

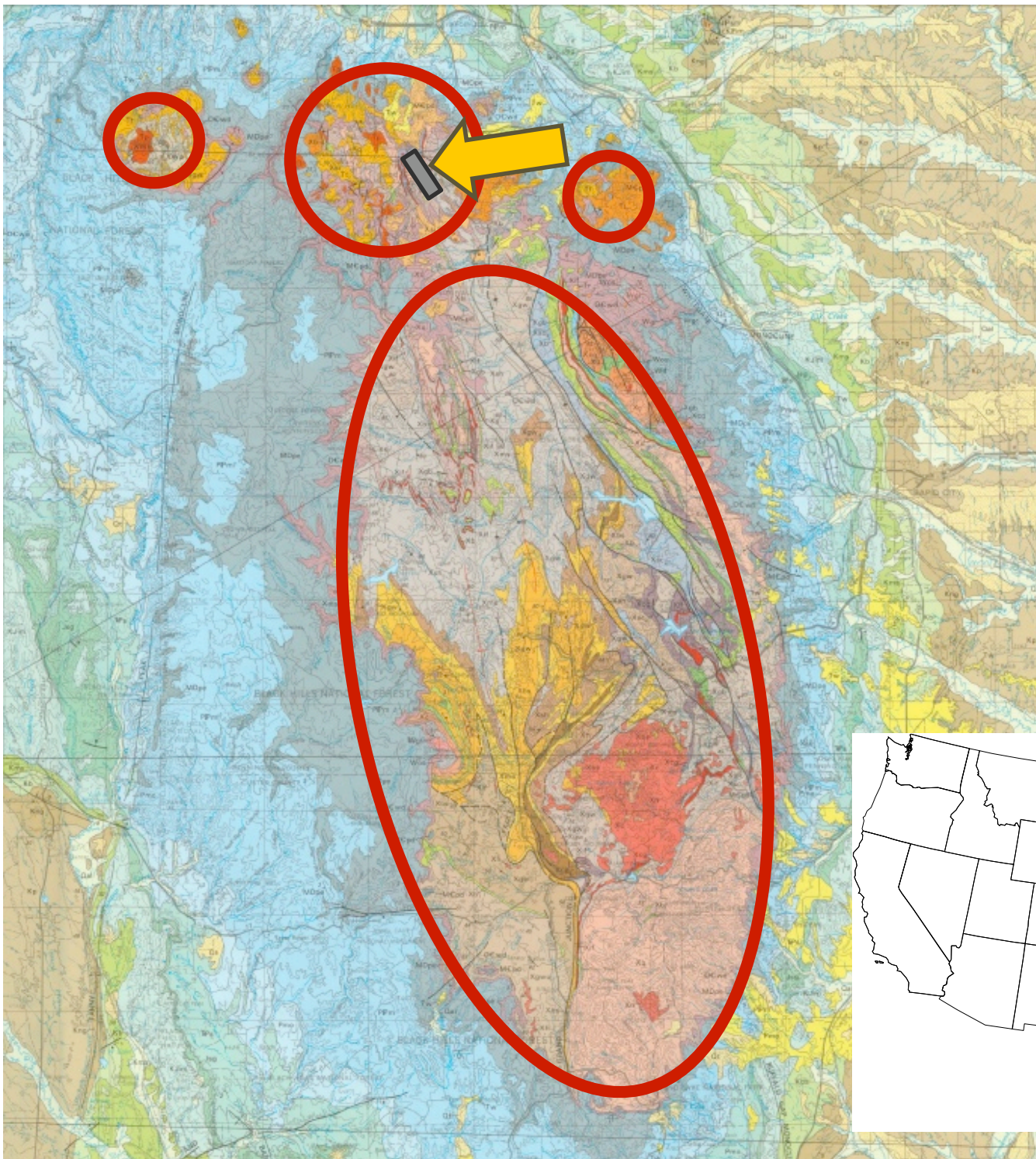
Hydrogeological Conceptual Model for DUSEL Homestake

What was the effect of mining operations on the hydrogeology?

- Ground water flow system
- Interaction with surface water
- Effects of flooding and dewatering of mine
- Deformation

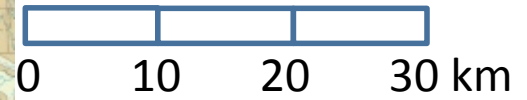


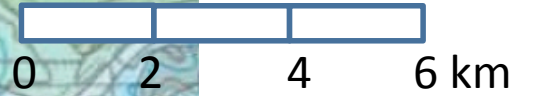
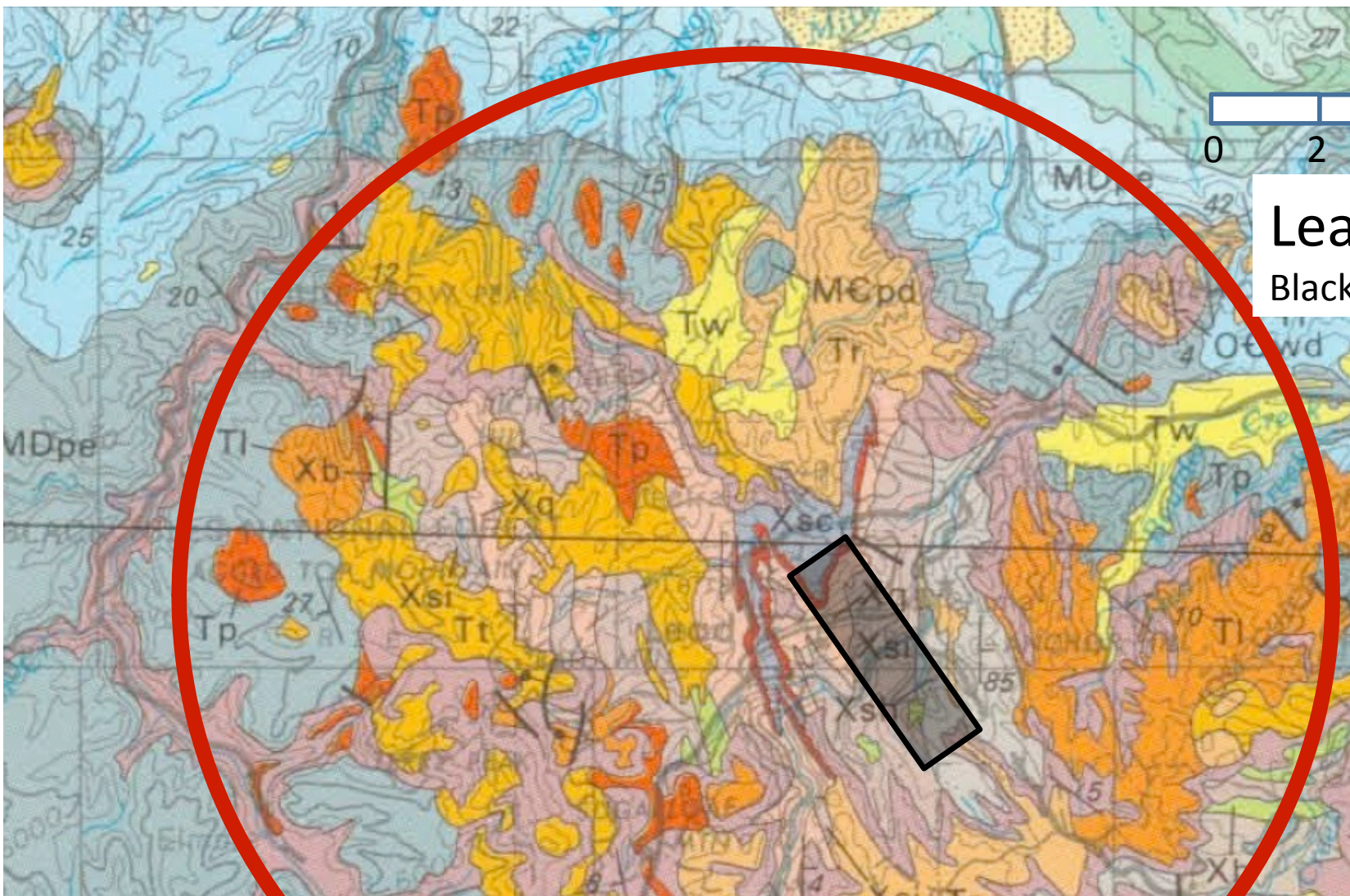
Homestake Gold Mine, Lead, SD, ~1885



