Universität Hamburg
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ERC Starting Grant
Project POMPEI

Dynamics of dike propagation and patterns of dike-induced seismicity

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Introduction

Stress transfer may generate, anticipate or delay earthquakes on faults.

- Earthquakes that would have 'never' occurred by means of tectonic forces alone, are generally called 'induced'

- 'Anticipated' earthquakes are generally called 'triggered'

- Stress shadows

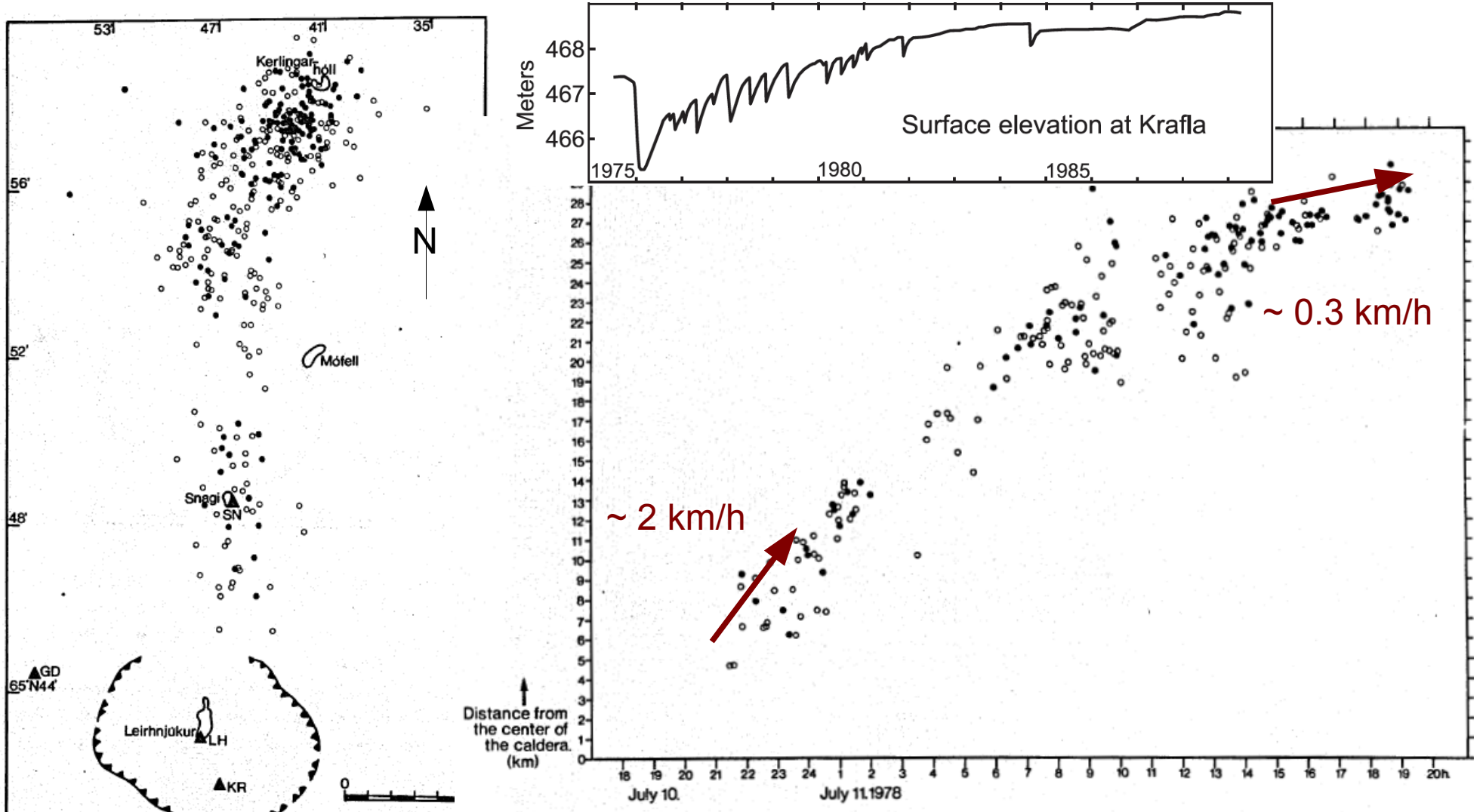
Outline

1) Pattern of seismicity induced by propagating dikes

2) Pattern of seismicity in the shadow of large diking events

3) Earthquakes triggered by dike-induced stresses

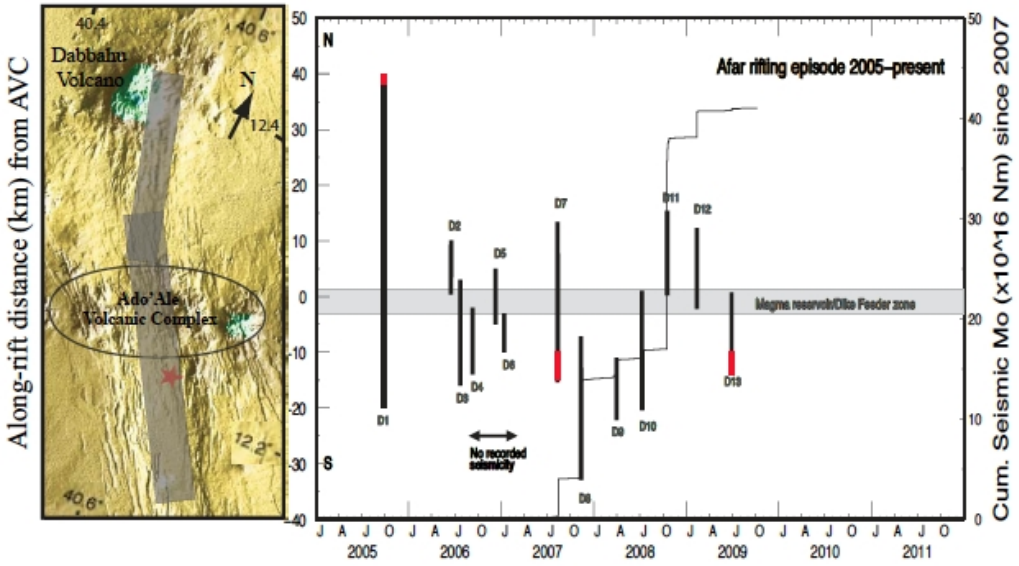
1) The pattern of seismicity induced by propagating dikes

