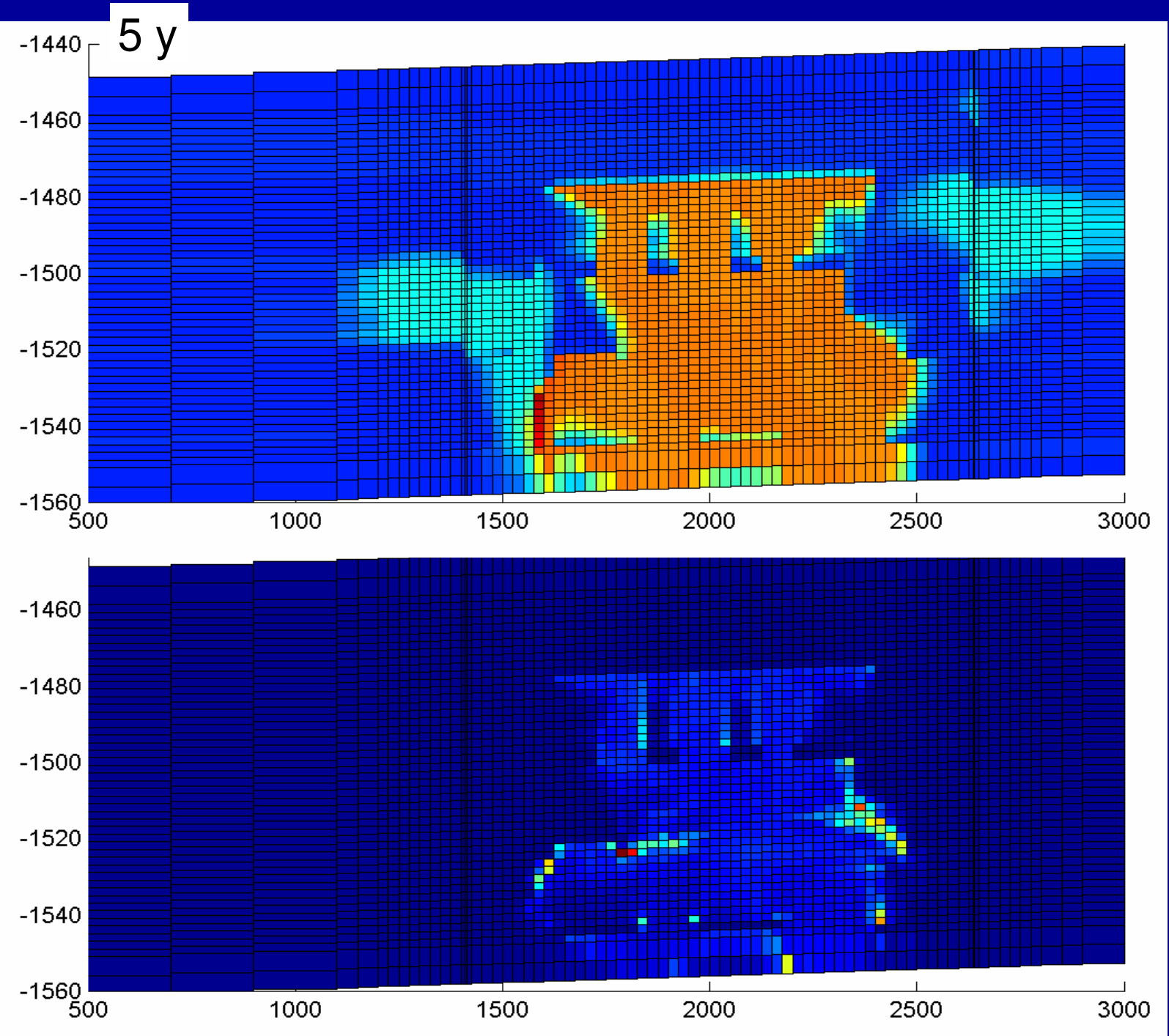
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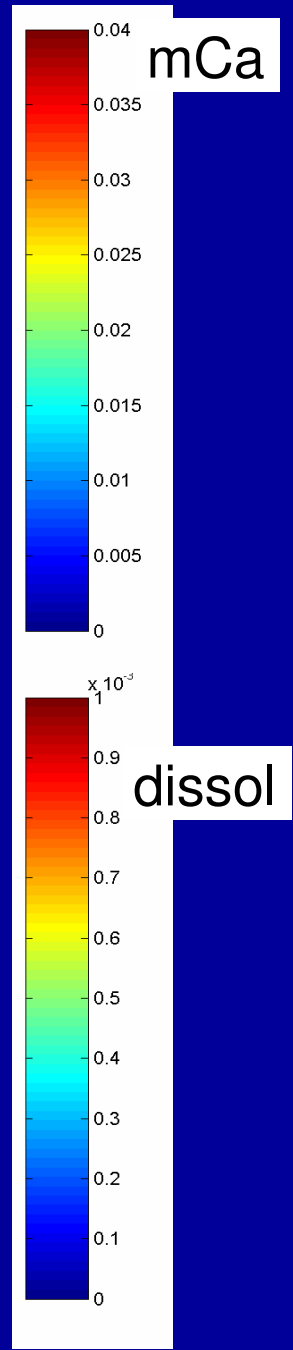
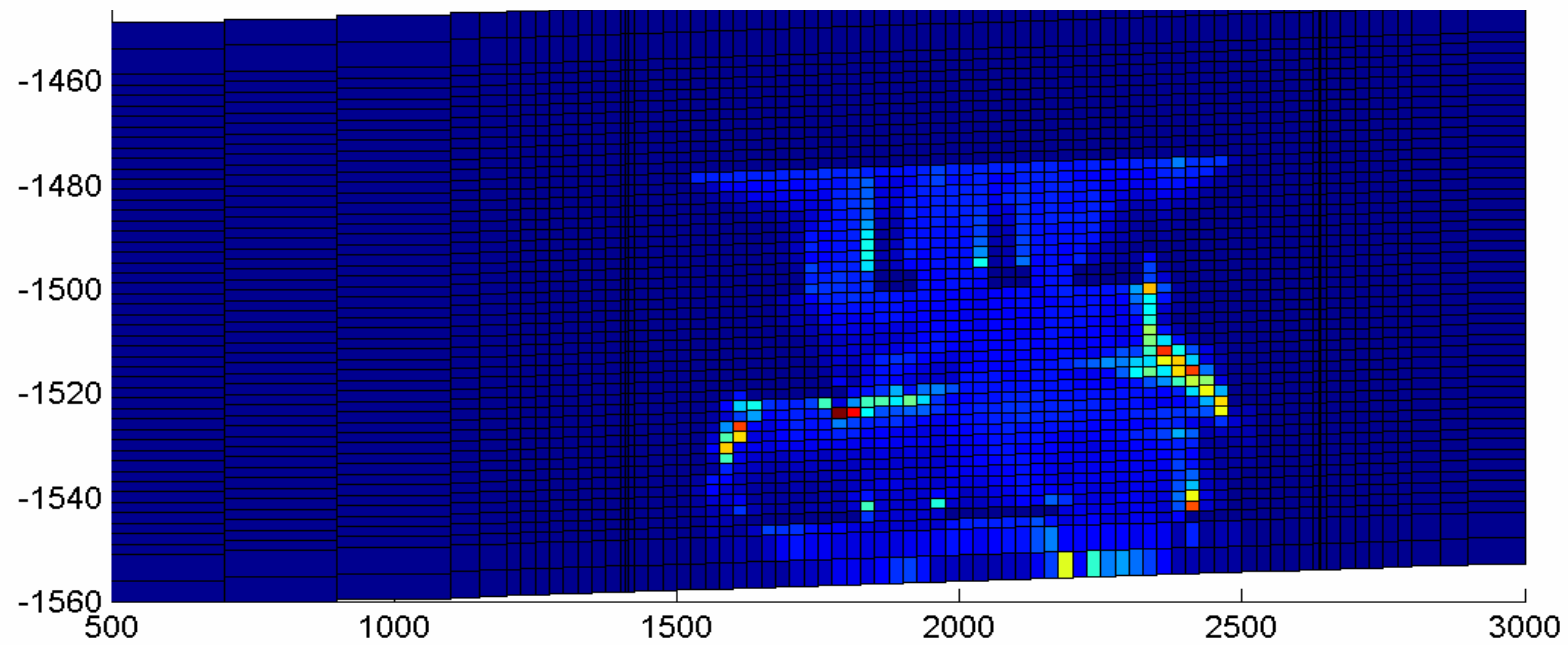
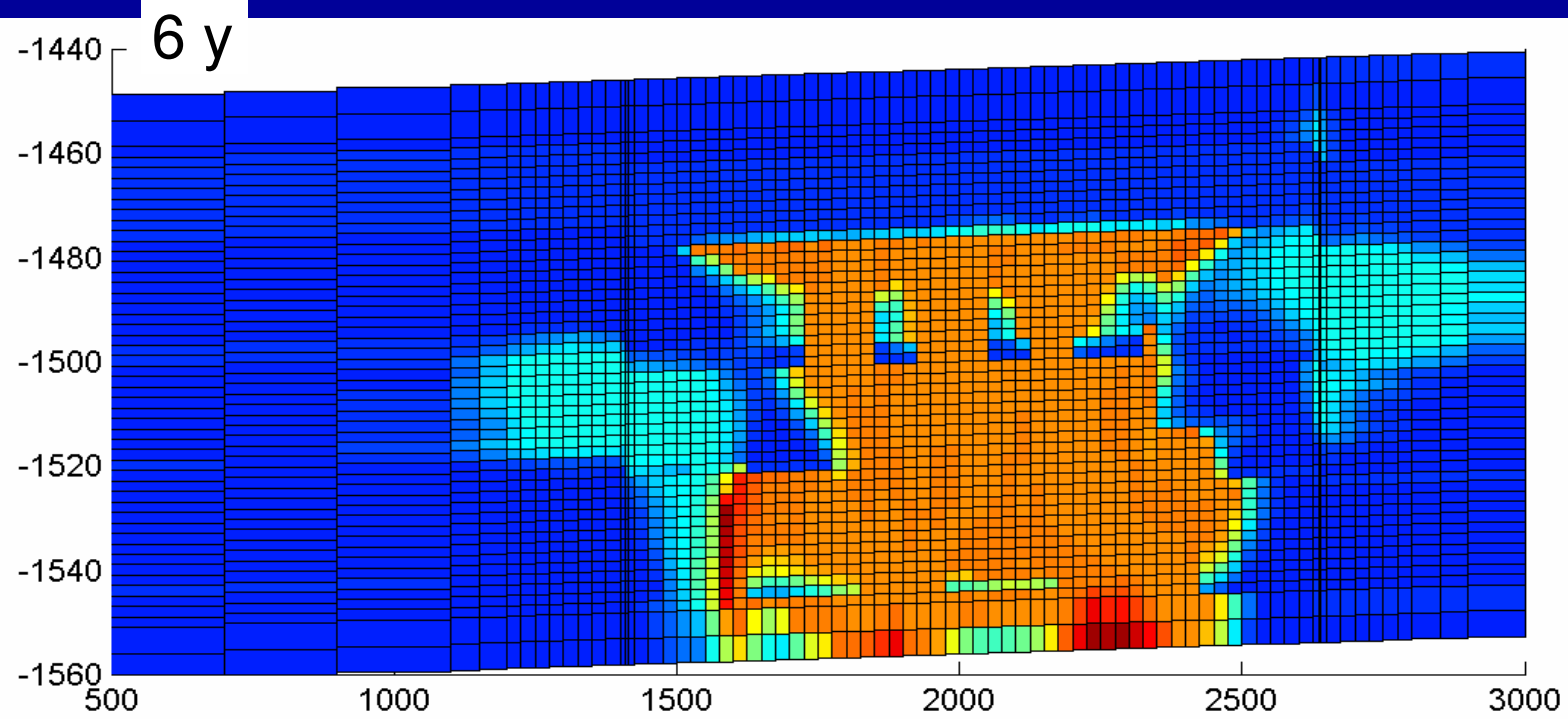
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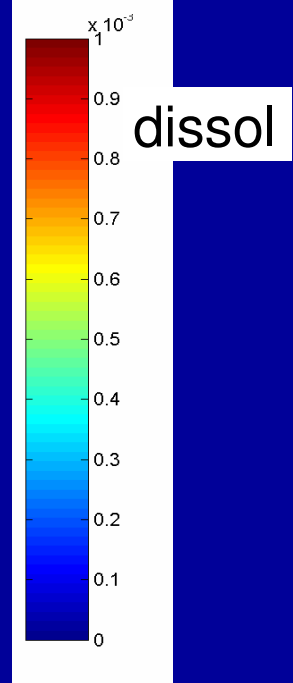
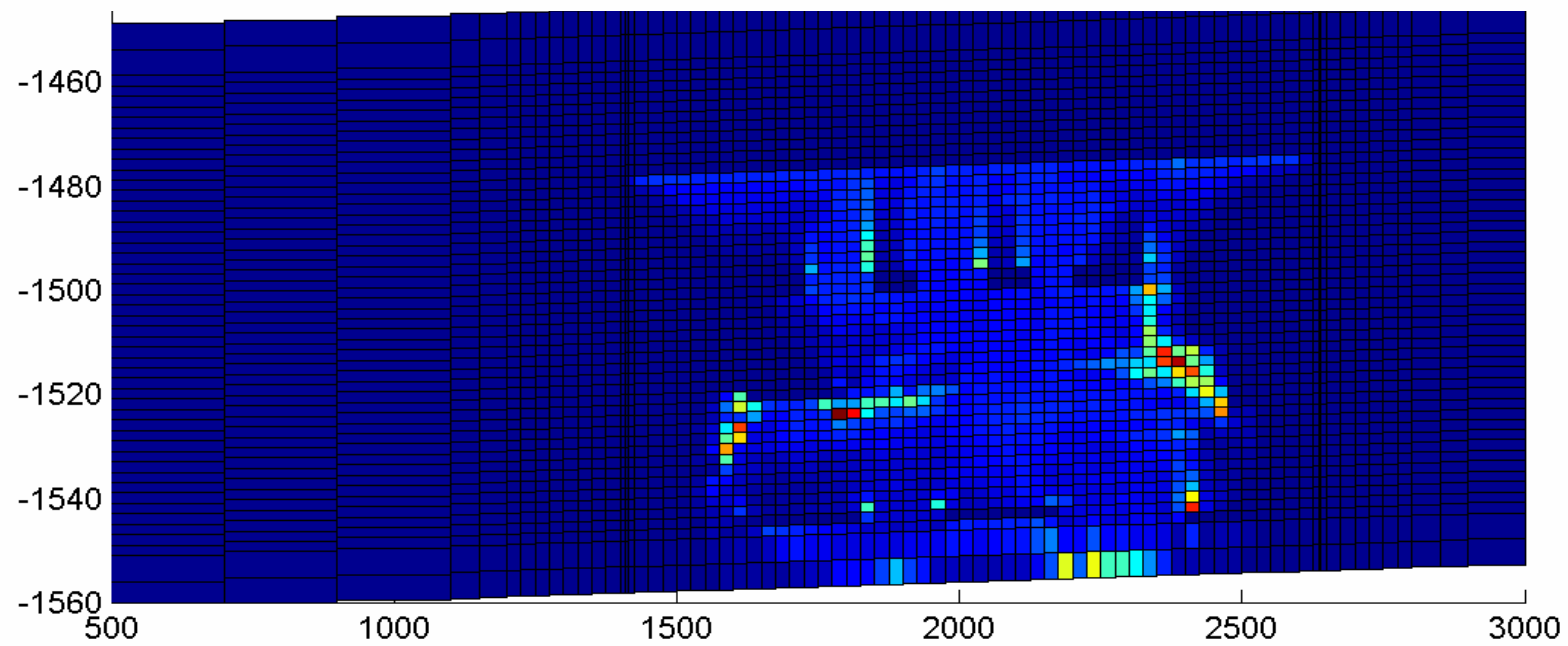