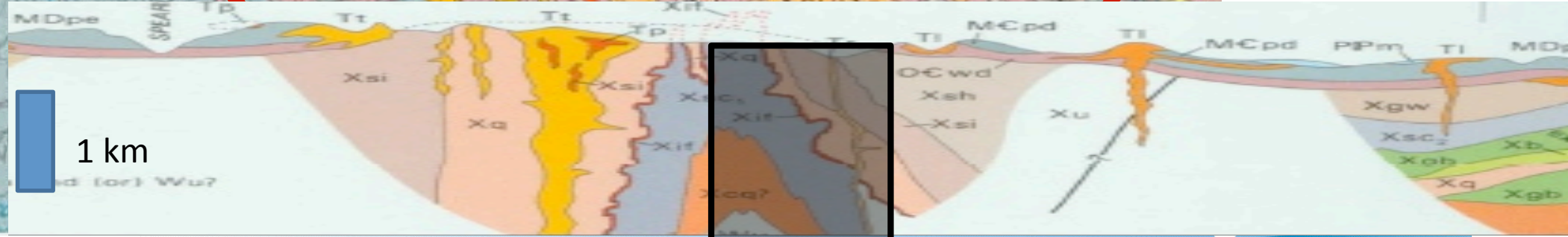
Regional Geology

Black Hills, SD

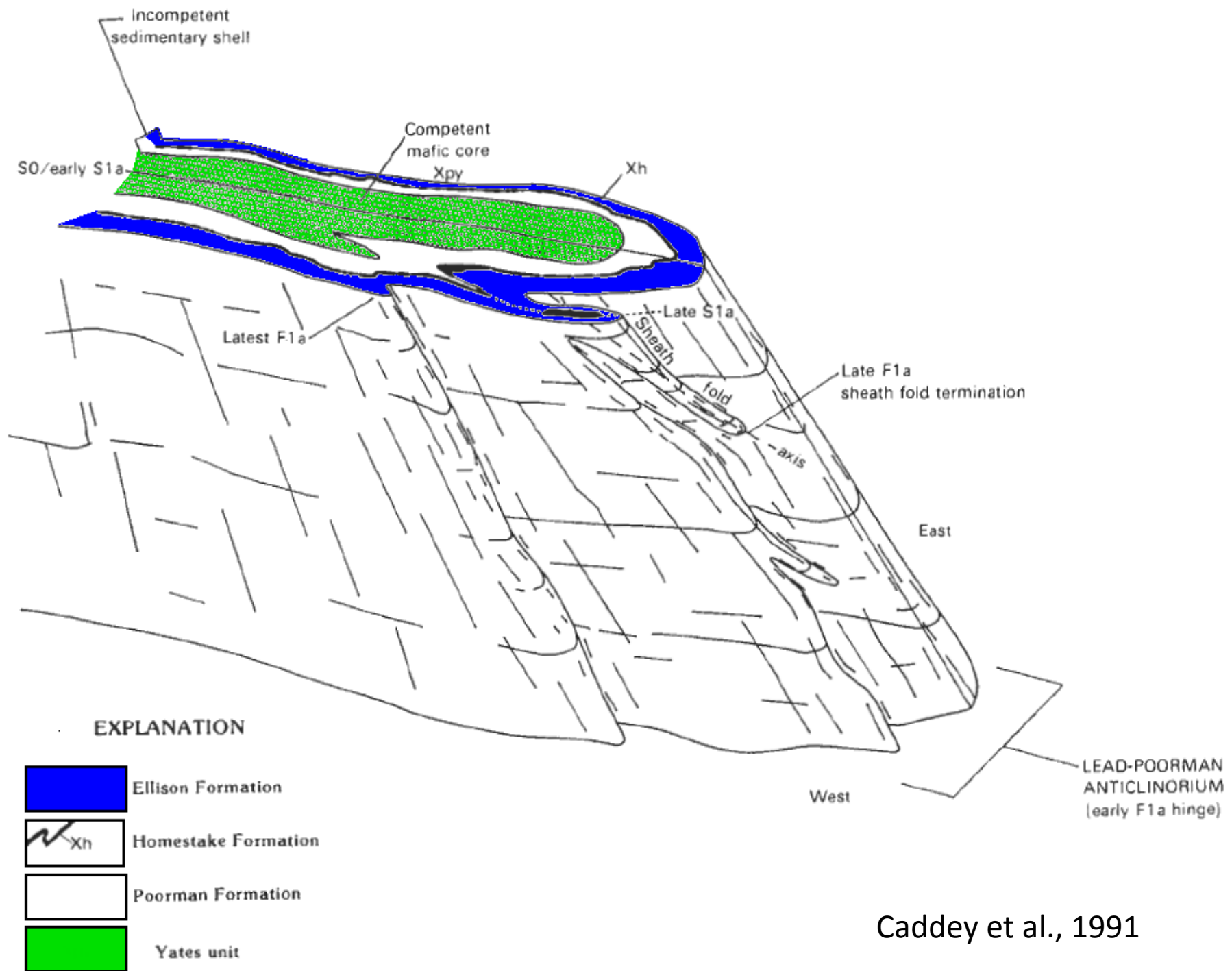




Lead Dome
Black Hills, SD



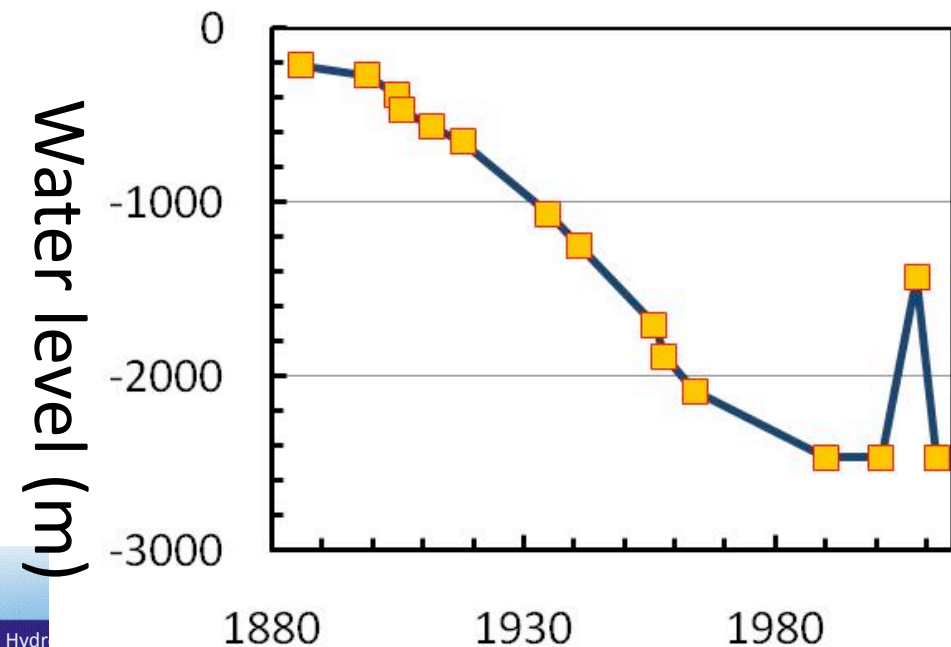
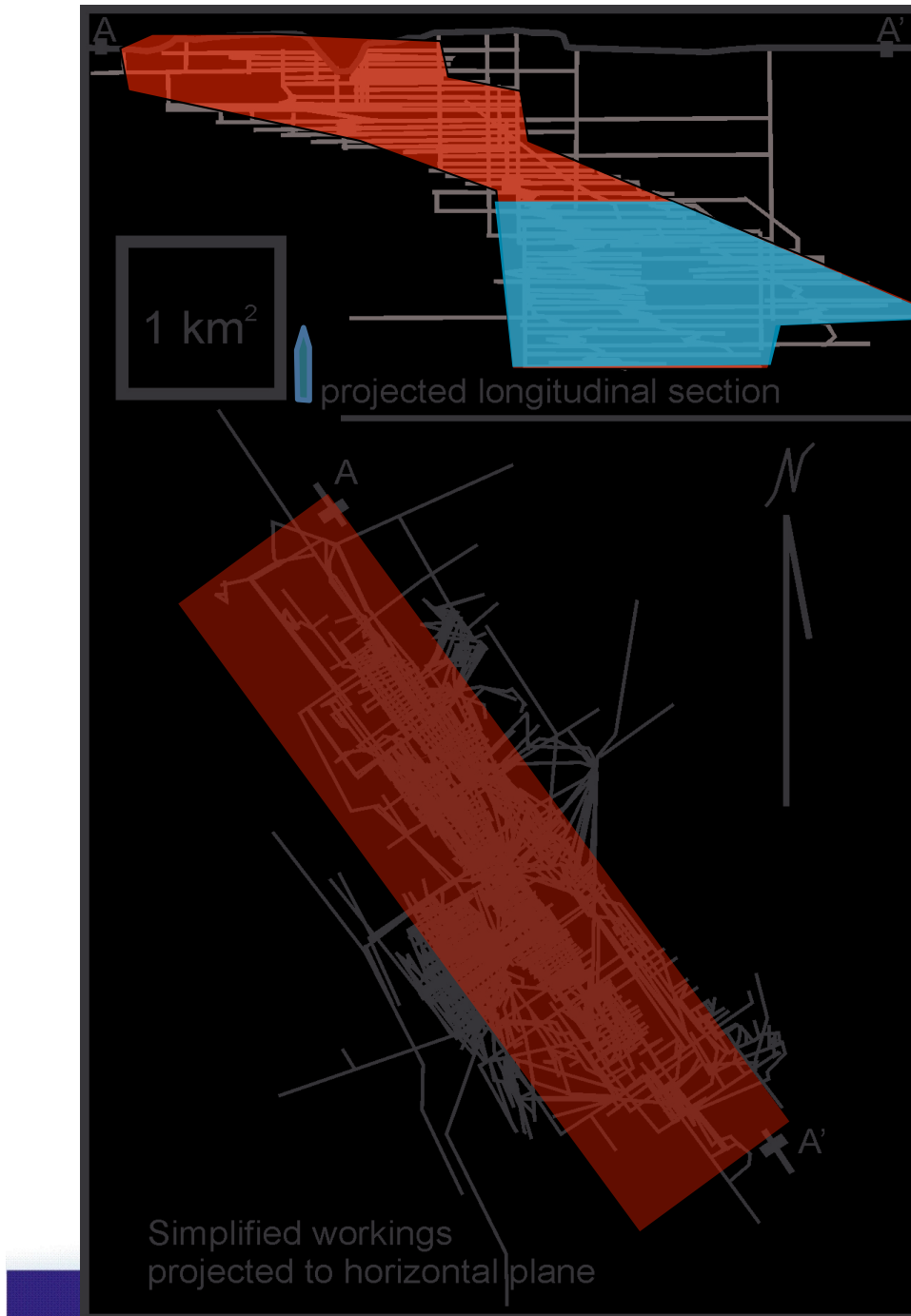
1 km

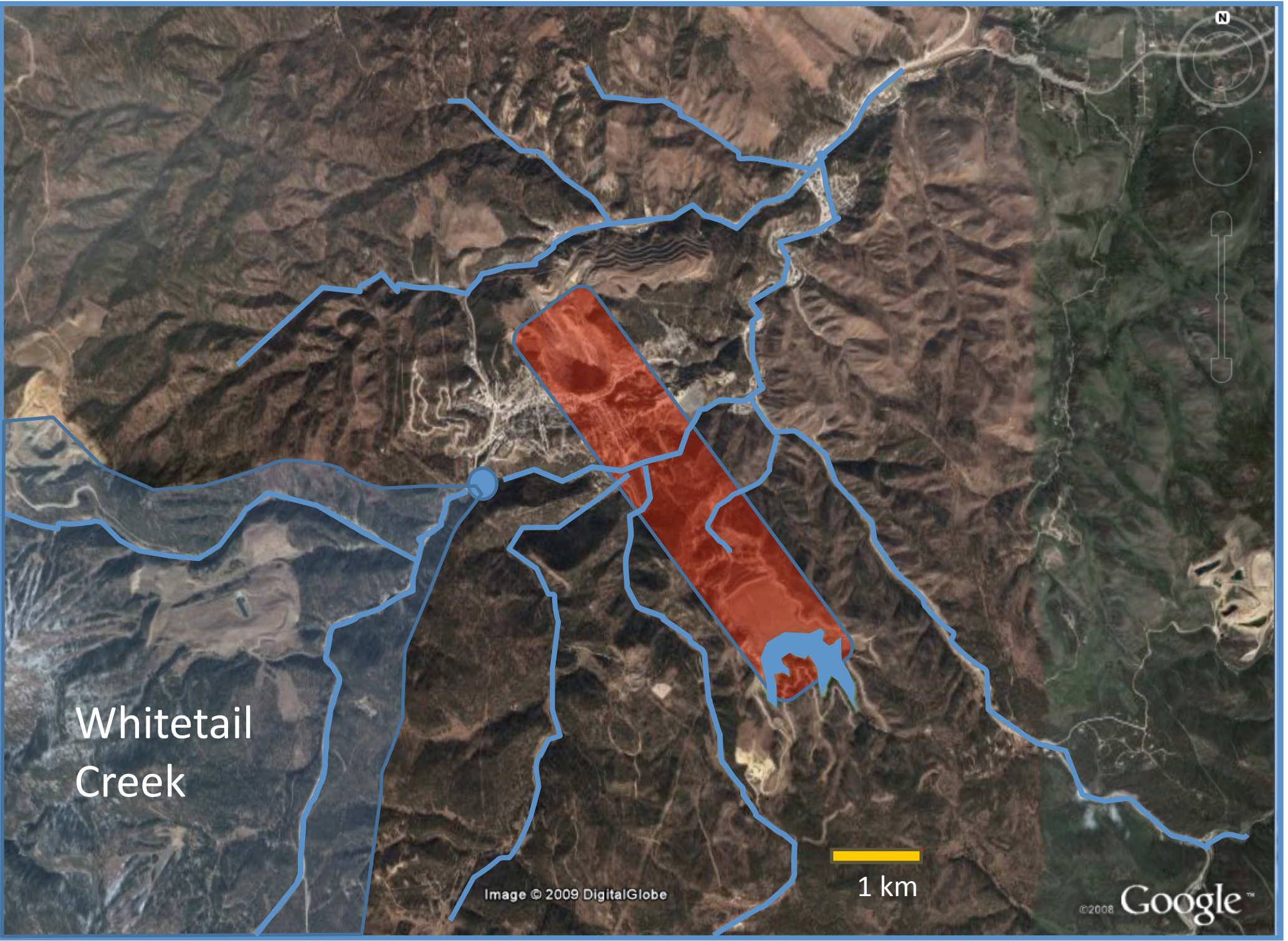


Caddey et al., 1991

Geometry and History

1. Mining → downward tunneling, 100 years until 2002
2. Flooding → mine fills with water, 1 km deep by 2008
3. Draining → mine dewatered by 2012





