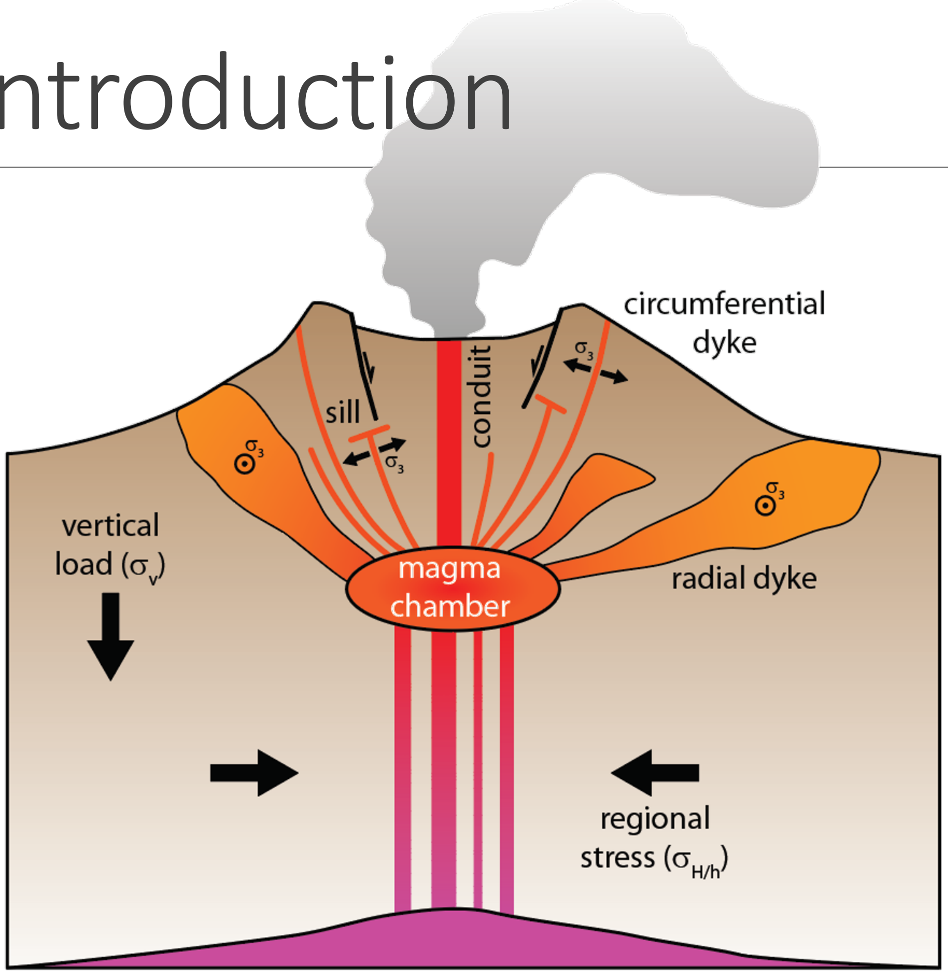
Joint inversion of regional stresses and magma pressures using dyke trajectories