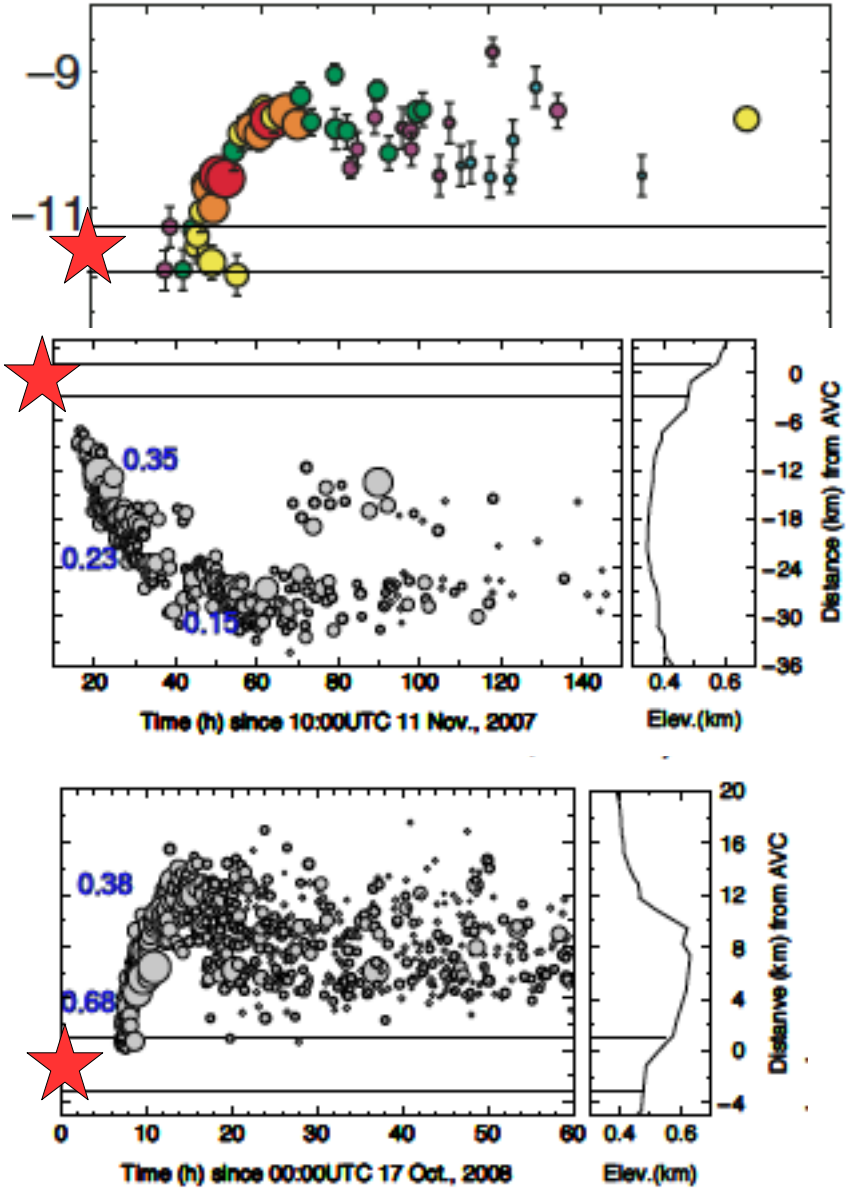


Migration of epicentres away from Krafla's caldera
From Einarsson and Brandsdottir, 1978

The pattern of seismicity induced by propagating dikes

Keir et al. 2009





Belachew et al., 2011

Physical modelling

Dike coupled to the magma chamber
(total mass is constant, Rivalta and Segall, GRL, 2008)

$$dM = \rho\, dV + V\, d\rho = \left(\rho \frac{dV}{dp} + V \frac{d\rho}{dp}\right) dp = \rho V \left(\beta_e + \beta_m\right) dp$$

$$\beta_m = 10^{-11} - 10^{-10}\, Pa^{-1}$$

(or much higher
if magma contains bubbles)

$$r_V = \frac{V^i}{\Delta V^c} = 1 + \frac{\beta_m}{\beta_c}$$

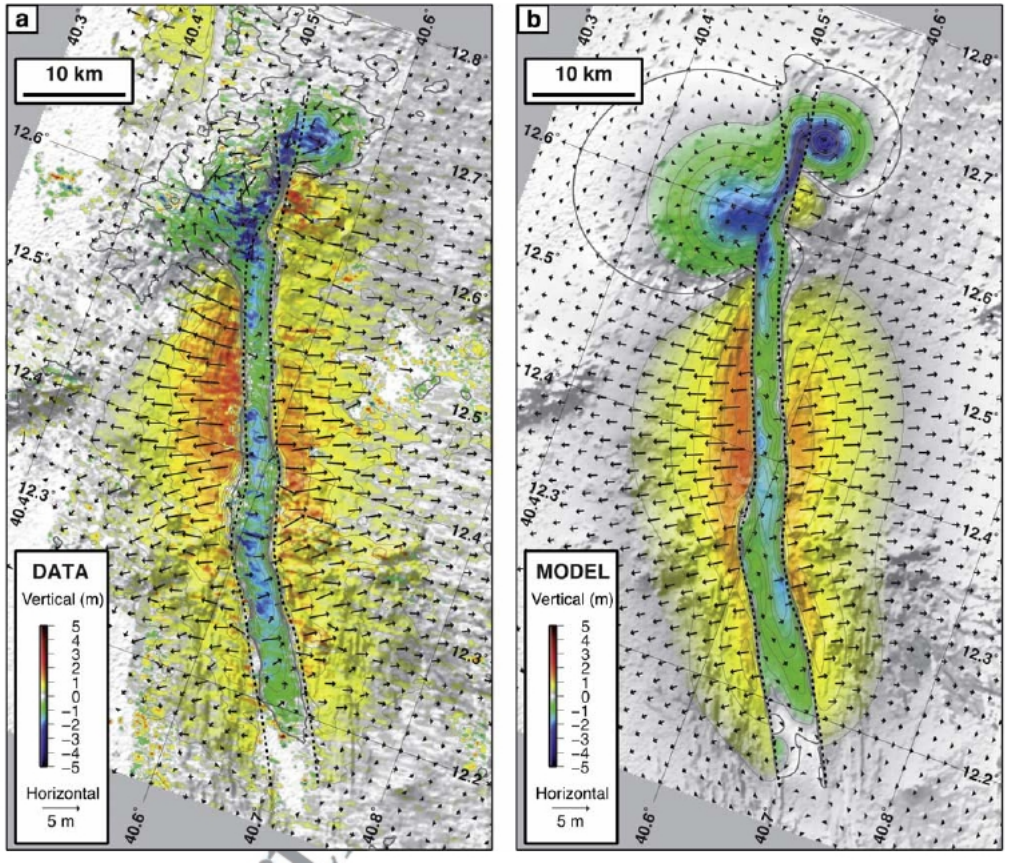
$$\beta_e(\textit{spherical chamber}) = \frac{3}{4\mu} \sim 10^{-11} - 10^{-10}\, Pa^{-1}$$

$$\beta_e(\textit{cigar} - \textit{shaped chamber}) = \frac{1}{\mu}$$

$$\beta_e(\textit{penny shaped crack}) = \frac{1}{p^i - \sigma} \sim 10^{-7}\, Pa^{-1}$$

$\beta_e(\textit{ellipsoid})$ depends on the aspect ratio
(Amoruso and Crescentini, 2009)

Physical modelling



Observed and modelled ground deformation
Sept. 2005 dike intrusion in Afar
From Grandin et al., 2009

