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Can we use aquifers to monitor magma chambers?

Using COMSOL Multiphysics to investigate subsurface strain changes and their effect on hydrological systems

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MEDiterranean SUpersite Volcanoes MED-SUV

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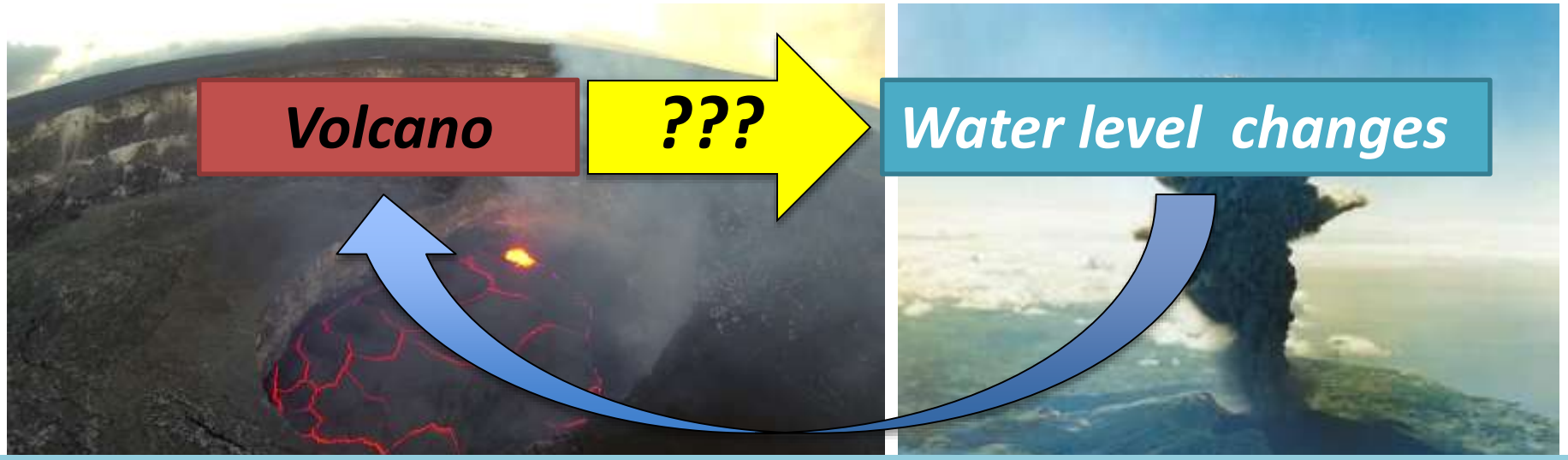
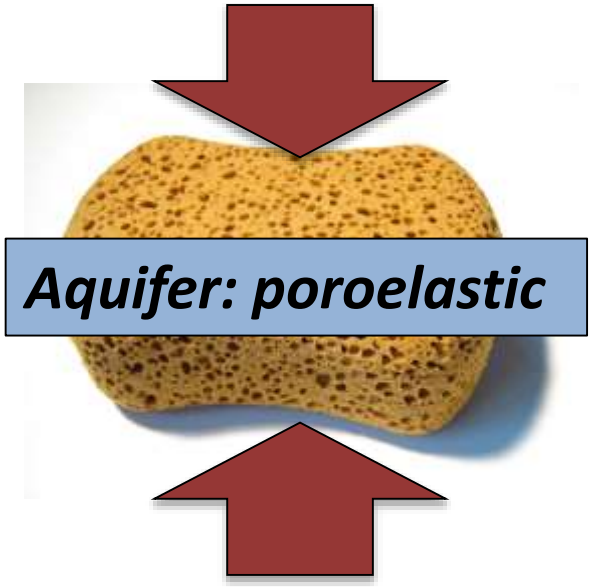
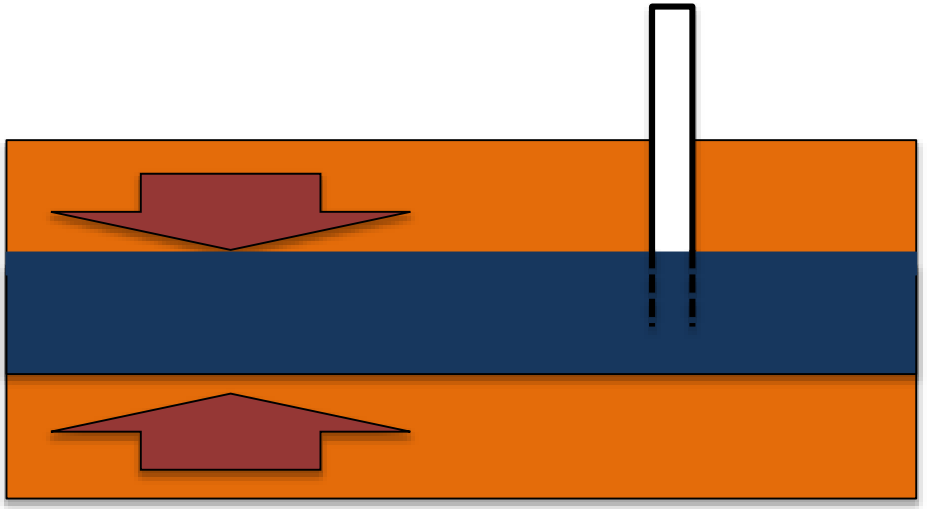
Water level changes – What do they tell us about volcanic processes?



In order to use water level changes to monitor volcanoes, we need to understand the processes that cause them

Pre-, co- and posteruptive hydraulic head changes: Caused by volcanic strain





- Compression → decrease in pore space → Pore pressure/hydraulic head/water level rise
- Volumetric strain caused by in- or deflating magma chambers, intruding dykes, excavating conduits,…

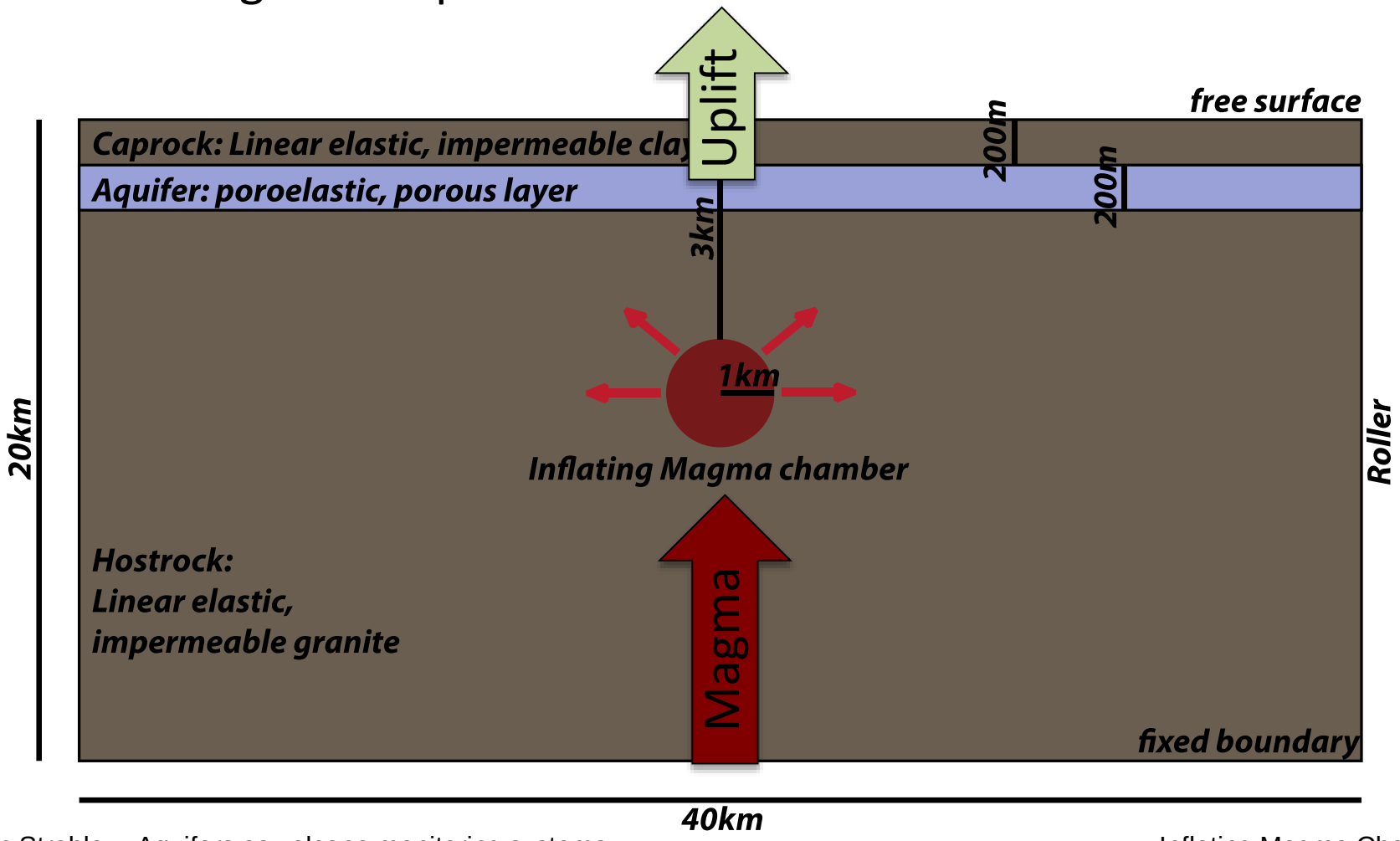
Pre-, co- and posteruptive hydraulic head changes: Caused by volcanic strain