Whitetail
Creek

1 km

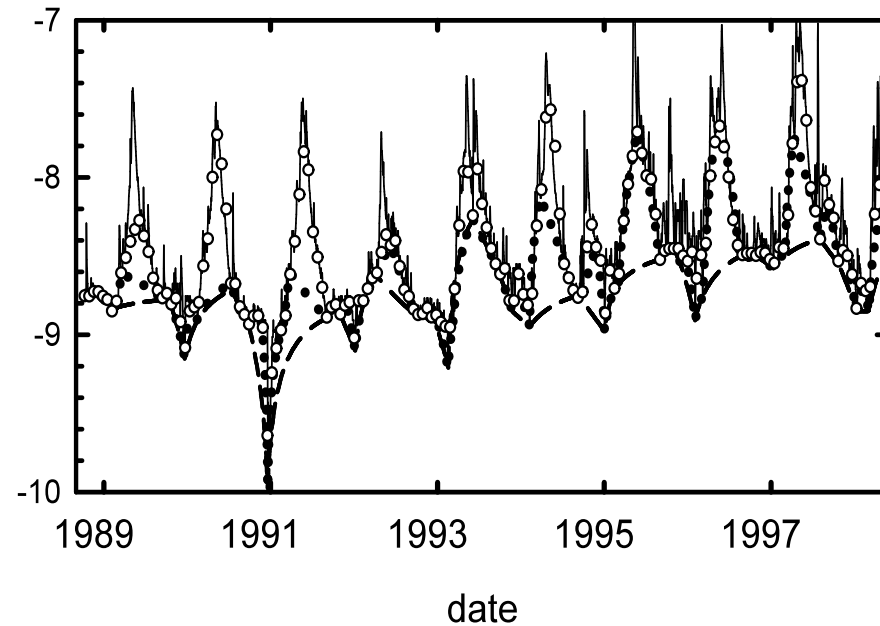
Image © 2009 DigitalGlobe

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Surface Water



Stream hydrograph, Whitetail Creek, Lead, SD



Baseflow separation analysis

Precipitation: 0.7 m/yr

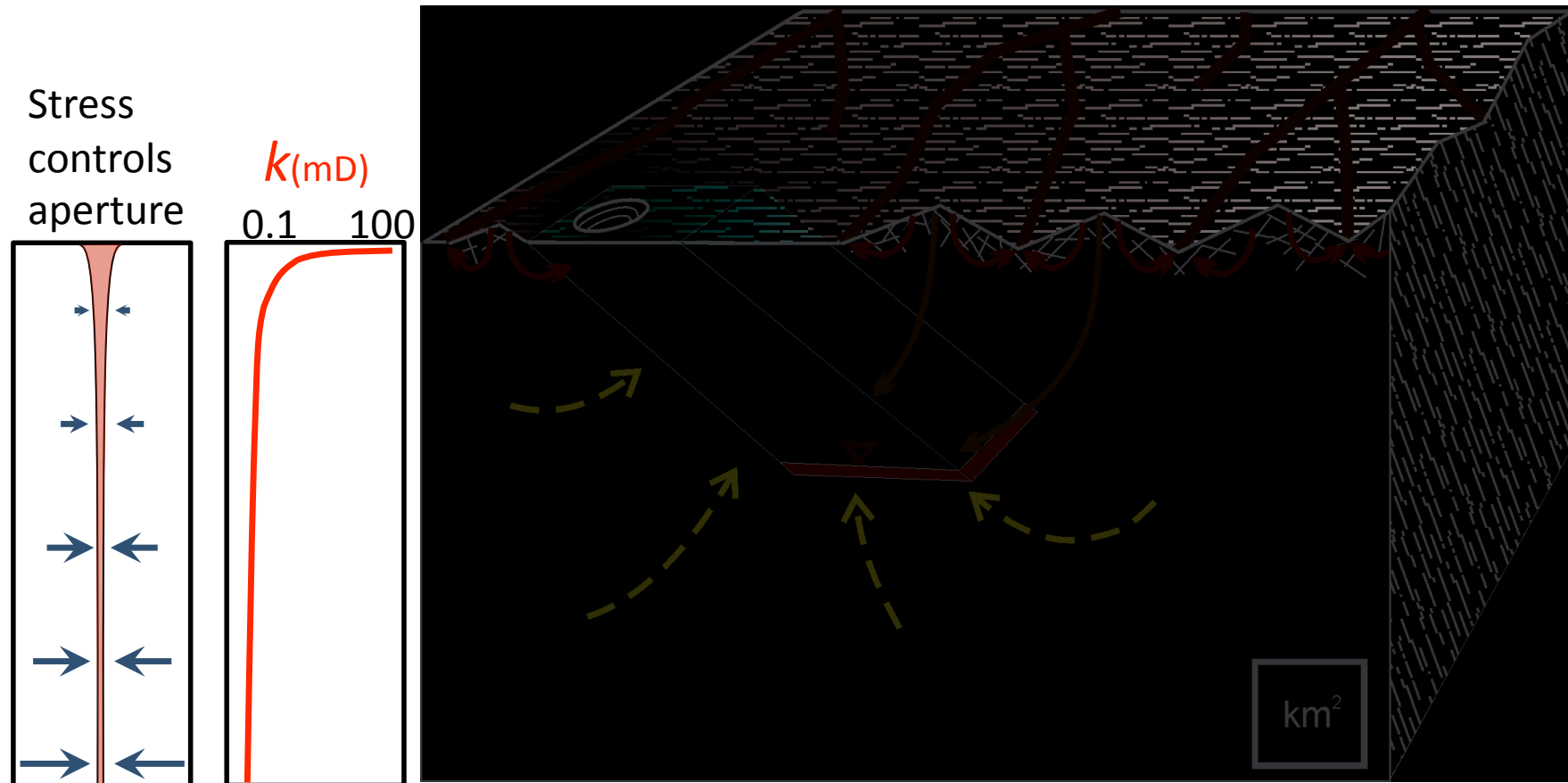
Runoff: 0.26 m/yr

Baseflow/Recharge: 0.1-0.15 m/yr

Geology



Conceptual Model



- | | |
|-----------------|------------------------------|
| 1. Flow system | 2. Mining/Flooding/ Draining |
| Shallow | 3. GW/SW |
| Deep, recharged | 4. Deformation |
| Deep, storage | |

Properties

Hydraulic conductivity $K = C_1 \psi \bar{\delta}^3$

Porosity $n = \psi \bar{\delta}$

Specific Storage $S_\sigma = \psi (C_n + \bar{\delta} \beta)$

Fracture Compliance $C_n = C_2 (1 - \delta/C_3)^2$

Young's Modulus $E = \frac{3(1-2\nu)}{C_n \psi}$

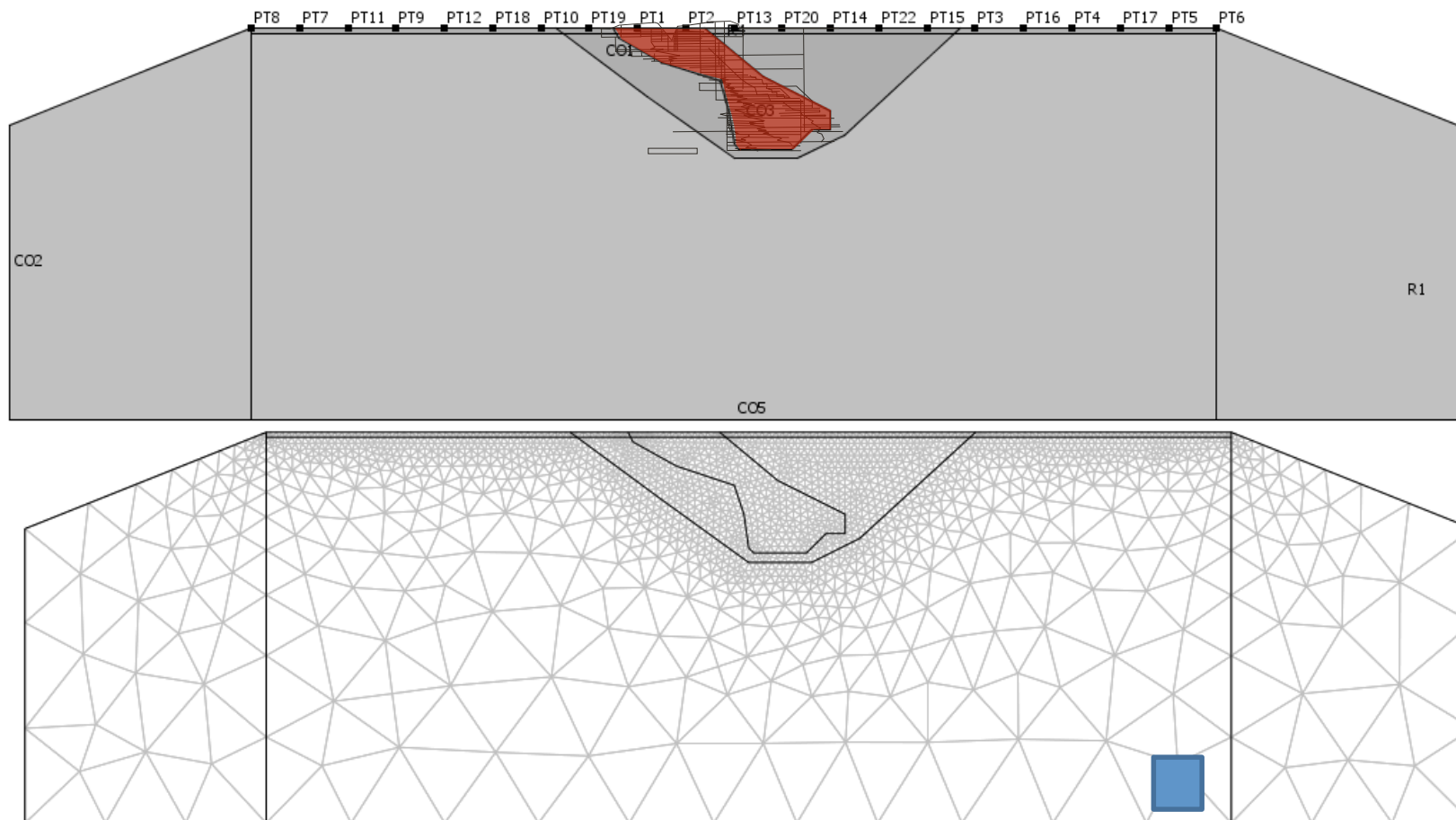
Aperture and effective stress
$$\delta = \delta_o - \frac{(\delta_o - \delta_{\min}) \sigma_e}{\frac{(\delta_o - \delta_{\min})}{C_{ni}} + \sigma_e}$$