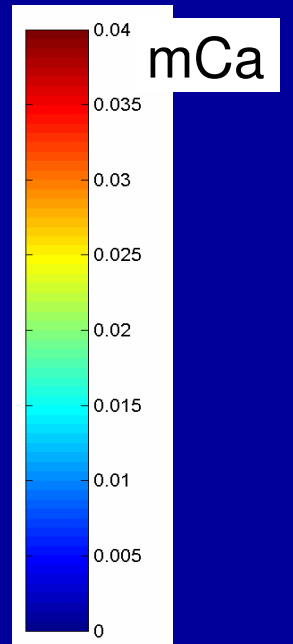
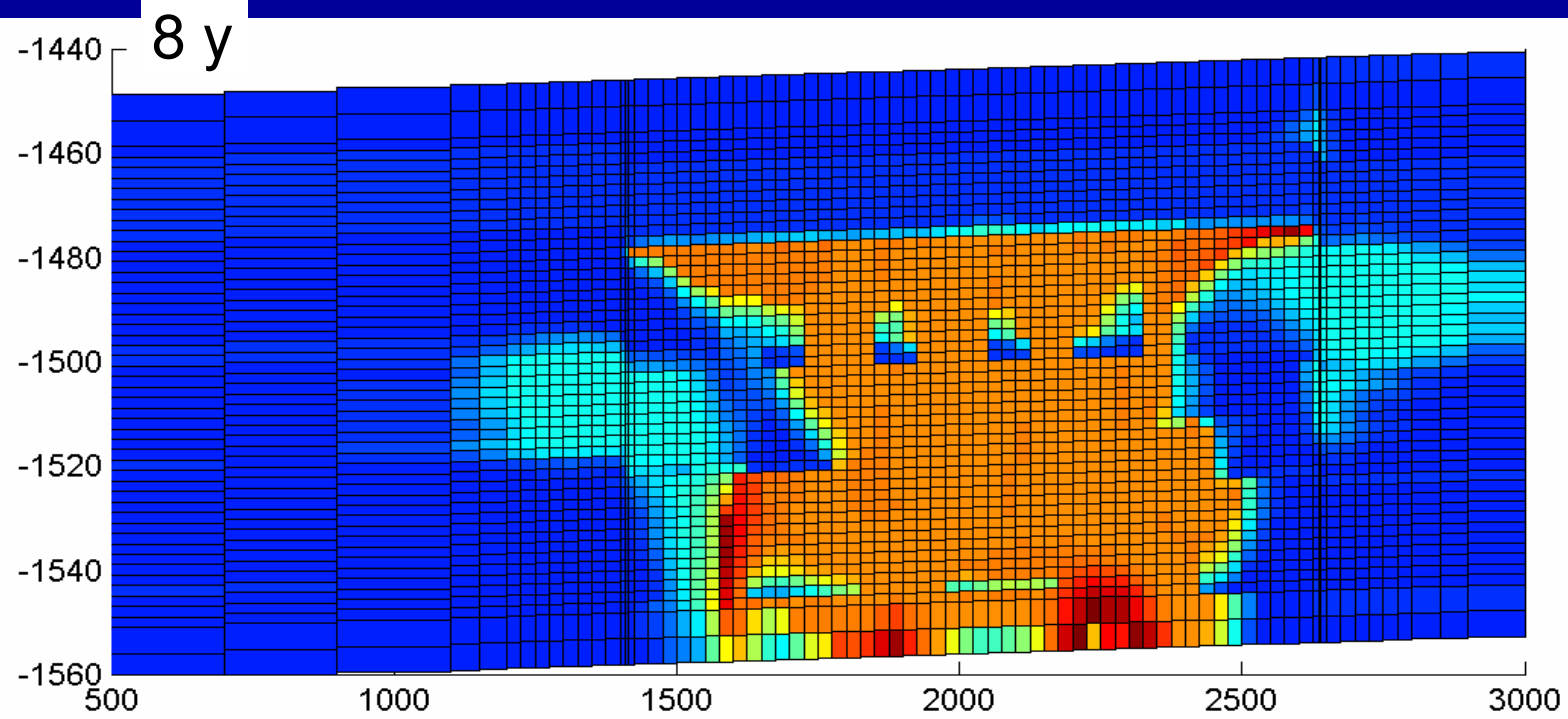
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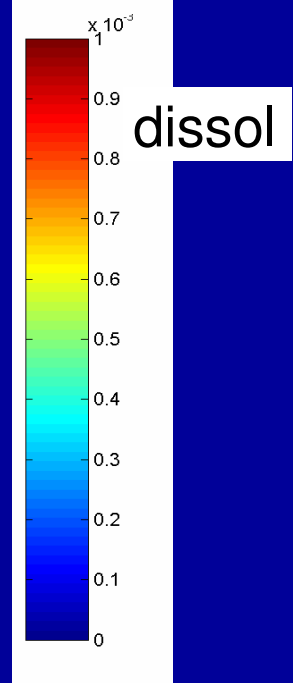
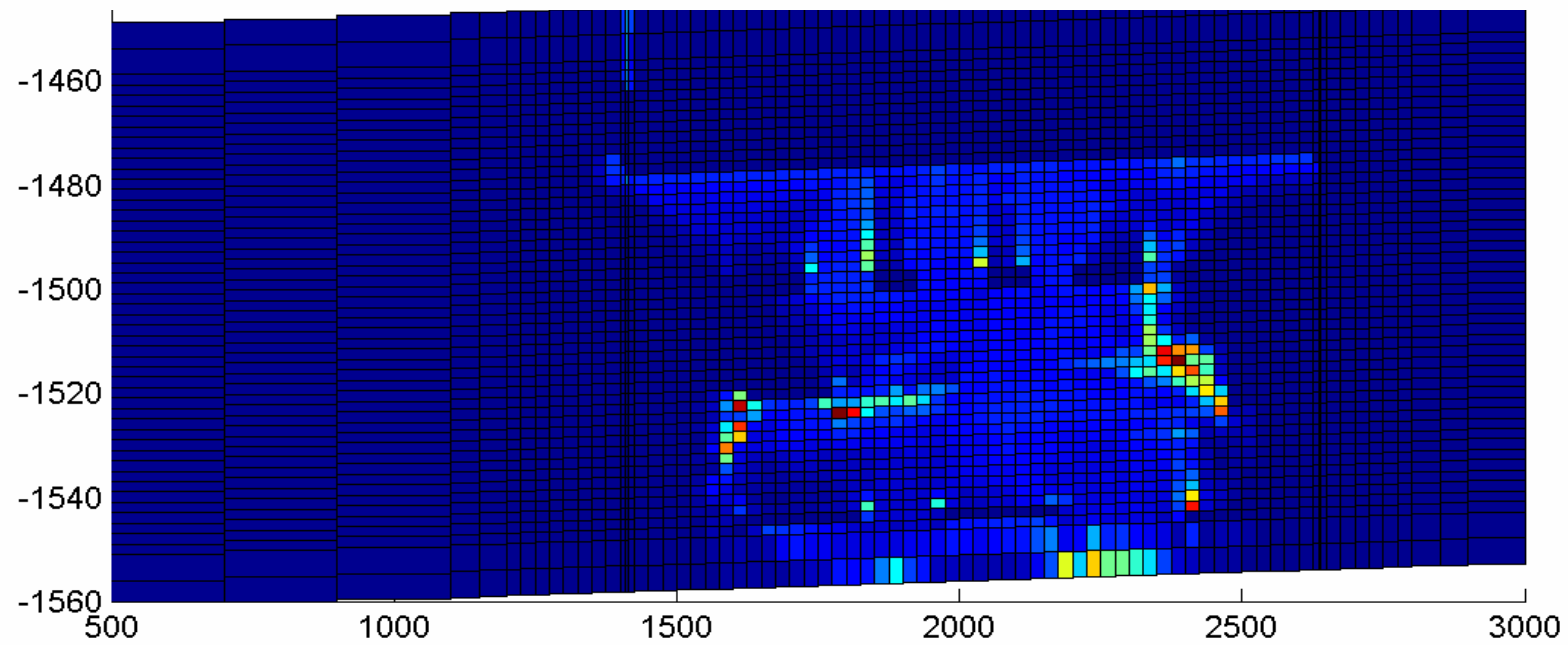
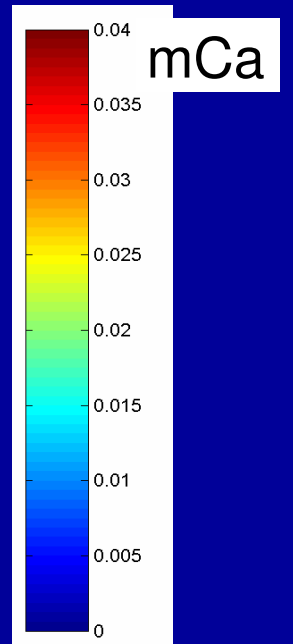
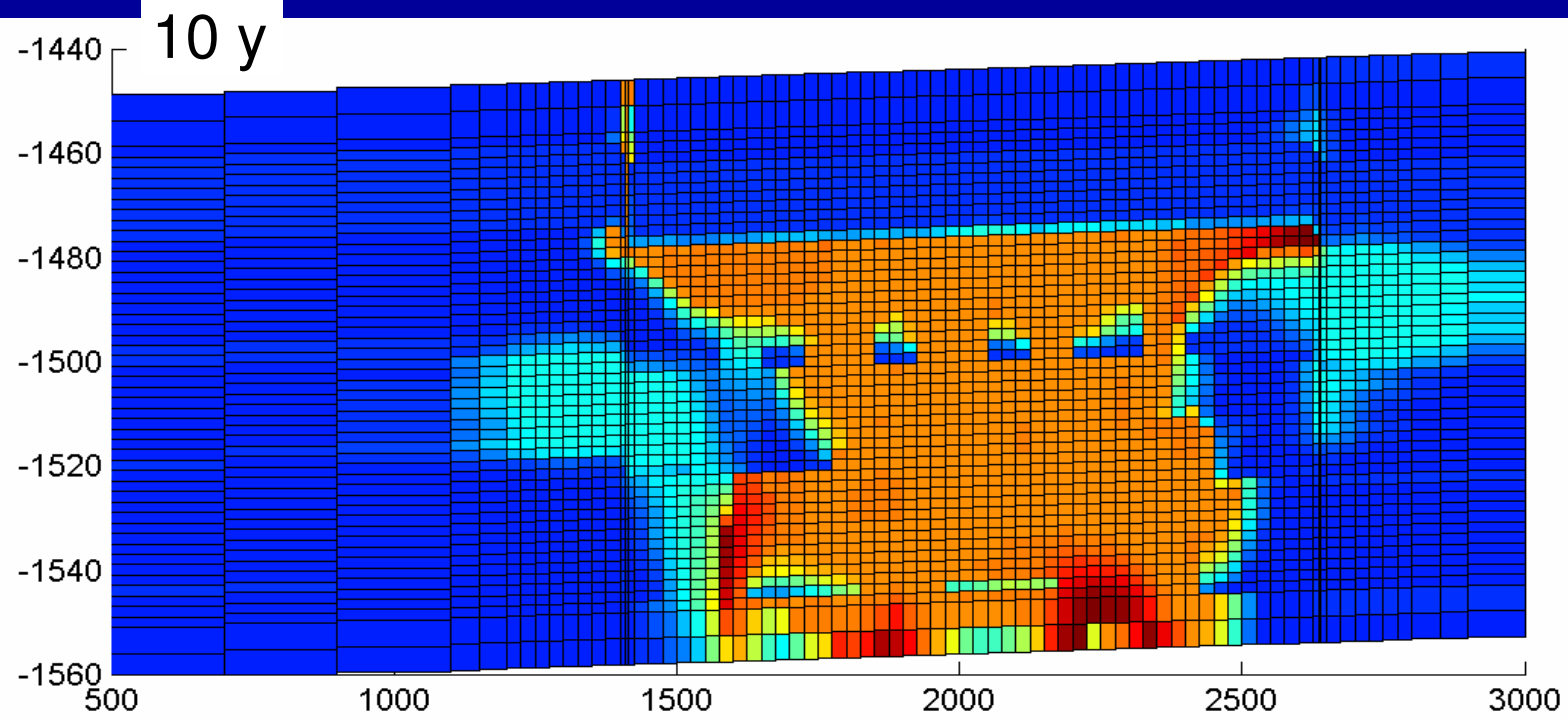
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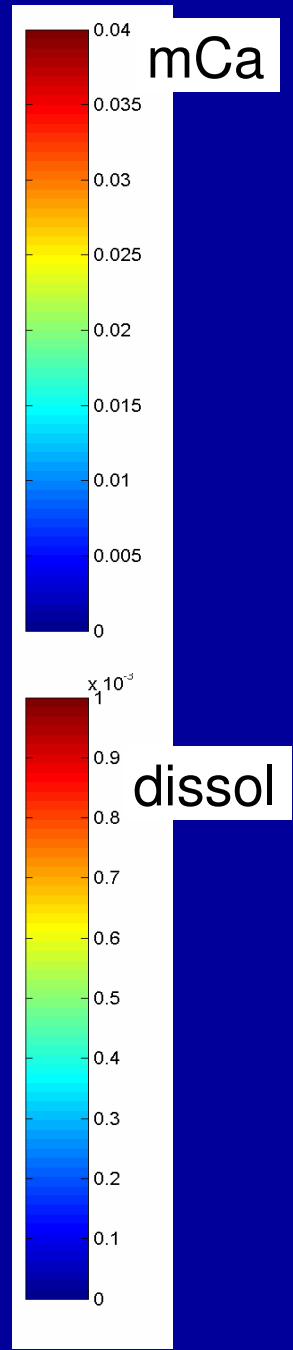