- How exactly does an inflating magma chamber or an intruding dyke affect the local hydrology, and what are observed signals (well monitoring, gravity, ground deformation)?

Using the Poroelasticity Module provided by COMSOL to solve the equations that couple Hydrology and Solid Mechanics

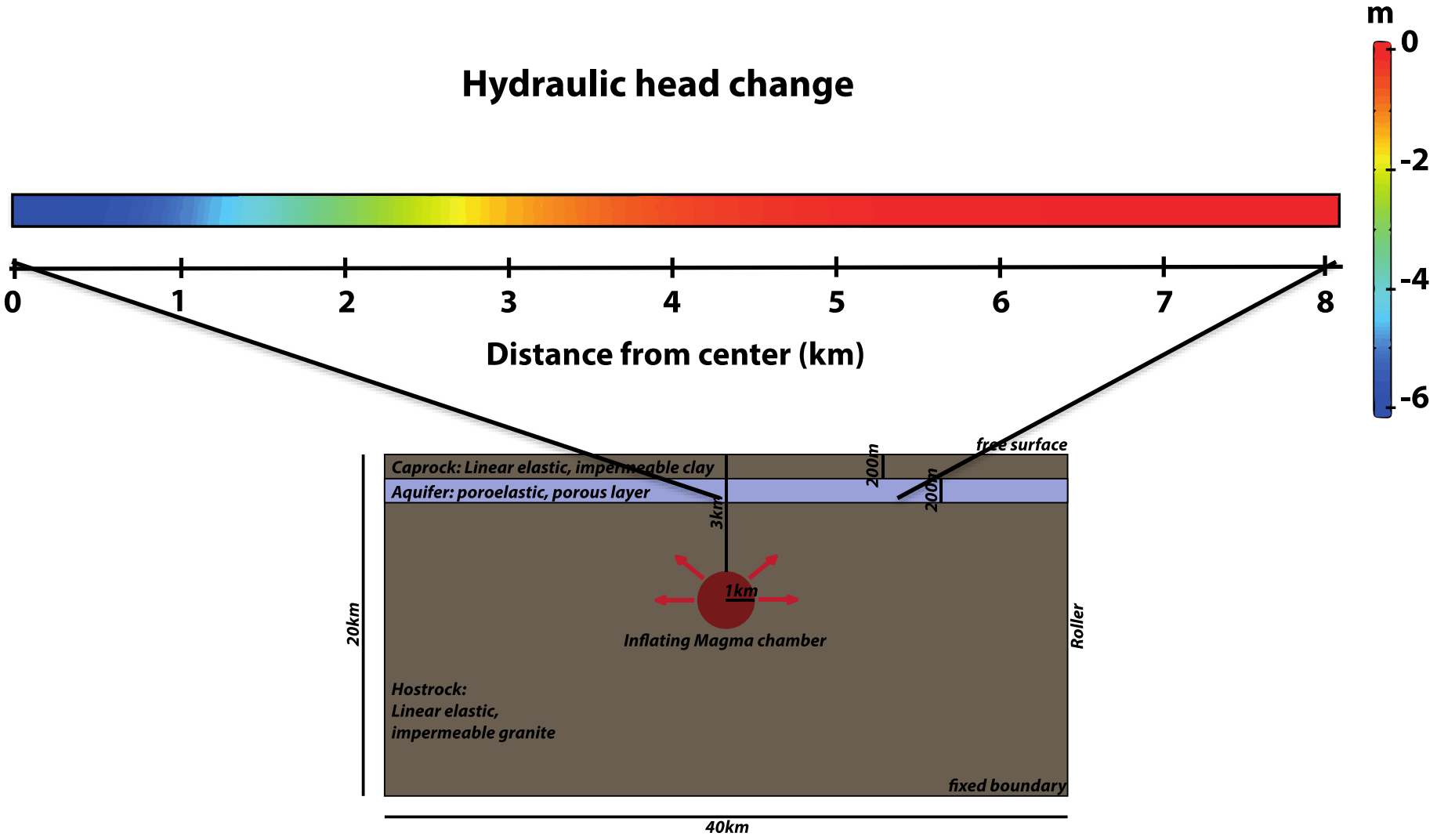
Inflating Magma Chambers: Model Set up

- Often precedes eruptions → important for monitoring
- Causes ground uplift → **dilatational strain** above the chamber



Inflating Magma Chambers: Hydraulic head change

- dilatational strain above the chamber → water level falls



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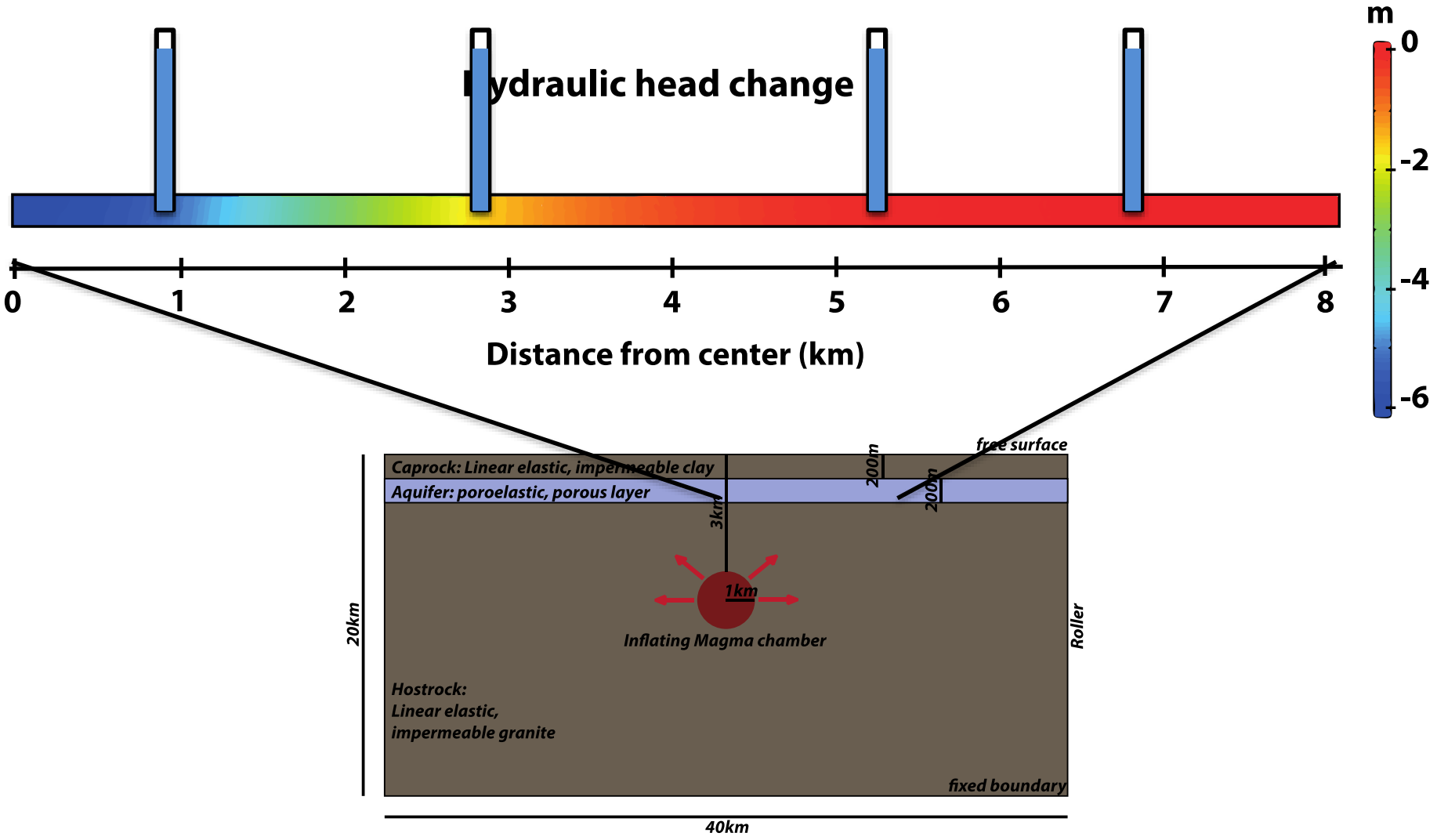

