Are geodetic models physically relevant for understanding magma transport processes?

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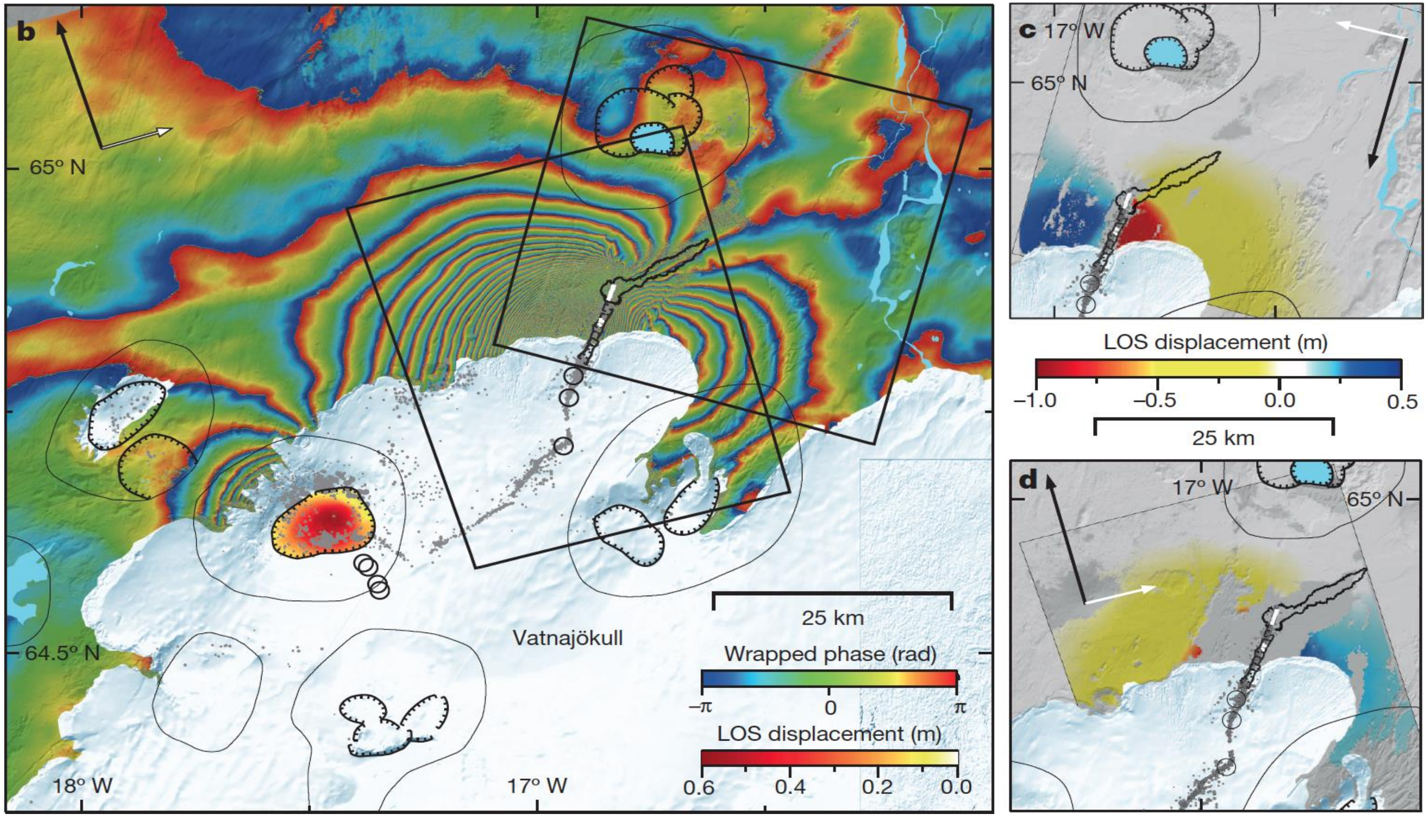
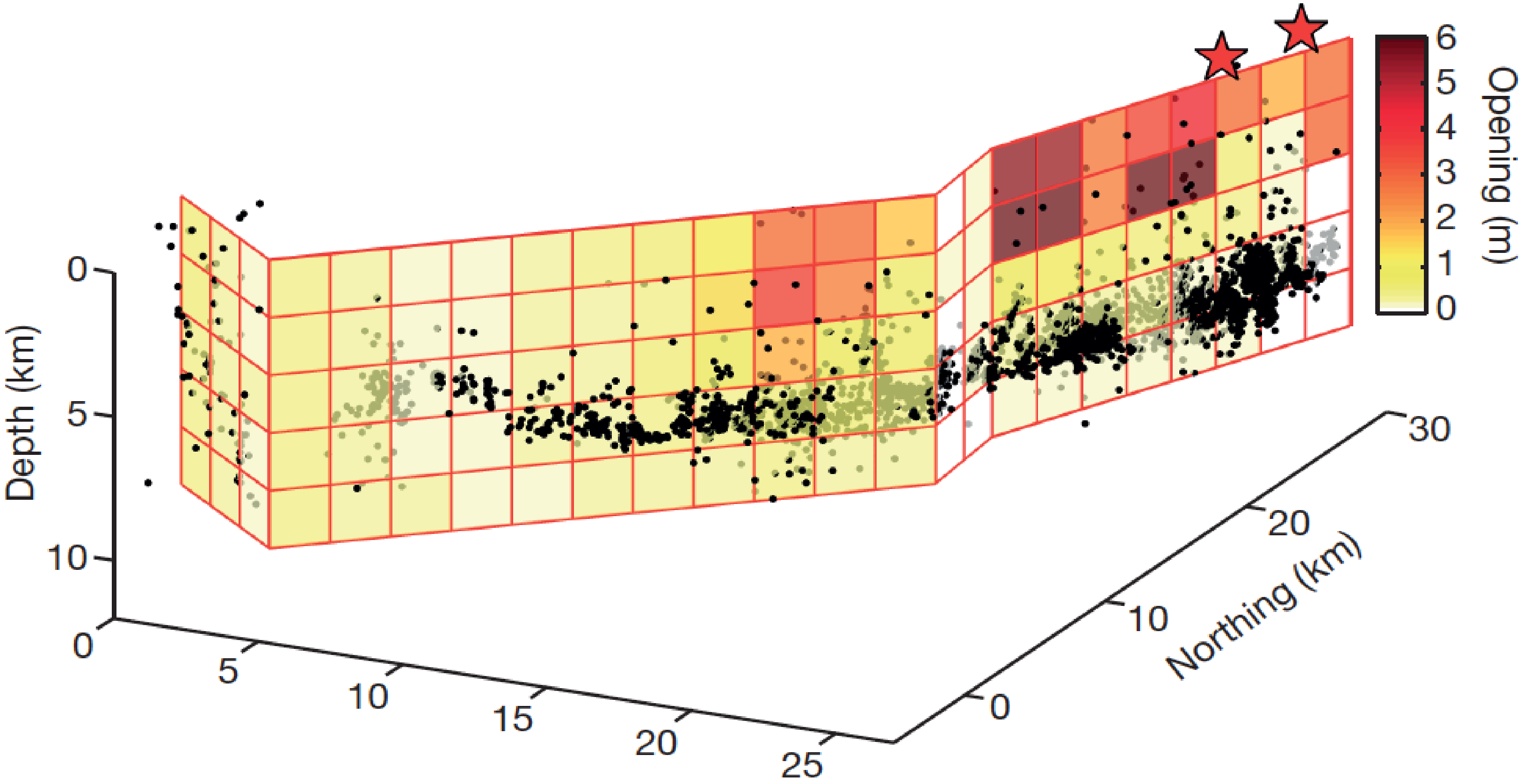
Geodetic surveying and modelling



Bardarbunga – Holuhraun intrusion

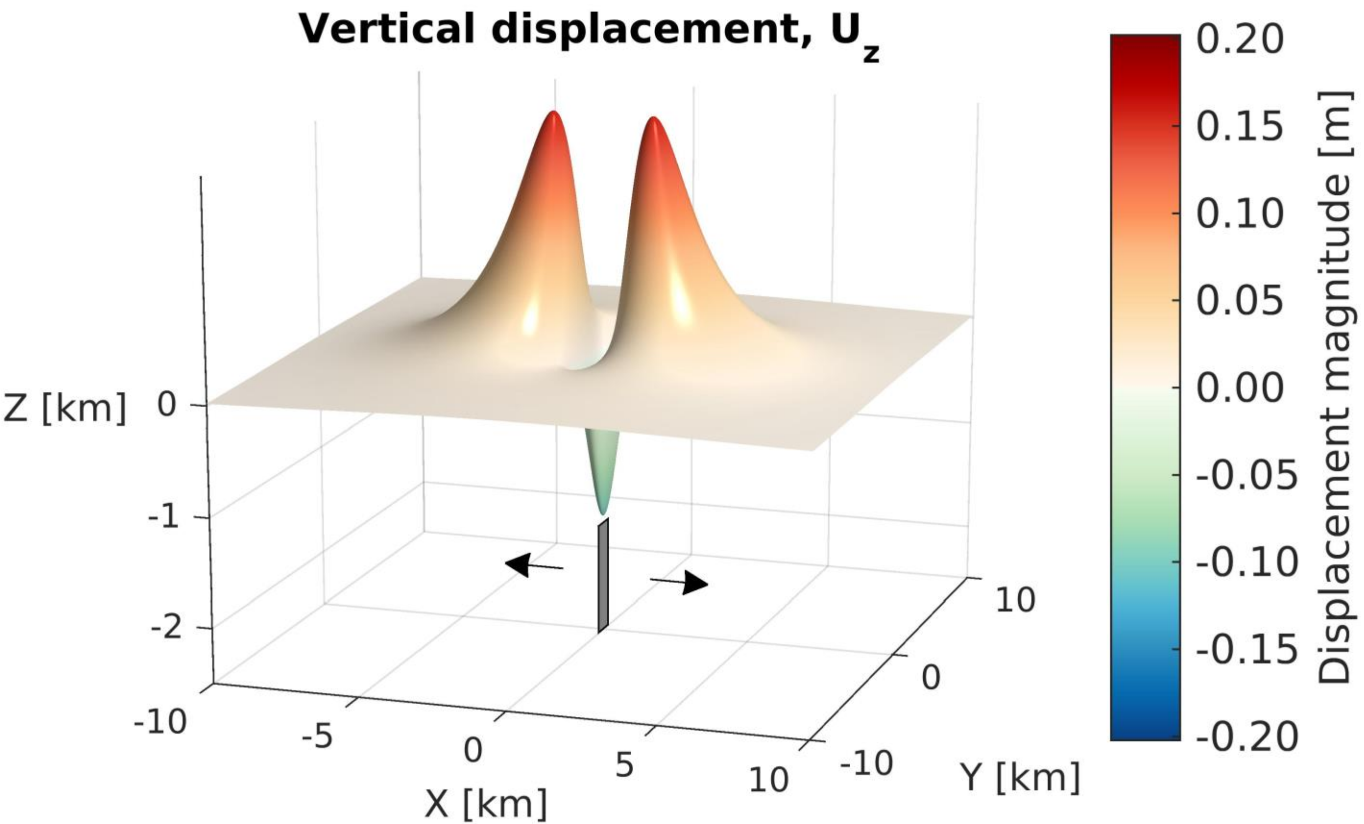
Sigmundsson et al. (2015)

Geodetic surveying and modelling



Sigmundsson et al. (2014)