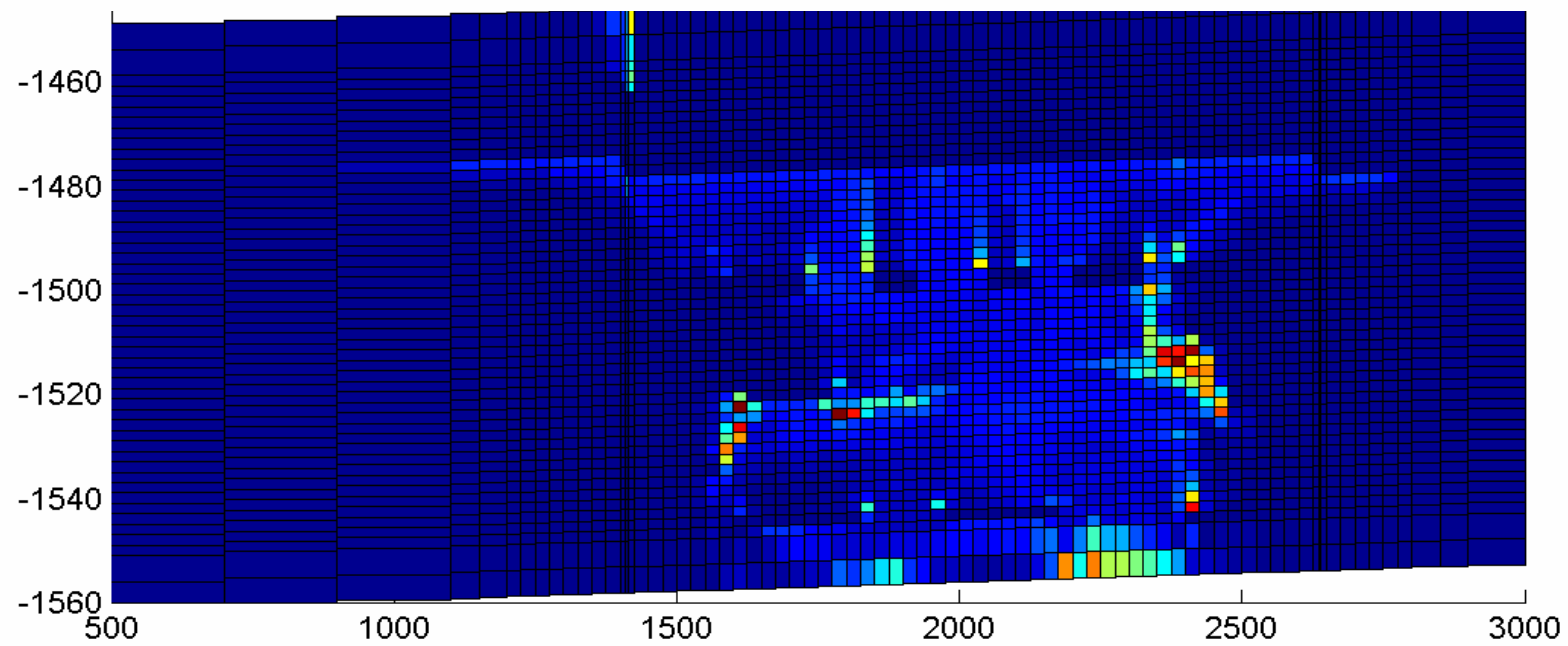
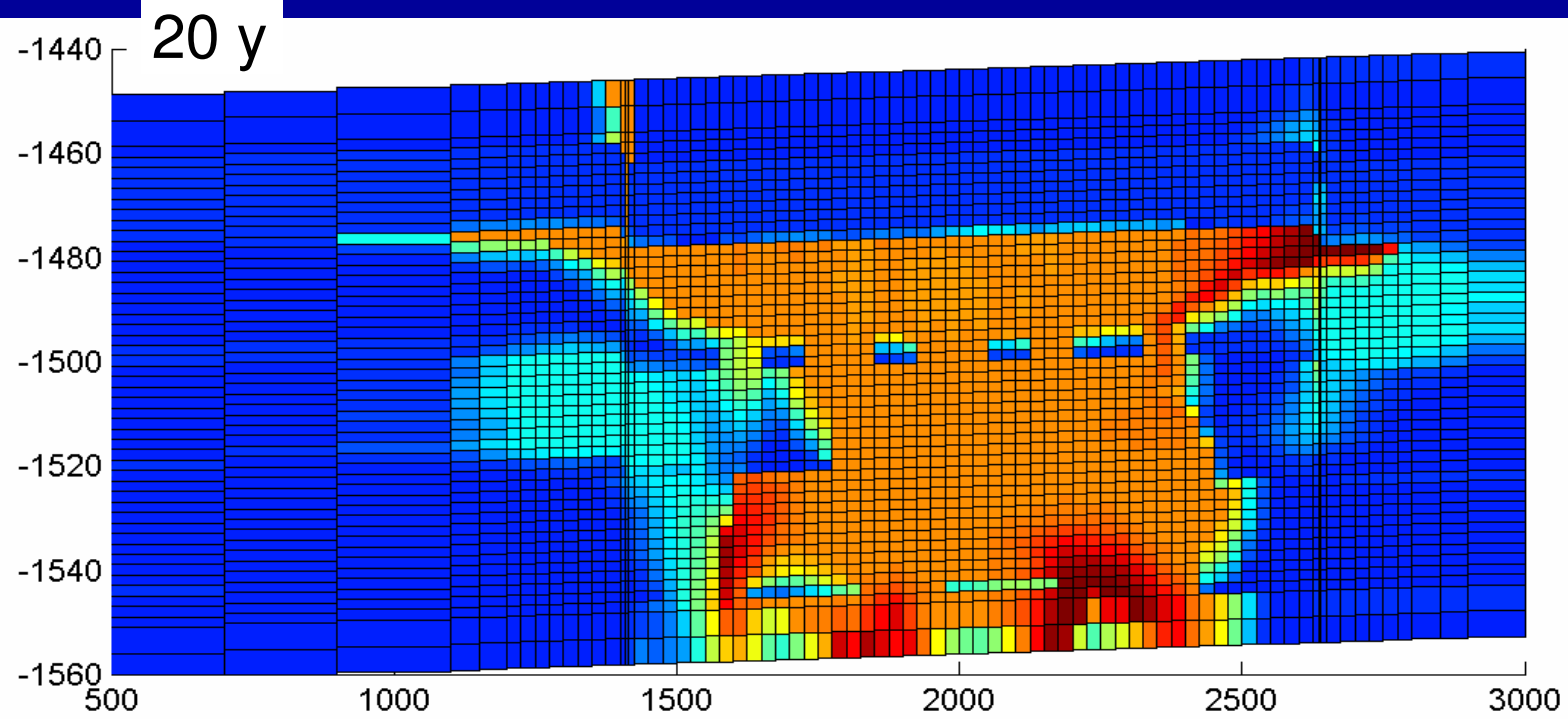
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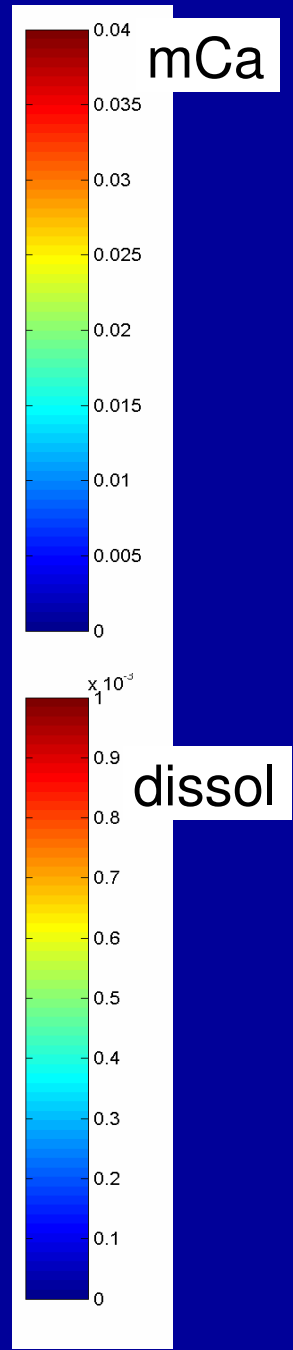
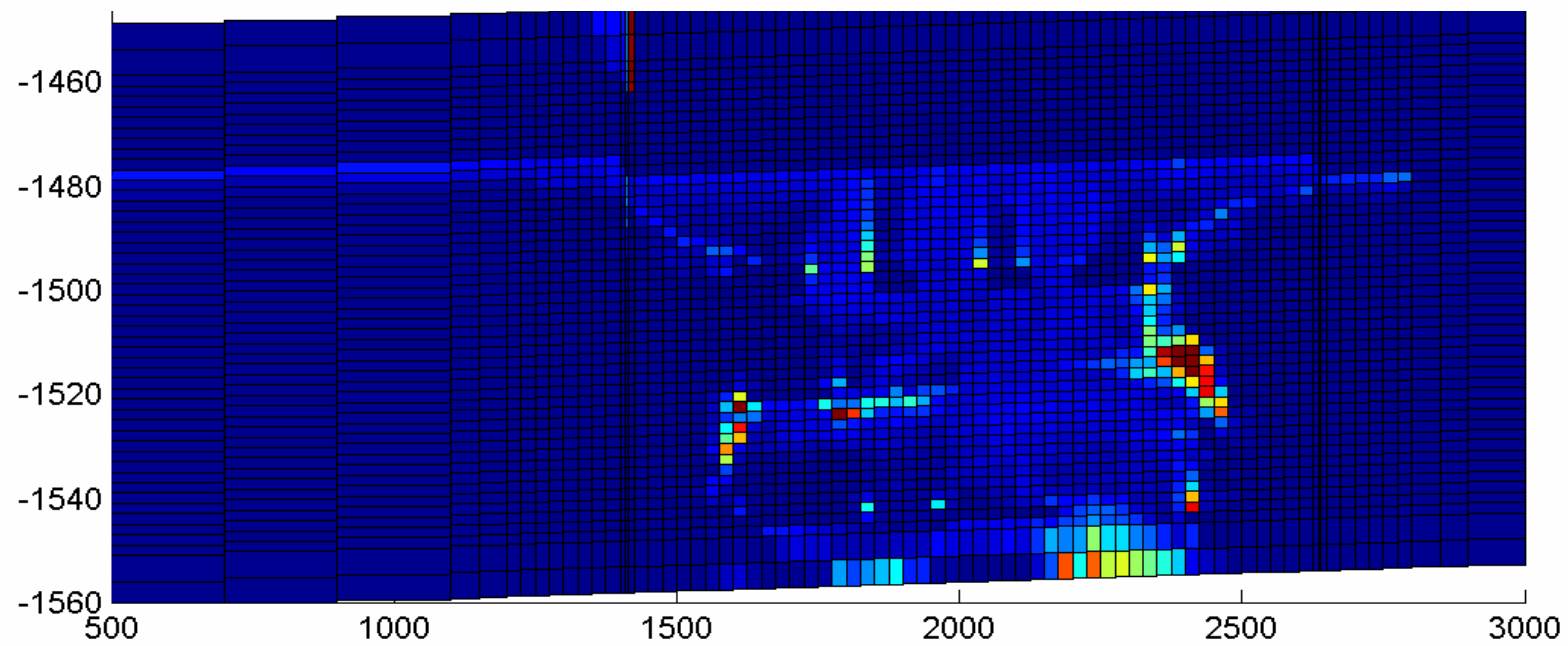
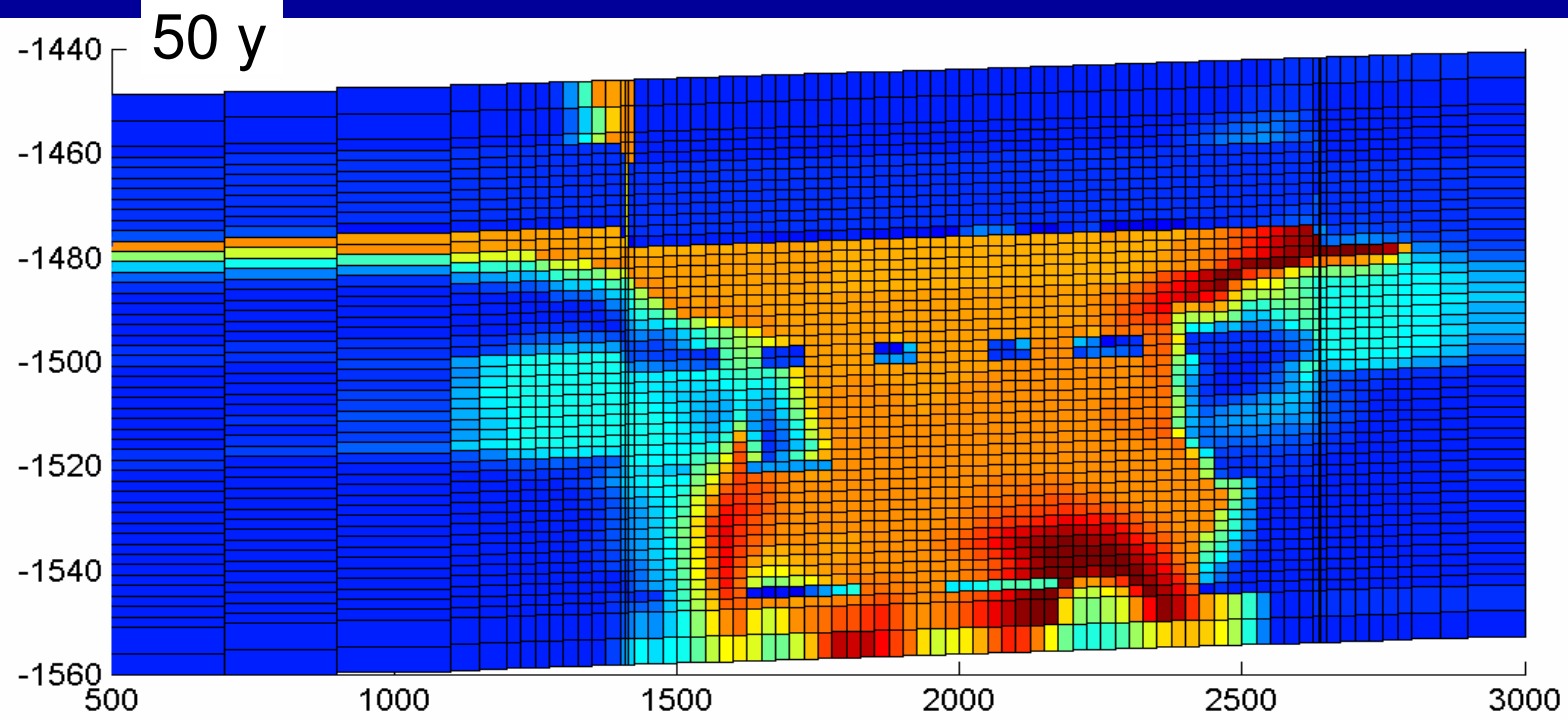
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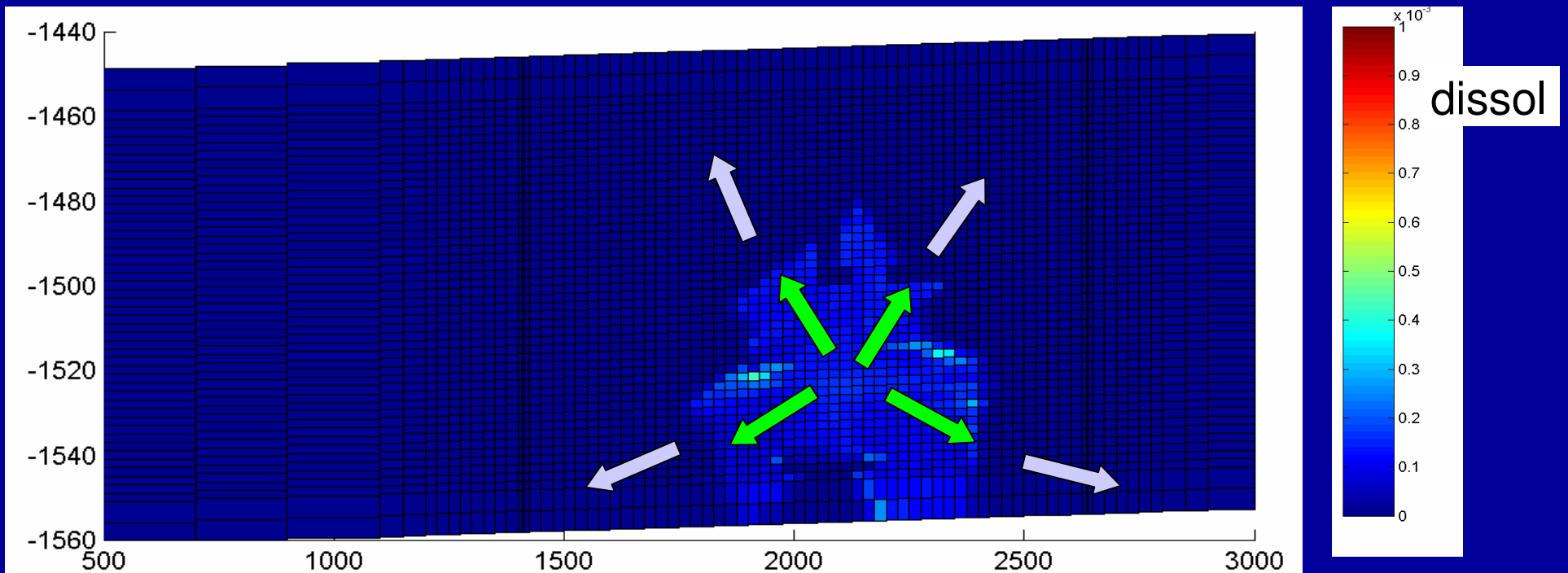