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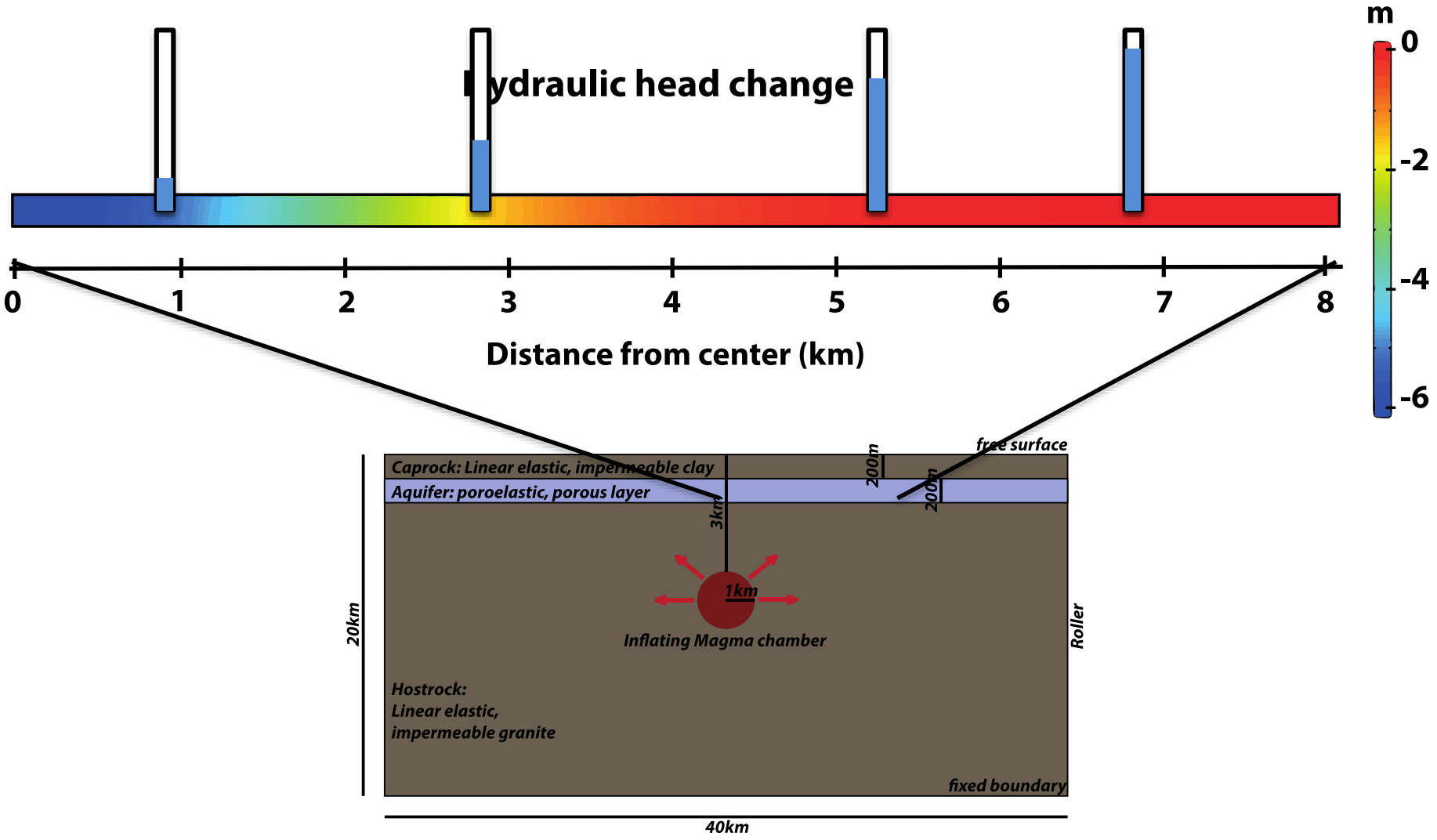
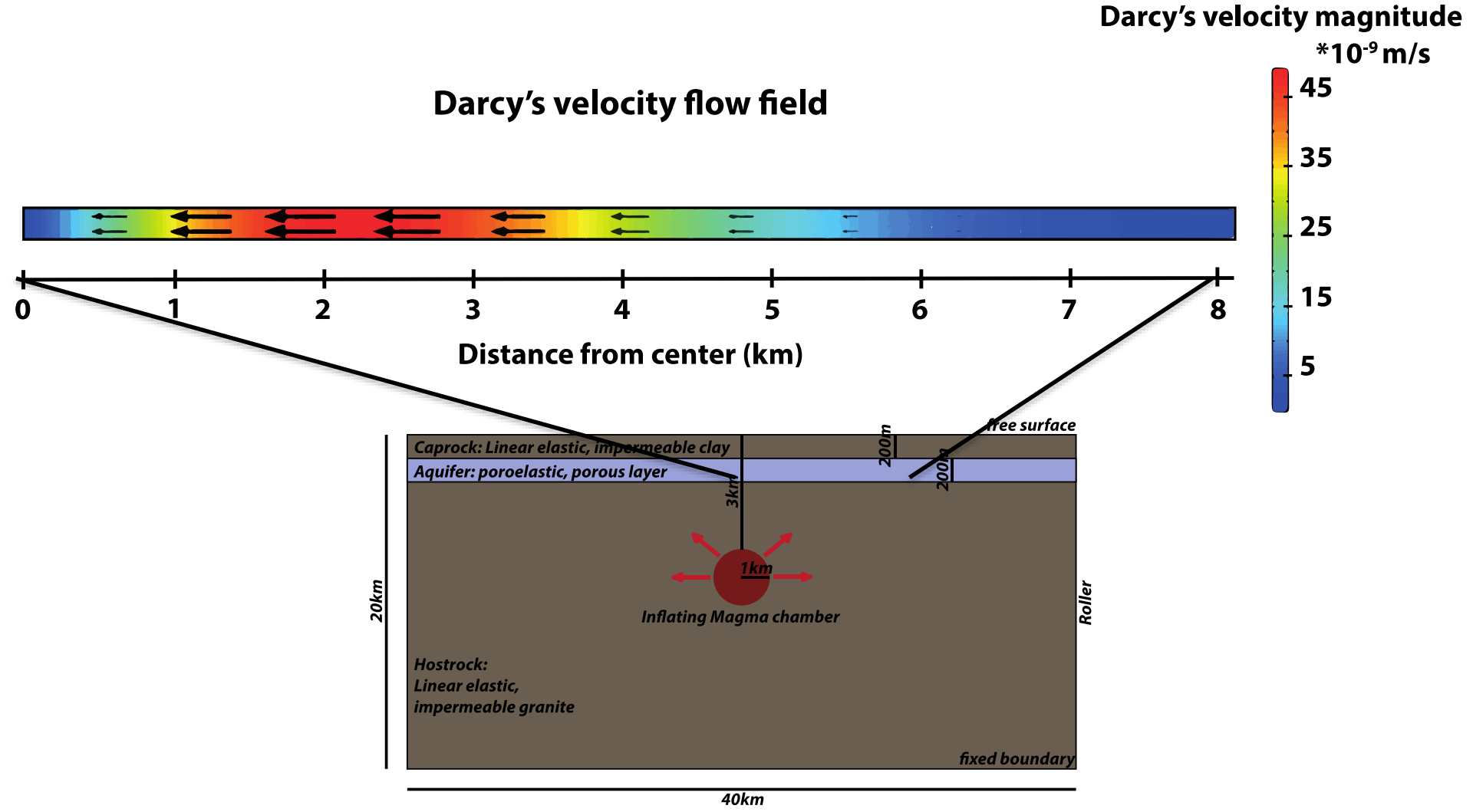
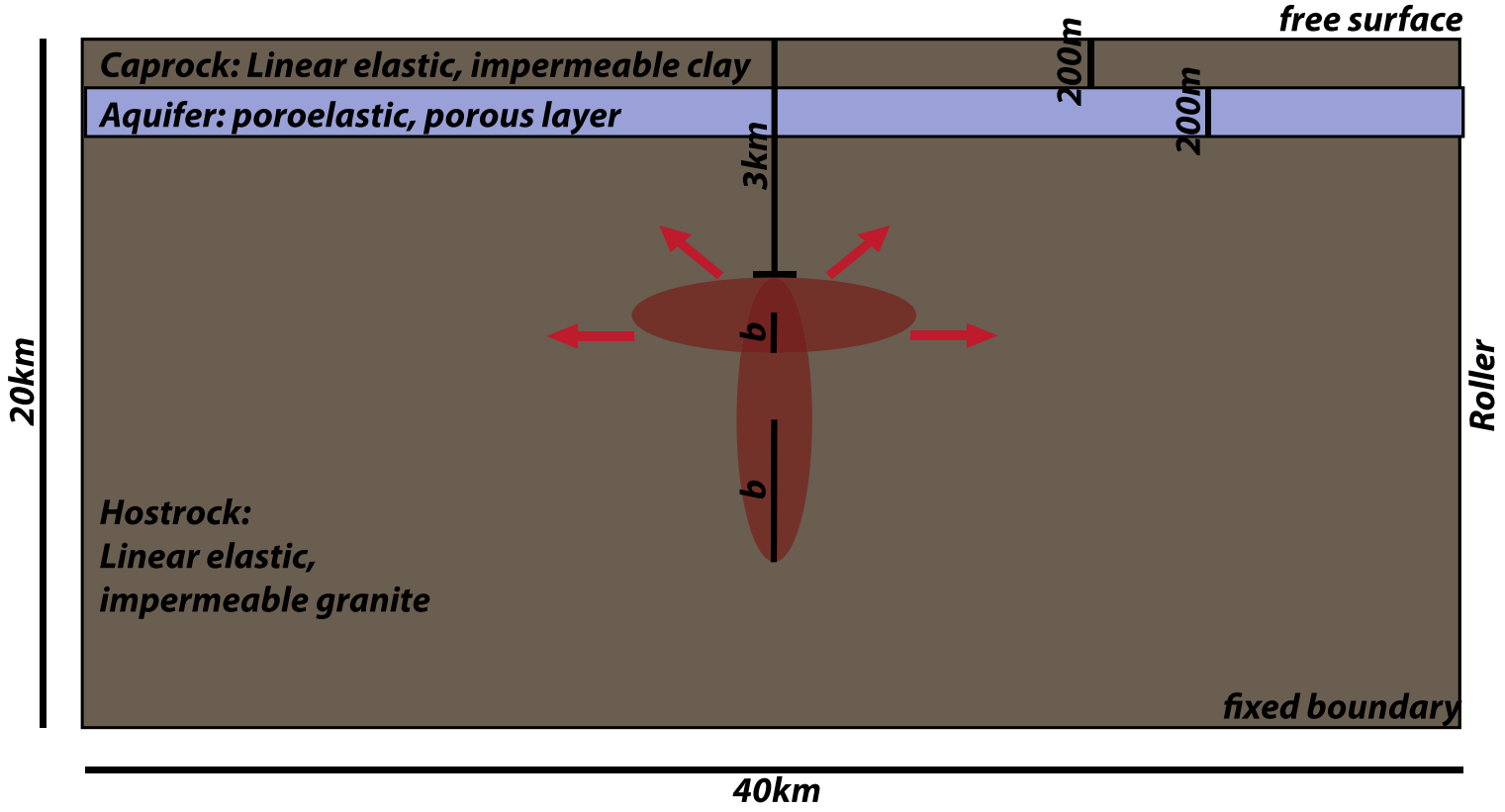