Geodetic model for dykes



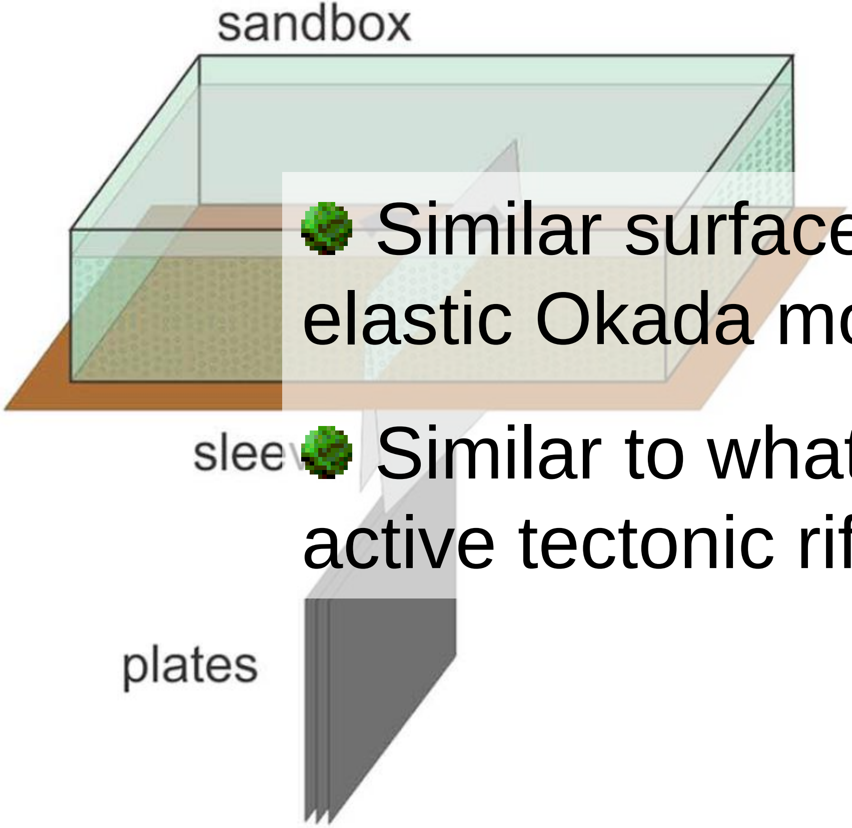
- Okada (1985): rectangular dislocation in elastic half-space

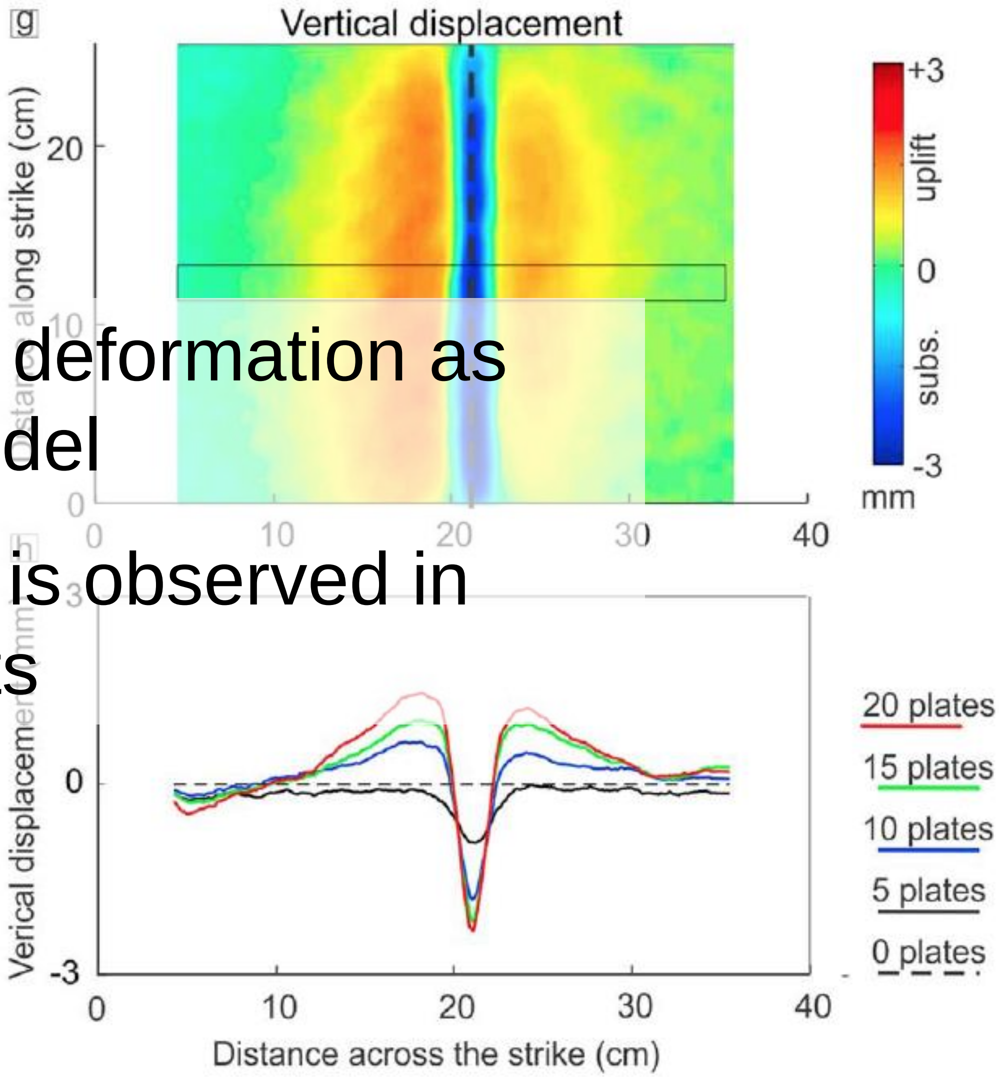
Main physical assumptions of Okada model

- No tectonic stress: ”wrong” boundary conditions
- Pure tensile opening, no propagation, no viscous flow
- Pure elastic deformation of the host rock

1. *What are the effects of tectonic stresses?*
2. *Are other physical assumptions relevant?*
3. *How do they affect dyke-induced surface deformation patterns?*

Sandbox geodesy





- Similar surface deformation as elastic Okada model
- Similar to what is observed in active tectonic rifts

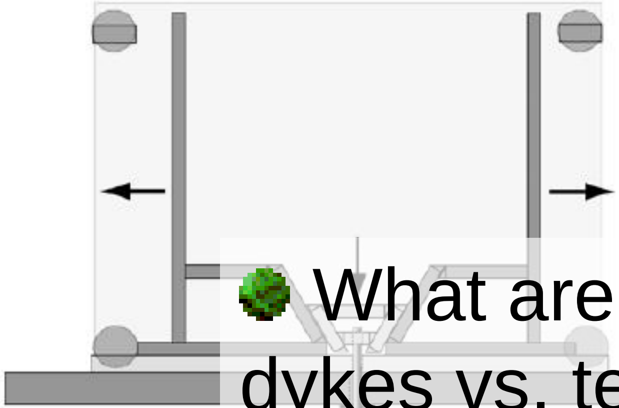
(Trippanera et al., 2014; 2015)

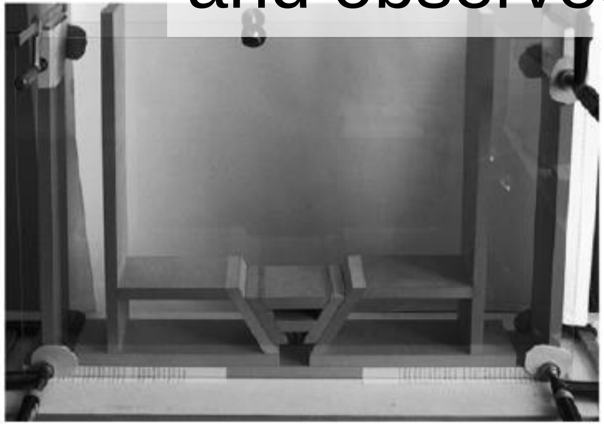
Main physical assumptions of Trippanera et al.

- No tectonic stress: ”wrong” boundary conditions
- Pure tensile opening, no propagation, no viscous flow
- Coulomb host rock

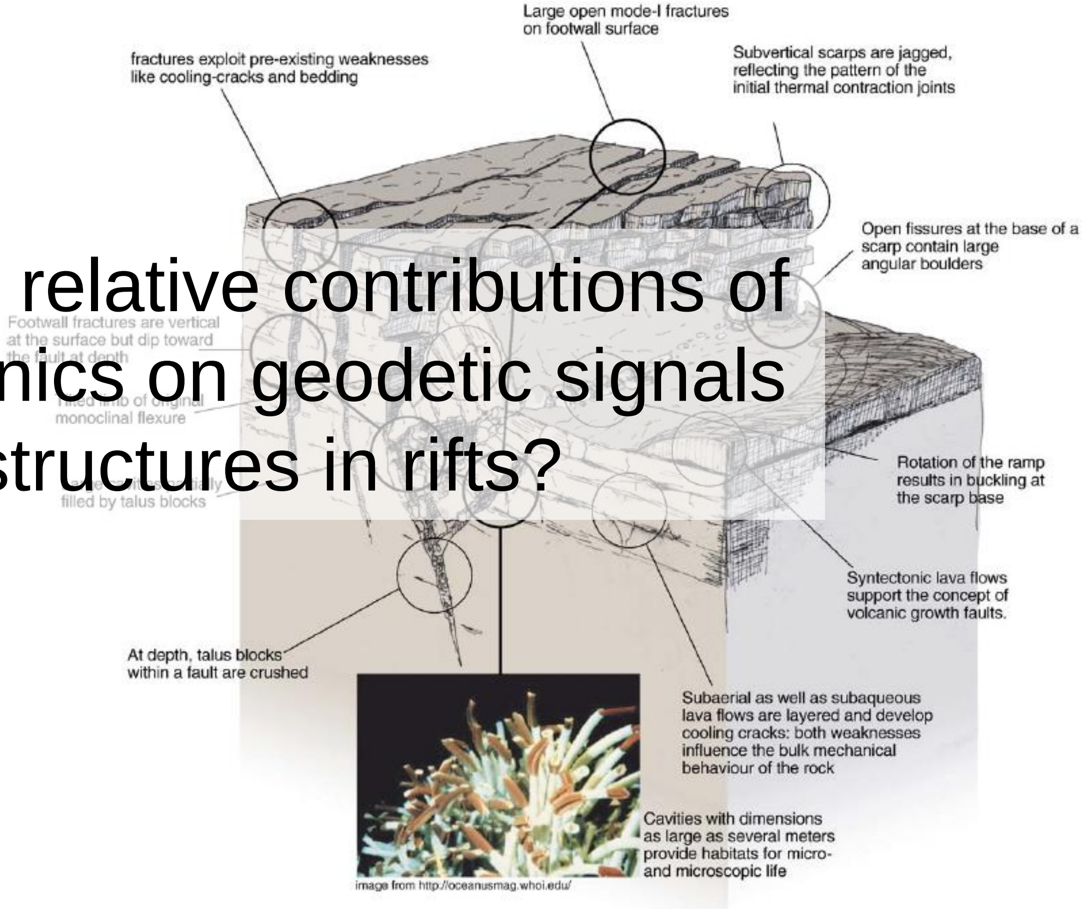
1. *Are ”injection” plates realistic for emplacing dykes*
2. *How do these assumptions affect surface deformation patterns?*
3. *Do tectonics control observed structures?*

Same structures as in tectonic rifts *(Holland et al., EPSL, 2006; 2011)*





🌳 What are the relative contributions of dykes vs. tectonics on geodetic signals and observed structures in rifts?

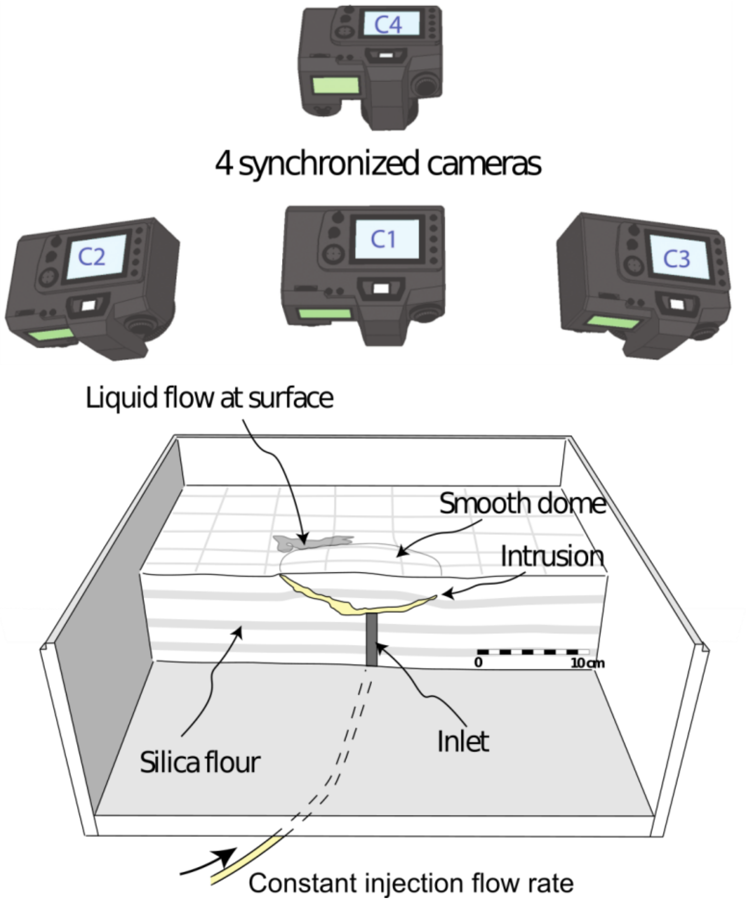


Questions

- What is dyke-induced surface deformation outside a tectonic rift?
- Does host rock rheology affect dyke-induced surface deformation?