ΔV Chambers: - 0.42 km^3
- 0.12 km^3

ΔV Dike: +1.5 km^3

ΔV_Dike / ΔV_Chamber =
r_V = 2.8

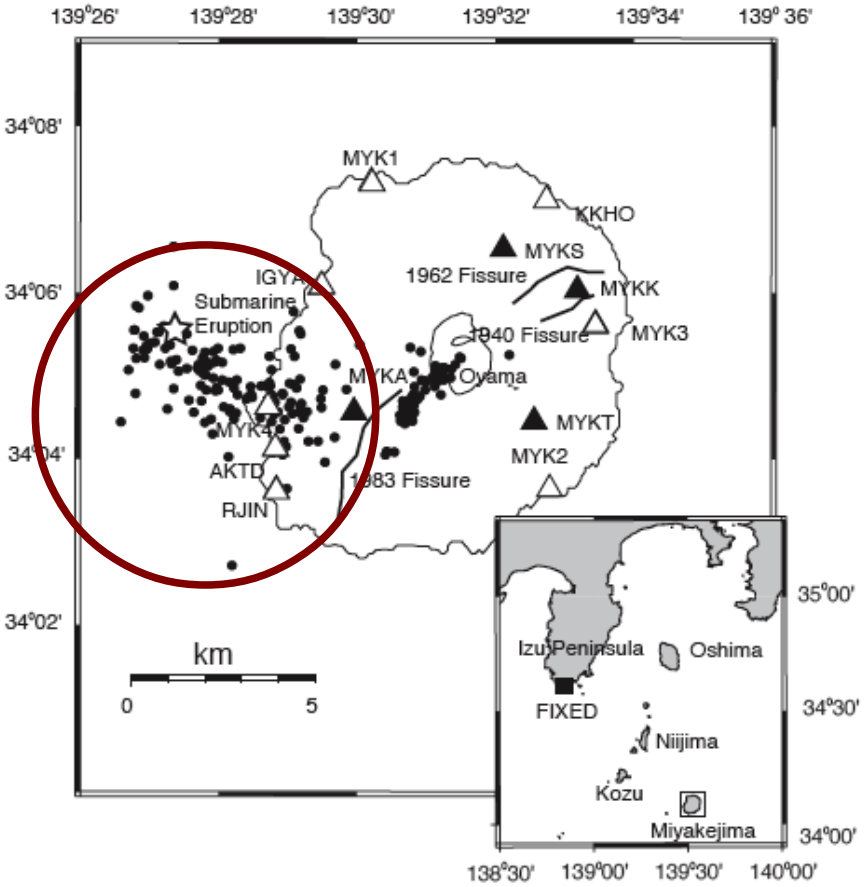
Model B)

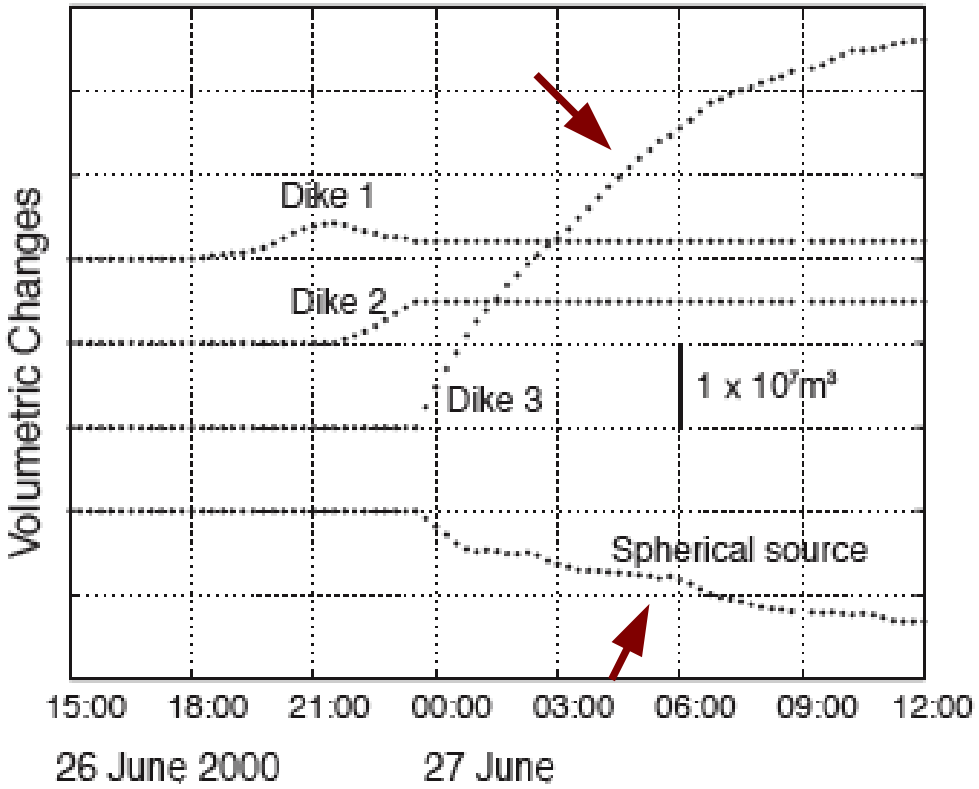
ΔV Chambers: - 0.42 km^3
- 0.12 km^3
- 0.37 km^3