Inflating Magma Chambers: Induced groundwater flow

- water level fall → groundwater flow



Parametric studies – Influence of the source shape



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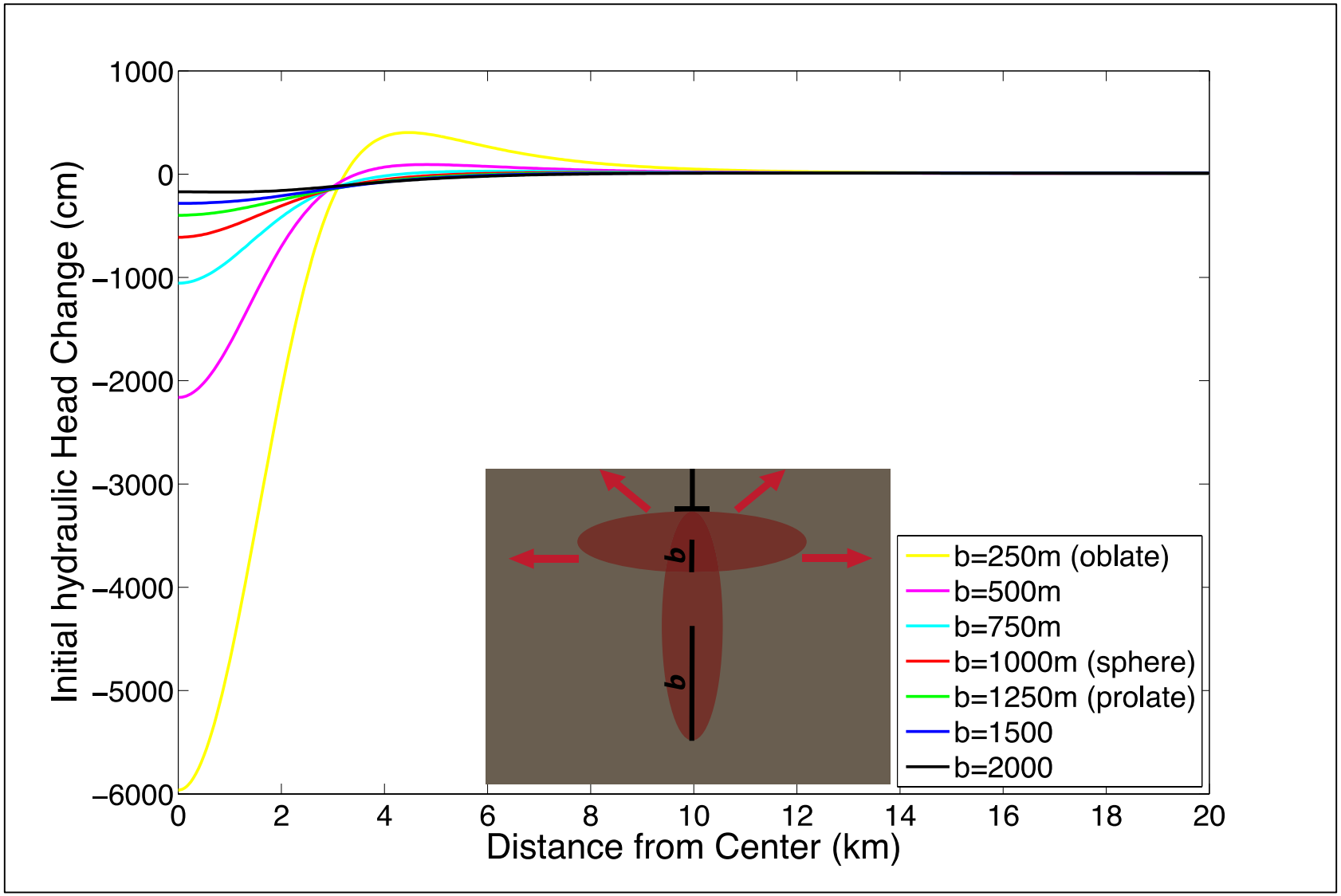
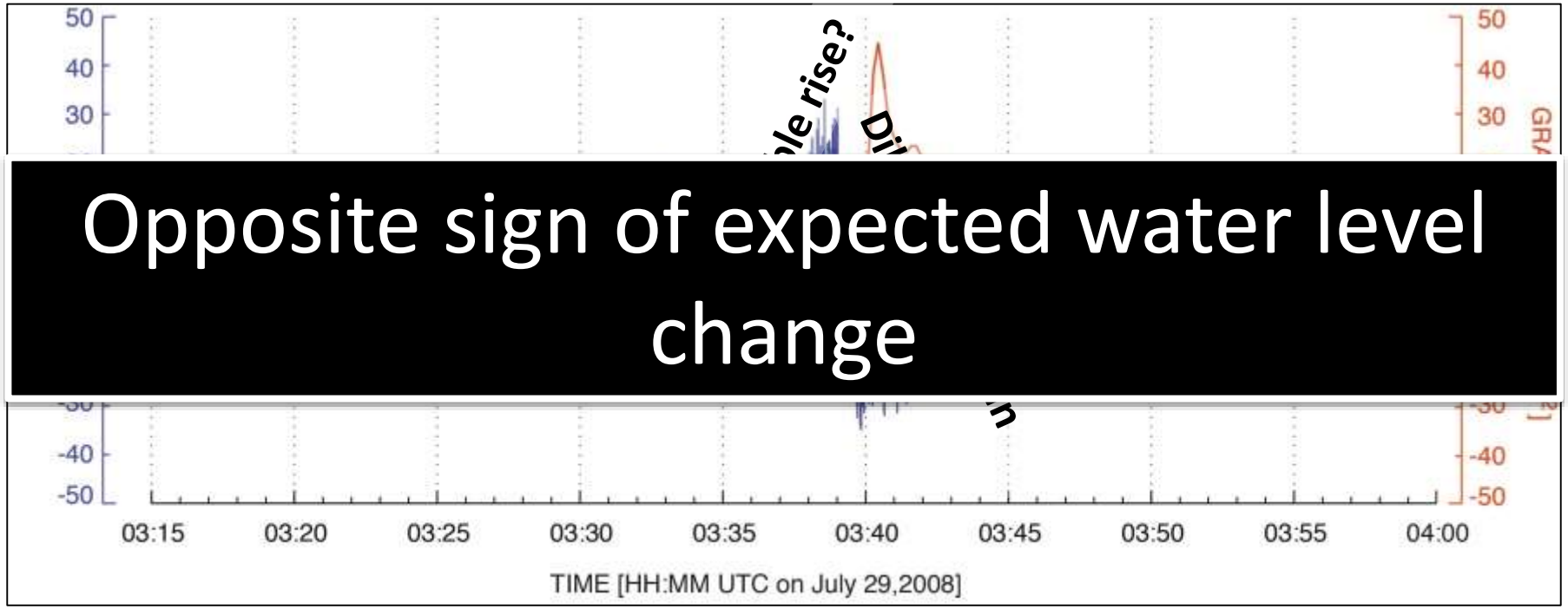