Laboratory modelling of dyke emplacement

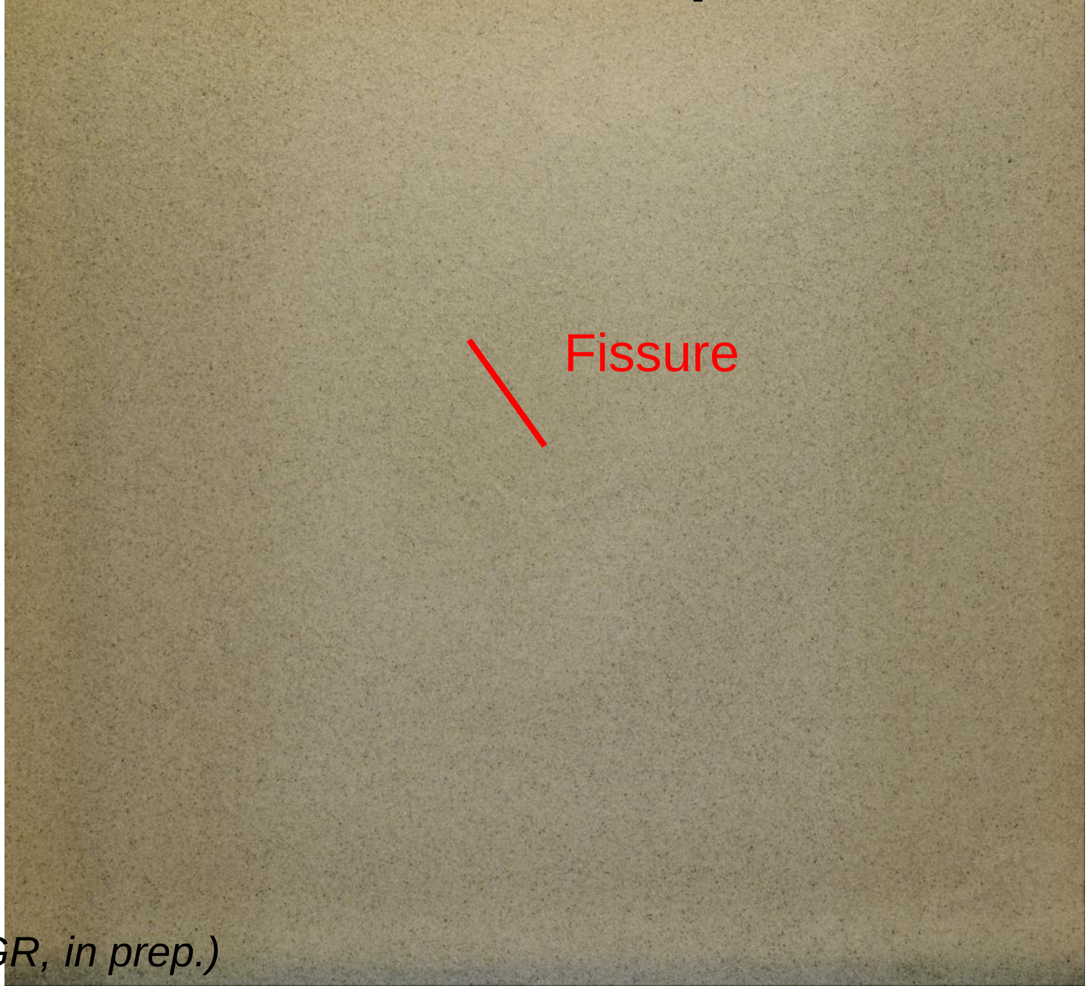
3D laboratory experiments: two types of host



(Galland et al., JGR, 2016)

- ***Gelatine***: elastic and incompressible material, tensile opening
- ***Silica flour***: cohesive Coulomb material
- Both types of experiments produce a **vertical dyke**

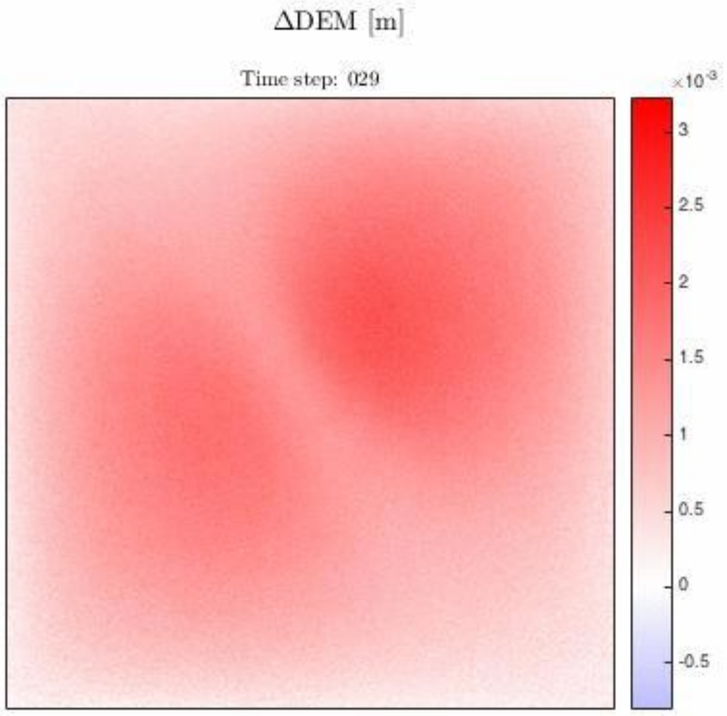
Gelatine elastic experiment

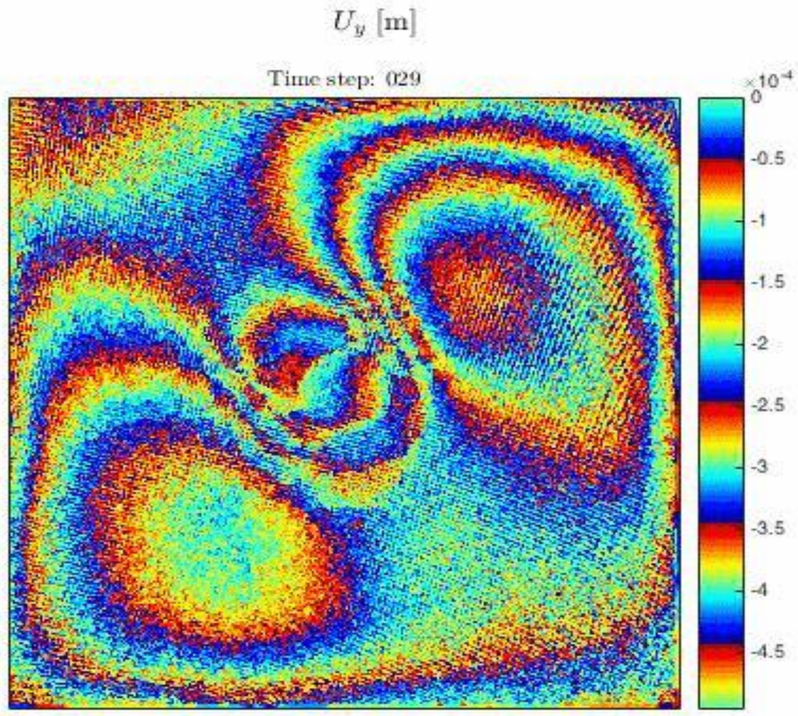


(Bertelsen et al., JVGR, in prep.)

Gelatine elastic experiment

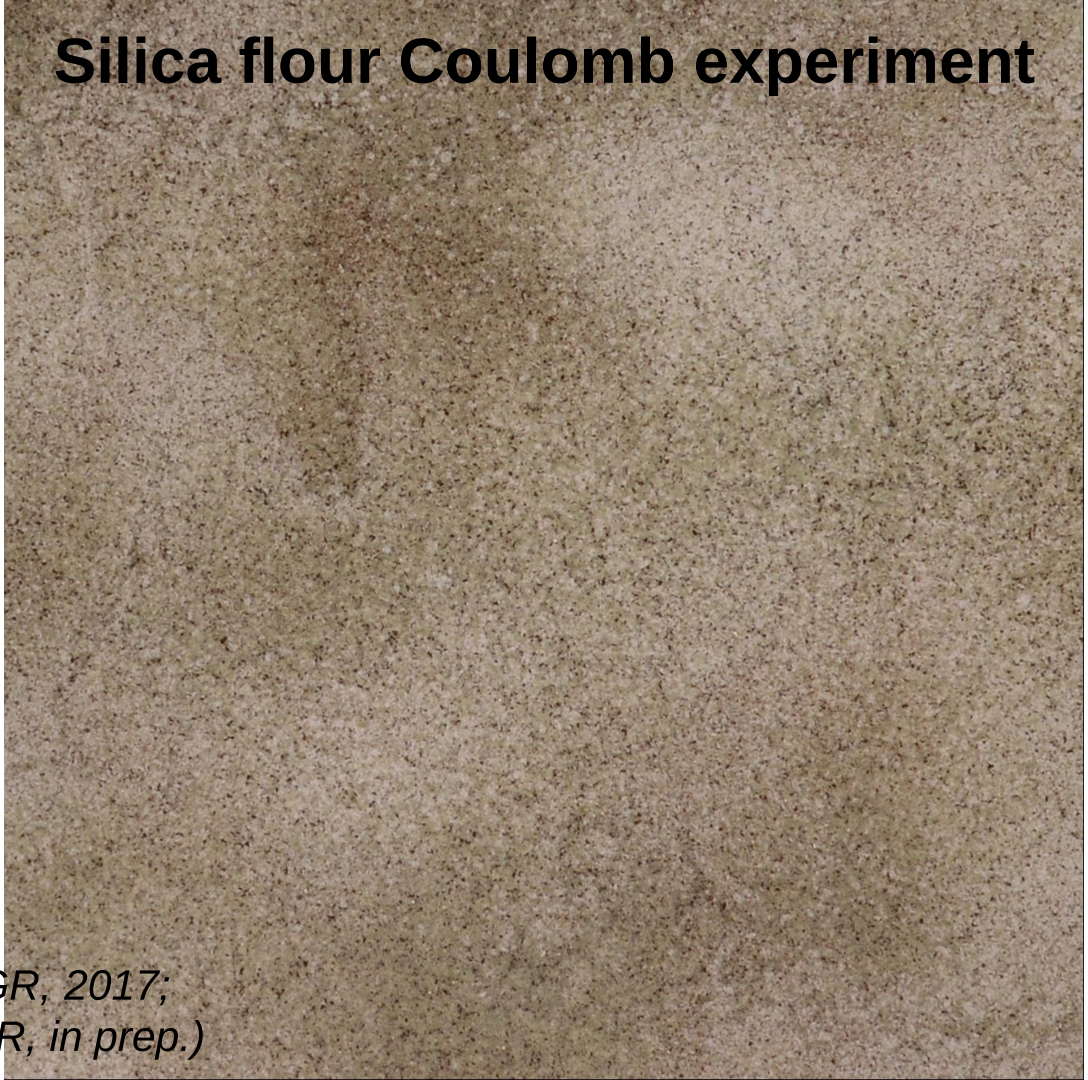
(Bertelsen et al., JVGR, in prep.)





2 topographic bulges + trough parallel to dyke (similar to Okada source)

Silica flour Coulomb experiment



(Guldstrand et al., JGR, 2017;
Bertelsen et al., JVGR, in prep.)