ΔV Dike: +2.0 km^3

r_V = 2.2

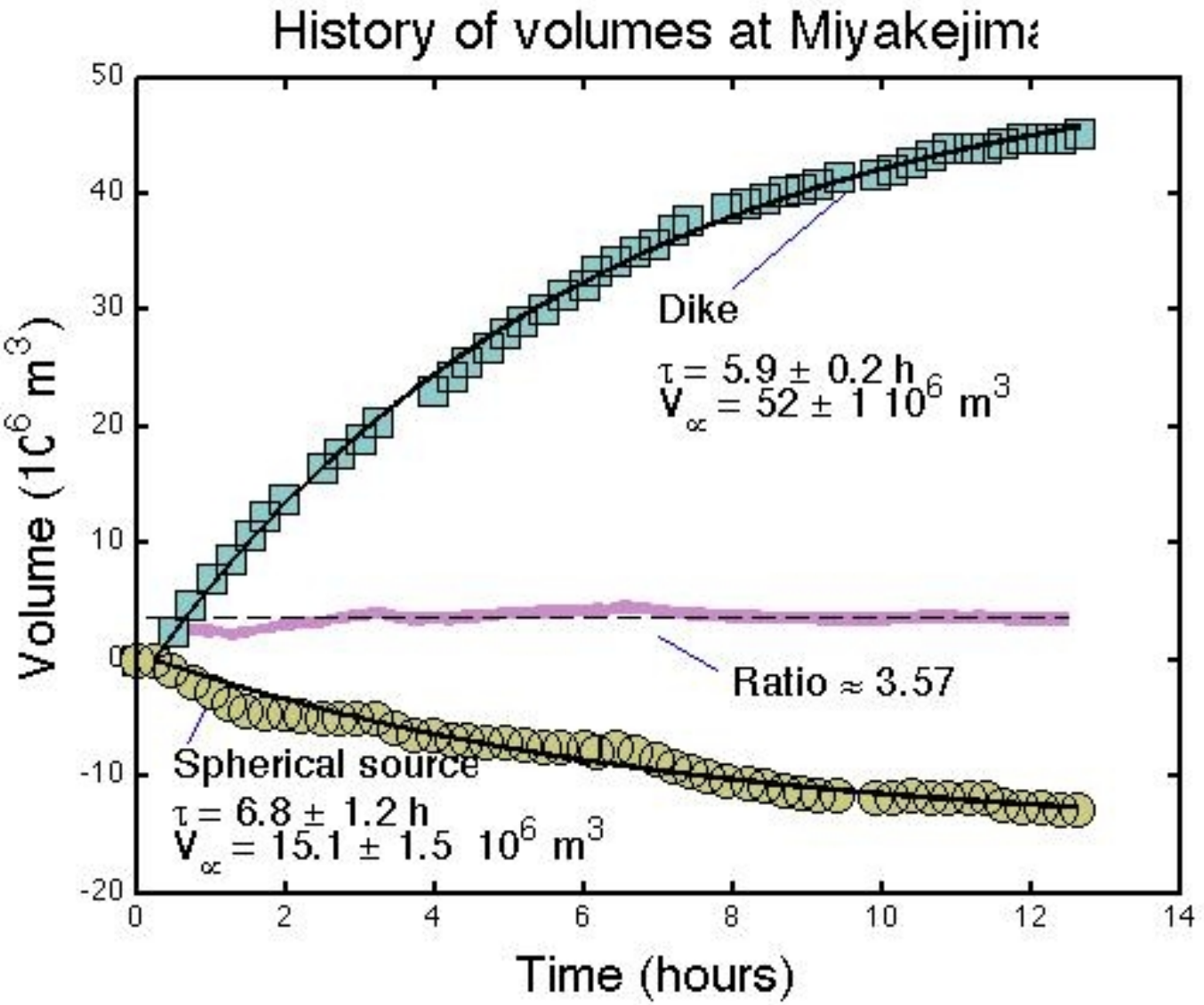
Physical modelling





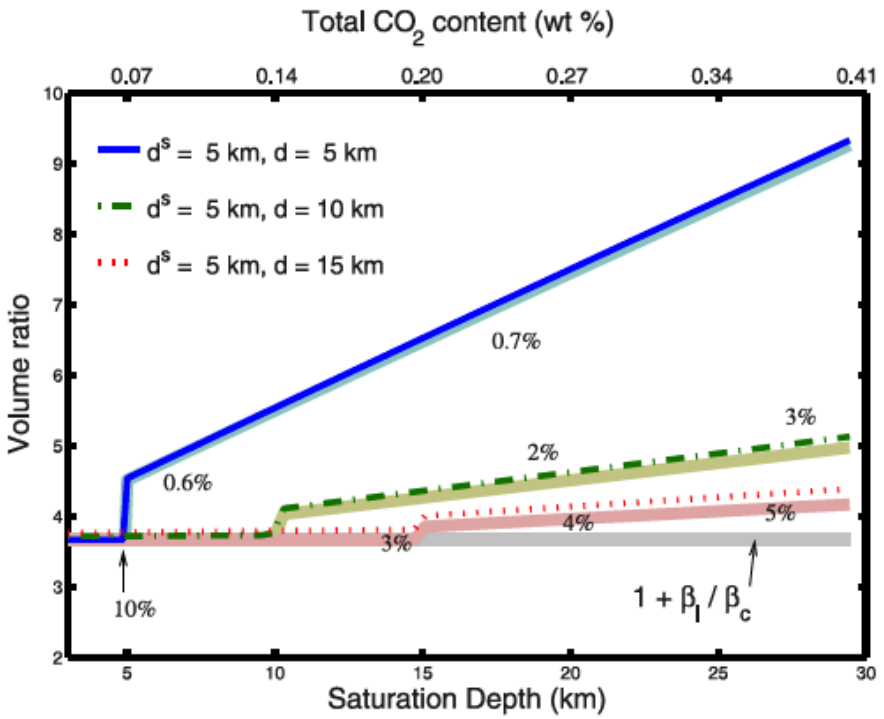
Seismicity and volumetric changes during the initial phase
of the 2000 dike propagation at Miyakejima
From Irwan et al., 2006