Real Case Application – Vulcanian Eruption at Soufrière Hills Volcano

- July 29, 2008: Explosive eruption at Soufrière Hills Volcano, Montserrat, West Indies
- Emptying the conduit causes **dilatational strain** in the surrounding

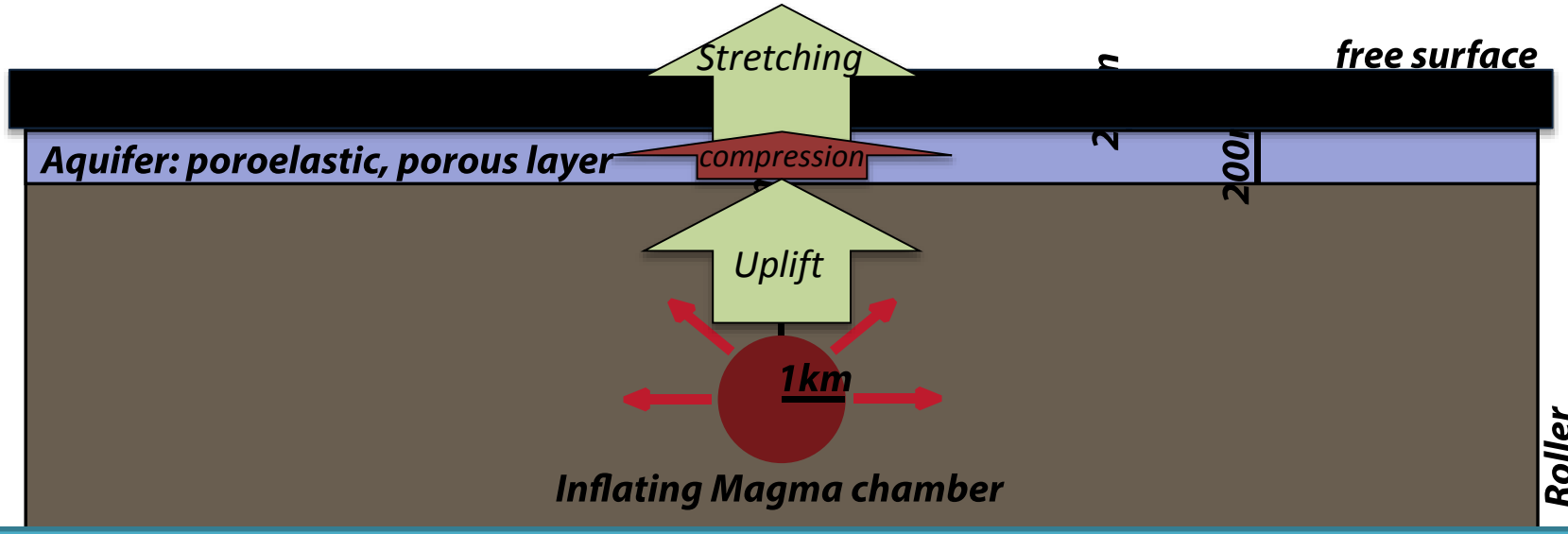
Application – Vulcanian Eruption at Soufrière Hills Volcano

- BUT: Accompanying the dilatational strain signal, we observed an increase in gravity – this can only be explained by a movement of mass TOWARDS the gravimeter, so a water table RISE