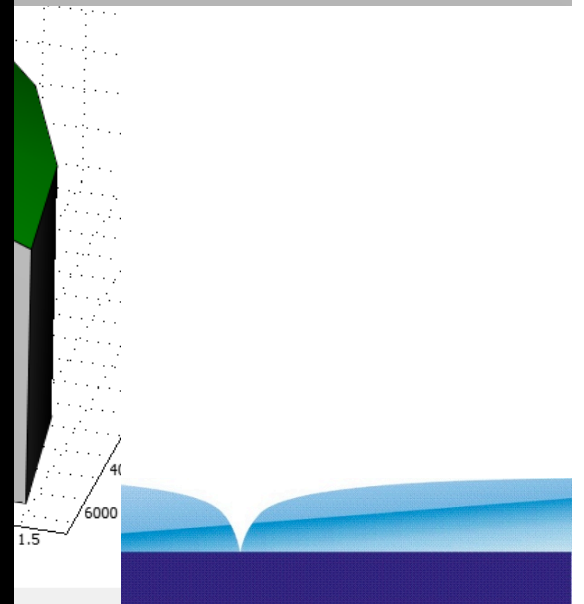
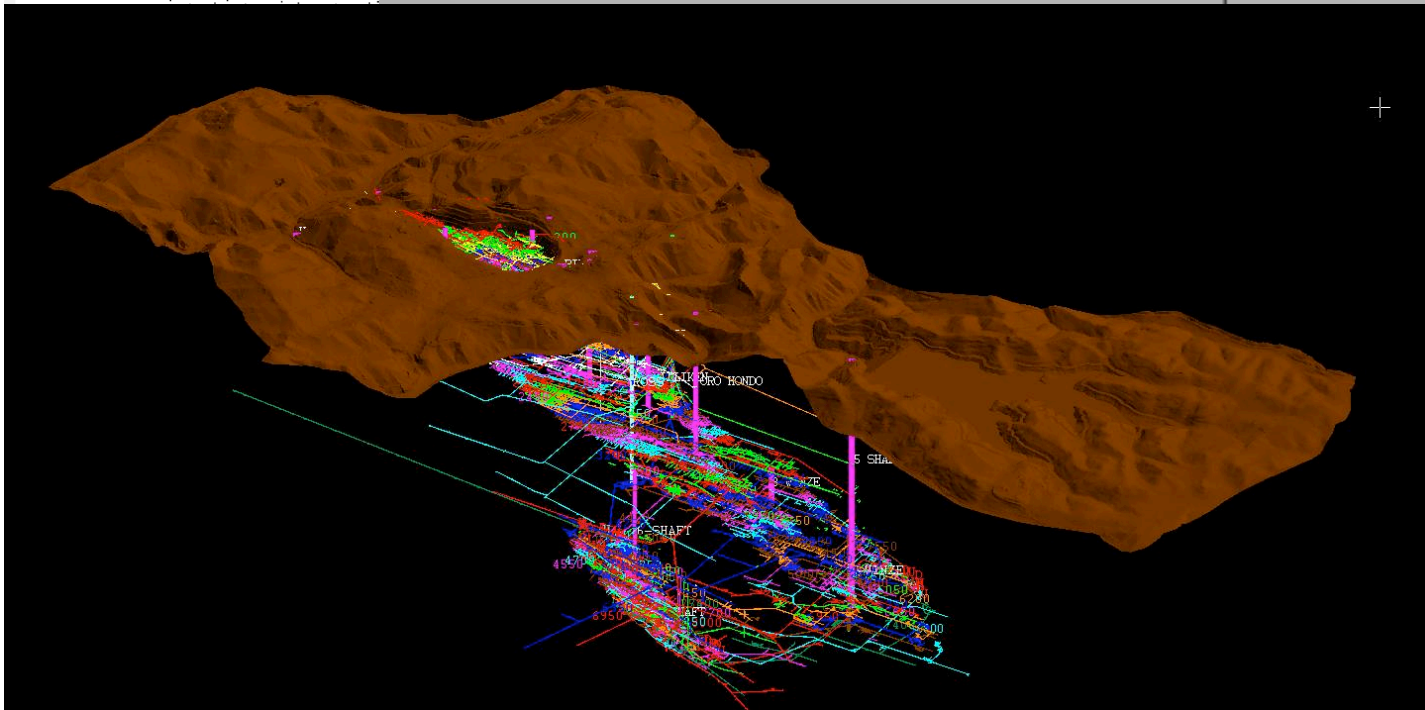
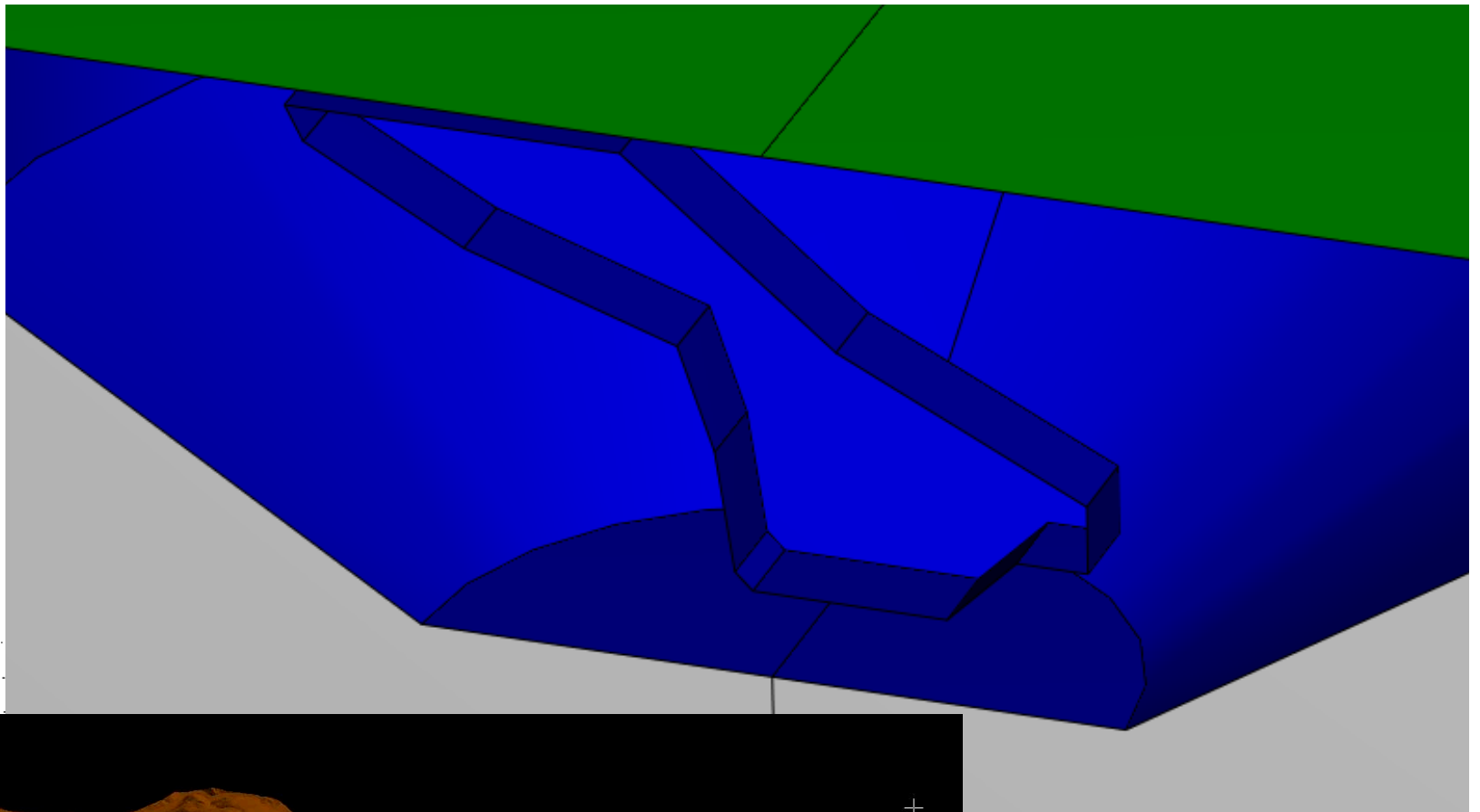
$\bar{\delta}$ = average frx aperture [1/L]

ψ = frx density [1/L]