MODELLING



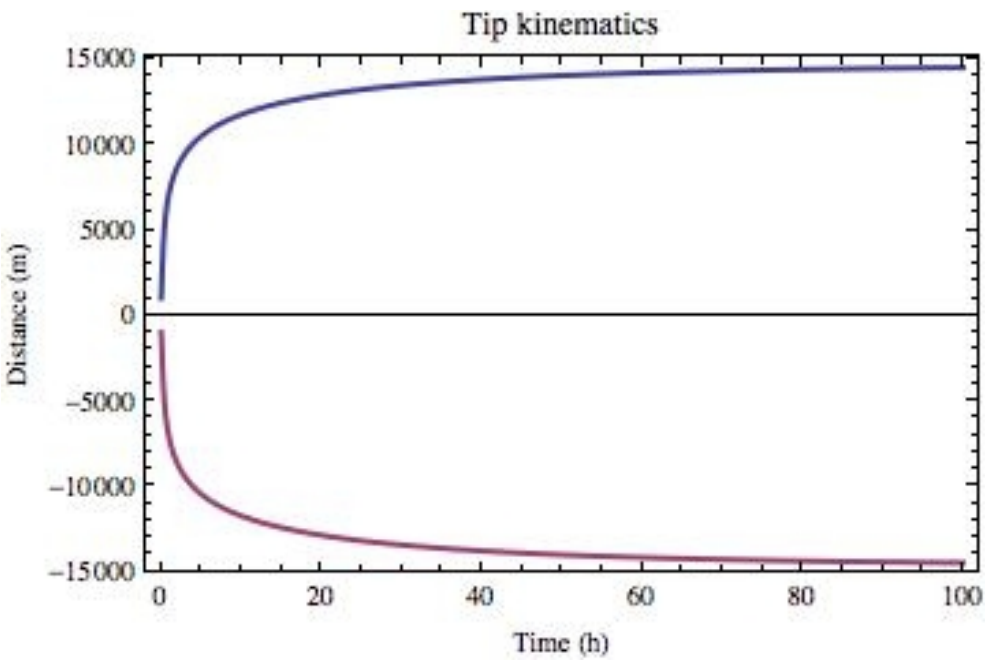
Rivalta, JGR, 2010

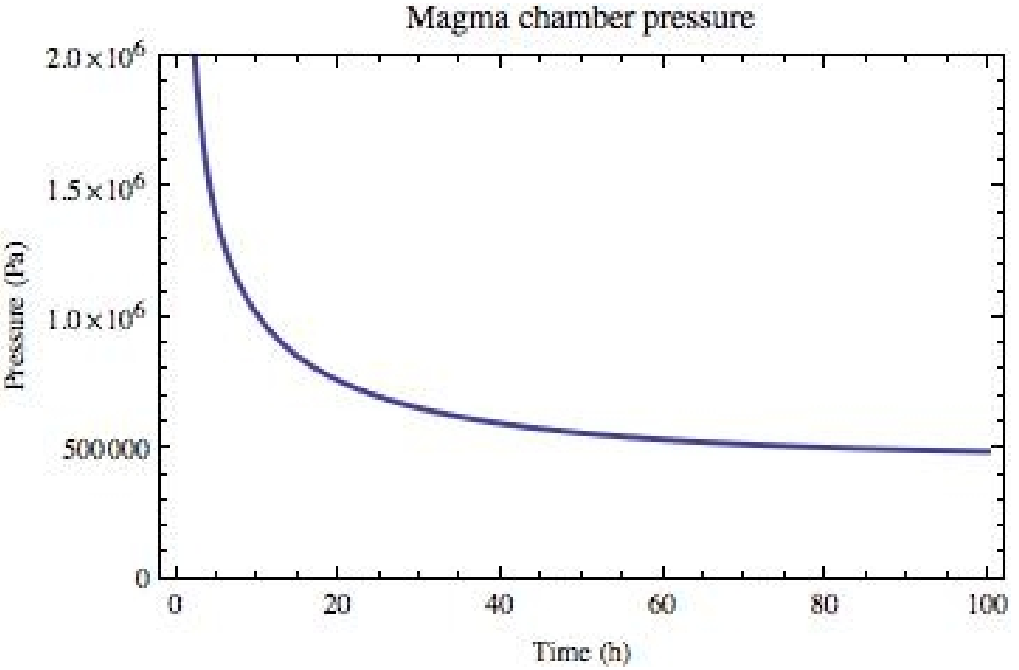
MODELLING

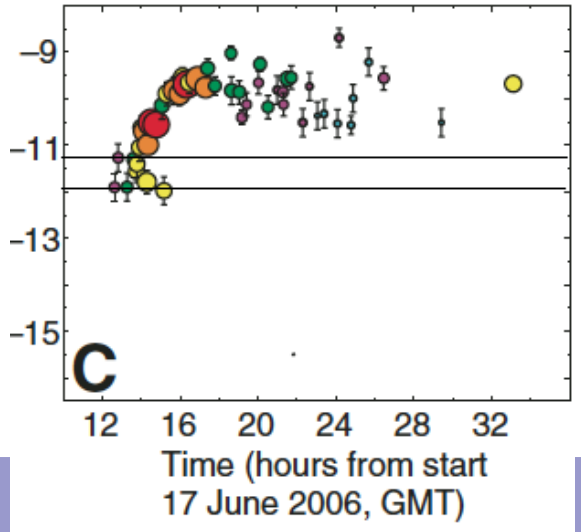


Rivalta and Segall, GRL, 2008

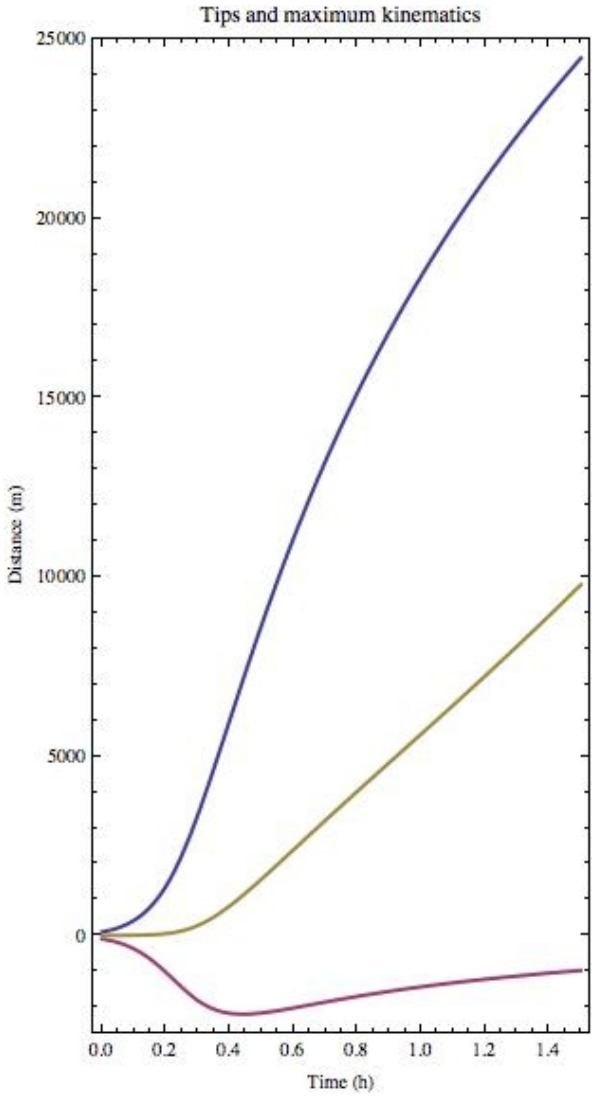
MODELLING: Propagation with no external gradient

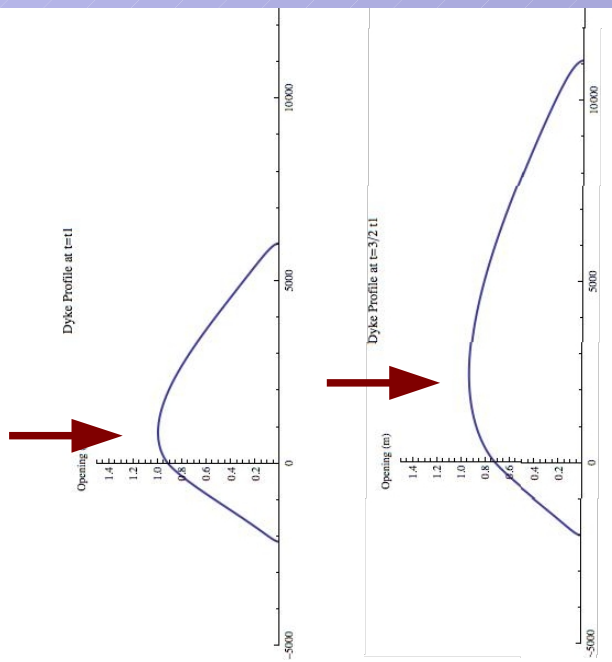






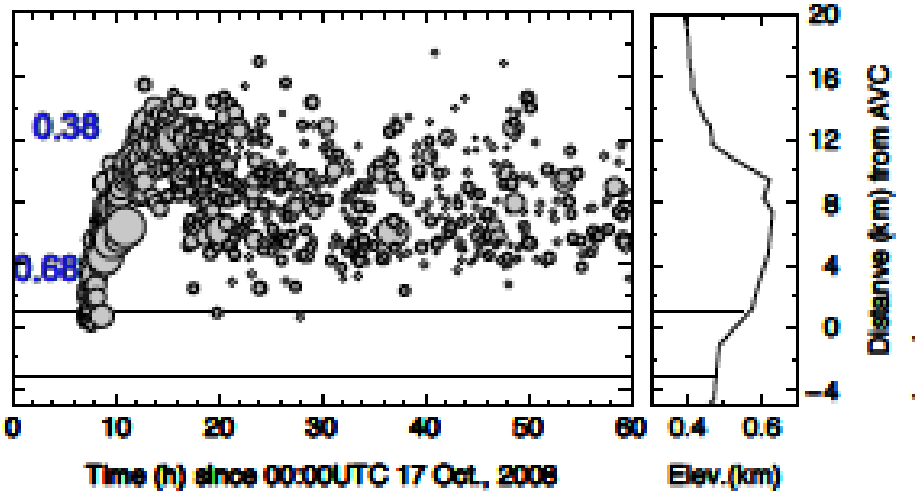
Propagation with an external gradient (preliminary)



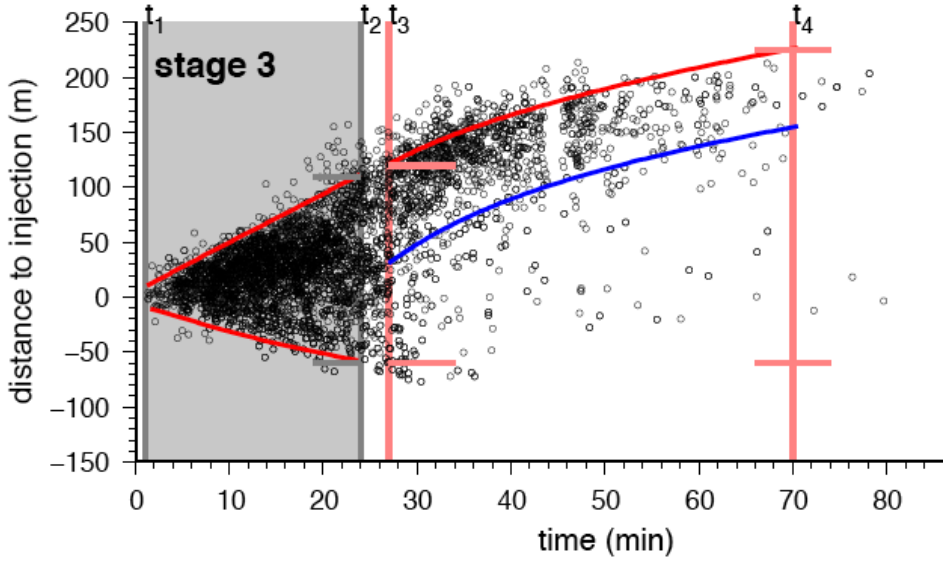


Tectonic gradient:

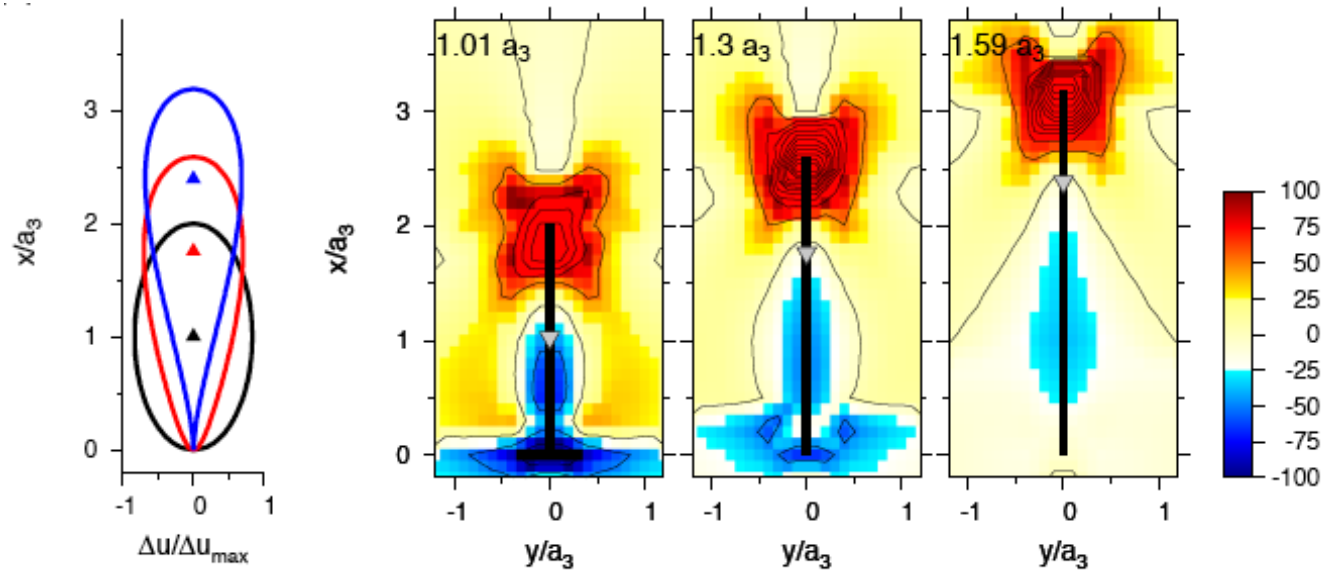
- Dike velocity
- Earthquake productivity
- Magnitude



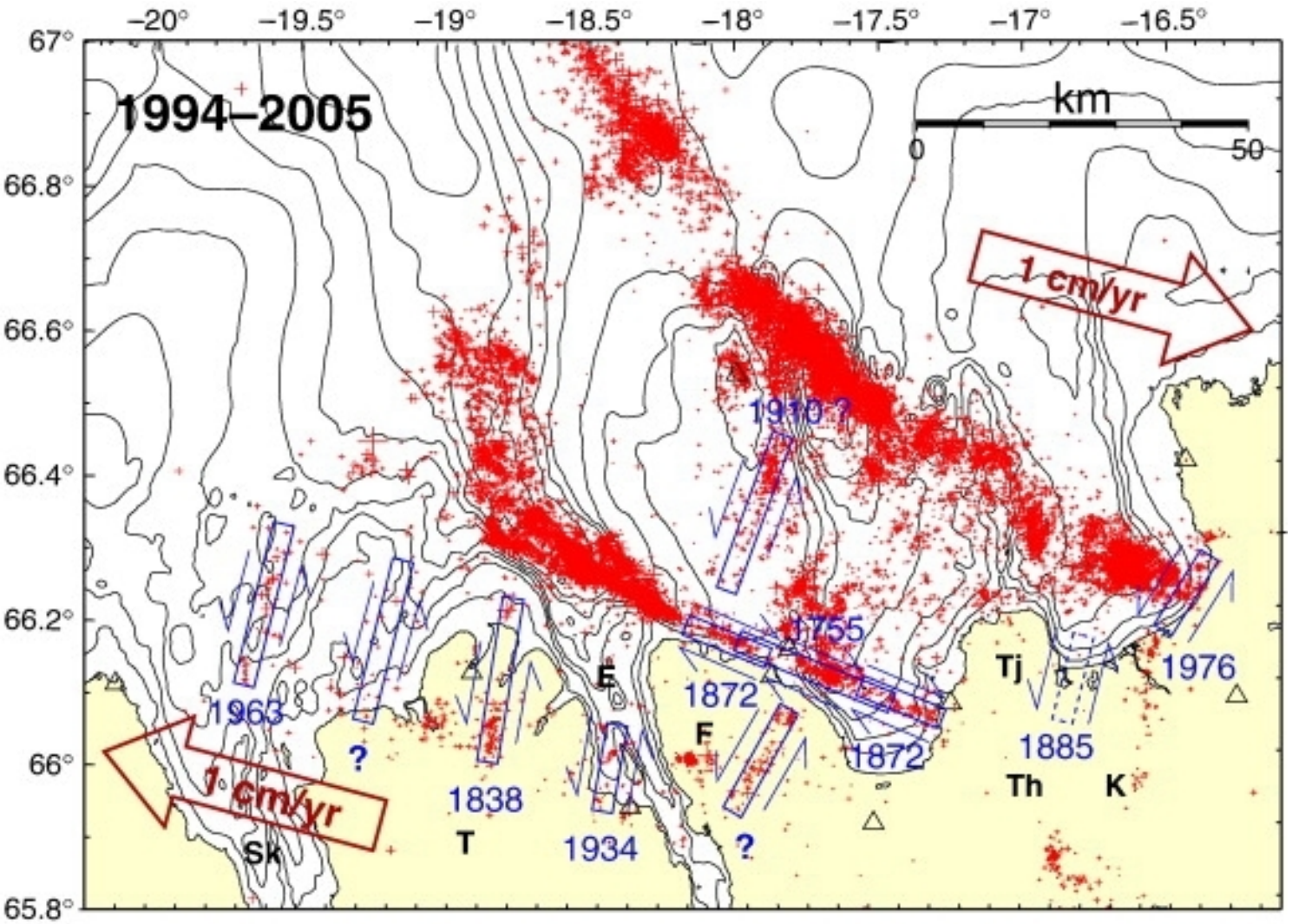
The pattern of seismicity induced by hydrofractures