Opposite sign of expected water level change

Application – Vulcanian Eruption at Soufrière Hills Volcano

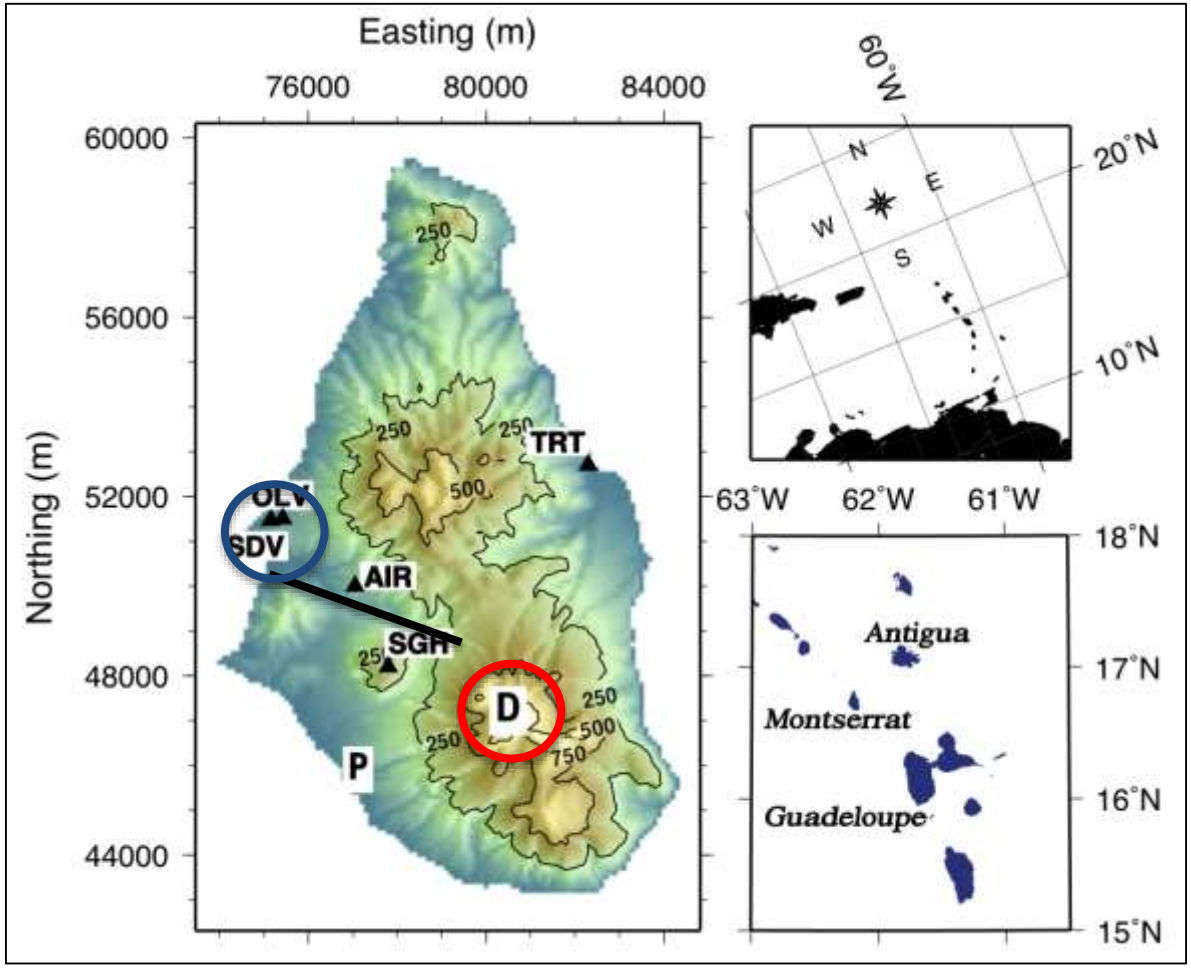


"Normal": Dilatation and water level fall

BUT: If the top layer is very stiff, the aquifer gets compressed

- **Opposite** strain and **opposite** water level signal!
- Depending on the geology, the signal switched sign

Application – Vulcanian Eruption at Soufrière Hills Volcano



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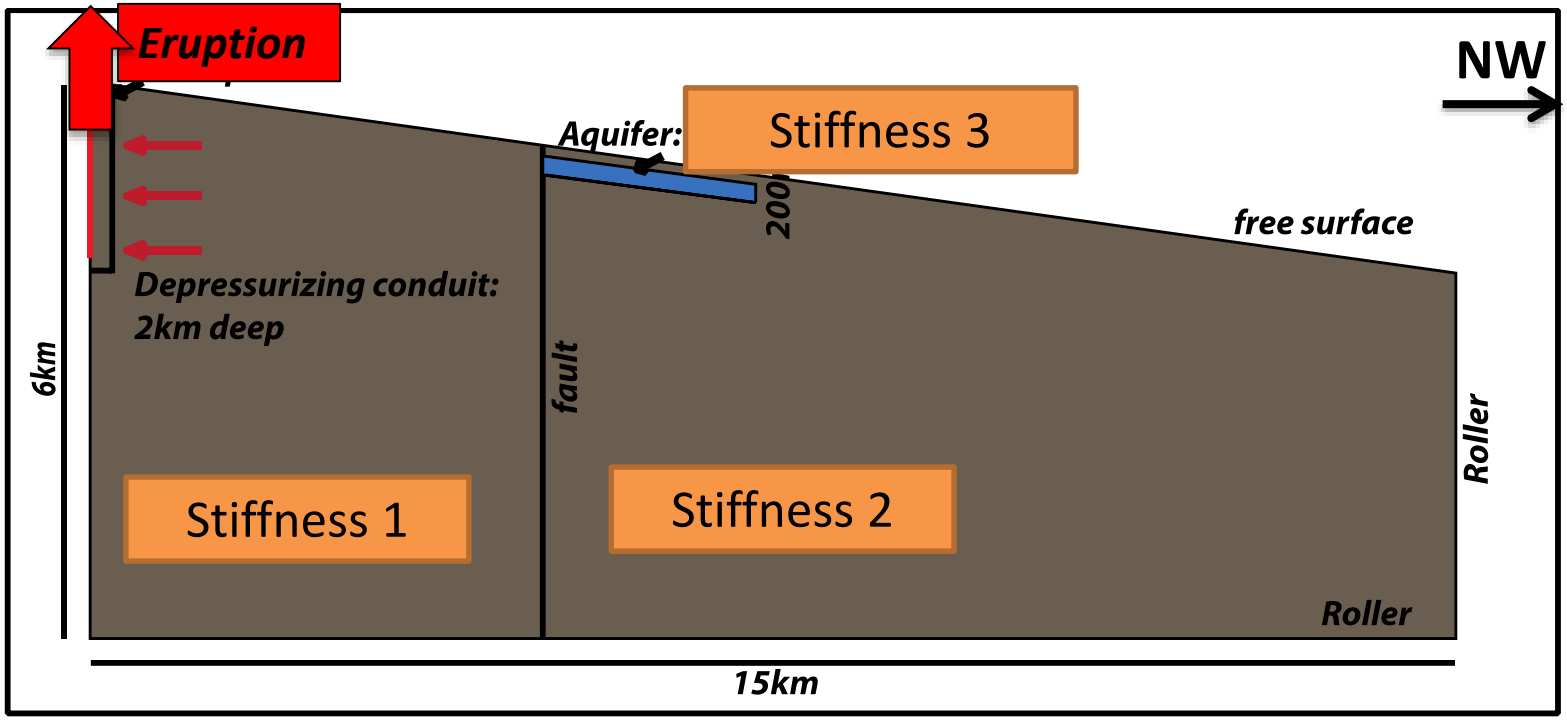

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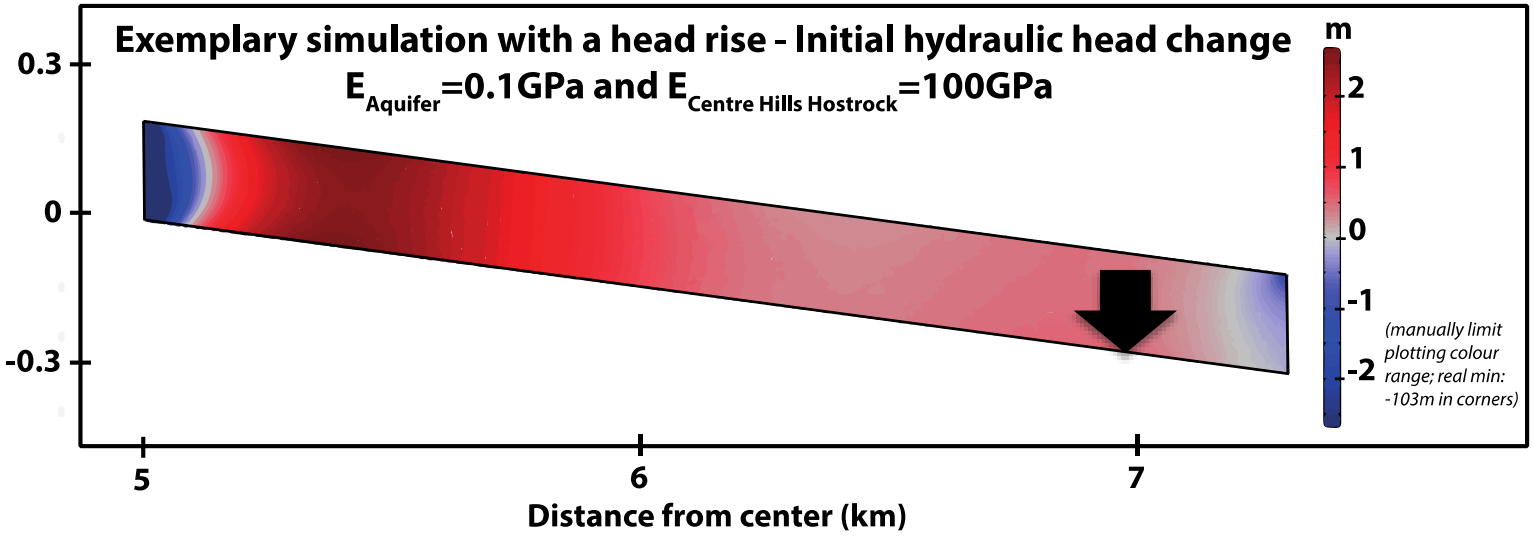

→ Water table at Gravimeter location: 40cm rise

Conclusions

- Pressurizing and depressurizing magmatic sources cause poroelastic responses in aquifers, consisting of measurable hydraulic head changes and groundwater flow, which in turn can influence geophysical signals

- Volcano observatories could use these changes to monitor volcanic processes

- Hydraulic head changes are determined by a variety of parameters, including rock properties, source strength and shape and subsurface geometry

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Thanks for listening!