# Carbonate dissolution regimes

## PRIMARY DRAINAGE

*residual* water equilibrates with free CO<sub>2</sub> and carbonates  
mC, mCa, mMg increases, solid carbonates dissolve  
negligible porosity increase (10<sup>-4</sup>)

*for a given rock volume, the water volume involved is the residual water*



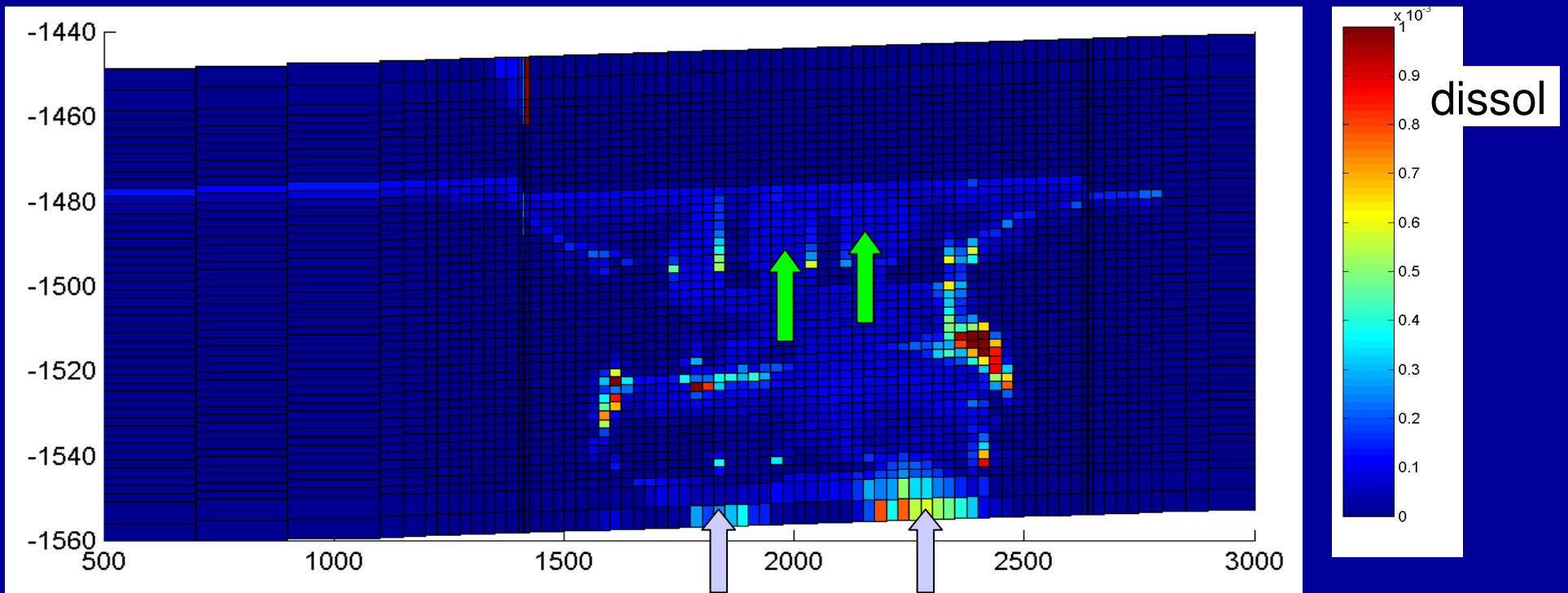
# Carbonate dissolution regimes

**IMBIBITION** (due to gravity, waterflooding, aquifer activity)

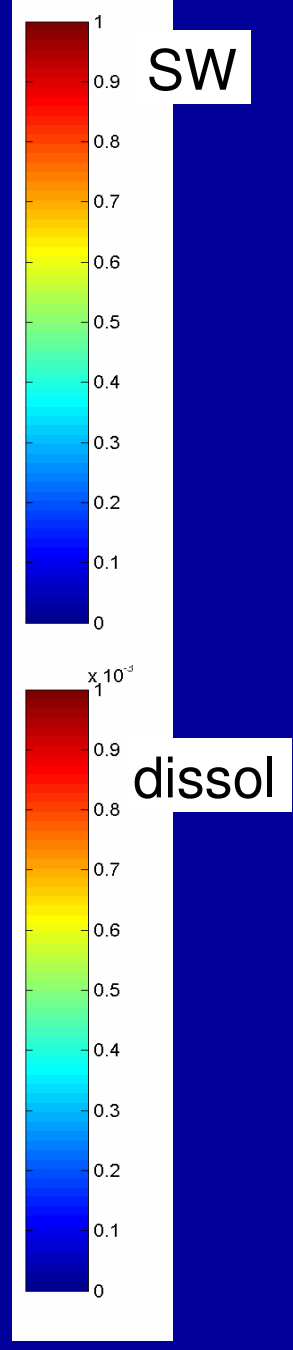
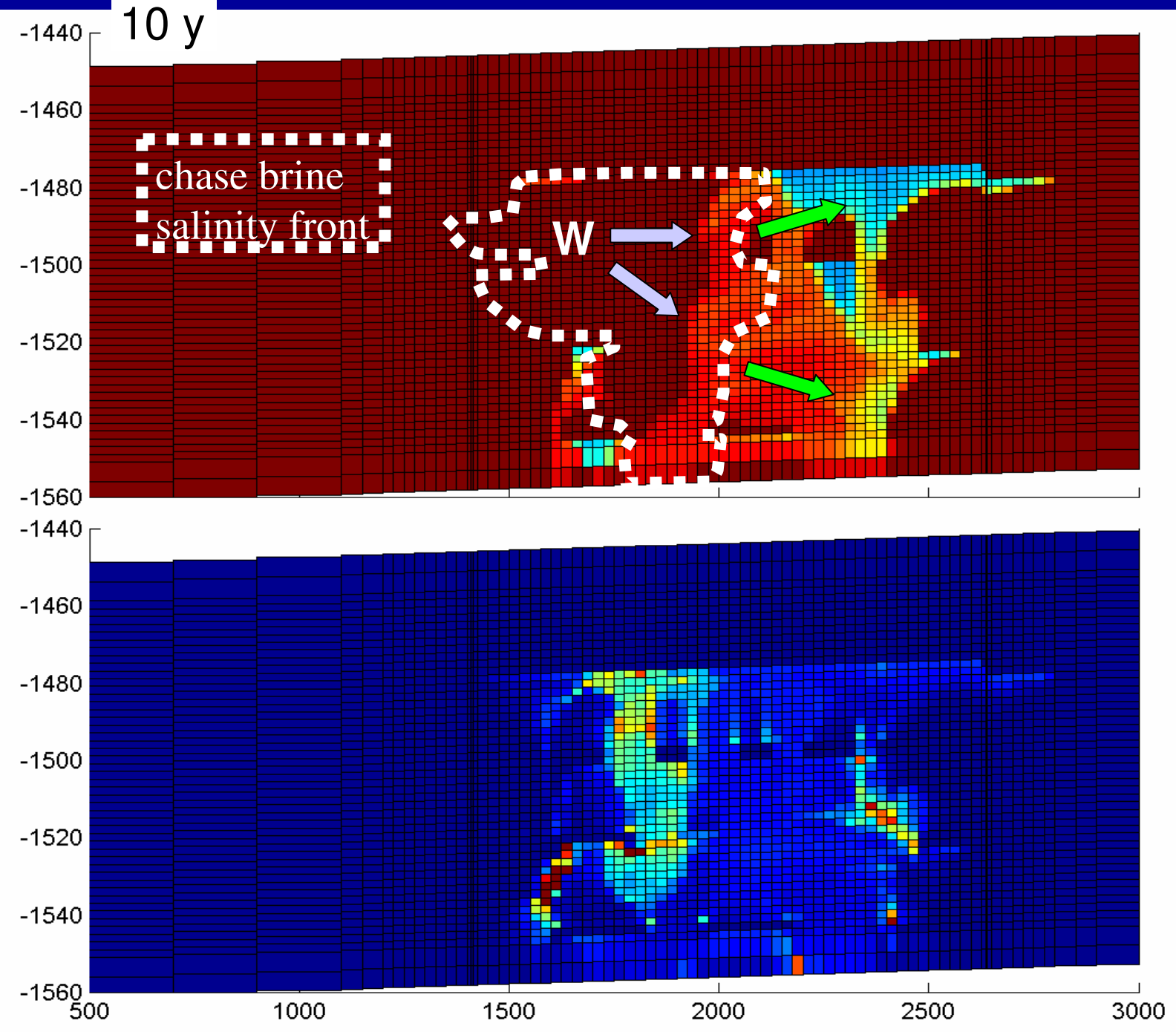
*pristine mobile water dissolves residual CO<sub>2</sub>  
and equilibrates again dissolving carbonate*

weak porosity increase ( $10^{-4}$ - $10^{-3}$ )

*the water volume involved is the volume needed to dissolve residual gas*



CHASE  
BRINE  
IMBIB



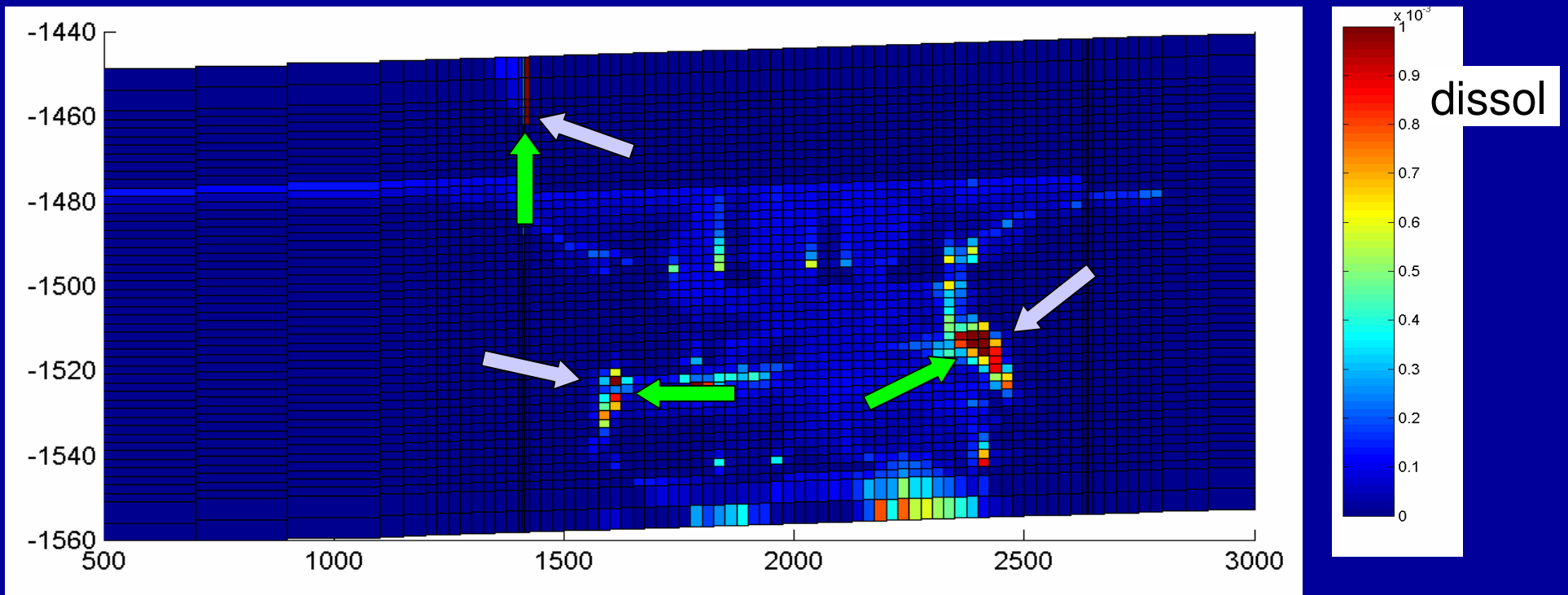
# Carbonate dissolution regimes

**MIXING** (due to multiple injections, cross-flow, pumping)

*pristine mobile water mixes with mobile CO<sub>2</sub> and /or CO<sub>2</sub>-contaminated brine and equilibrates with carbonate*