DR. FRANTZ MAERTEN & DR. LAURENT MAERTEN – *YOUWOL GEOSCIENCE, FRANCE*

DR. ROMAIN PLATEAUX – *OPL, TAIWAN*

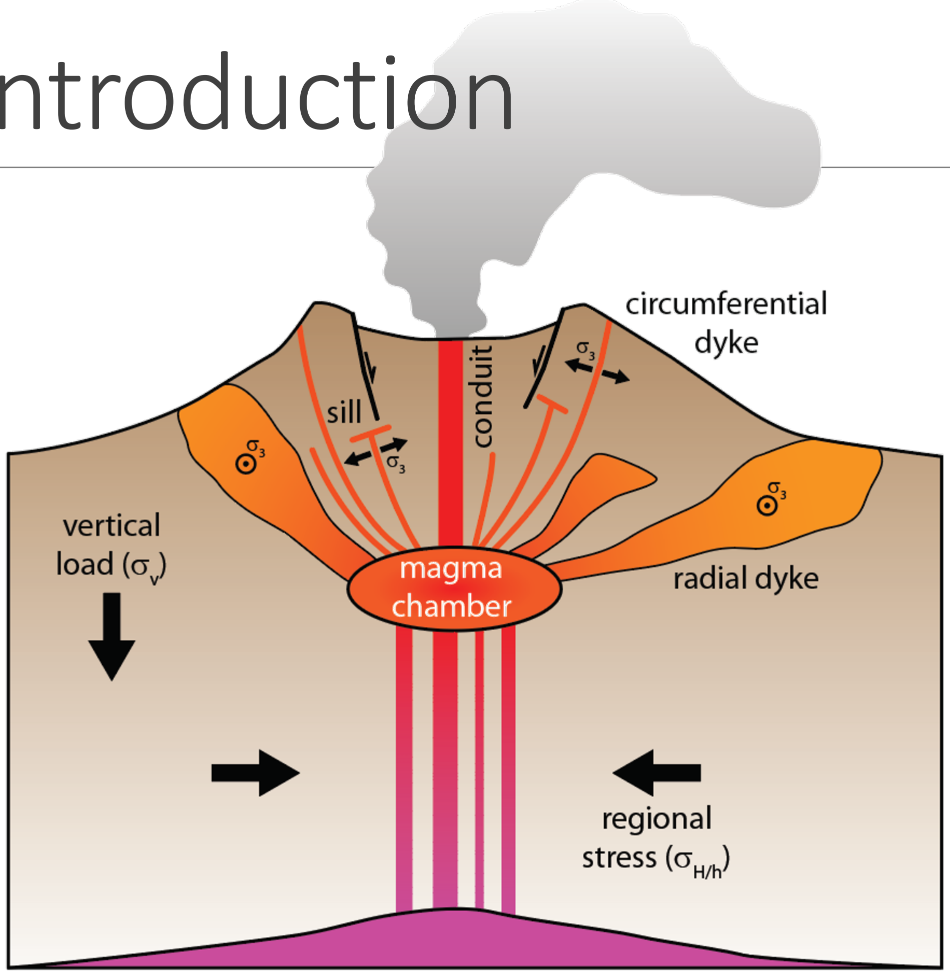
DR. PAULINE CORNARD – *UNIVERSITY OF INNSBRUCK, AUSTRIA*

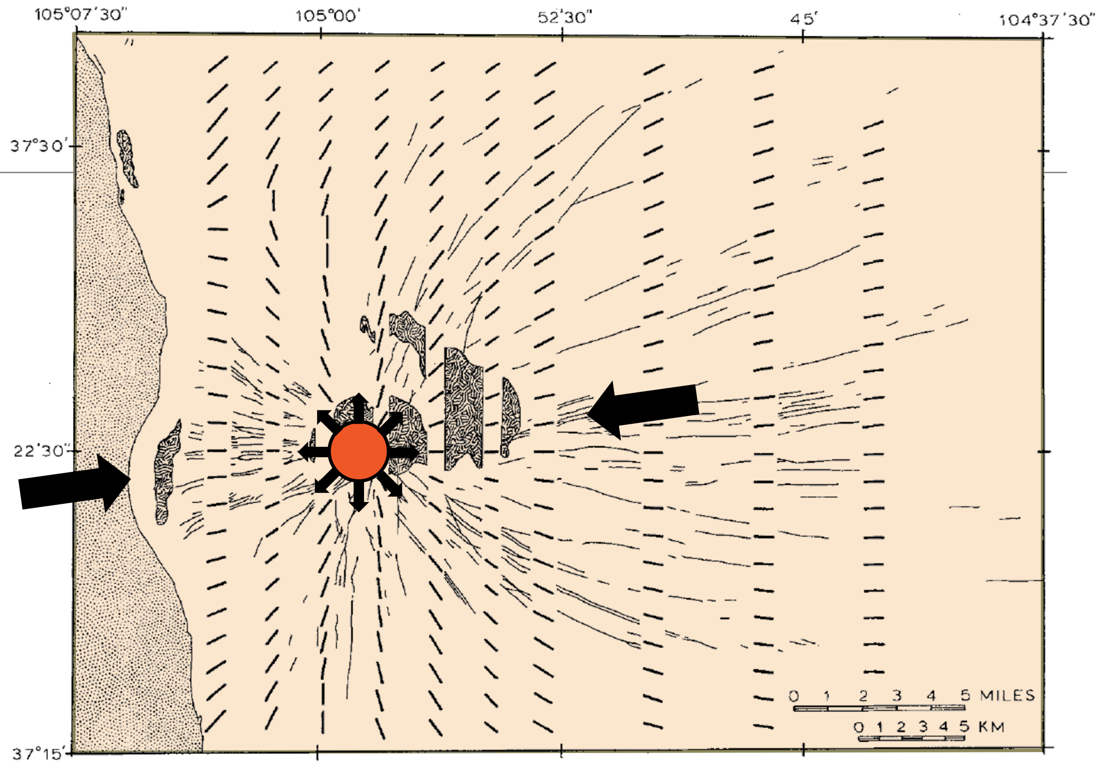
Introduction



Goal:
- Recover regional stresses and magma chamber pressures from observed dykes