Silica flour Coulomb experiment

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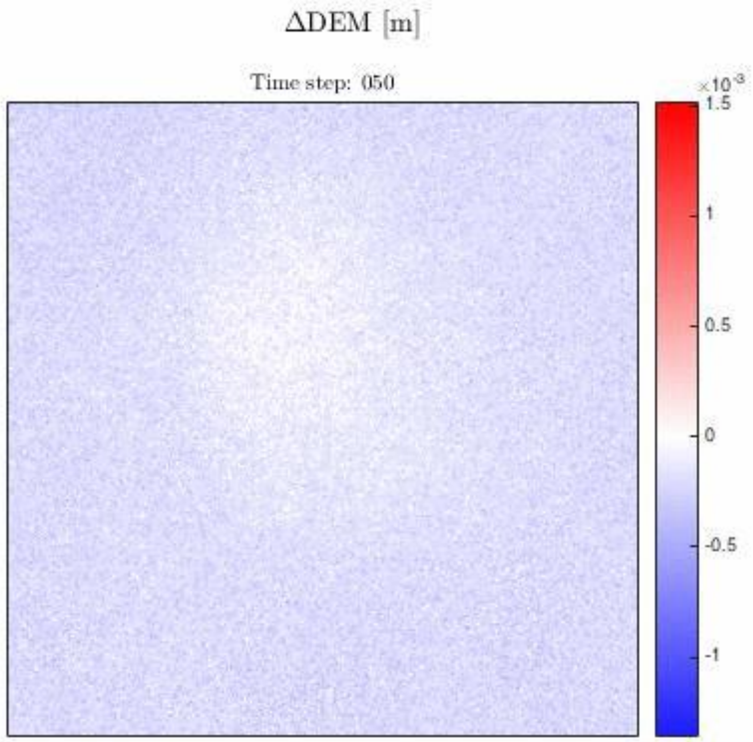
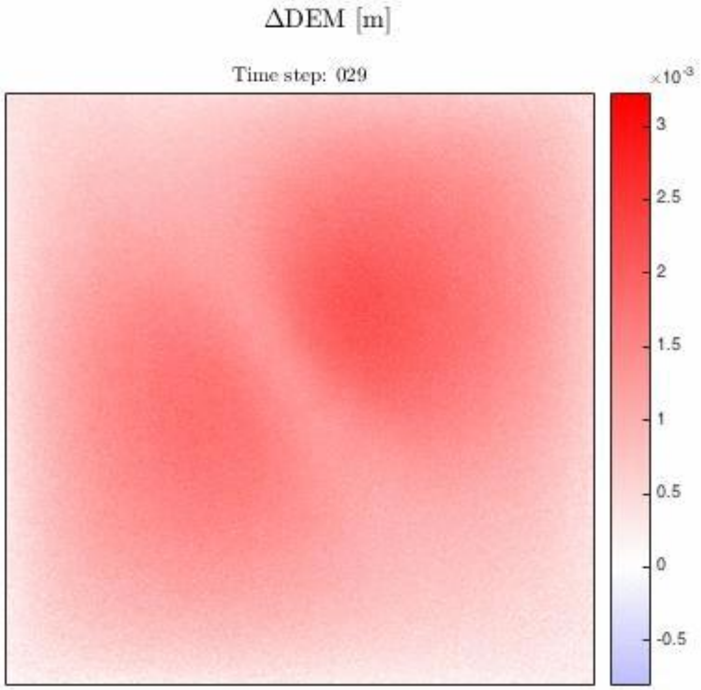
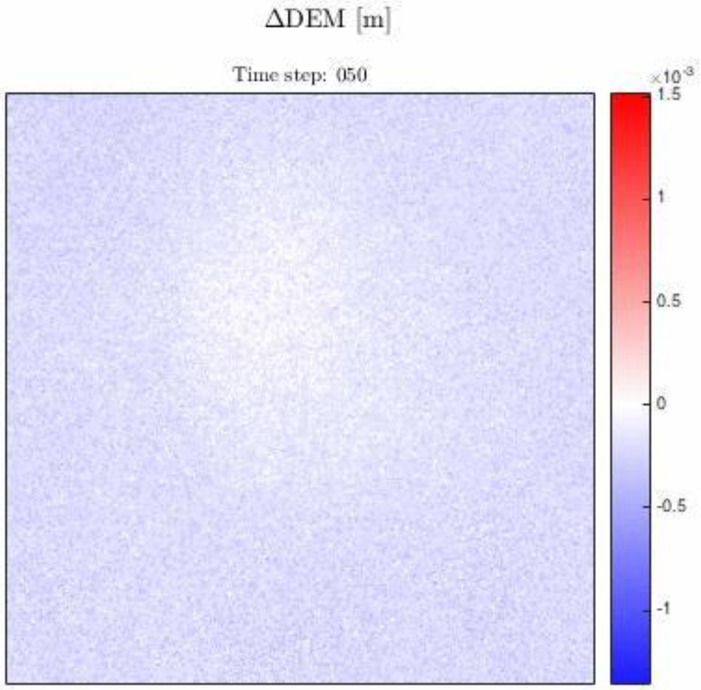


1 topographic bulge – Only uplift

Differences between elastic and Coulomb experiments

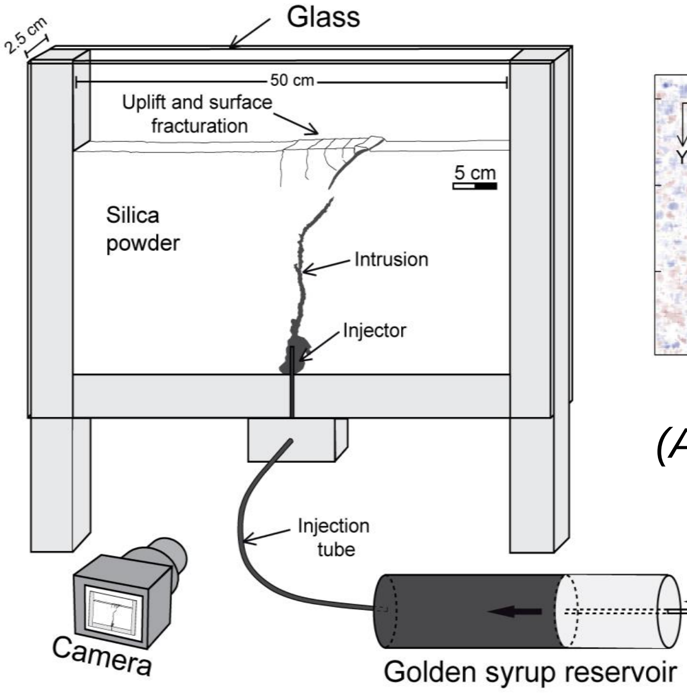


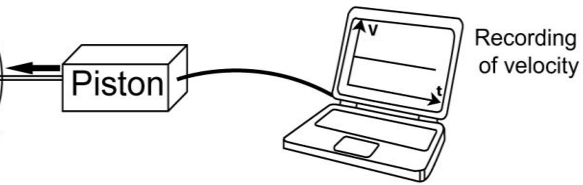


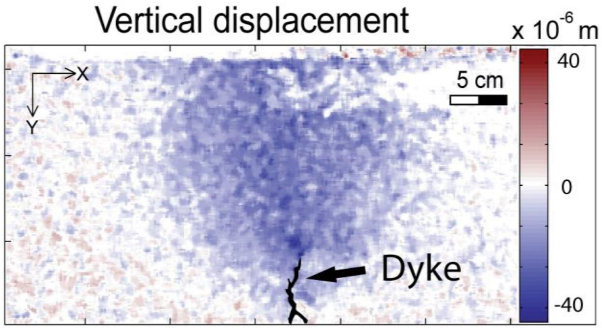
Gelatine: 2 topographic bulges + trough parallel to dyke (similar to Okada source)

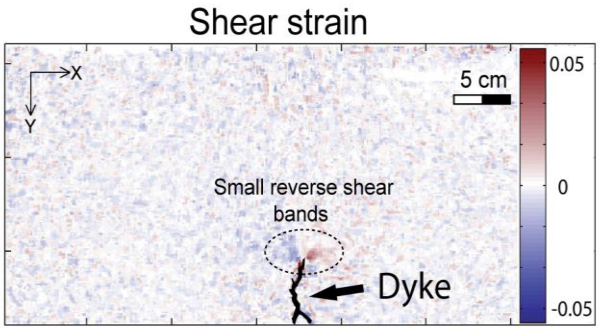
Silica flour: topographic uplift above dyke

Emplacement mechanism in the Coulomb crust?

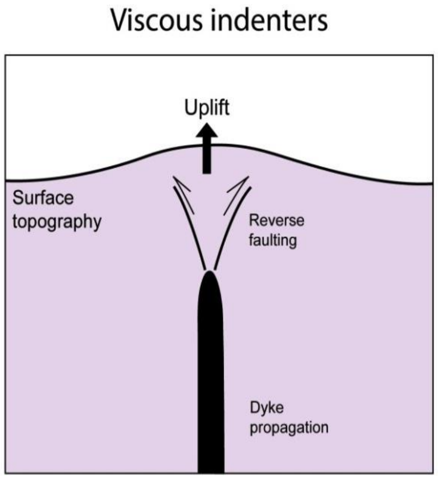








(Abdelmalak et al., EPSL, 2012)



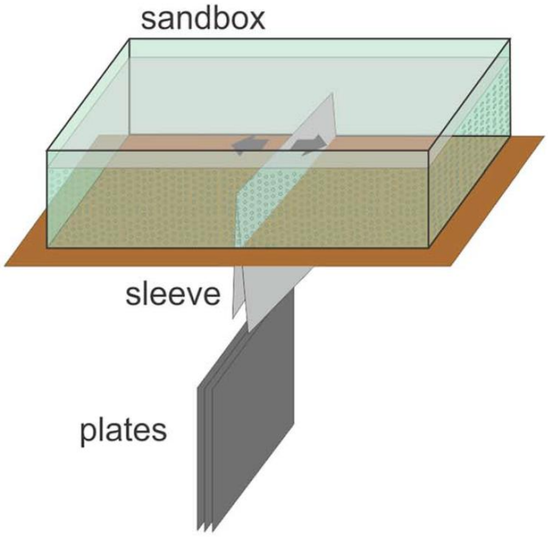
- Surface uplift only
- Small-scale reverse faults
- **Viscous indenter** mechanism

Preliminary conclusions

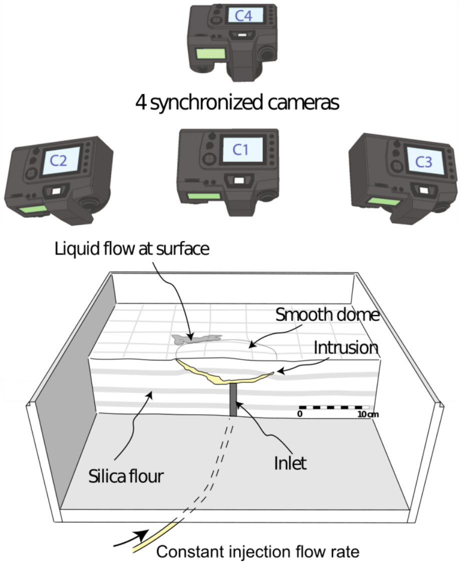
- Different dyke emplacement mechanisms: tensile opening and viscous indenter. Both are supported by field and geophysics (11 extra slides...)

- These distinct emplacement mechanisms trigger drastically distinct surface deformation patterns

Differences between sandbox models



(Trippanera et al., 2014; 2015)



(Galland et al., 2016)

- Same stress boundary conditions
- Same Coulomb host rock
- Different ”dykes”

- Implementation of dyke emplacement mechanism is crucial for interpreting geodetic signals!