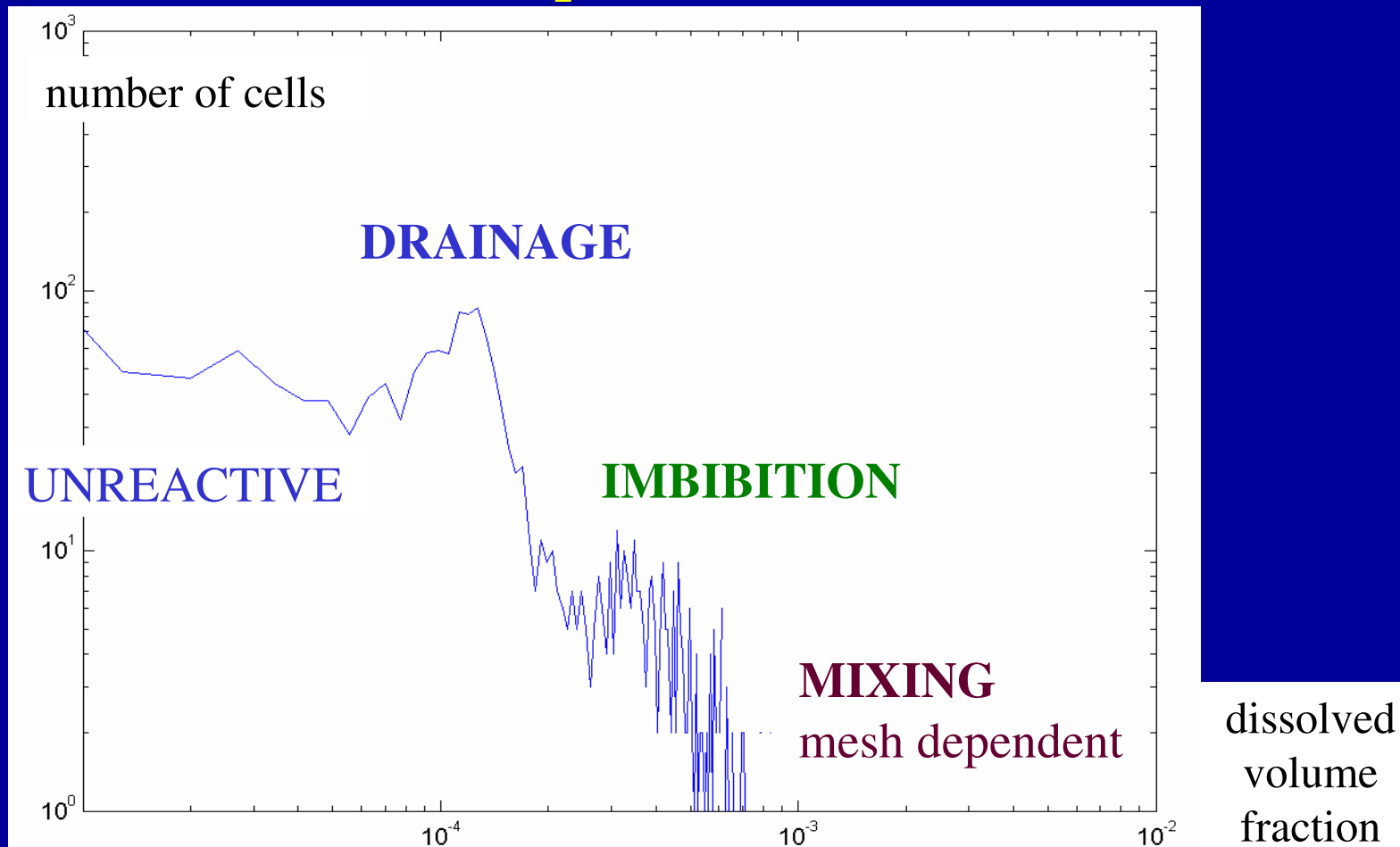
*potentially strong porosity increase*

*the reaction continues as long as the converging flow is maintained*

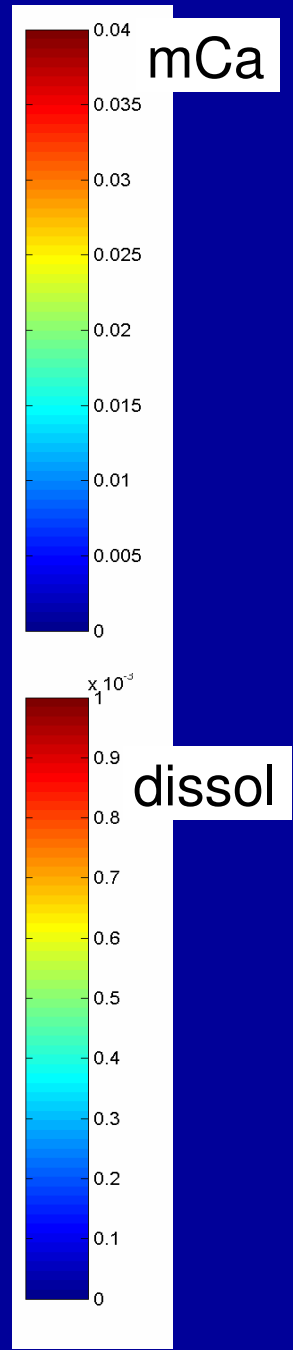
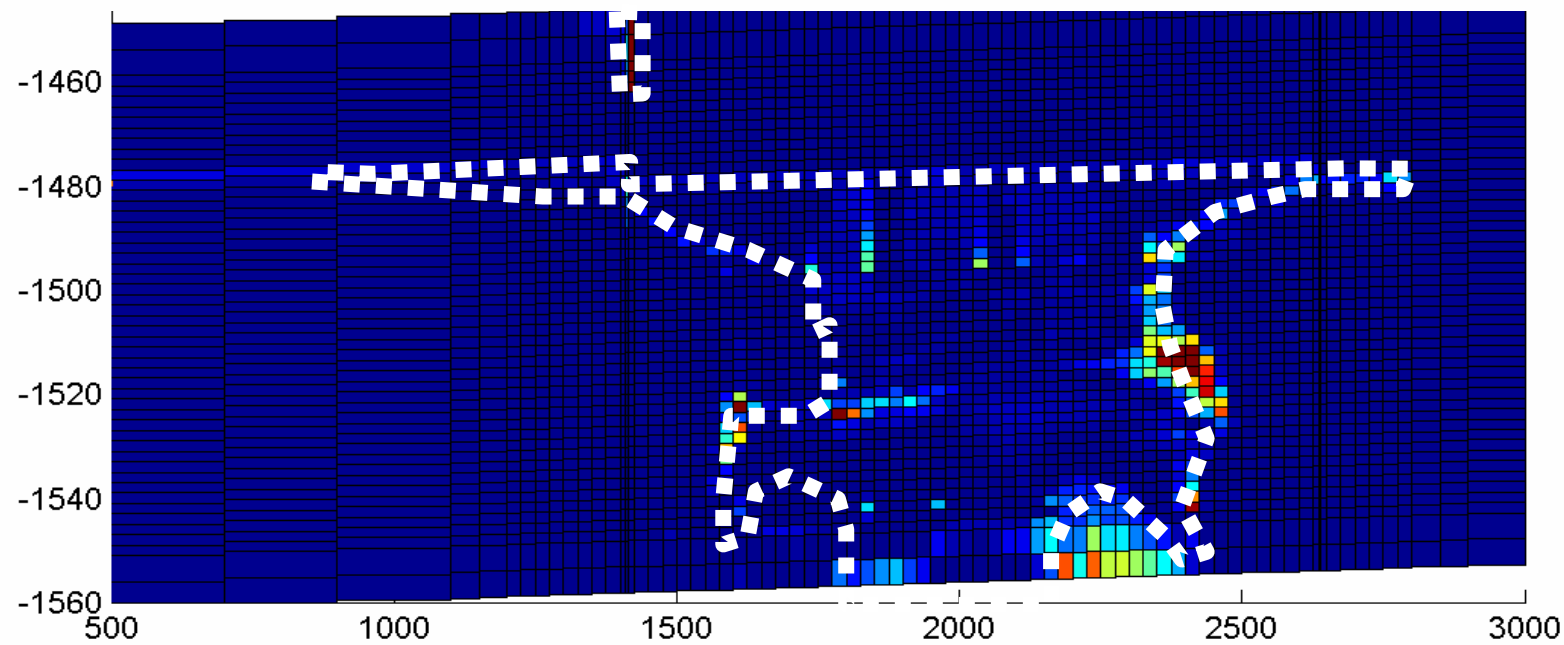
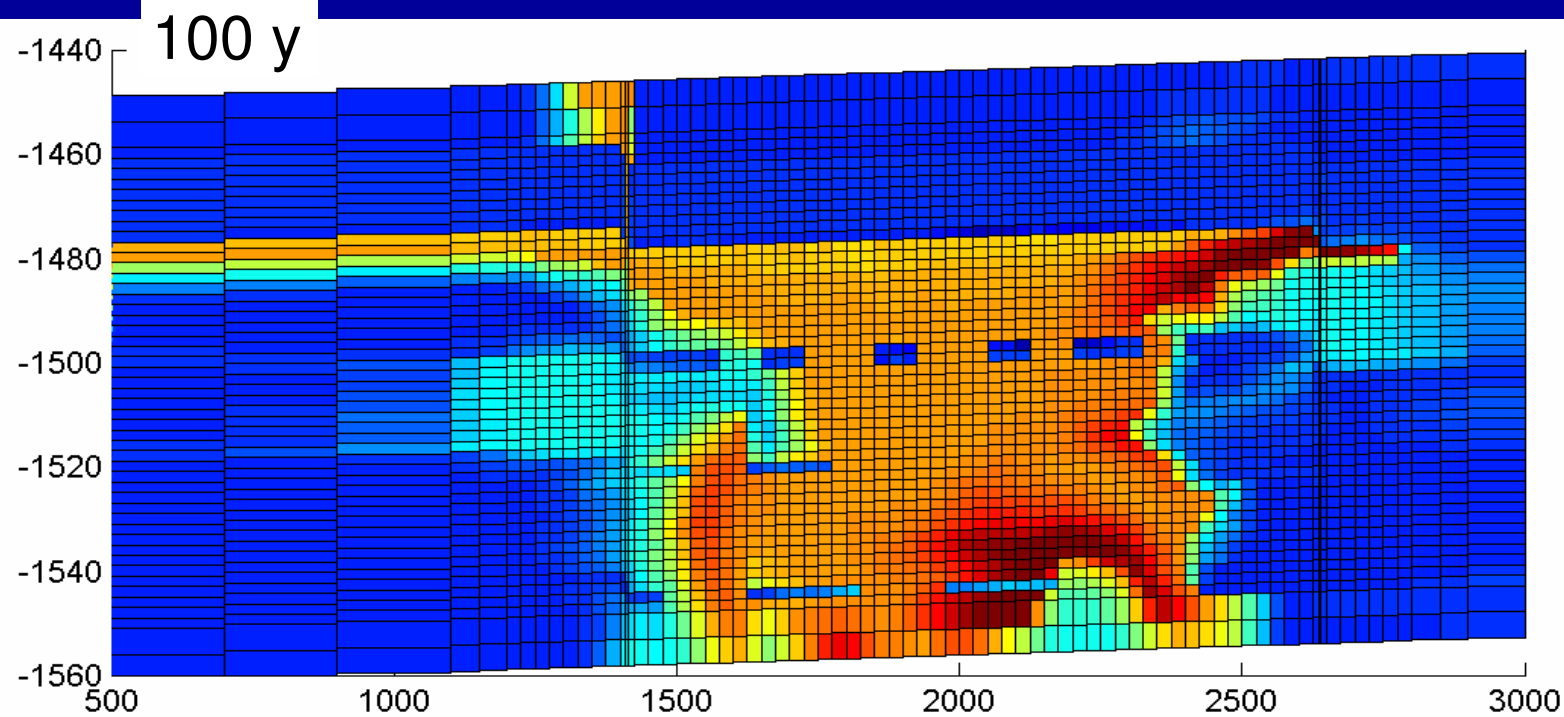


# Carbonate dissolution regimes

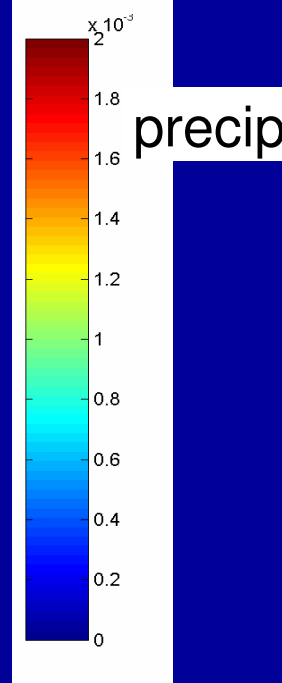
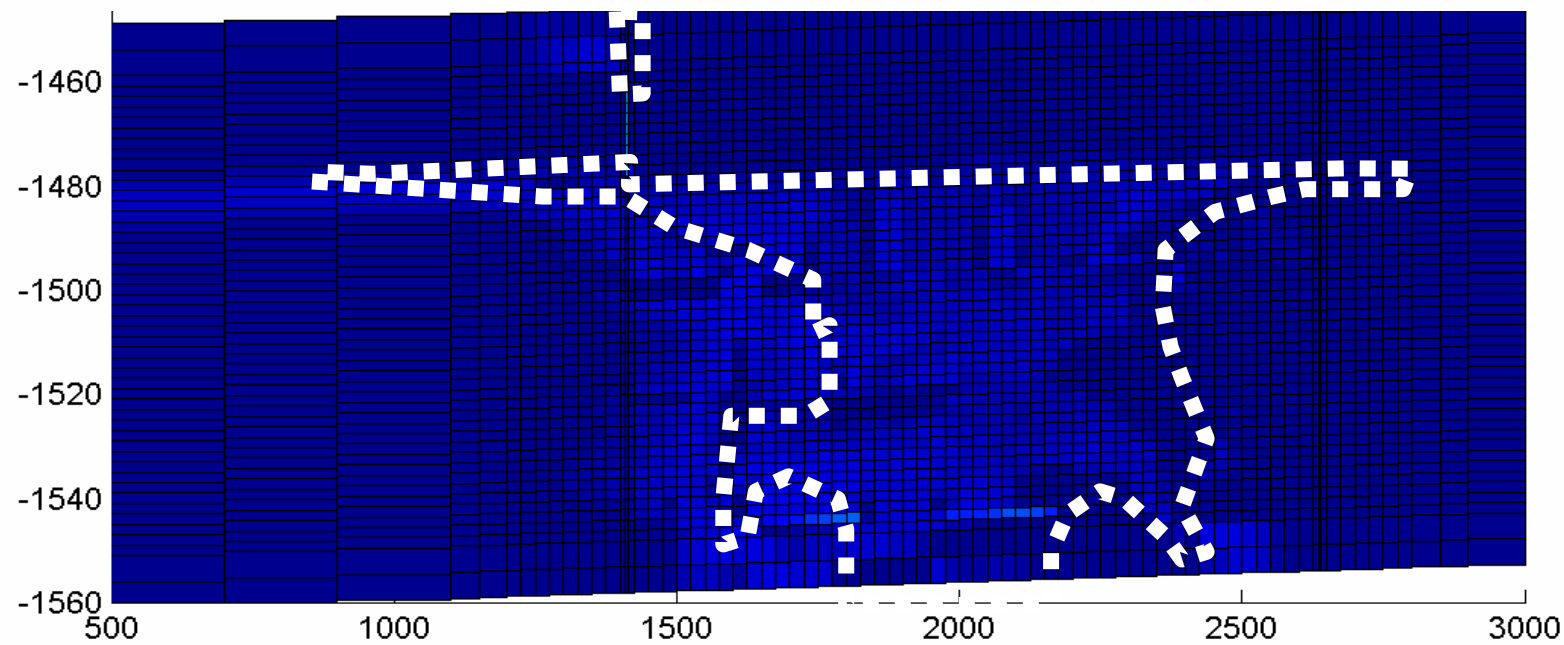
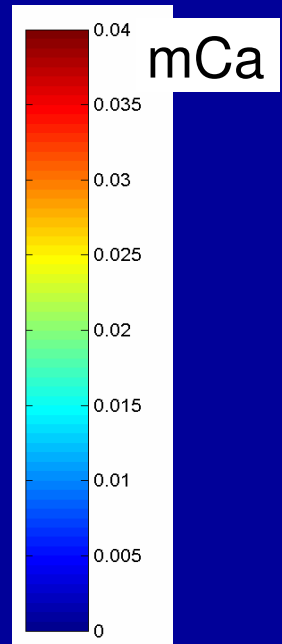
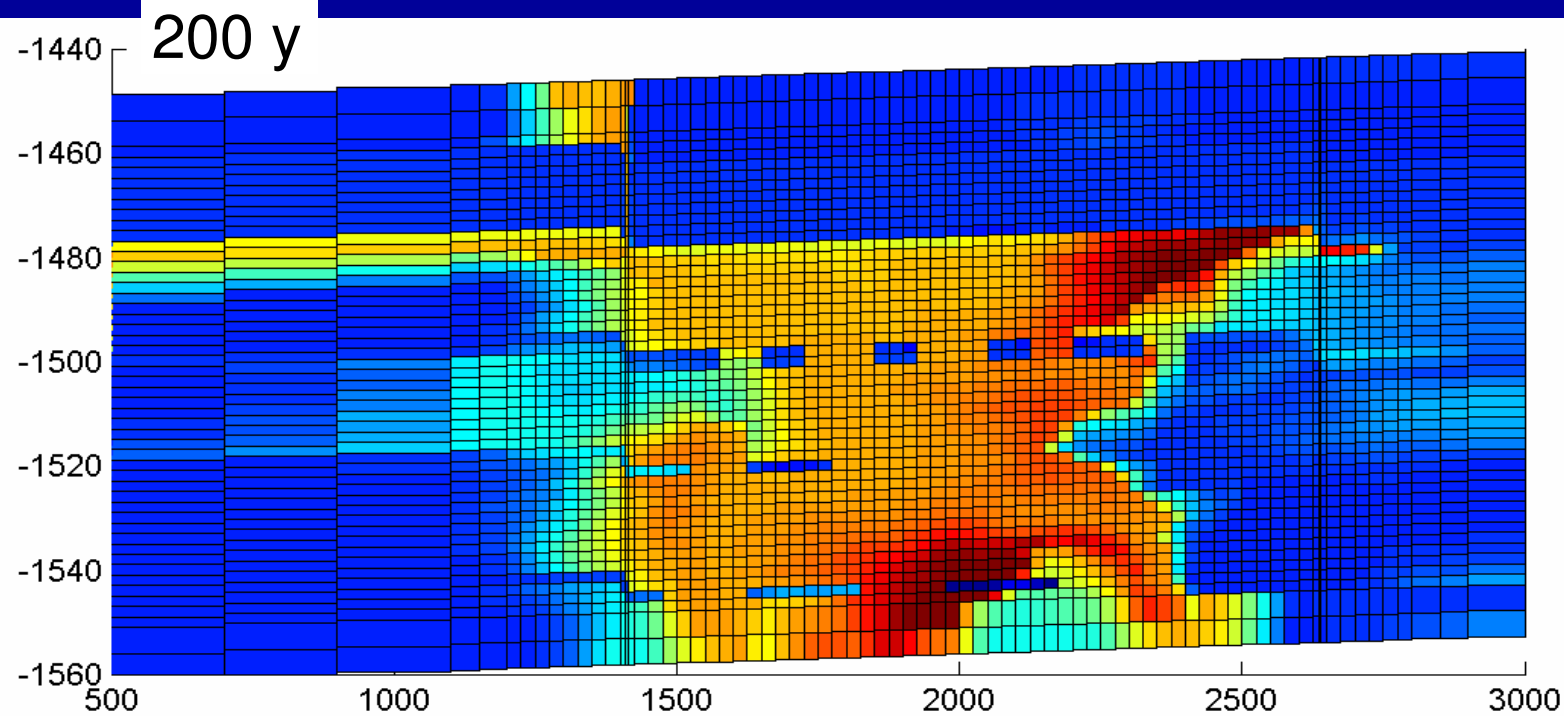
*histogram of short term porosity change due to carbonate dissolution after CO<sub>2</sub> injection (10 y)*