Introduction





Spanish Peaks, Colorado, USA (Muller & Pollard, 1977)

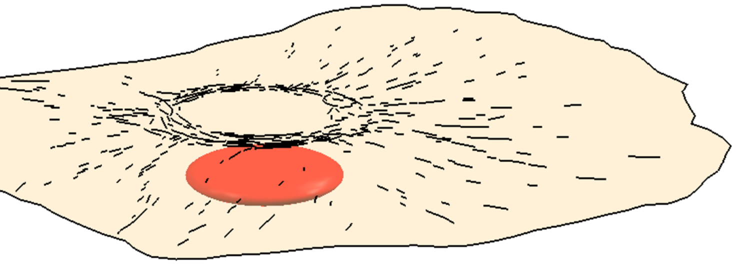
Goal:
- Recover regional stresses and magma chamber pressures from observed dykes

Existing methods:
- Analytic solutions (Ode, 1957; Muller & Pollard, 1977; Baer & Reches, 1991)
  - ➔ Simple geometry
- Classic paleo-stress inversion techniques
  - ➔ Reduced stress tensor, no pressure inversion

Method: 3D multi-parametric inversion

Data

Magma chambers



Dykes

Geometry:

- Location
- Depth, size and shape
- Dyke strike and dip

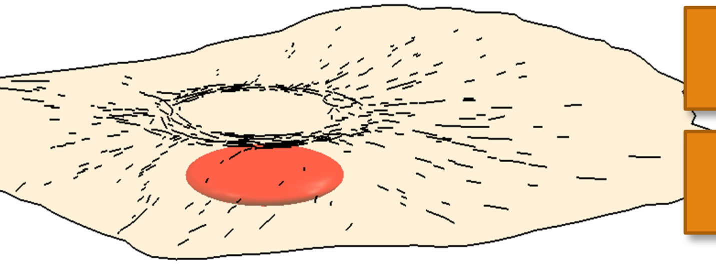
Method: 3D multi-parametric inversion

Data | **Pre-processing**

Magma chambers → e.g. Arch (BEM)

Remote stresses

Pressures



Dykes

Geometry:

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Geomechanical simulations:

- Full stress tensor
- Gravity / half space
- 8+ independent simulations
- Heterogeneity
- Topography
- …

Method: 3D multi-parametric inversion

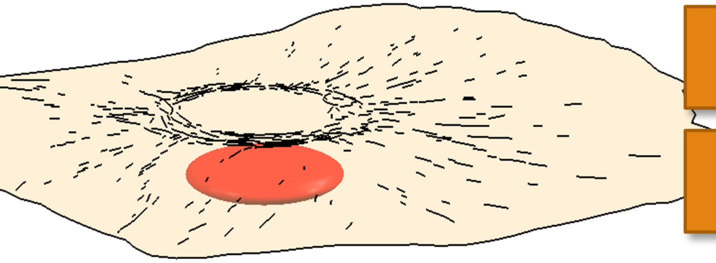
Data | **Pre-processing** | **Inversion**

Magma chambers → e.g. Arch (BEM) → Superposition

Remote stresses

Pressures

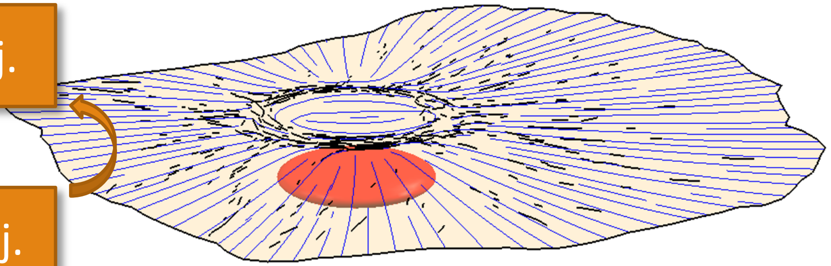
e.g., Monte Carlo



Dykes → Observed dykes traj.

objective function(s)

Perturbed stress traj.