Main conclusions

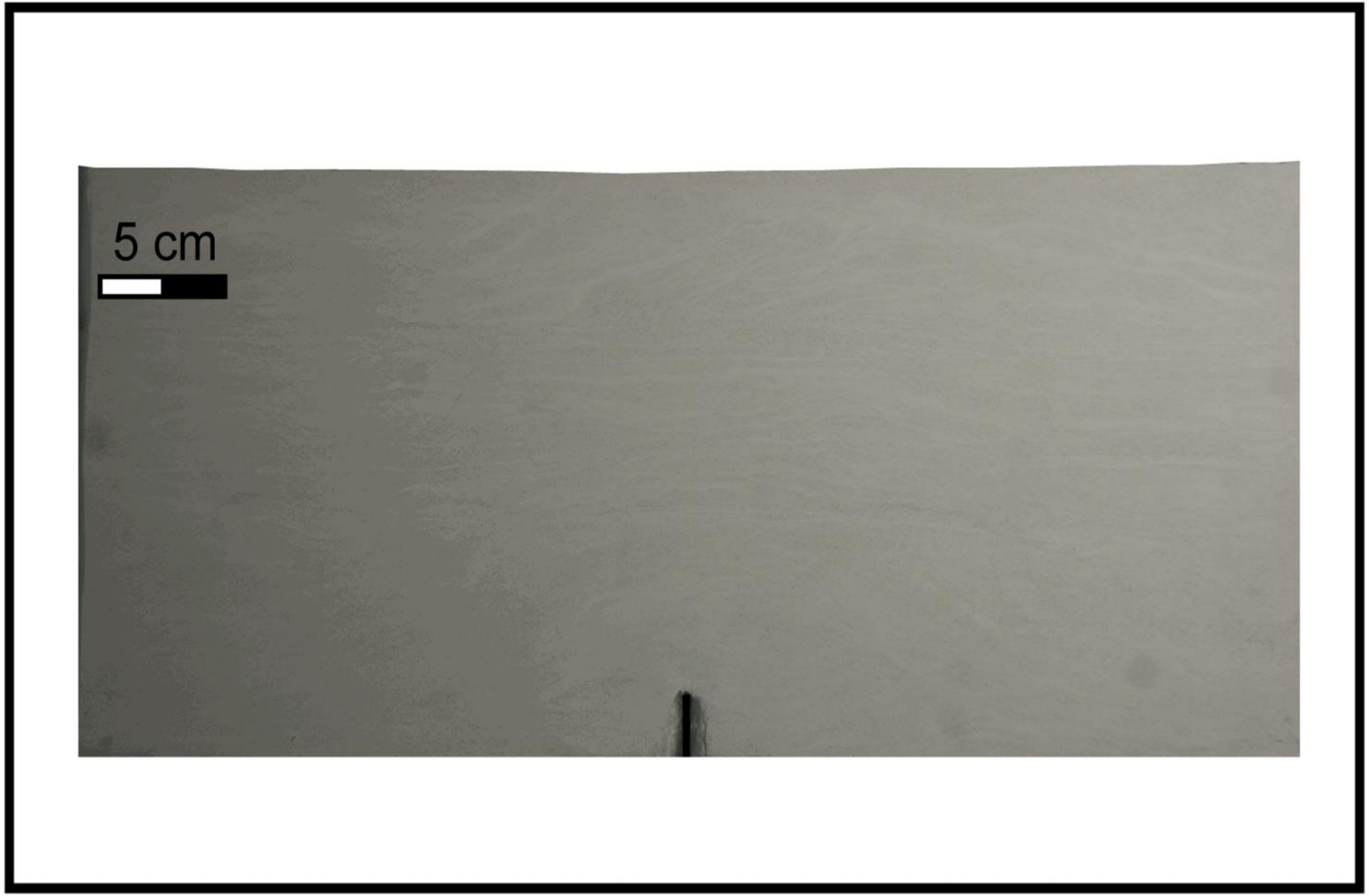
- Dyke emplacement mechanism matters in geodetic models!
- Physically relevant geodetic modelling requires solid understanting of the physics of dyke emplacement
- Very distinct models trigger similar surface deformation: data interpretation/fit is not unique!
- This implies that good data fitting does not mean that the physics is understood

Are geodetic models physically relevant for understanding magma transport processes?

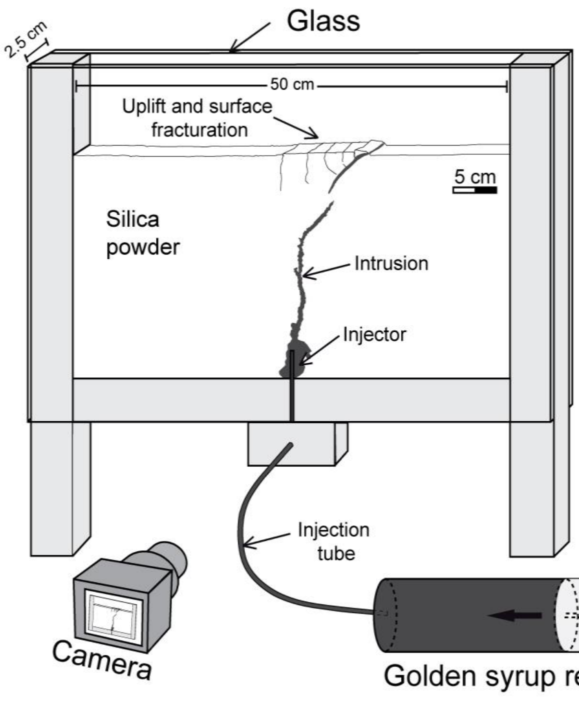

Thanks for your attention
Questions?

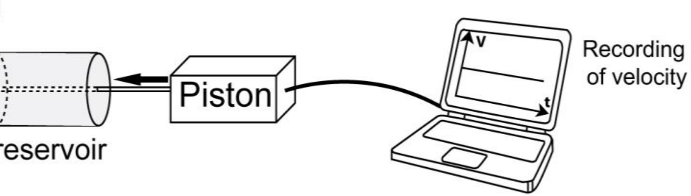
2D laboratory experiments

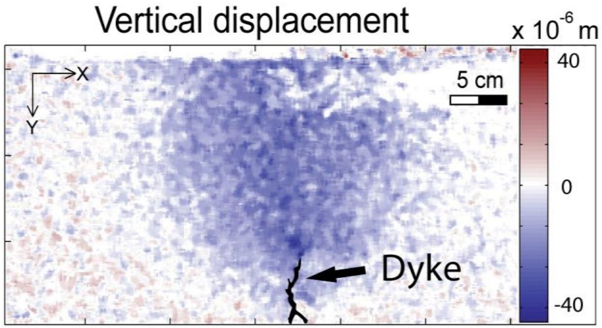
Abdelmalak et al., EPSL (2012)

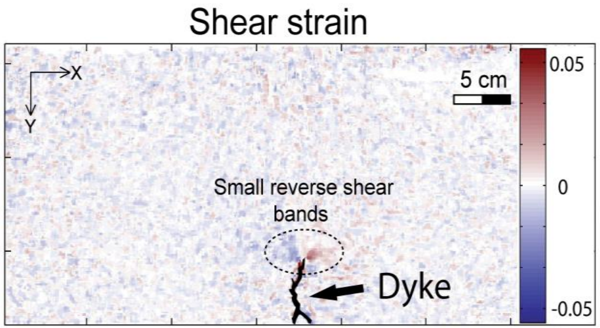


Emplacement mechanism in the Coulomb crust?

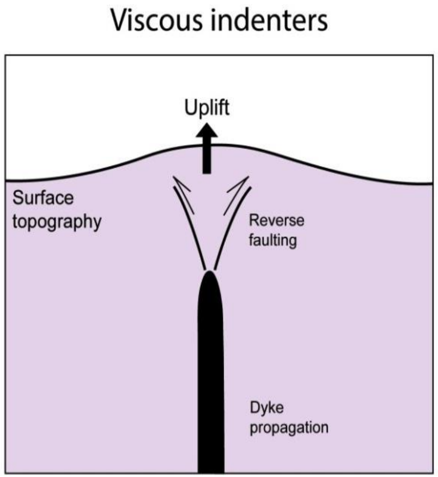








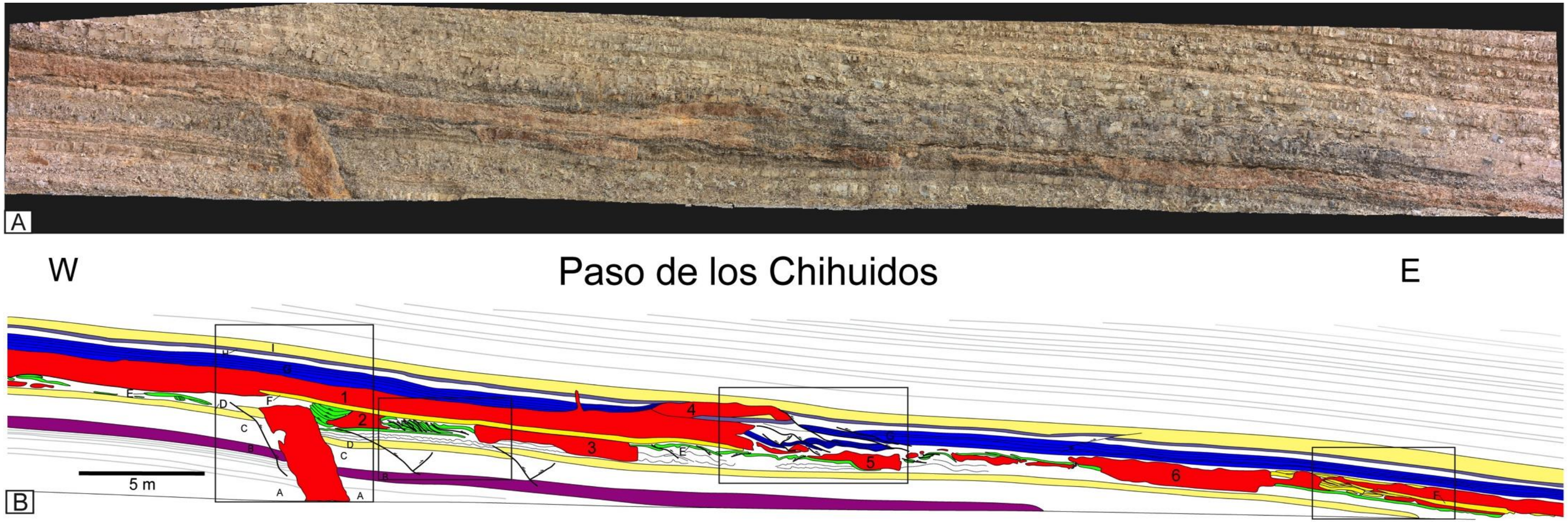
(Abdelmalak et al., EPSL, 2012)



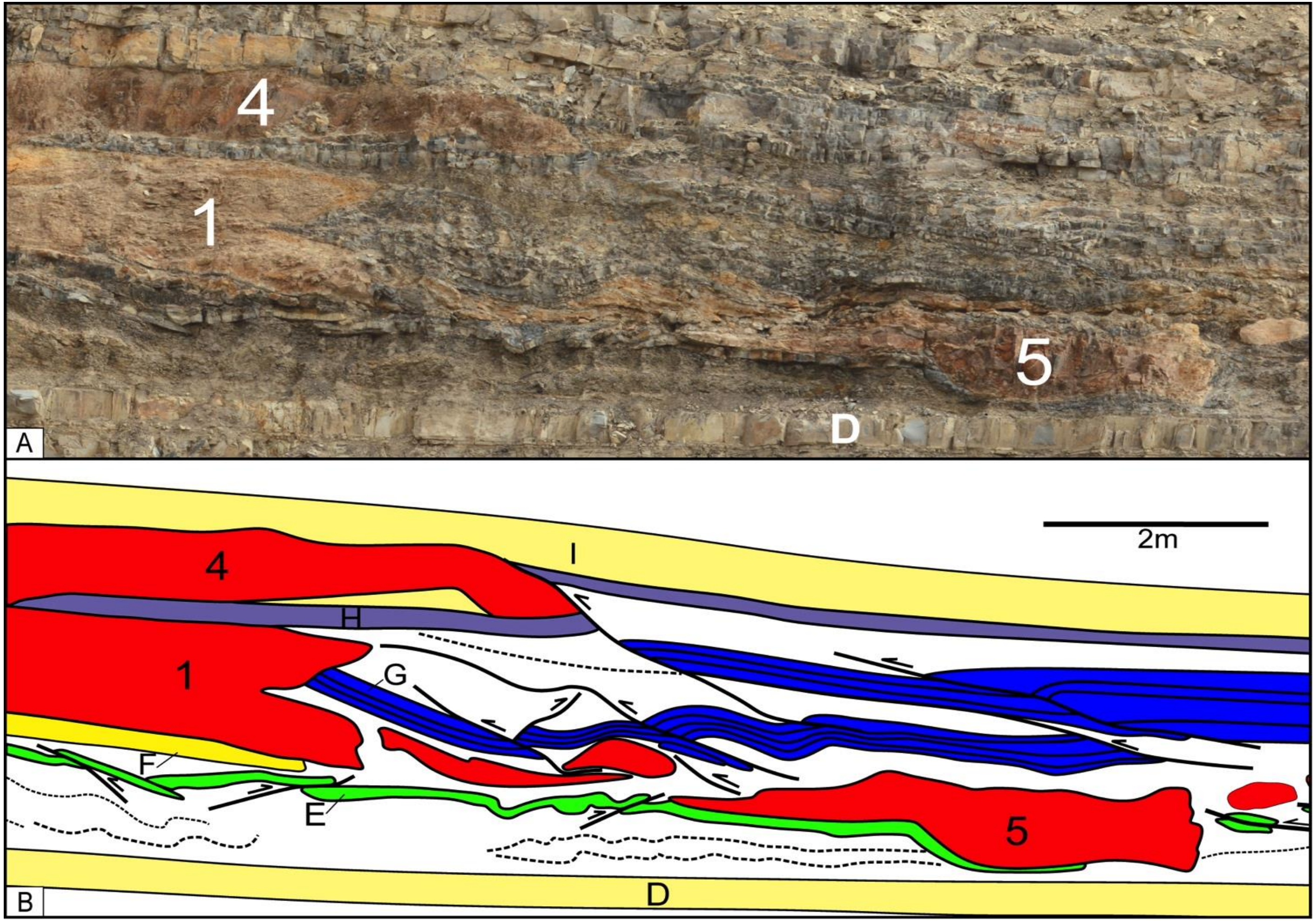
- Surface uplift only
- Small-scale reverse faults
- **Viscous indenter** mechanism