Numerical Model

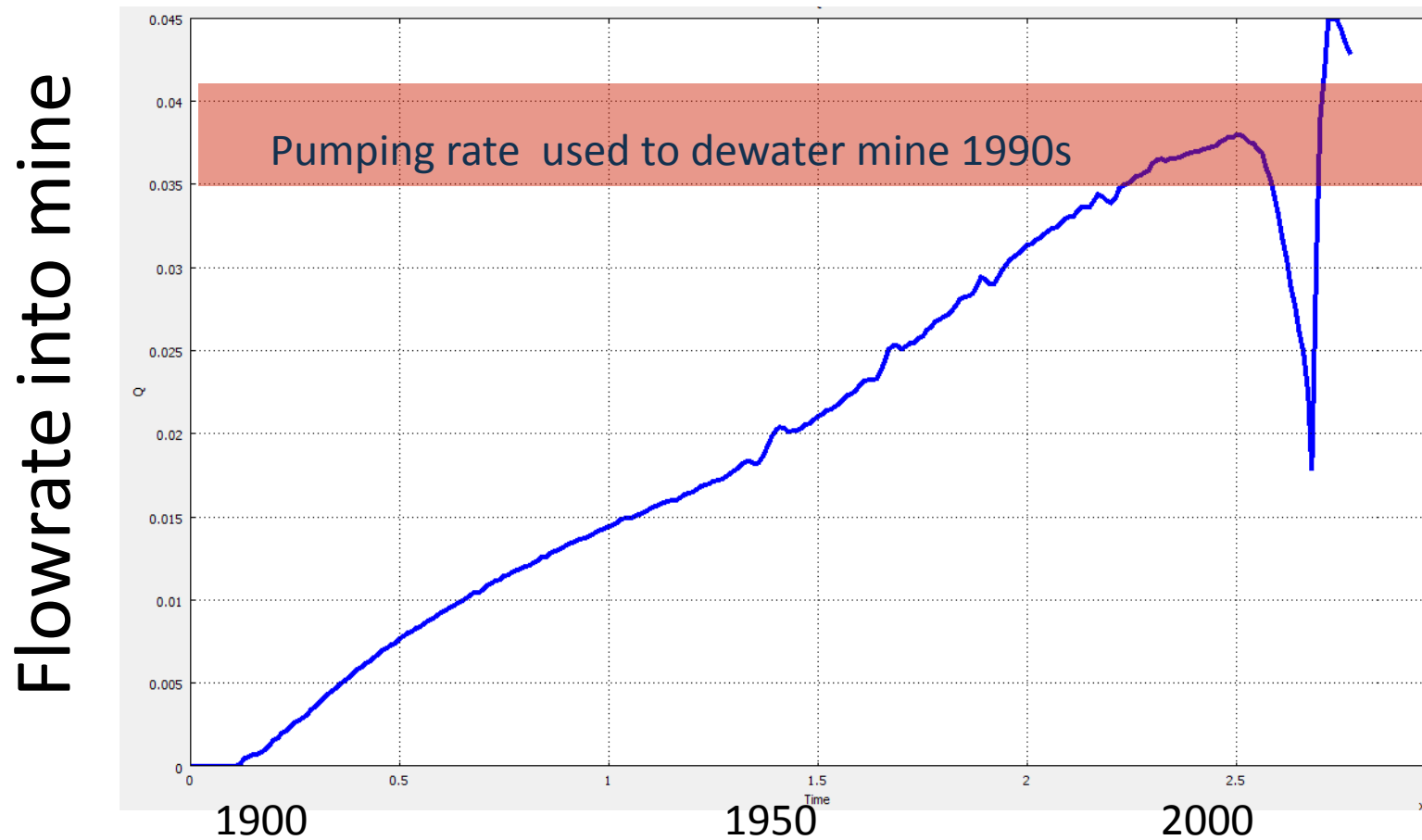
2-D, 3-D. Parameters from deformable fracture. Mine as dual medium with imposed head conditions. Streams as constant heads with 1 km spacing.





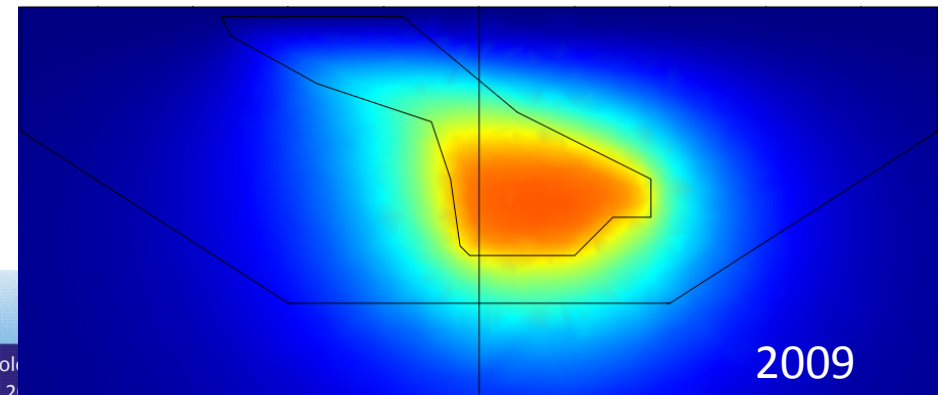
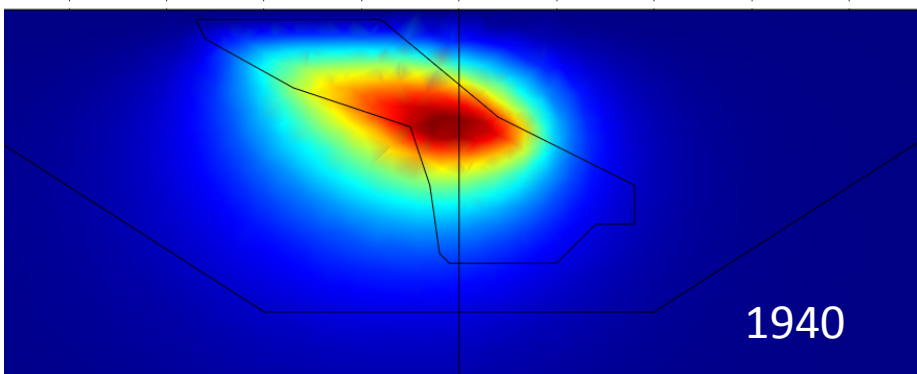
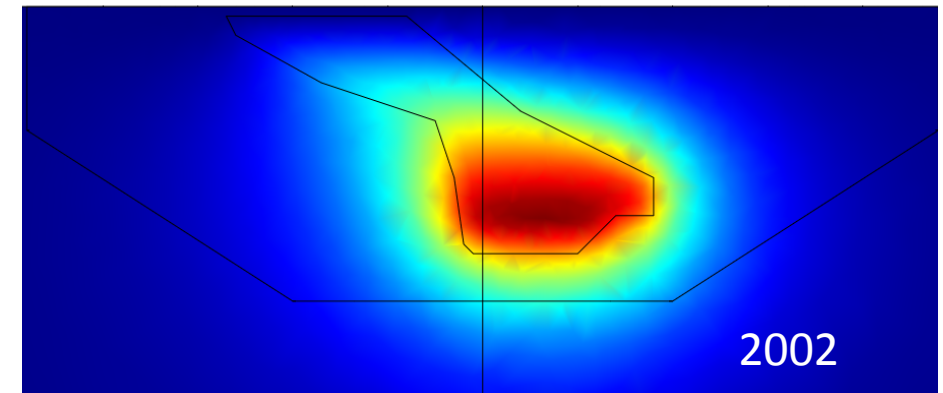
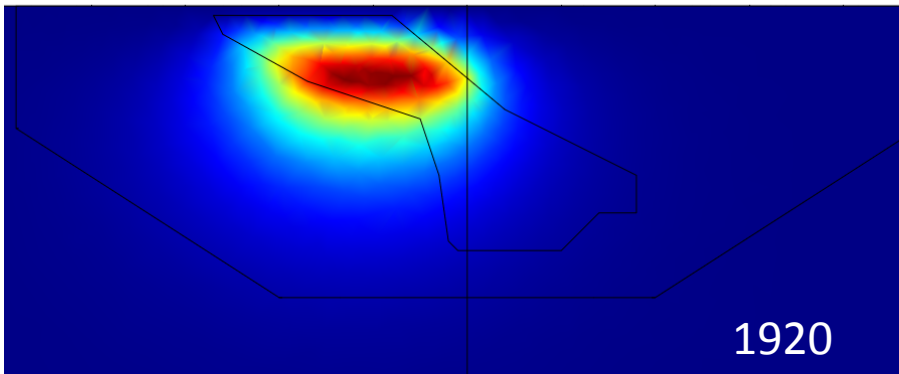
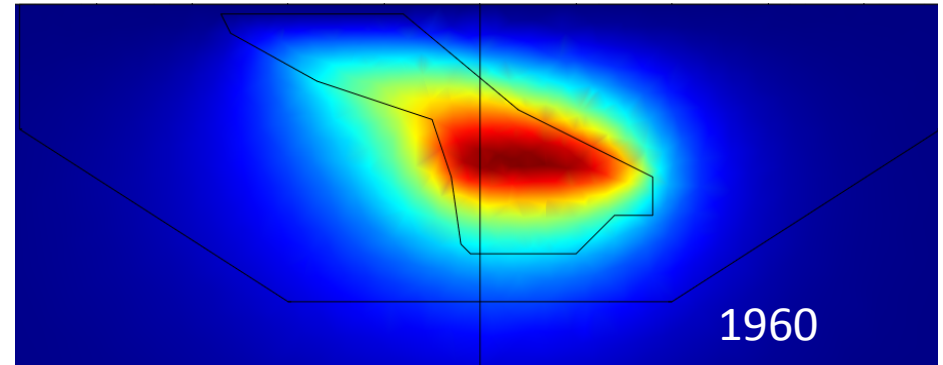
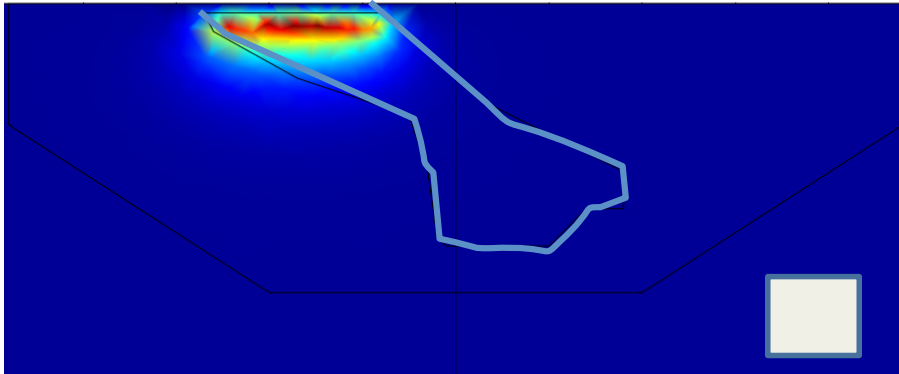
Calibration