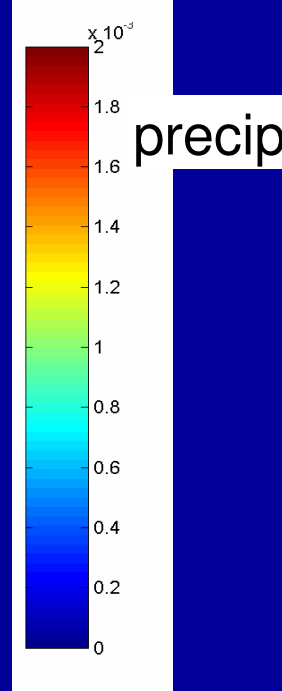
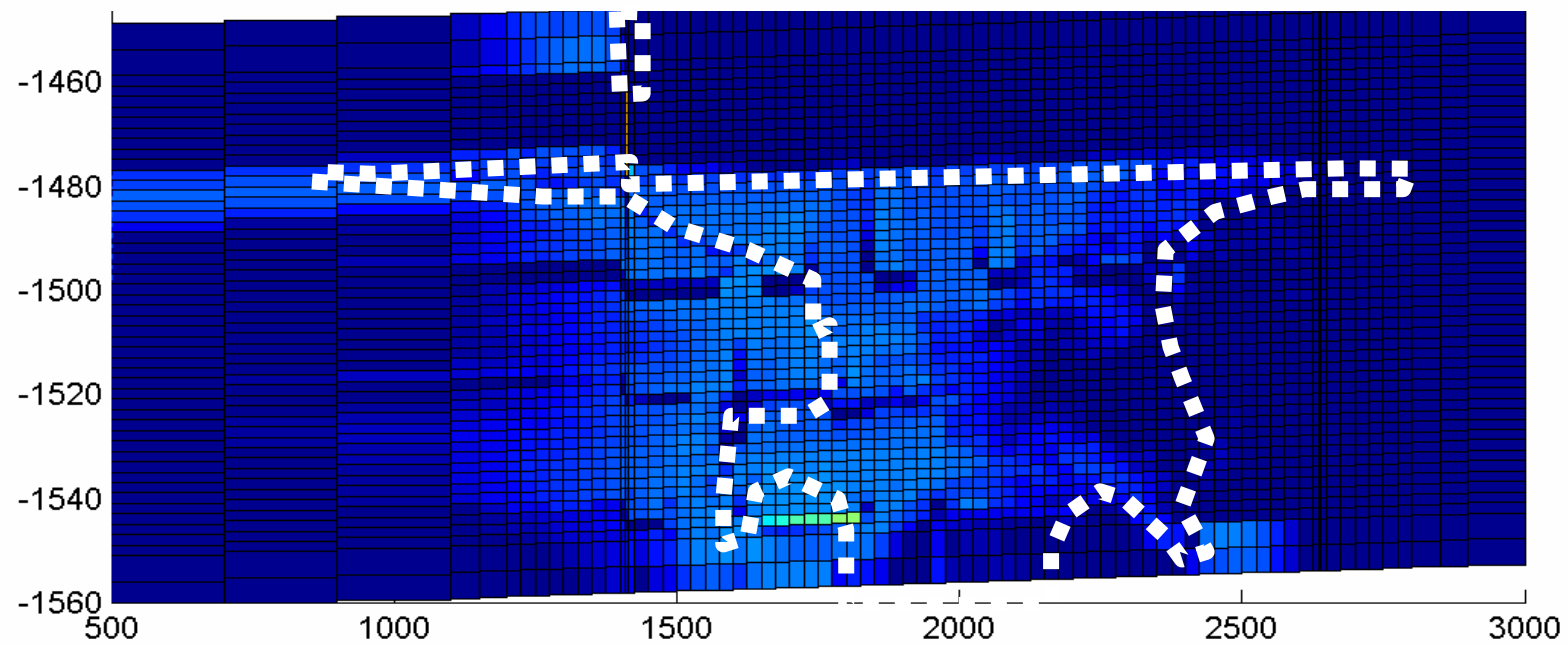
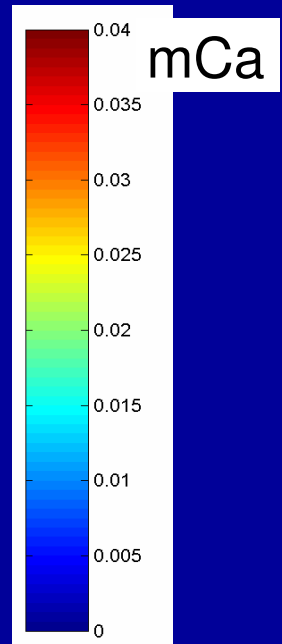
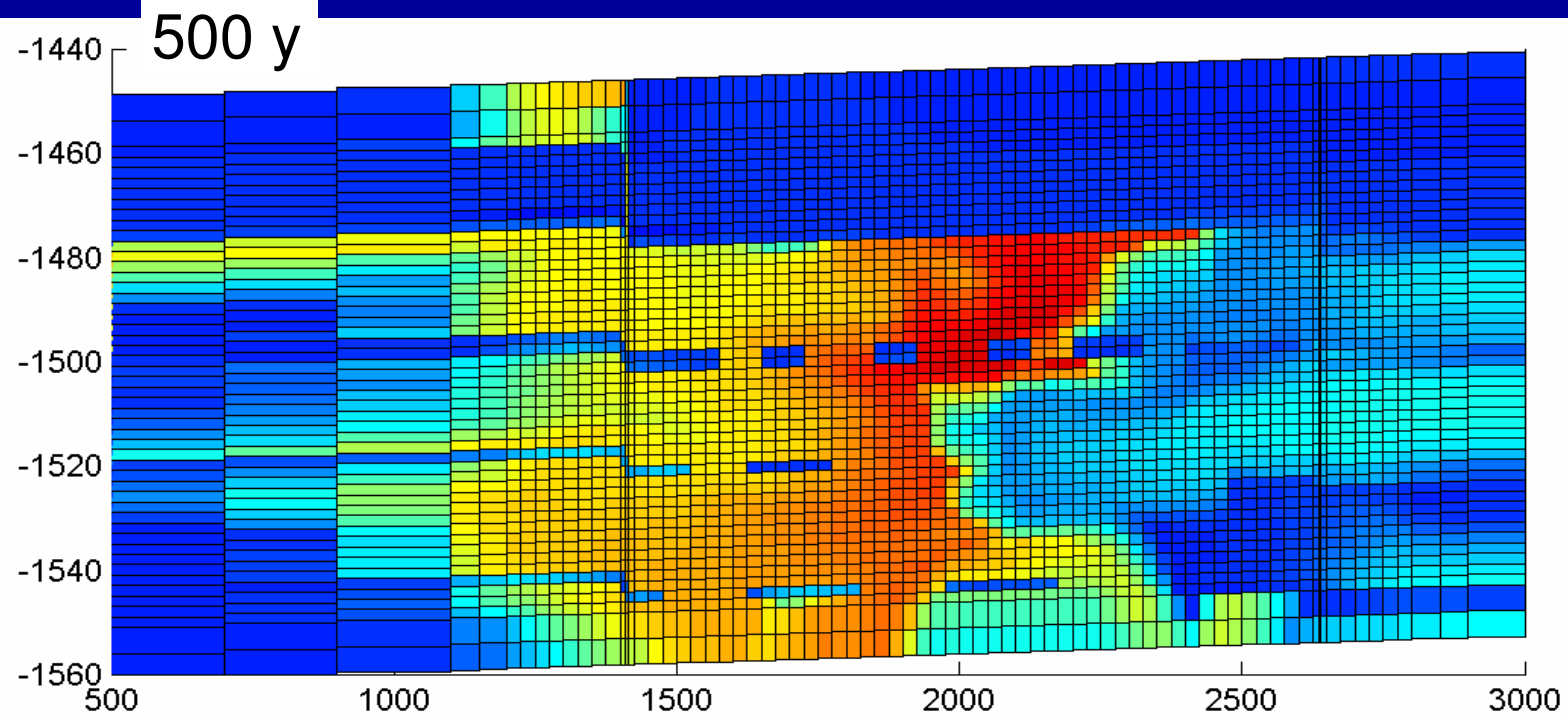
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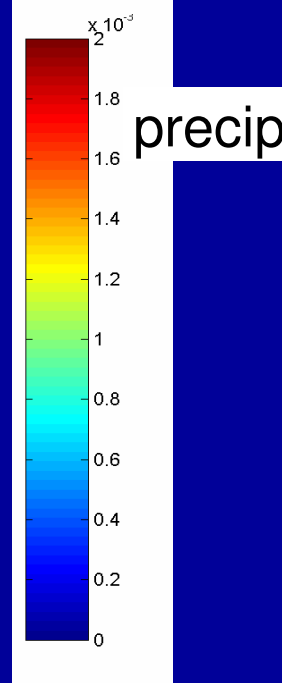
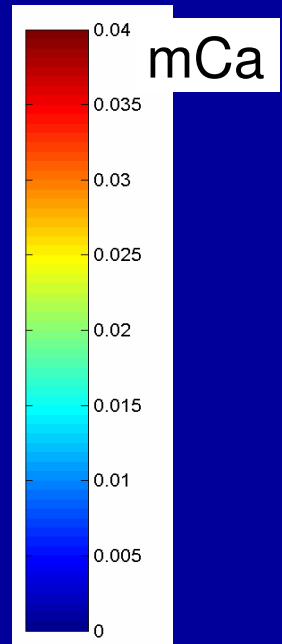
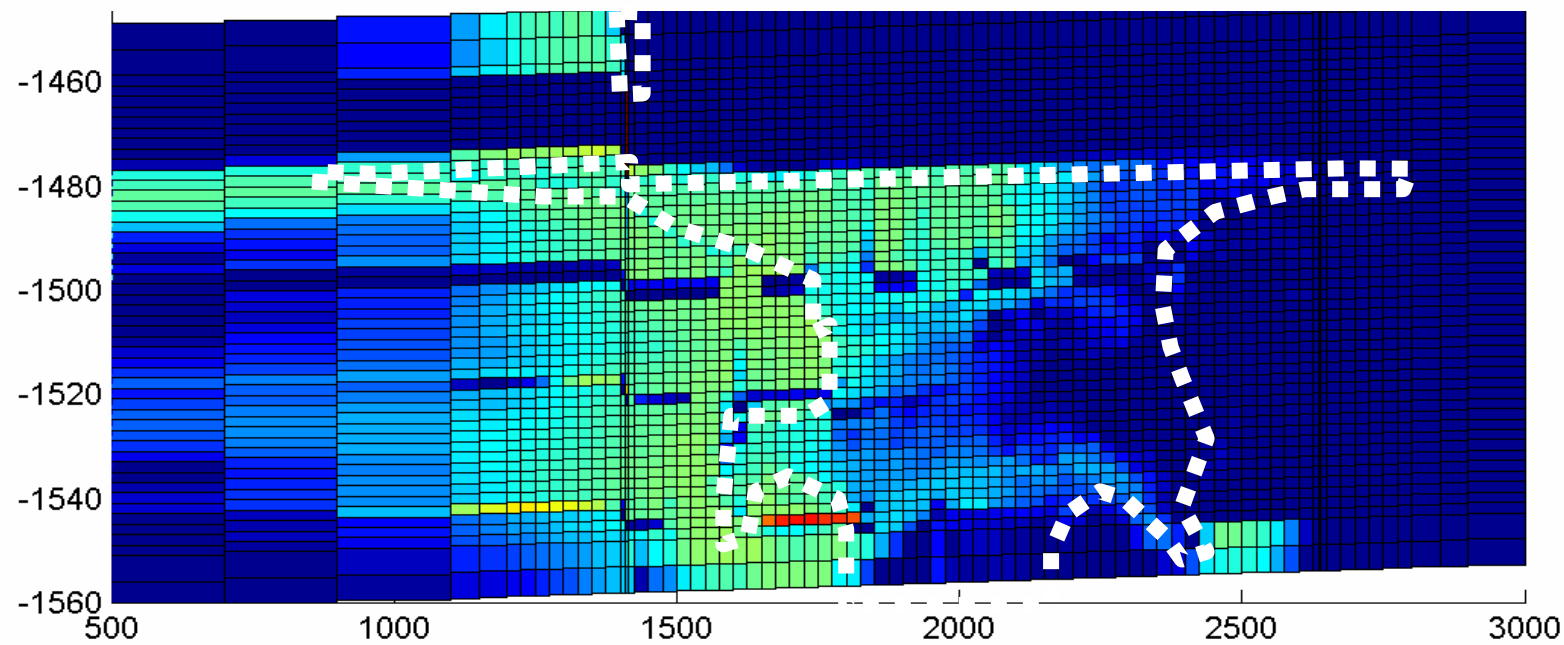
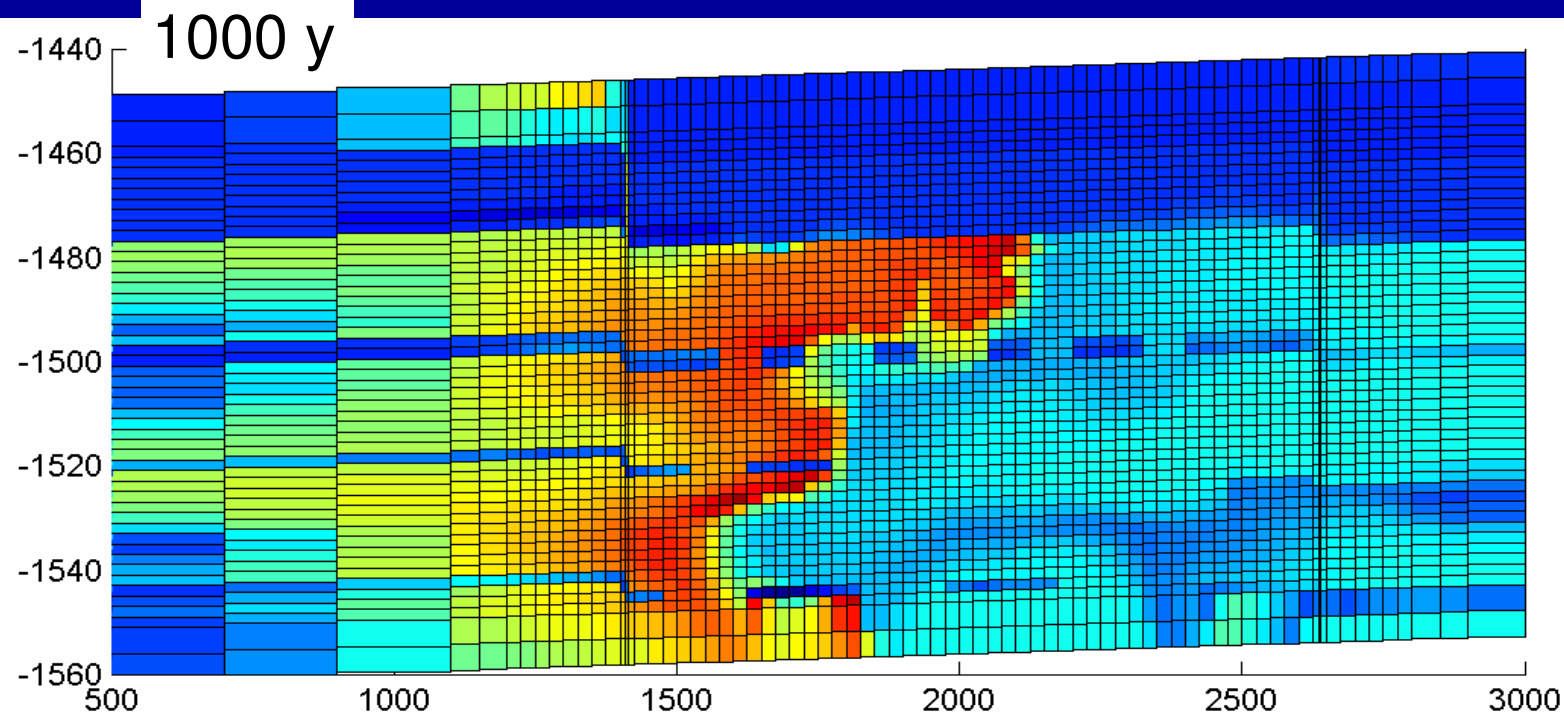
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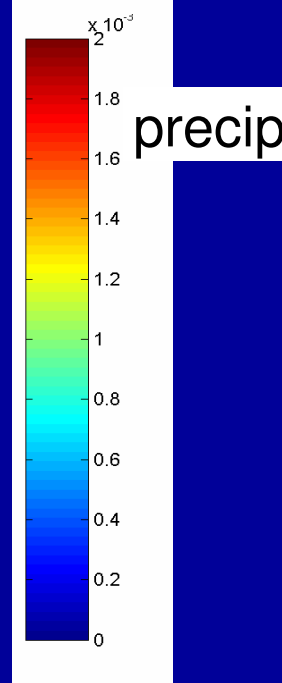
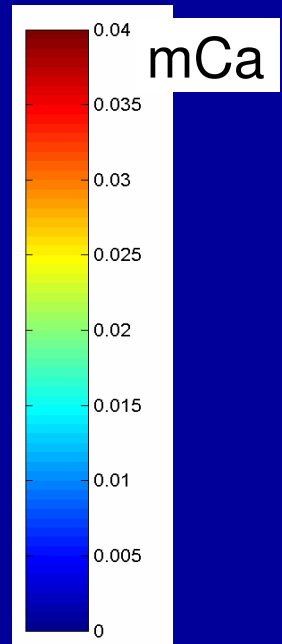