Neuquén Basin, Argentina

(Spacapan et al., JGS, 2016)



- Several sills and tips cropping out very well
- Finely layered host rock formations
- Detailed mapping of sill tips and host rock deformation



(Spacapan et al., JGS, 2016)

Neuquén Basin, Argentina

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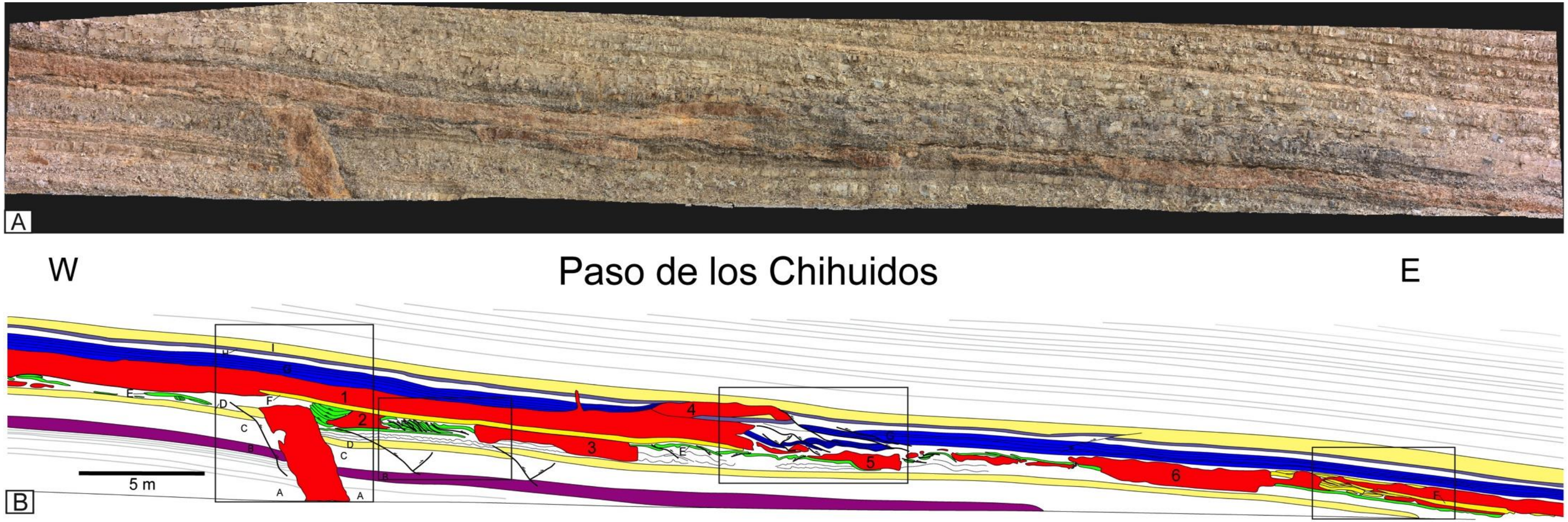

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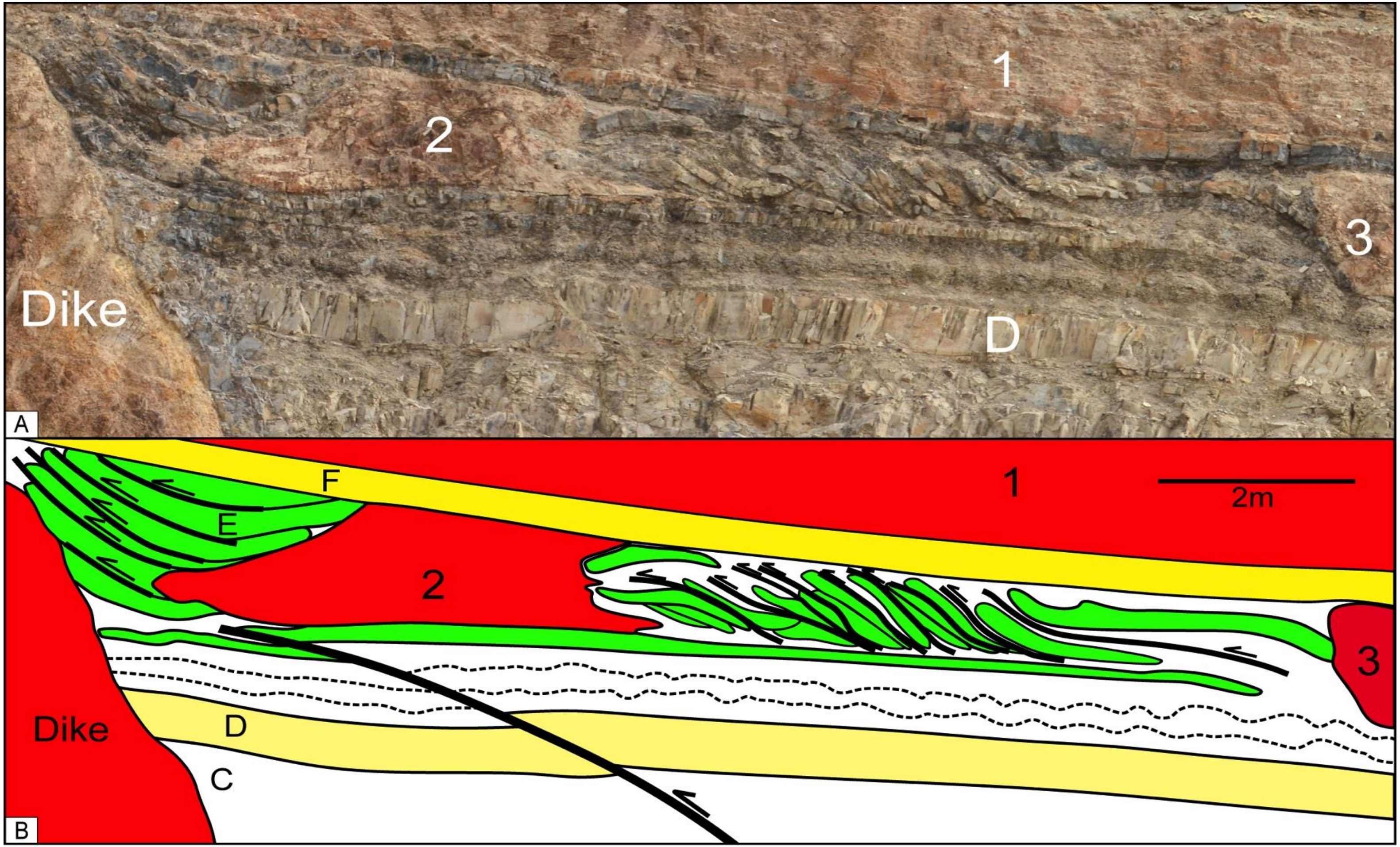

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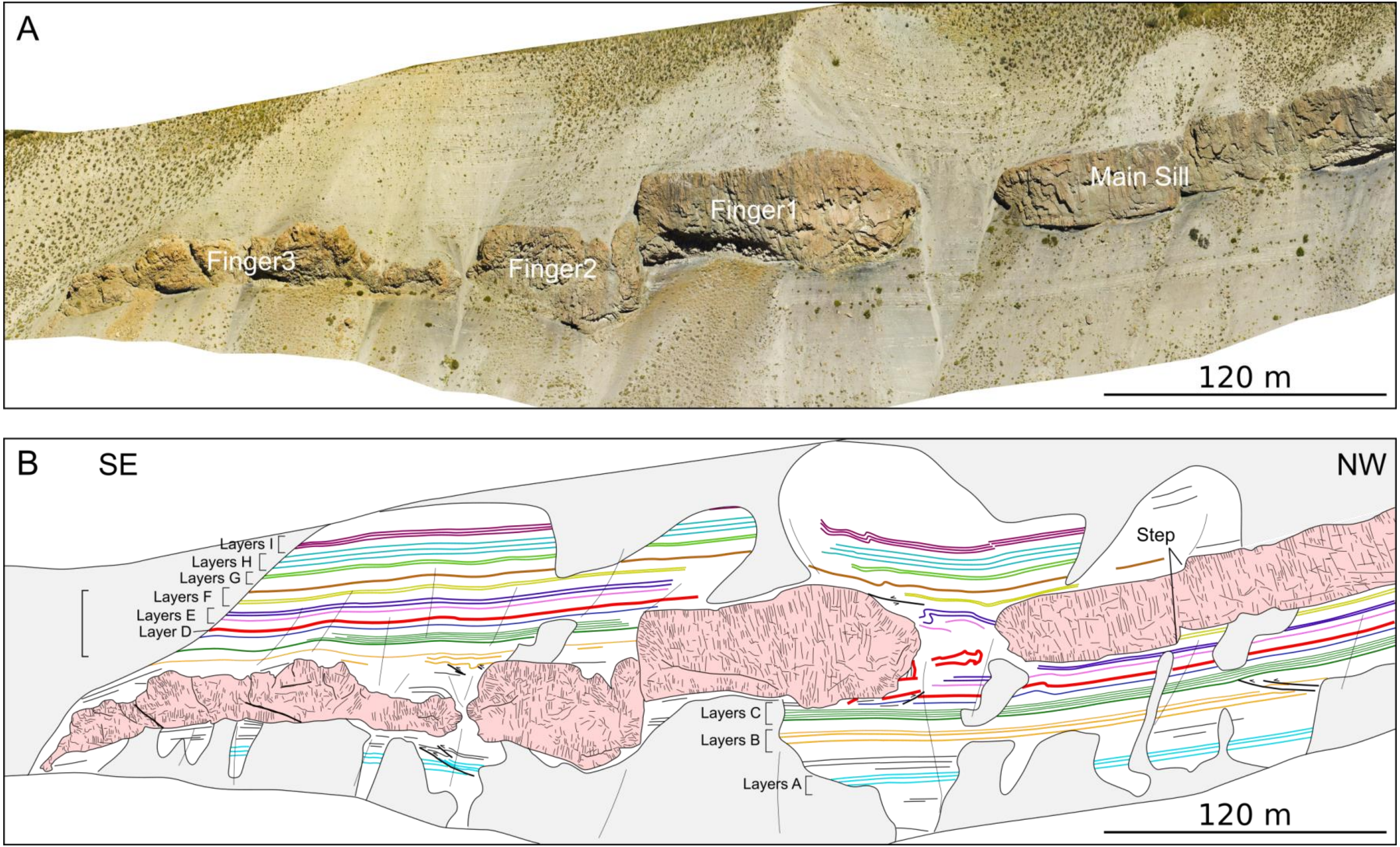
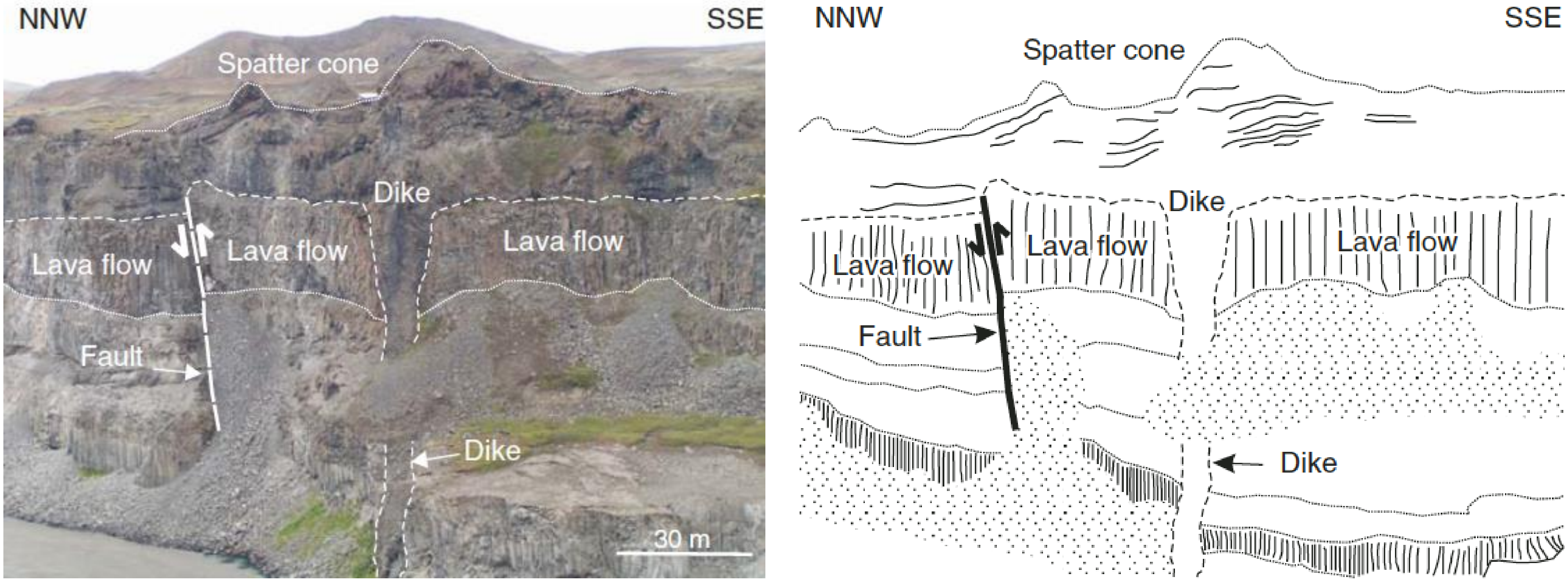