Adjust frx aperture and spacing to match dewatering rate

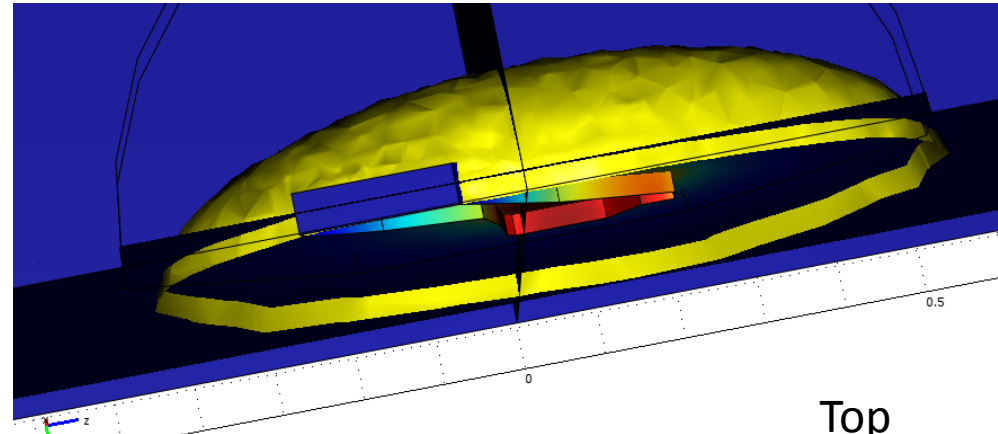


Time

Drawdown 1890-2009

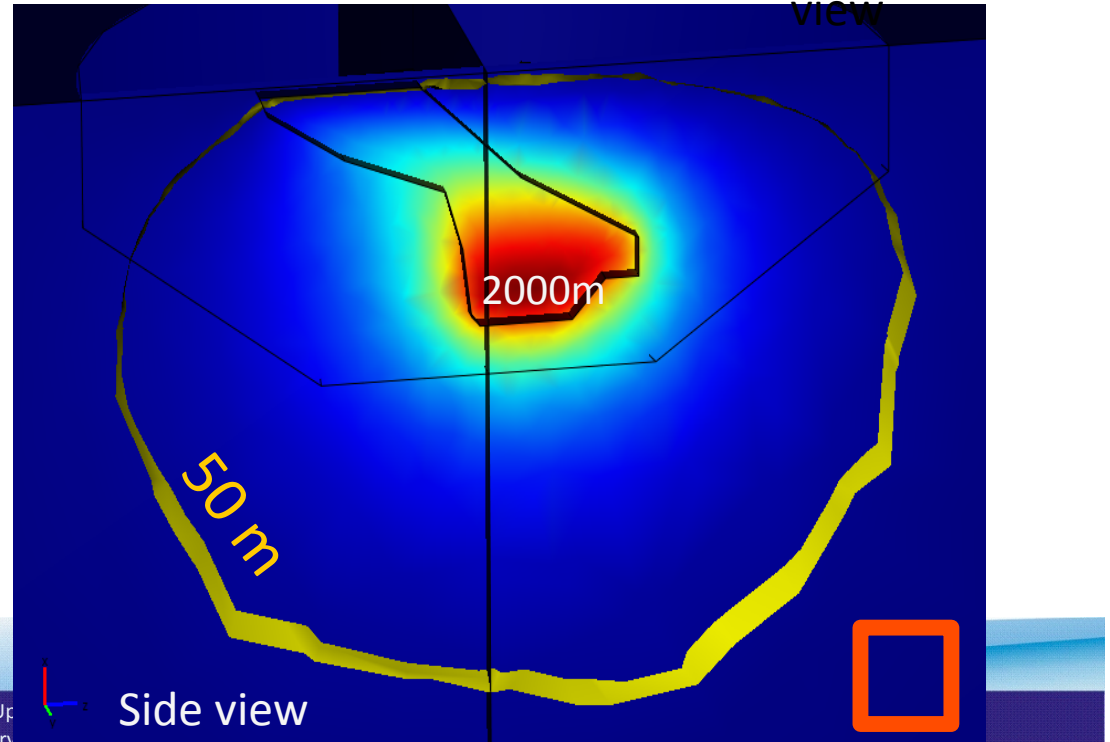
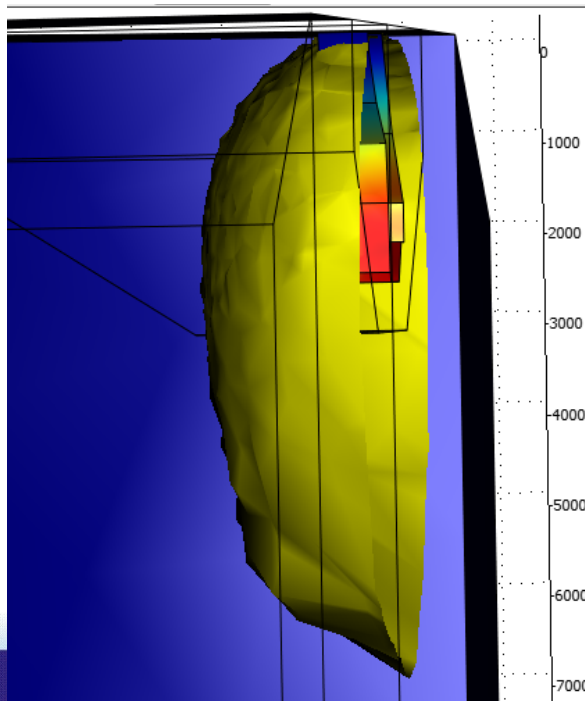


Drawdown 2009



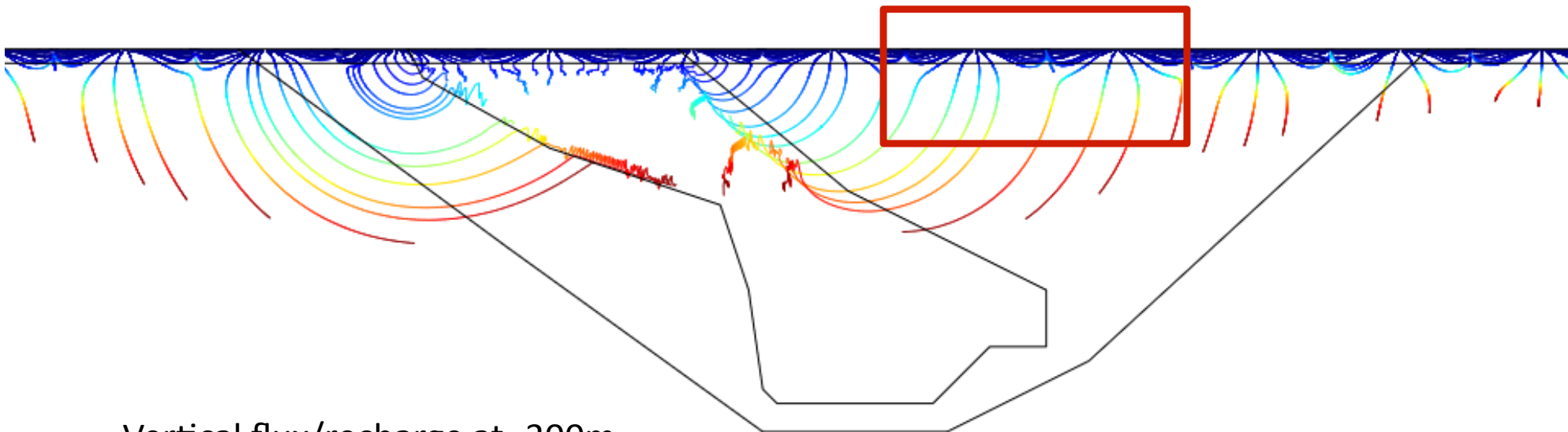
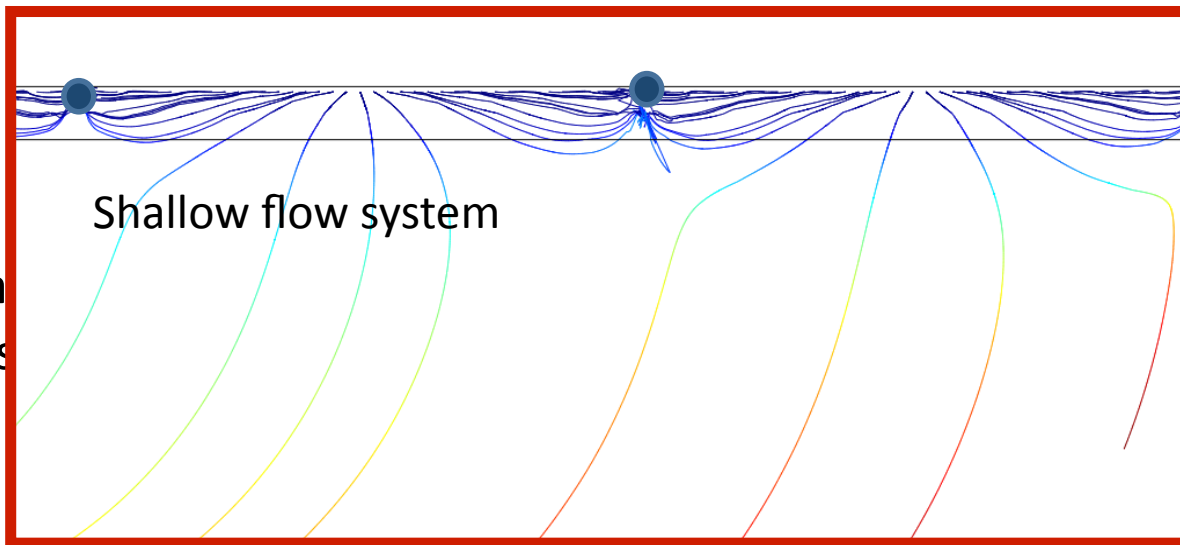
Top
view