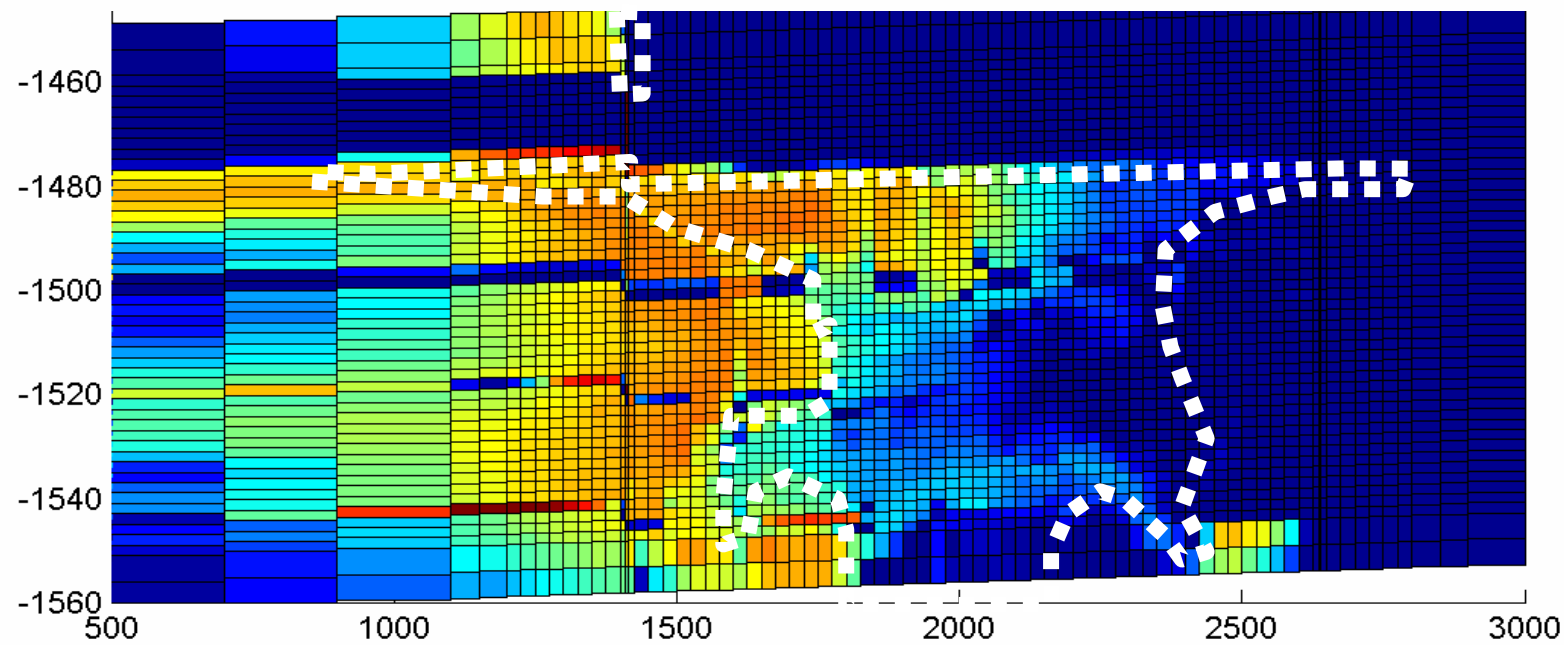
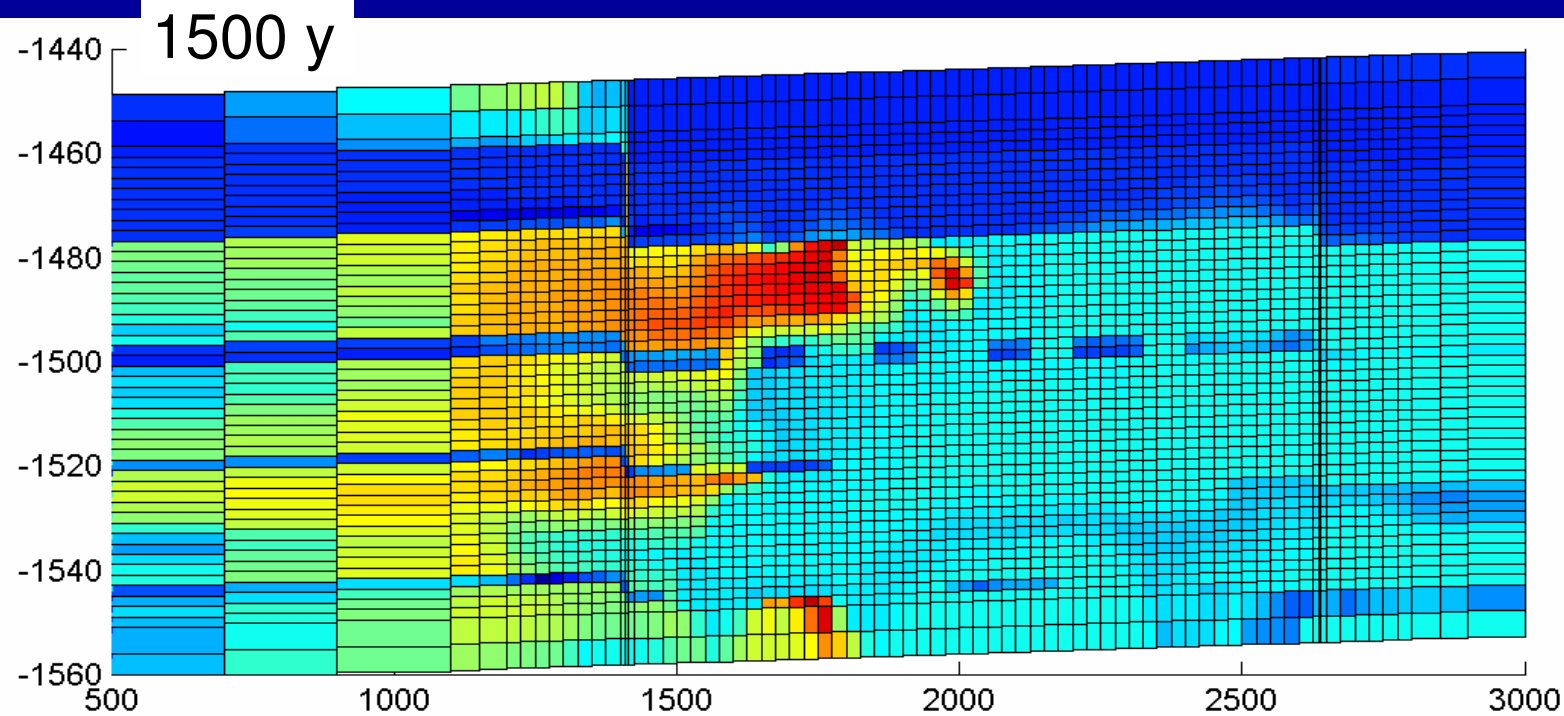
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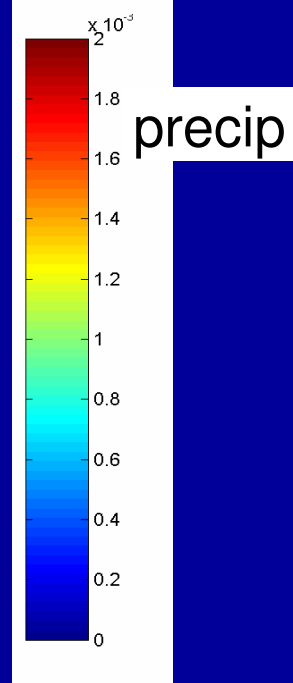
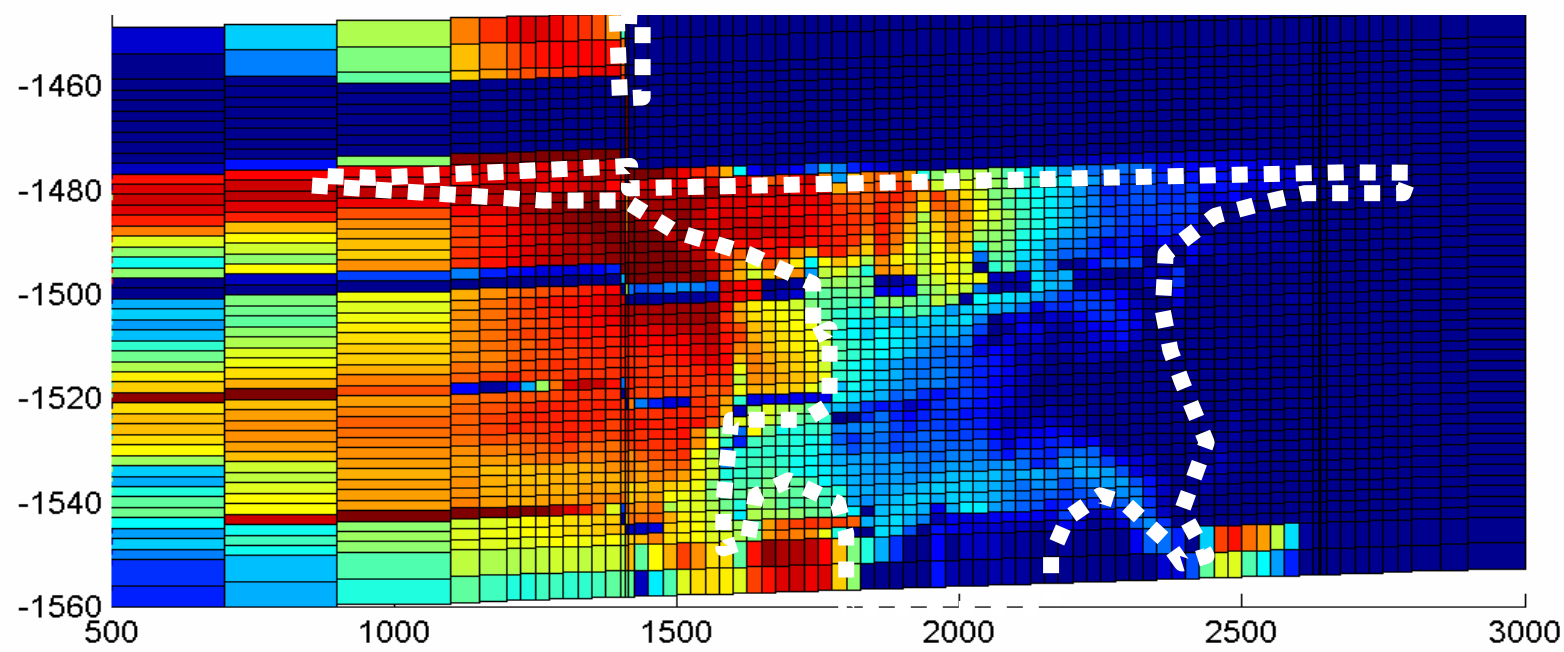
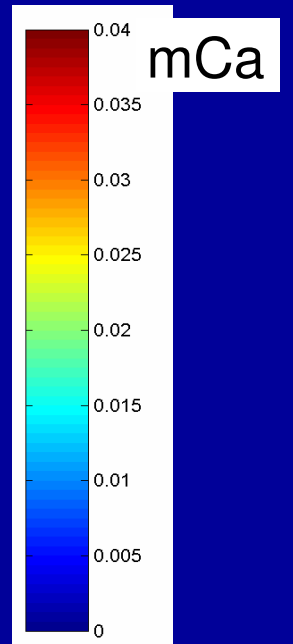
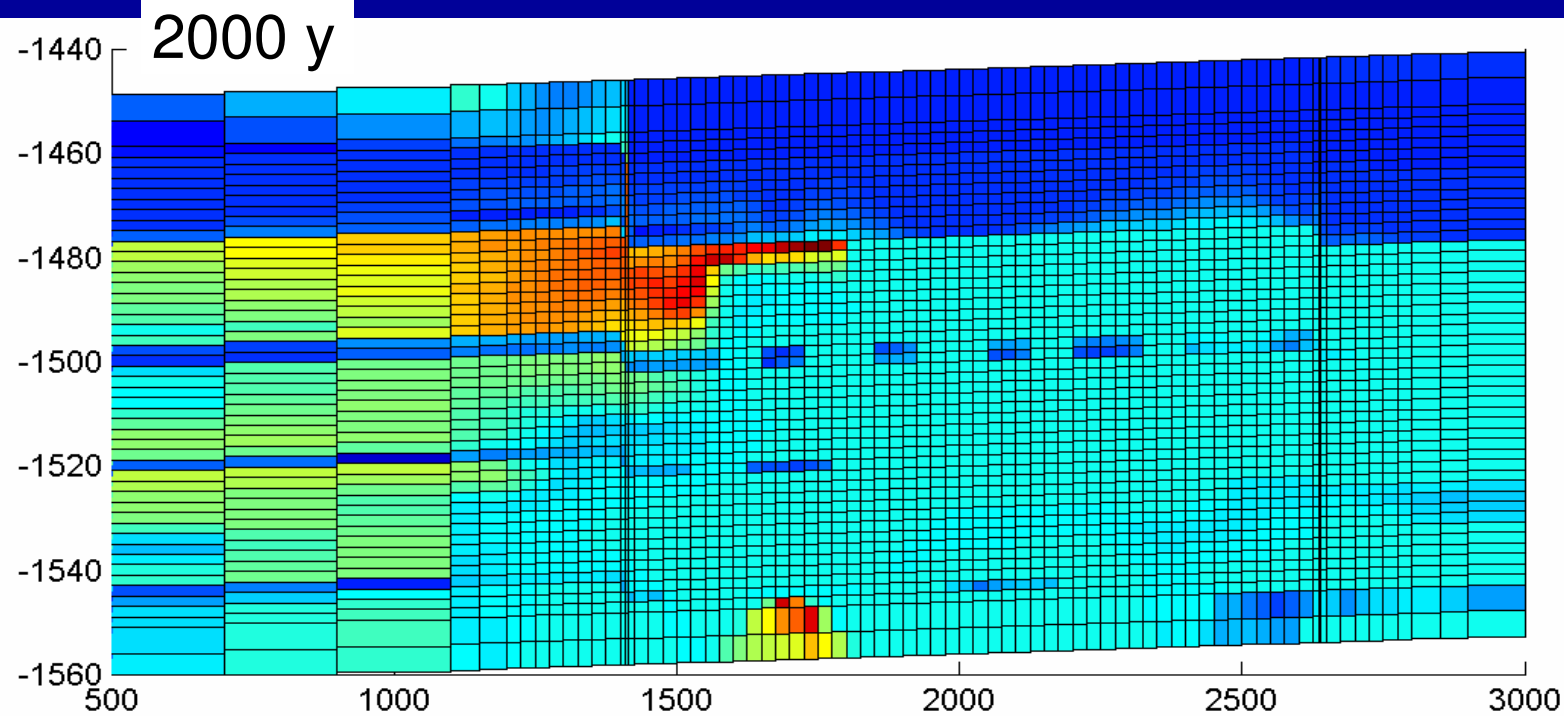
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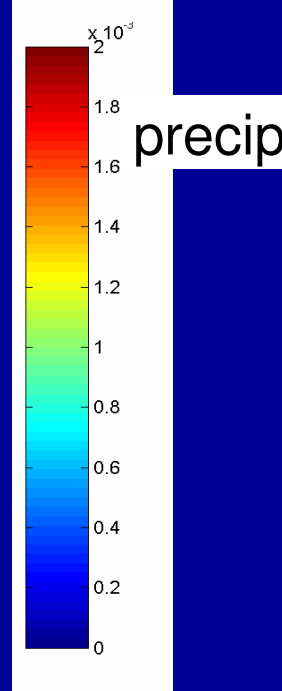
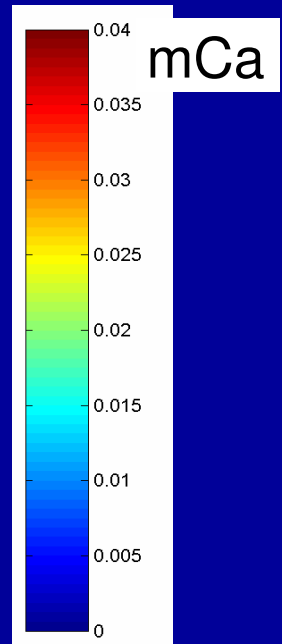
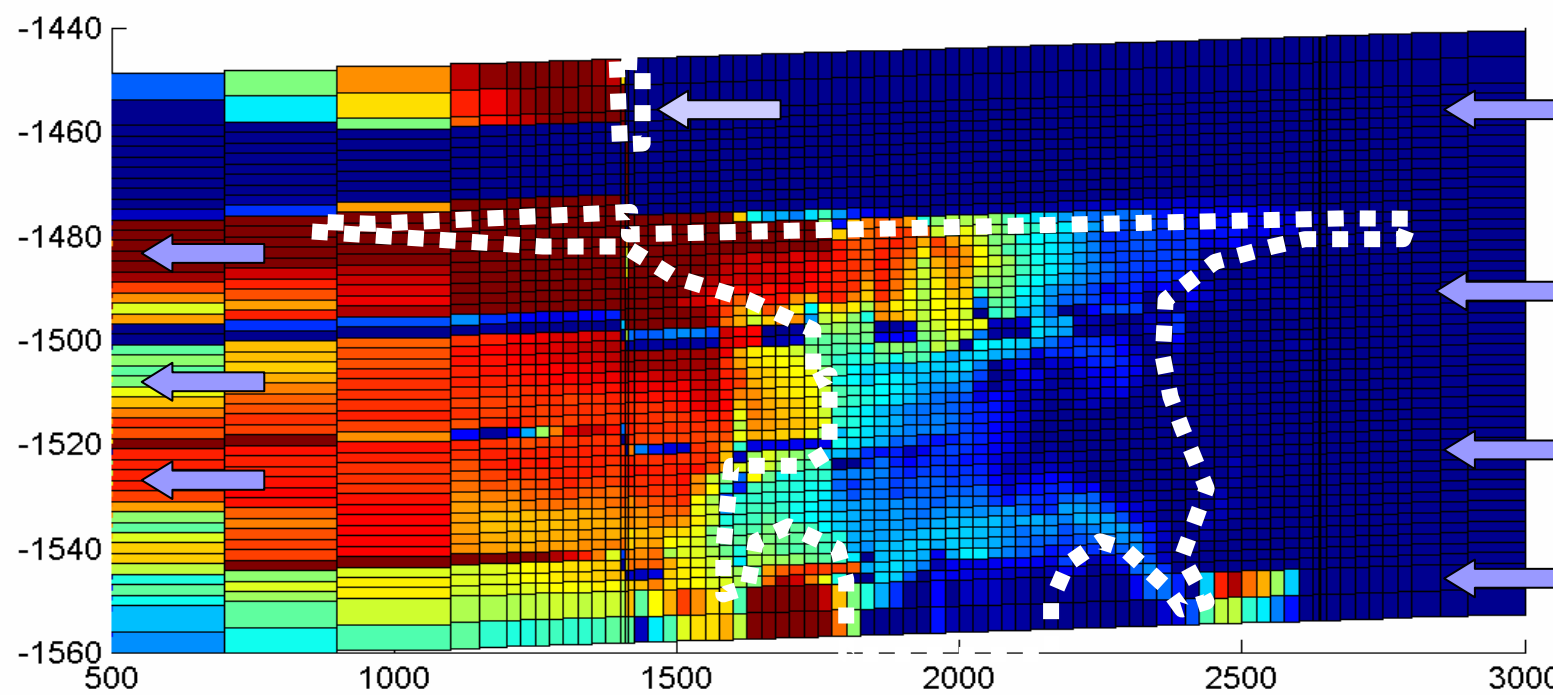
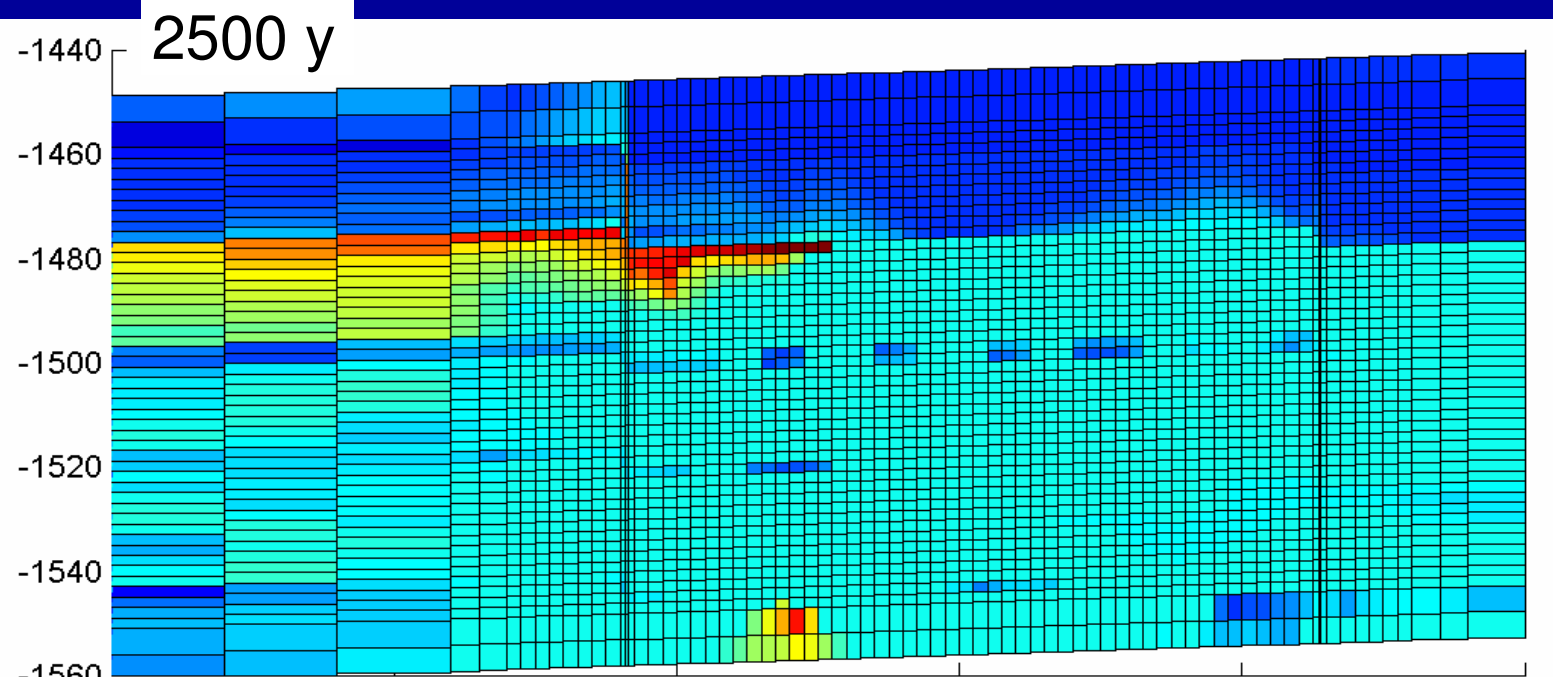