A
Finger3
Finger2
Finger1
Main Sill
120 m
B
SE
NW
Layers I
Layers H
Layers G
Layers F
Layers E
Layer D
Step
Layers C
Layers B
Layers A
120 m

Dyke-induced reverse faults

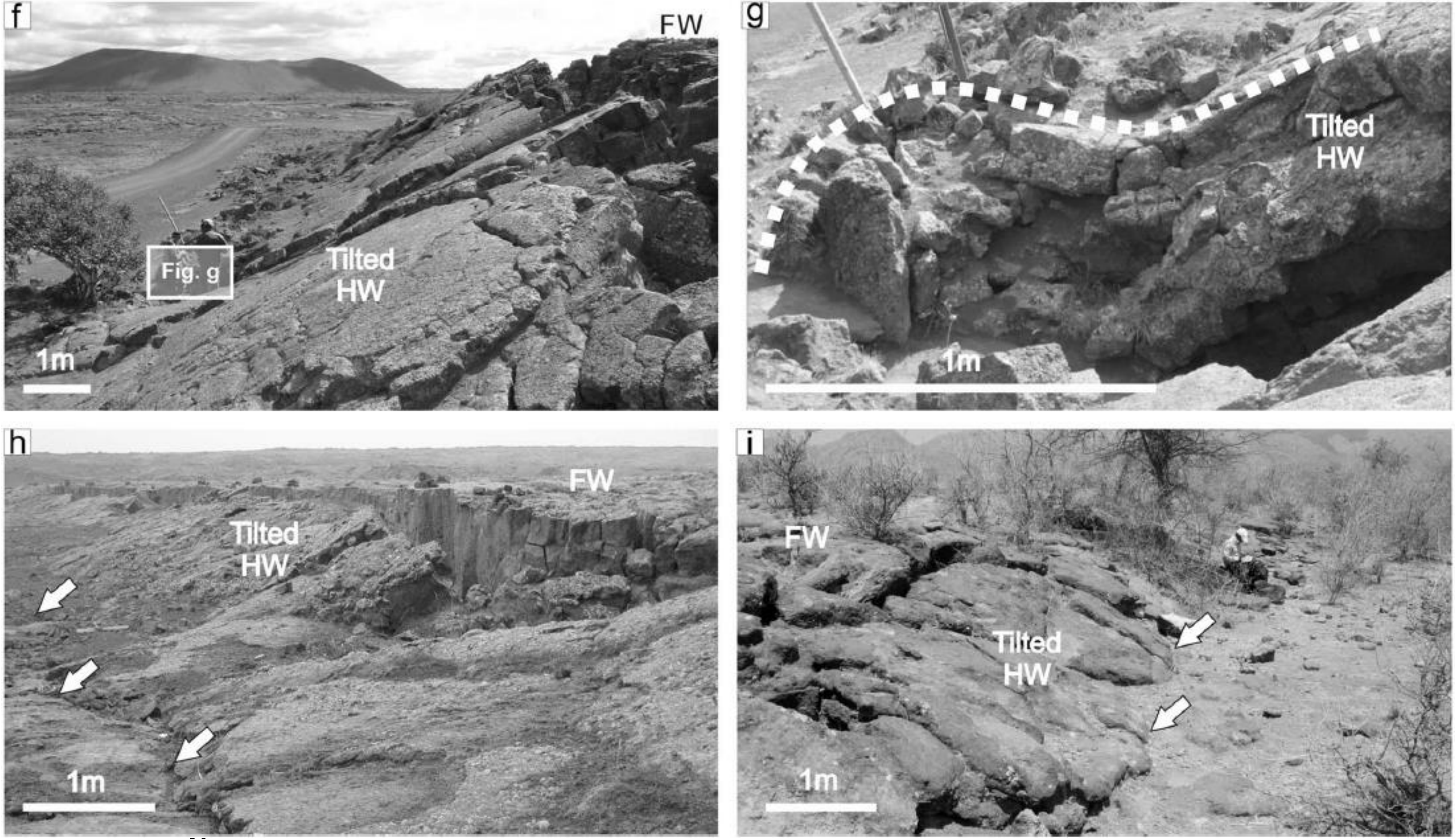
(Gudmundsson et al., 2008)



- Steep reverse fault coeval with dyke emplacement
- Fault-dyke relation is matching very well our modelling results

Dyke-induced reverse faults

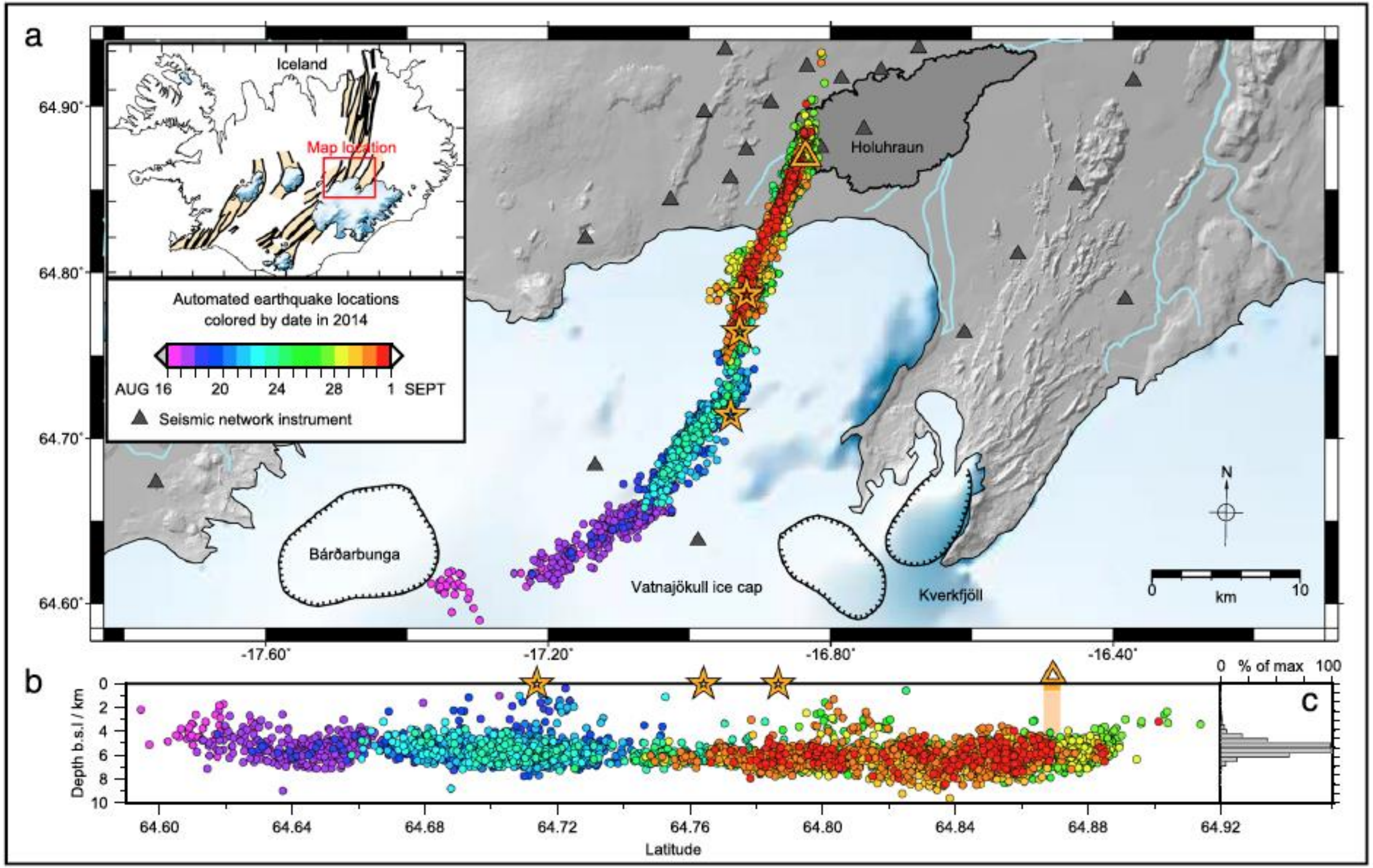
(Trippanera et al., 2014)



results

Dyke-induced shear failure

(Agustsdottir et al., GRL, 2015)