End view

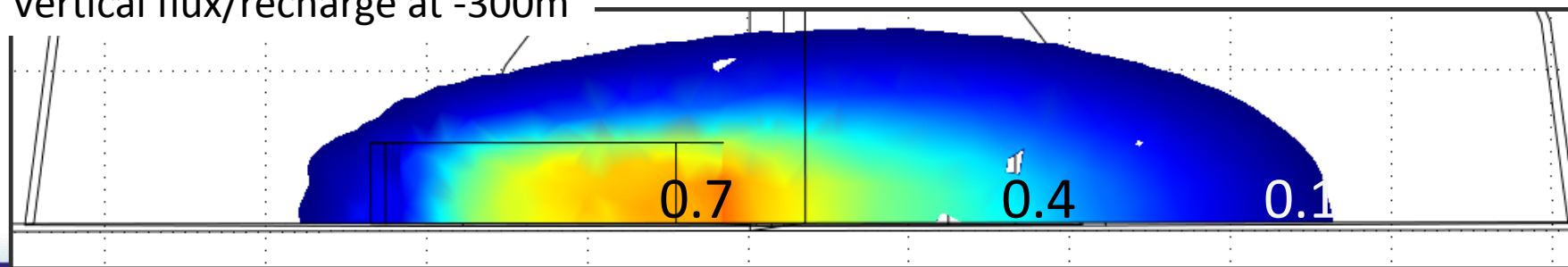


Side view

Pa
Points releas



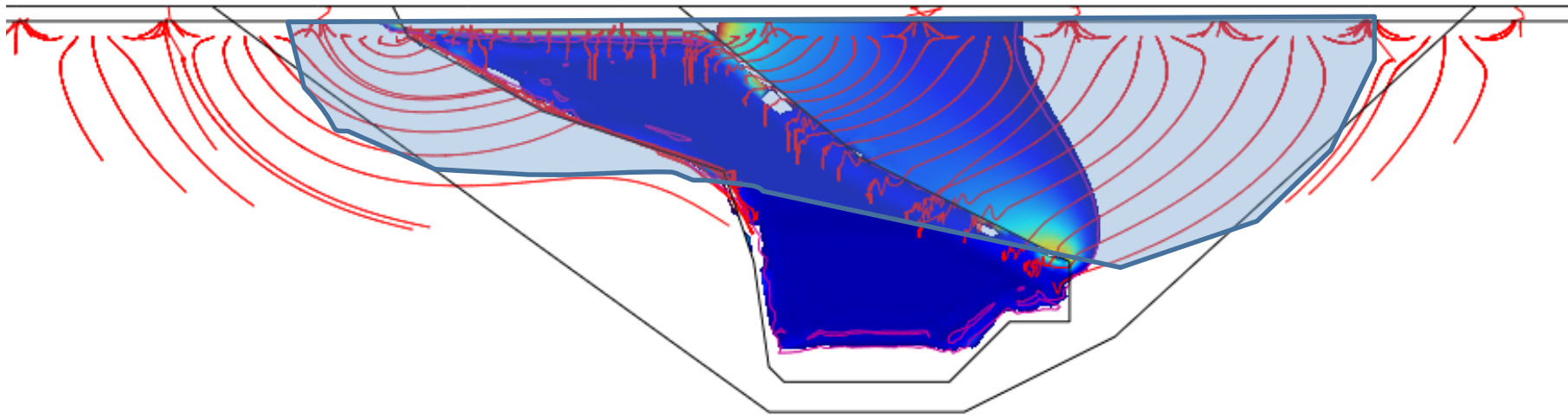
Vertical flux/recharge at -300m



Flow System

Pathlines and travel time

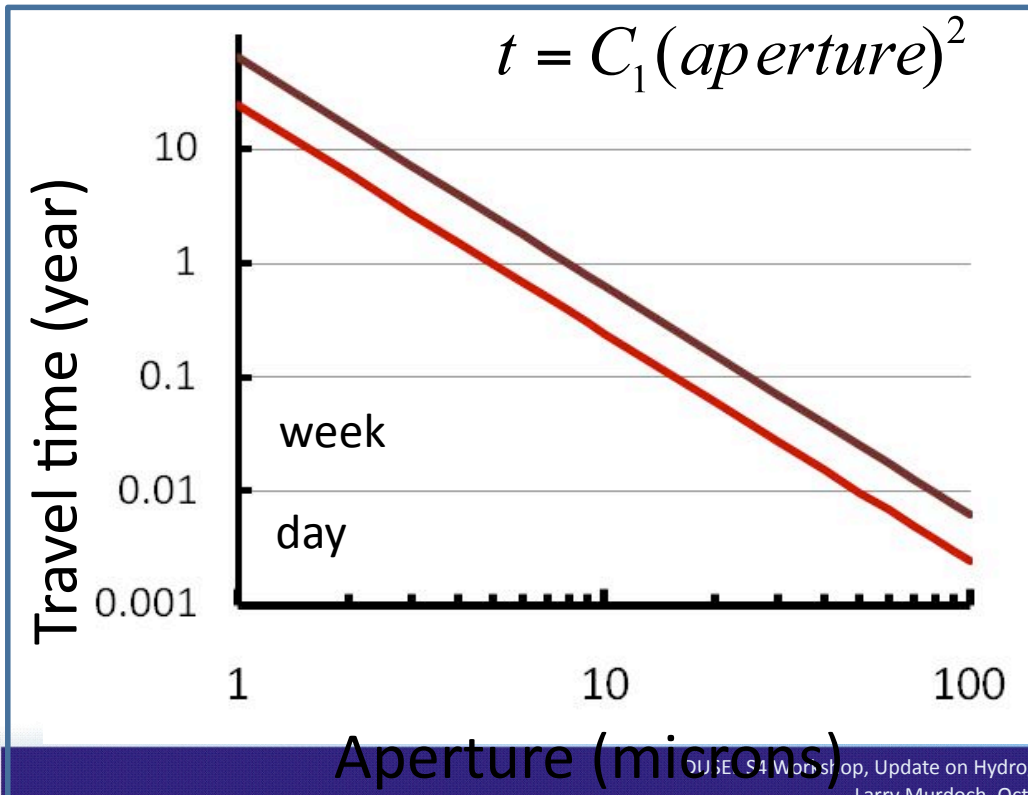
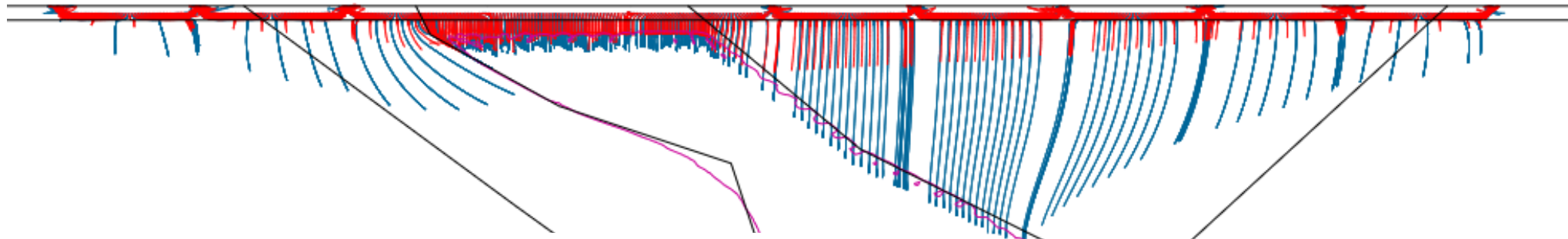
Points released at the start of mining, t=2009