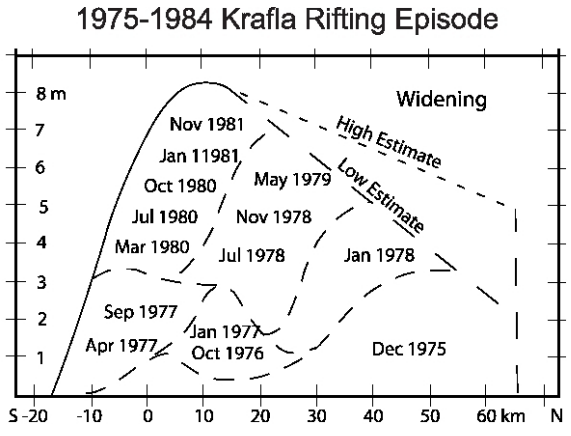
From Dahm et al., JGR, 2011

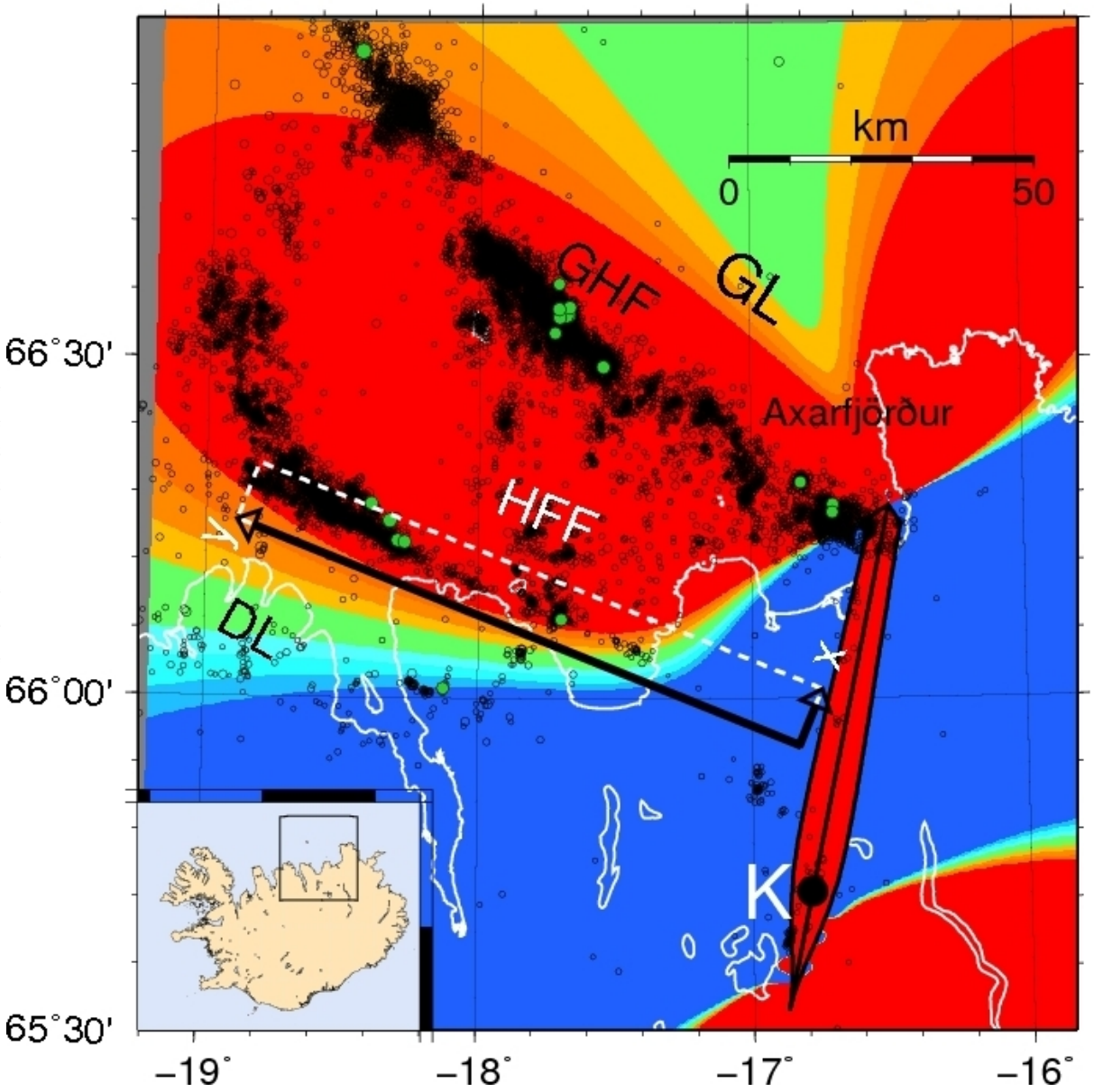


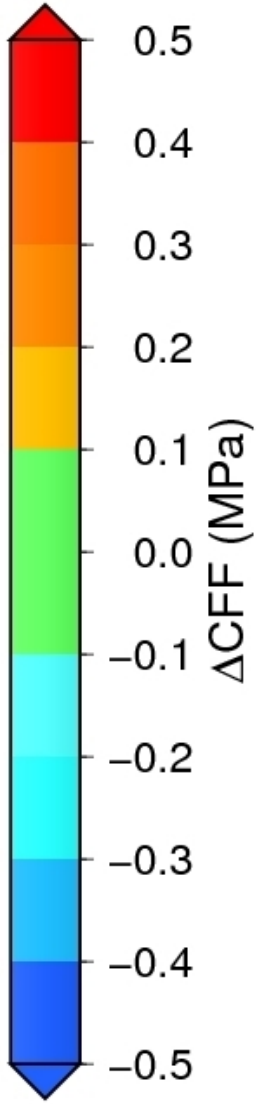
2) Dike-induced stress shadow – Instrumental and historical seismicity