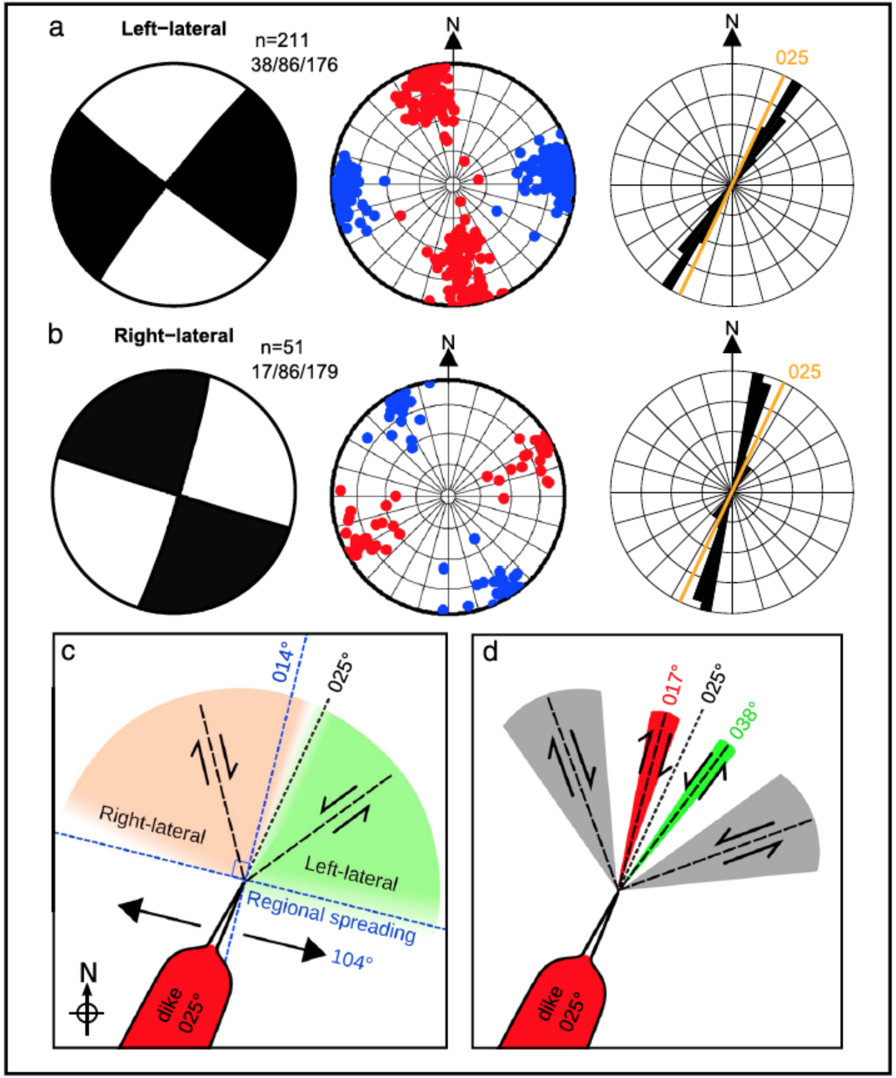


Dyke-induced shear failure

Bárđarbunga
Holuhraun

- Most earthquakes were left-lateral
- Dyke opening was interpreted as non-seismic

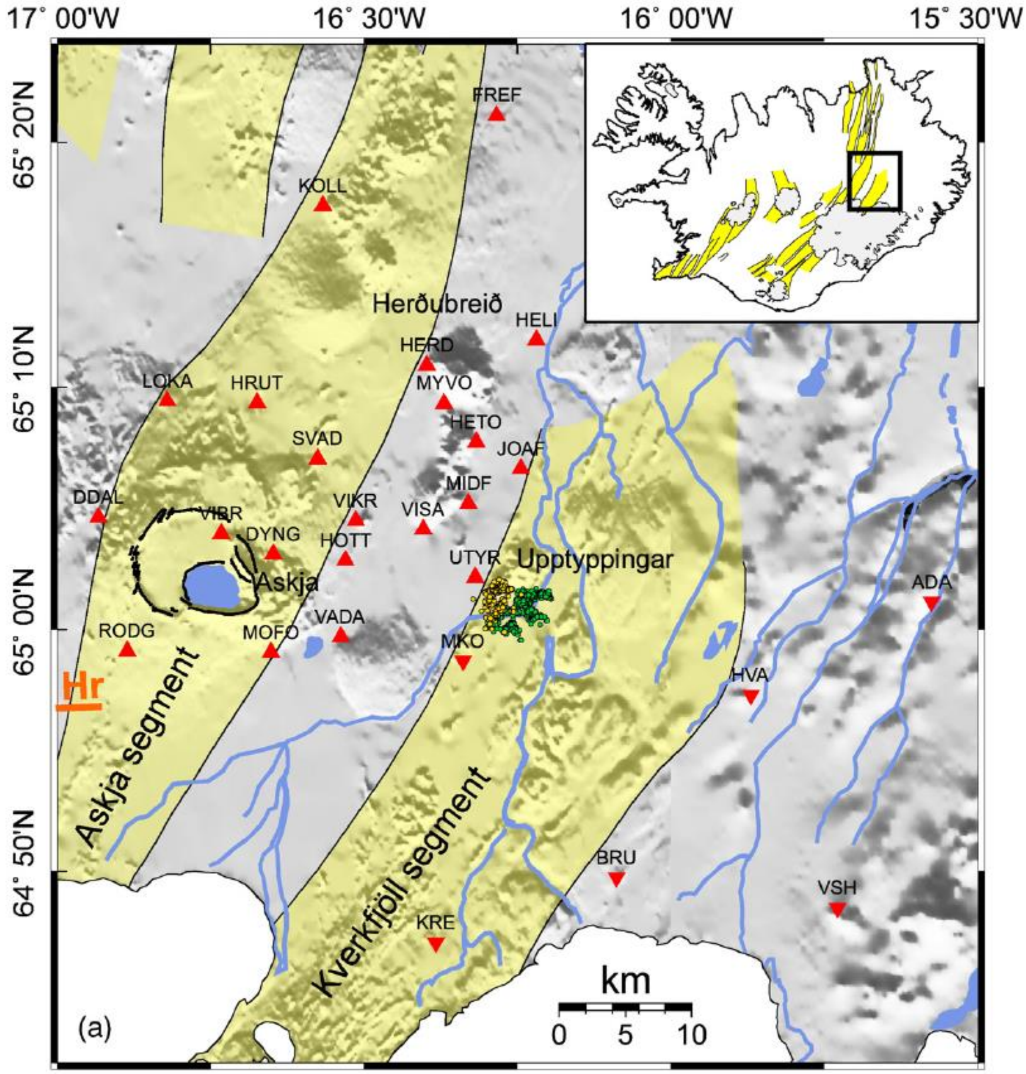
(Agustsdottir et al., GRL, 2015)



Dyke-induced shear failure

Askja Volcano
Iceland

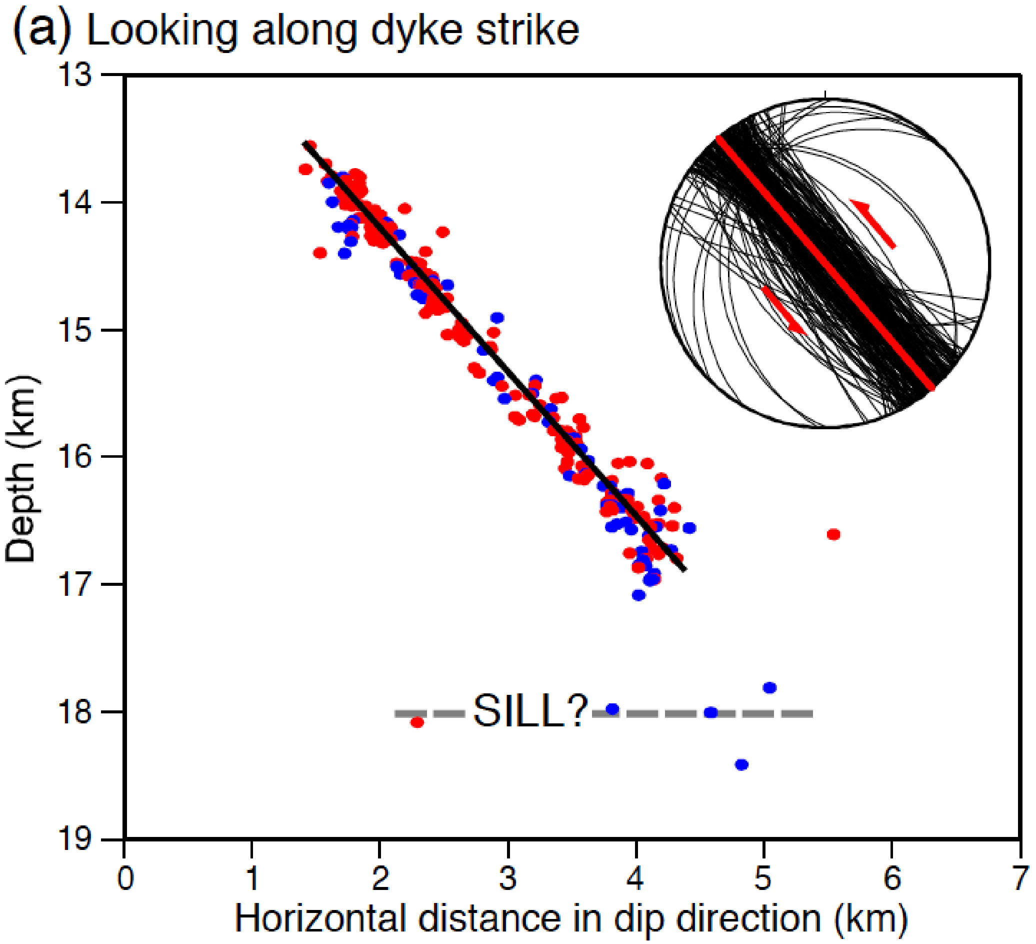
(White et al., EPSL, 2011)



Dyke-induced shear failure

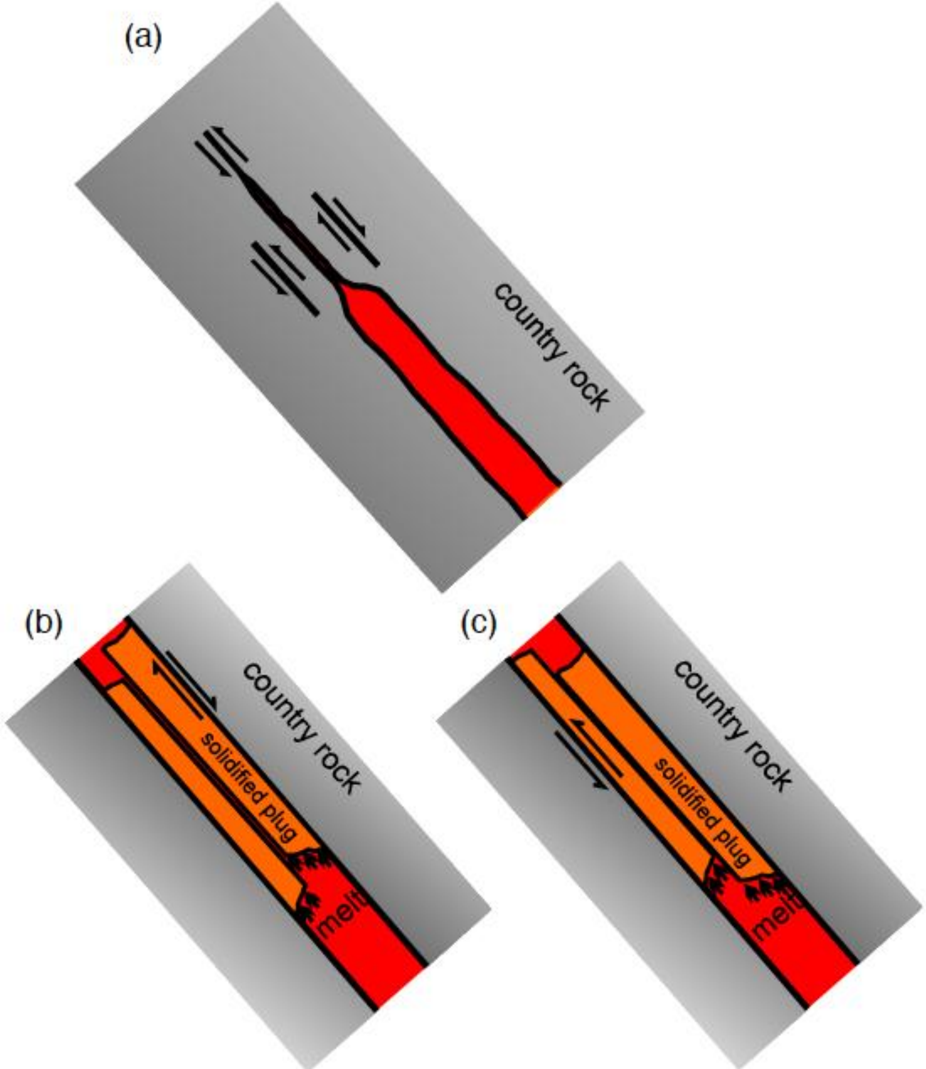
Focal mechanisms: shear parallel to dyke

(White et al., EPSL, 2011)



Dyke-induced shear failure

- Dyke tip pushes ahead
- Solidifies blocks of magma are remobilized



(White et al., EPSL, 2011)