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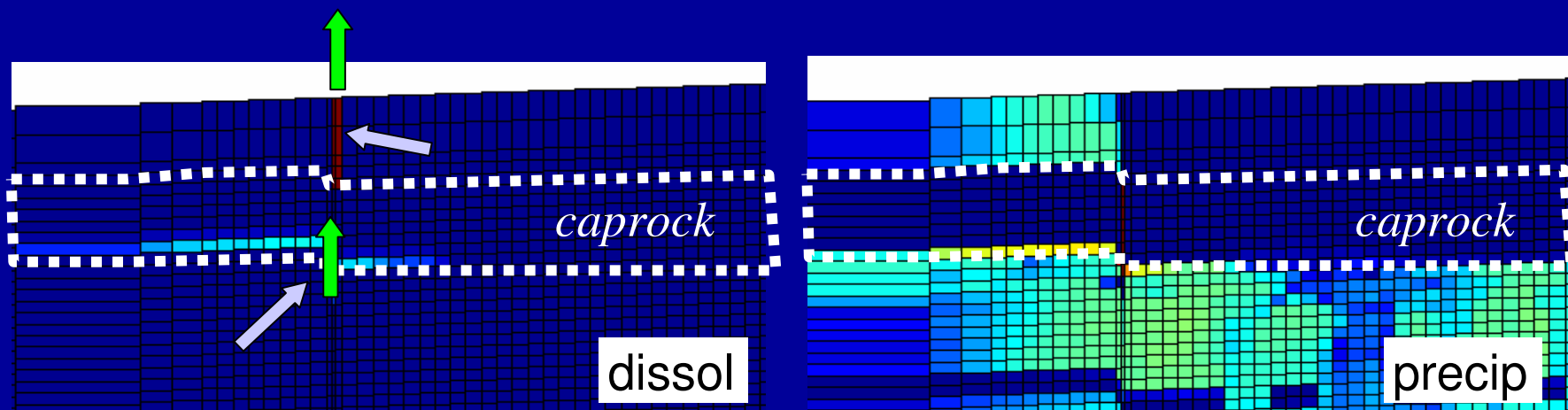
# Dissolution/mineralisation along leak pathways

## FRACTURE ROOT ZONES

*pristine water and gas (or CO<sub>2</sub>-charged water) converge  
subsequent mixing induces carbonate dissolution*

## FRACTURES ACROSS CAP ROCK

water is already CO<sub>2</sub>-rich and equilibrated with carbonate  
no more dissolution (no fracture enhancement)  
potential self-sealing due to mineralization



# Some concluding remarks

Using water enhances chemical effects but ...

**DECARBONATATION CAN BE MANAGED**

injection design is the key for the short term

Mid and long term evolution is also dominated by water movements

... need to keep the water fluxes under control after injection

(monitoring at least, search for remediation strategies)