Colored region, $dh/dz \approx 1$, Vertical Flux $\approx K$

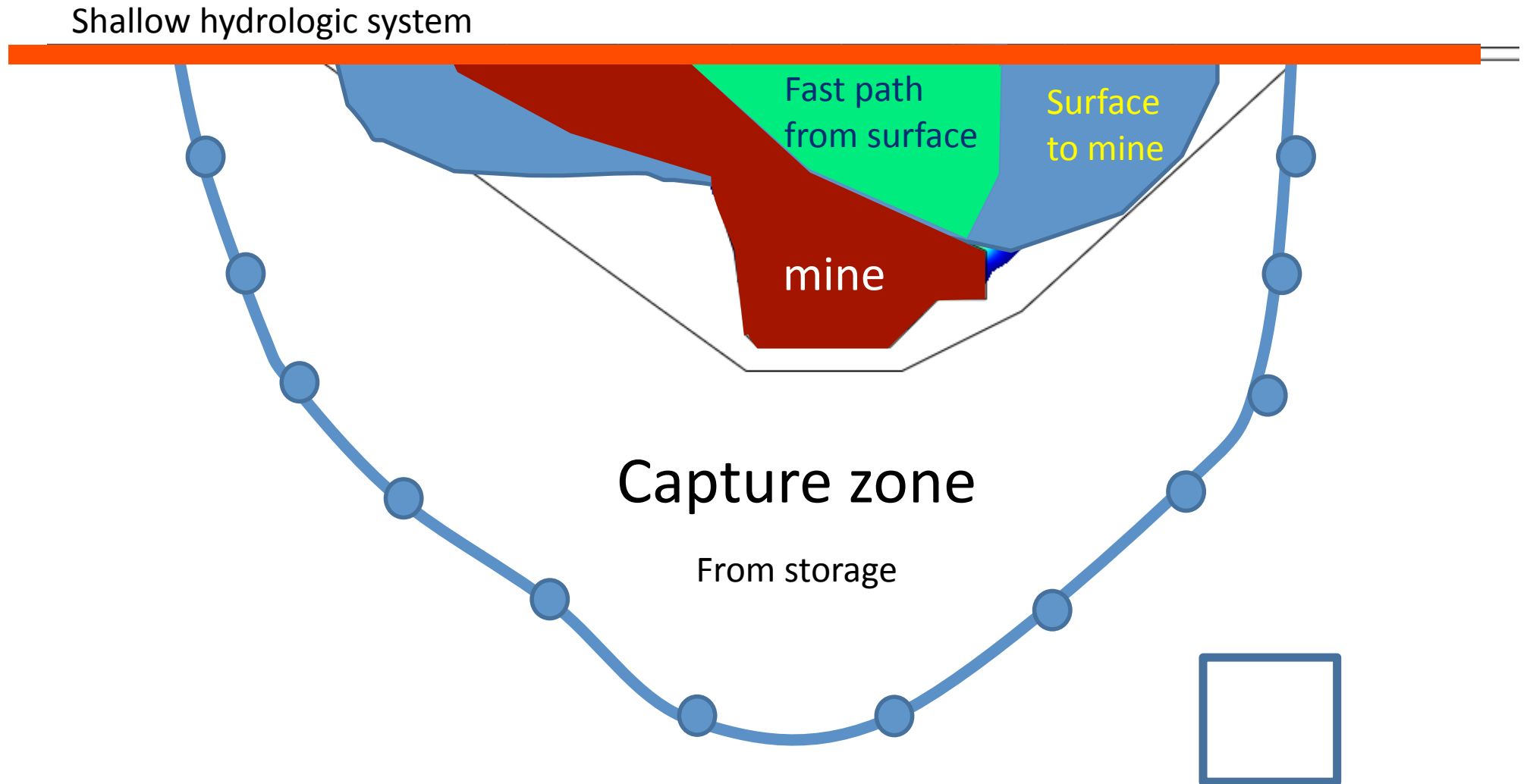
Travel Time from Surface

Red lines released 1 year ago, blue released 5 yrs ago
porosity $\sim 10^{-4}$

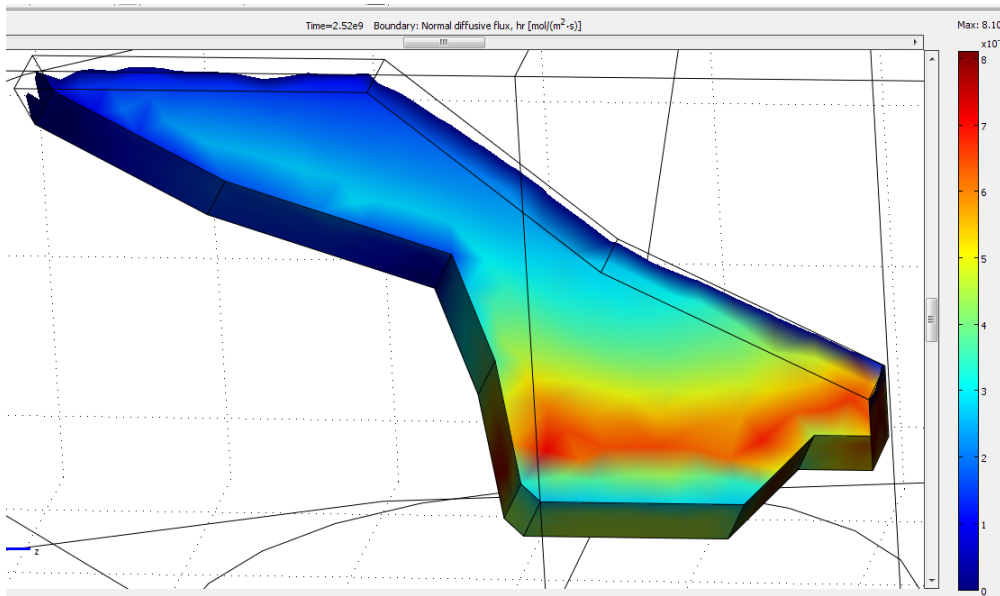


Pathlines

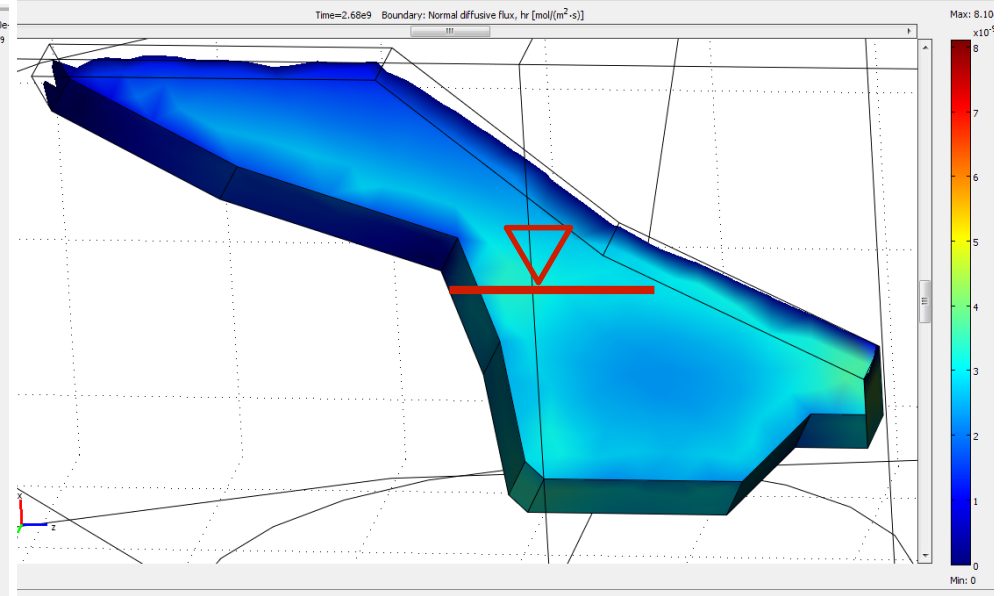
Particles released from storage at start of mining



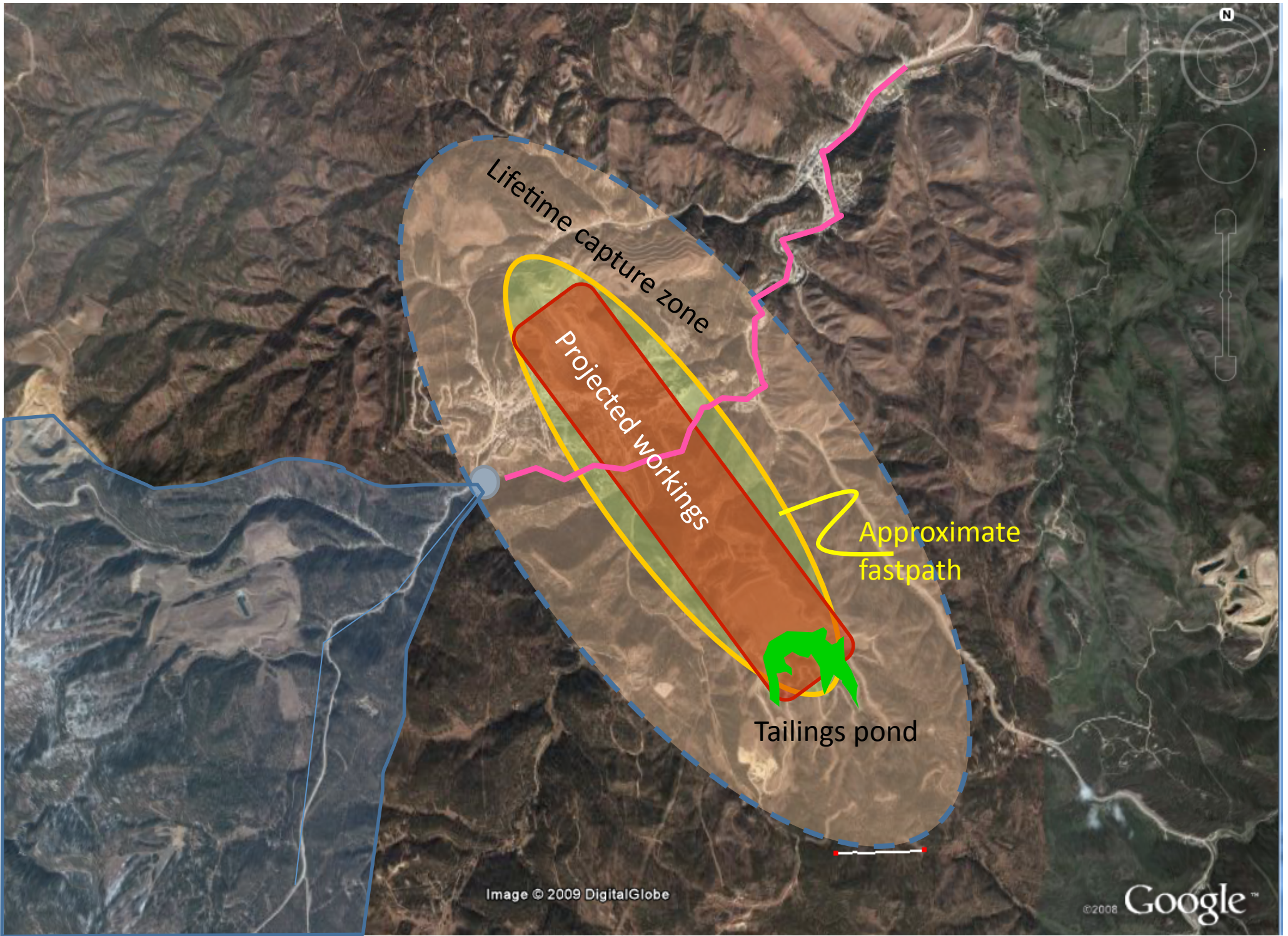
Inflow

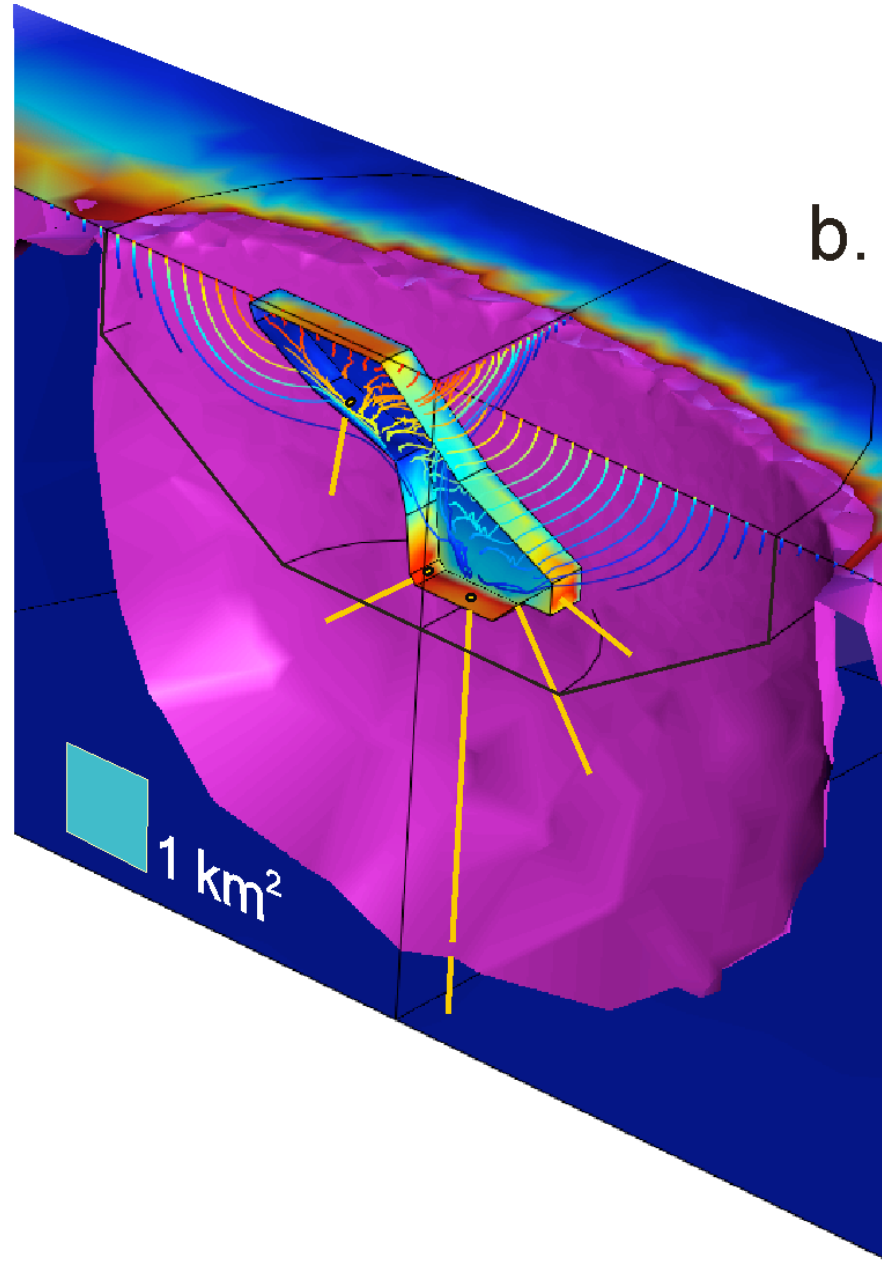


2001, End of mining



2008, max flooding

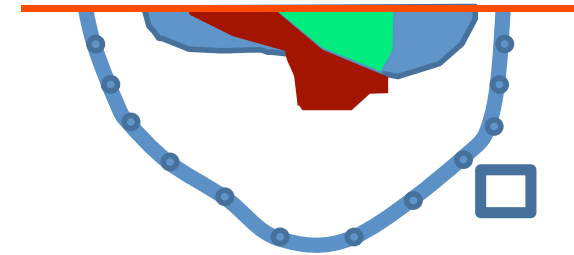




Conclusions

1. Flow system:

1. Shallow ambient system
2. Deep flow from storage
3. Deep flow from surface
4. Deep fast path from surface



2. Interaction with surface water

Max flux $\sim K$, Less than recharge rate

Surface hydro system remains intact, some drainage downward

Tailings pond in fastpath footprint \rightarrow potential for tracer test

3. Flooding/Dewatering

Probably limited contamination into enveloping rock

4. Deformation

$\sim 0.1\text{m}$ during flooding, max strain $\sim 10^{-4}$, ; strain rate $\sim 10^{-12} \text{ s}^{-1}$