2) Coulomb stress modelling

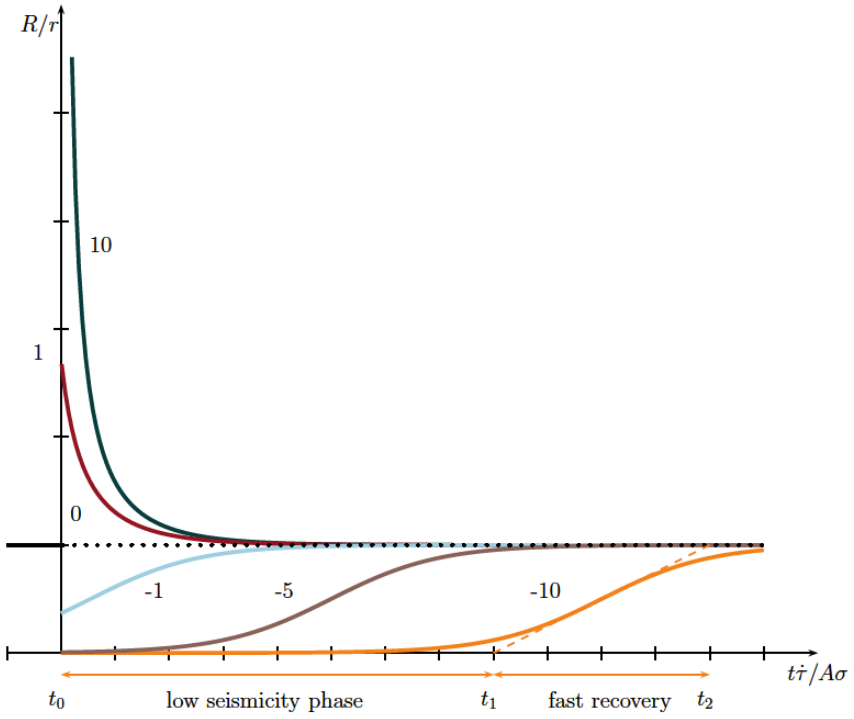


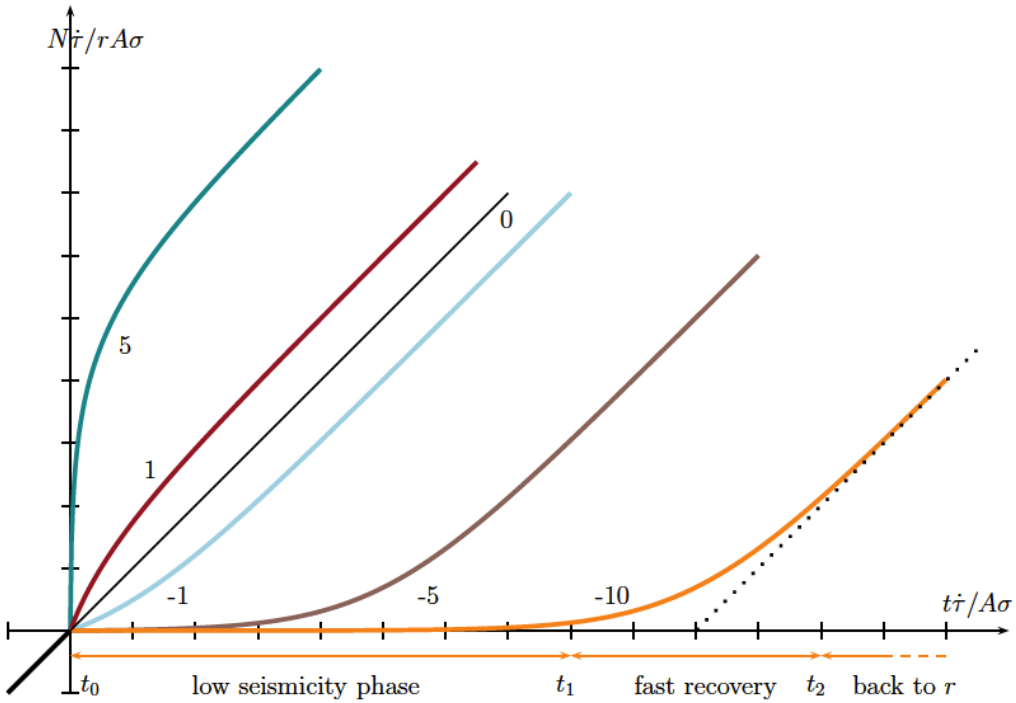




2) Modelled seismicity rate changes

Rate and state earthquake nucleation theory, Dieterich, 1994





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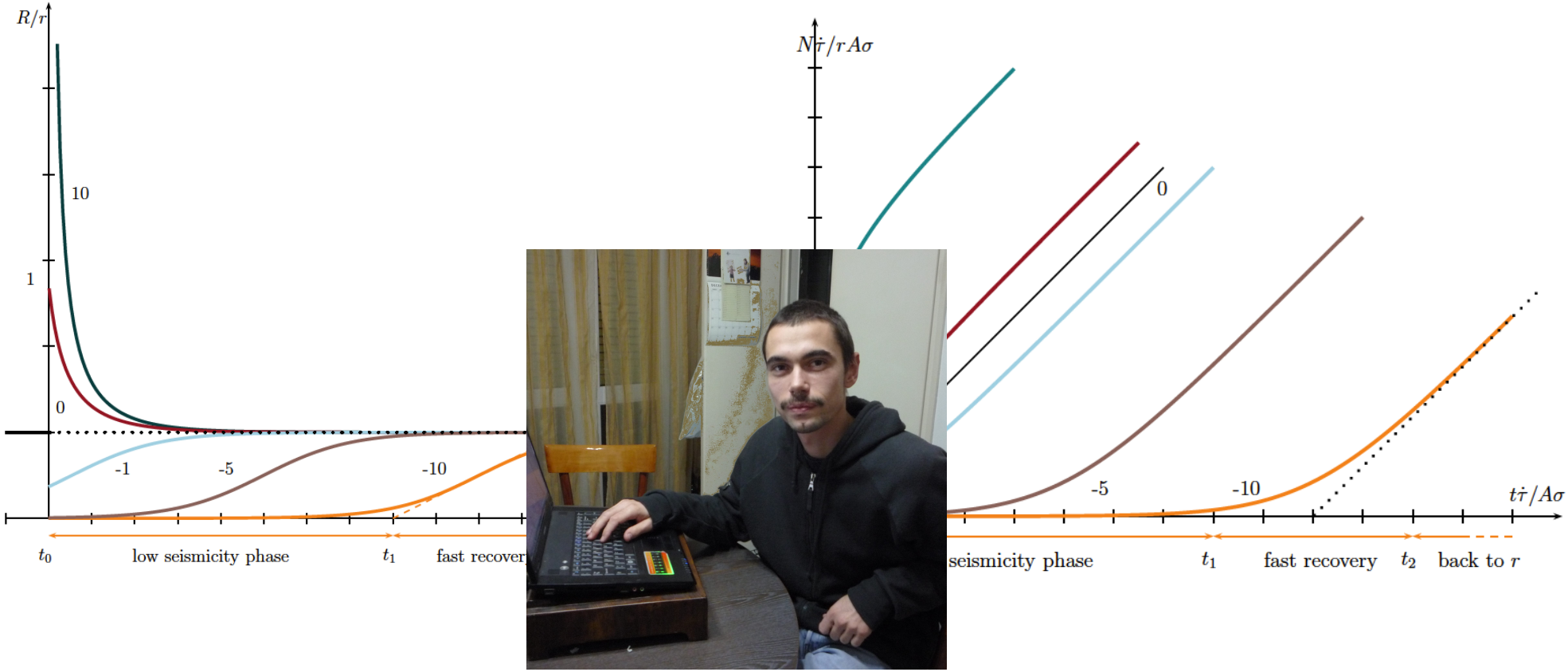
Rate and state earthquake nucleation theory, Dieterich, 1994

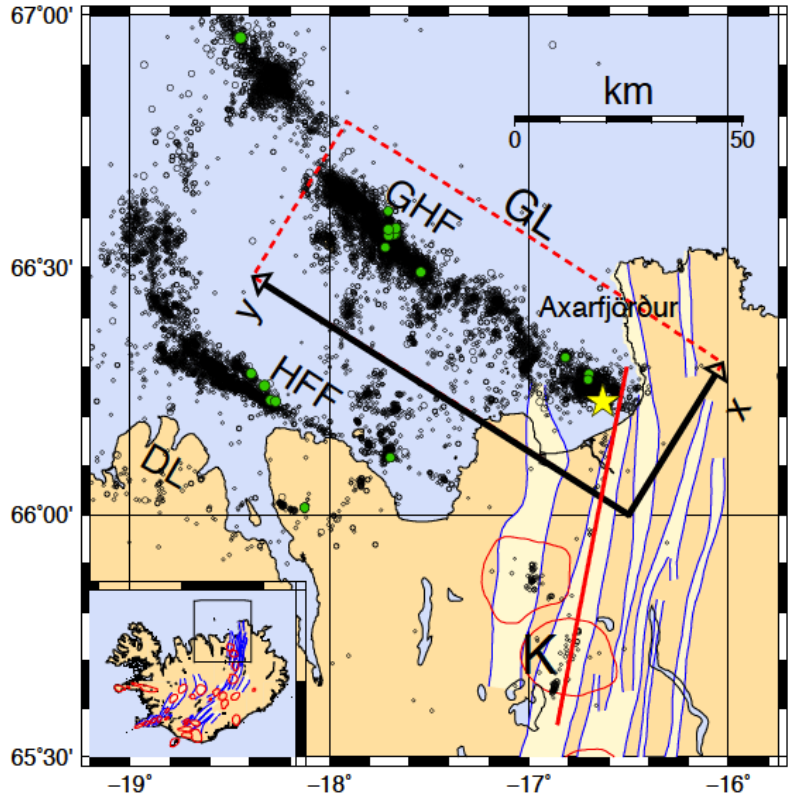


The 13 Jan 1976 M 6.2 Kopasker earthquake: triggered or not triggered?

Operatively, 'triggered' earthquakes have been taken as those occurring on faults which have experienced a positive Coulomb Stress Change.

Problematic because:

- Large areas may be linked to a positive or negative Coulomb stress change for small differences in the stress model



The statement that a specific earthquake was triggered should be given in a probabilistic way (along with the relative uncertainty).

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