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Picture references:
Gottsmann et al. (2011): On the geophysical fingerprint of Vulcanian explosions. EPSL, 306(1), 98-104
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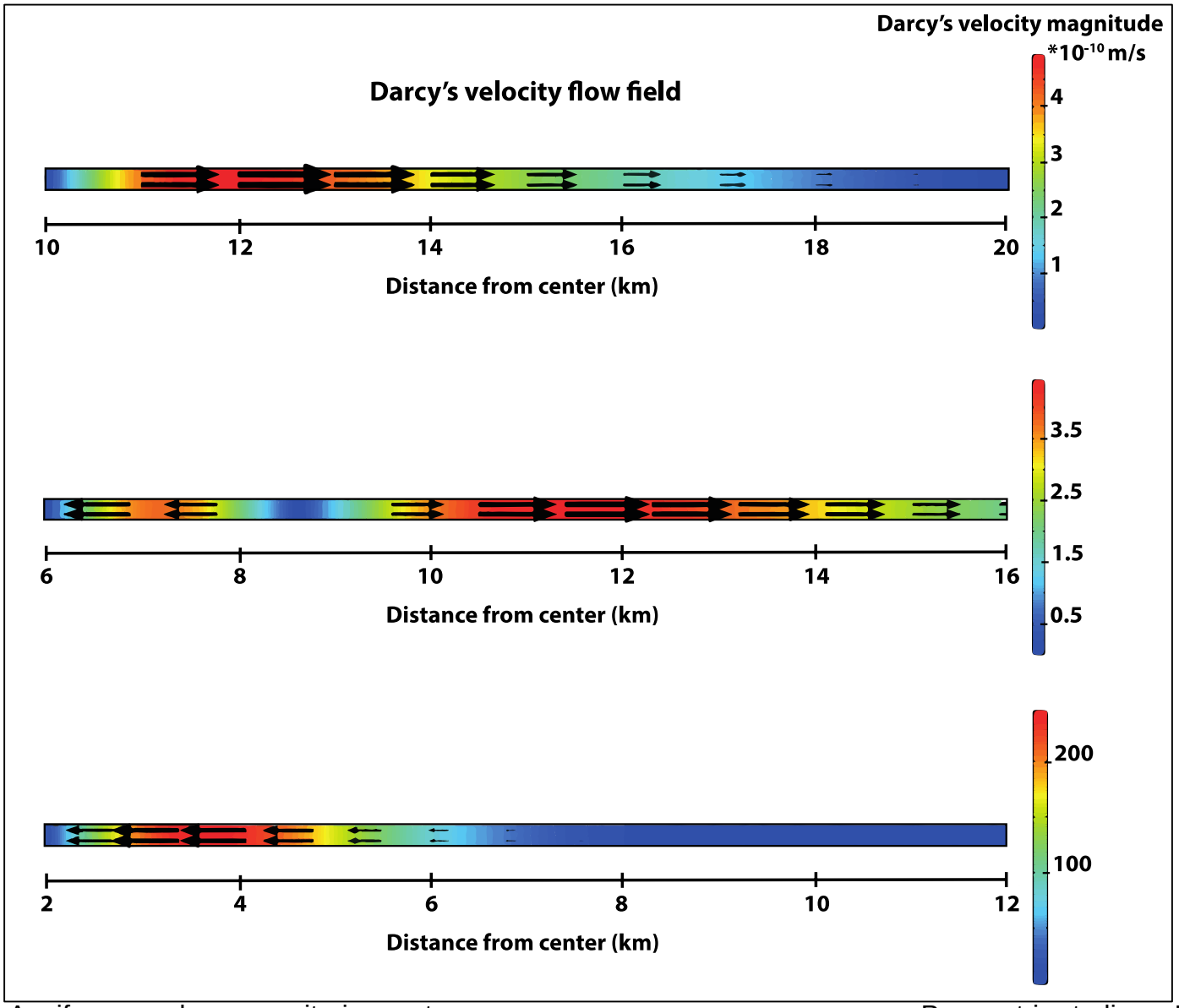
Parametric studies – Distance aquifer-magma chamber



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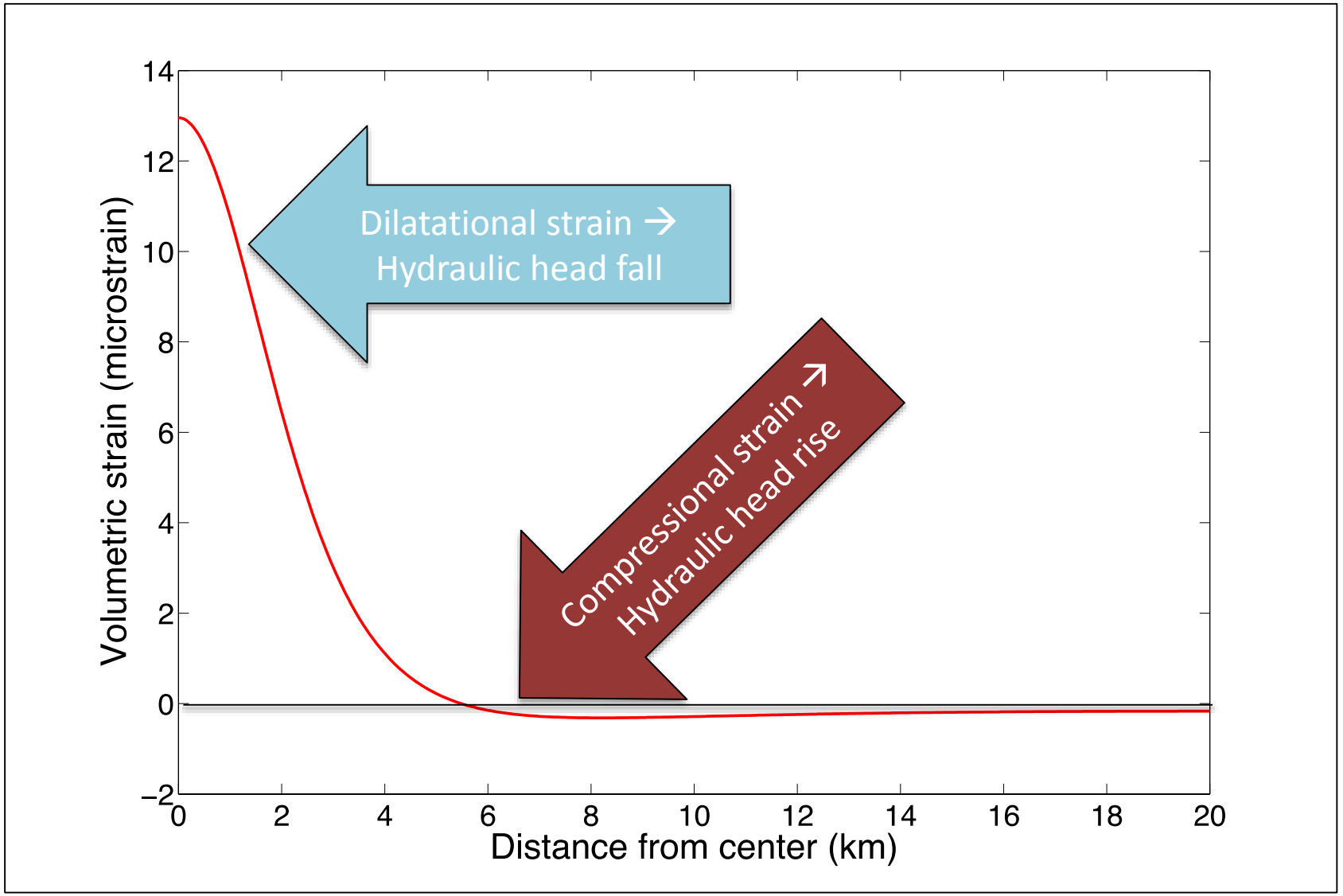
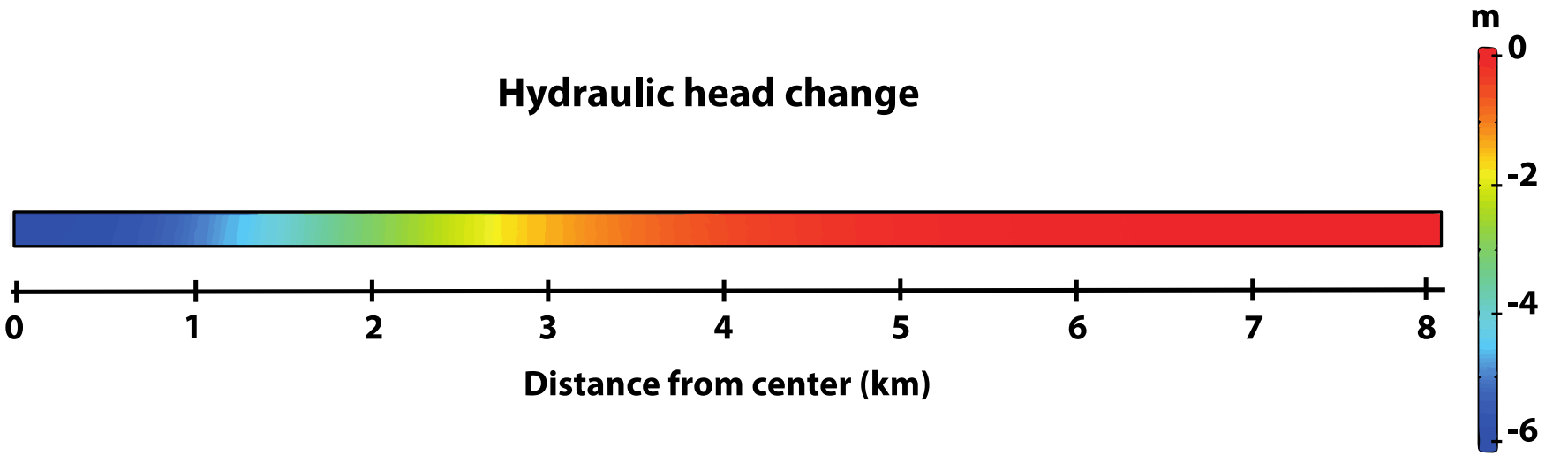
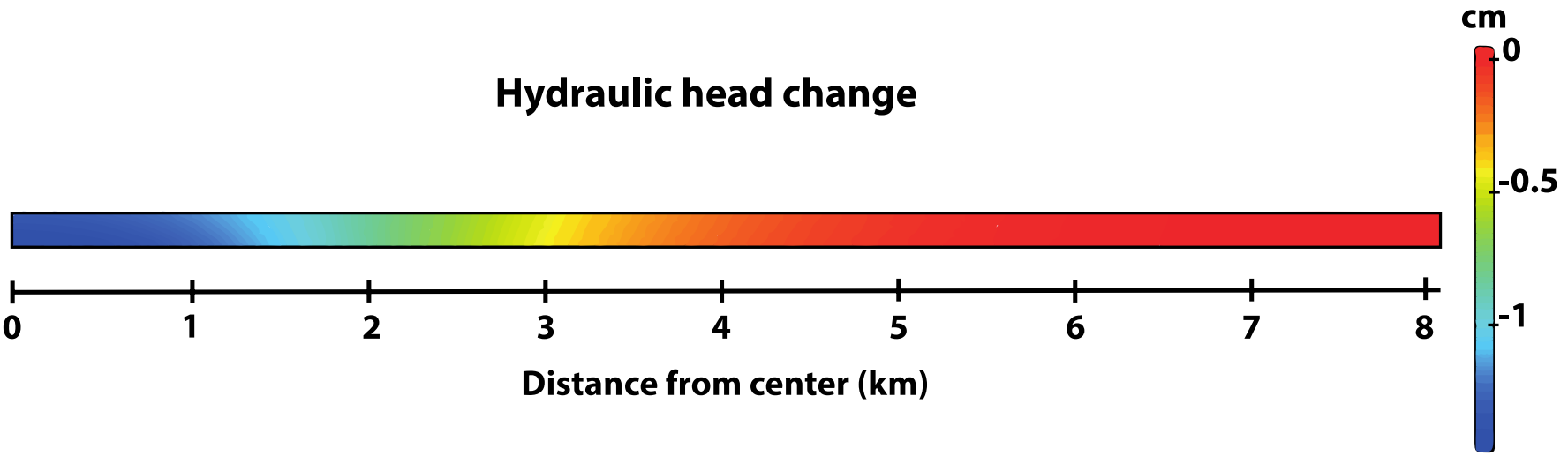


Parametric studies – Aquifer stiffness: Young's Modulus





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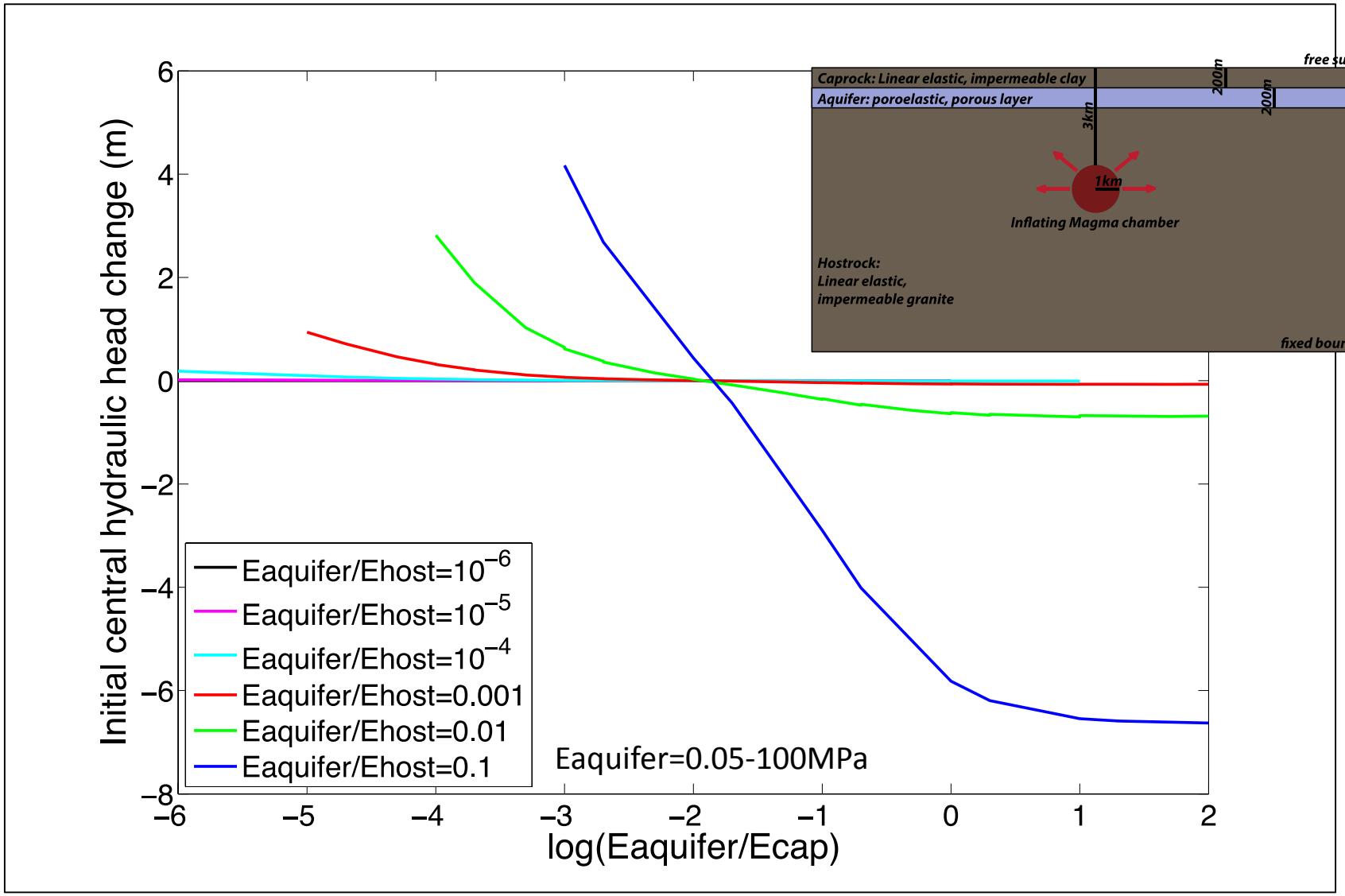

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