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Perturbed stress:
- Regional stresses
- Magma pressures
- Magma chamber mechanical interactions

Method: 3D multi-parametric inversion

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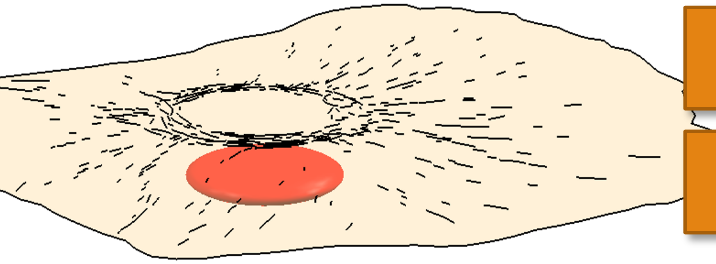
Magma chambers



Dykes

Pre-processing

e.g. Arch (BEM)

Remote stresses

Pressures

Inversion

Superposition

e.g., Monte Carlo

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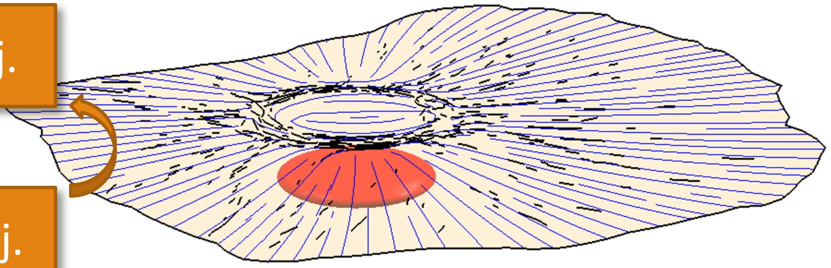
Perturbed stress traj.

Results

Regional stresses σ

Excess pressures p_e



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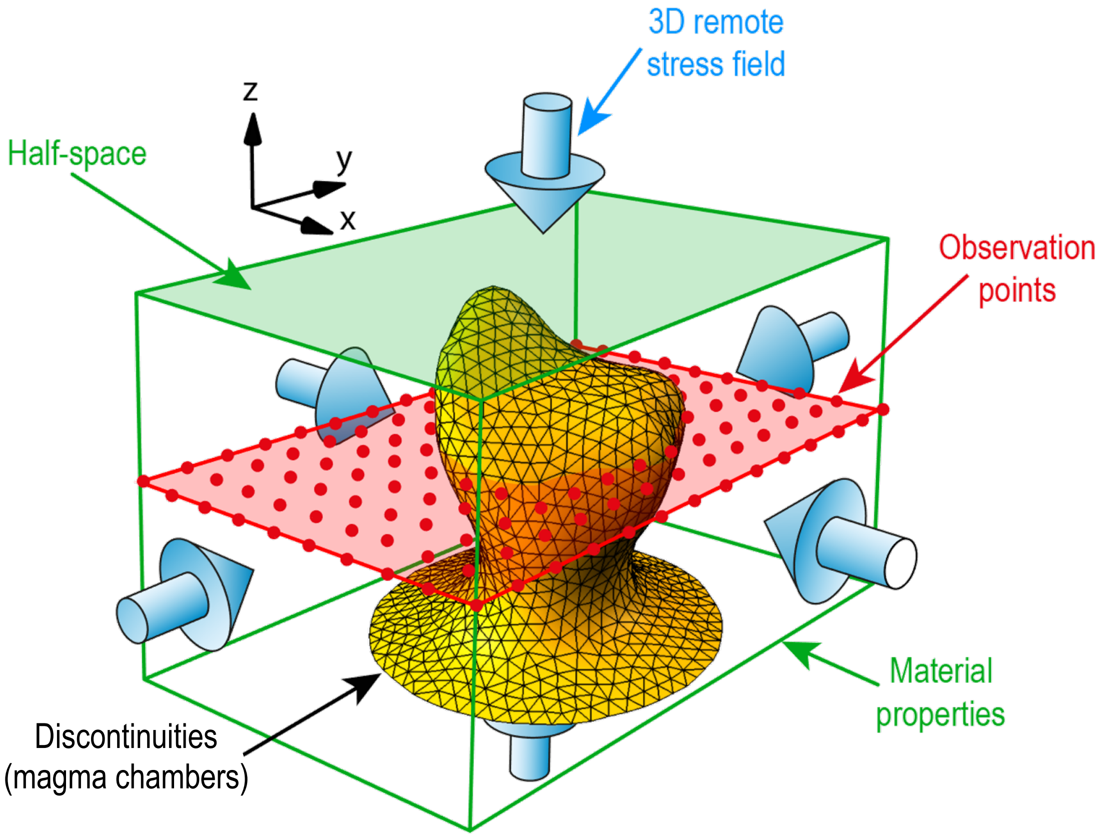
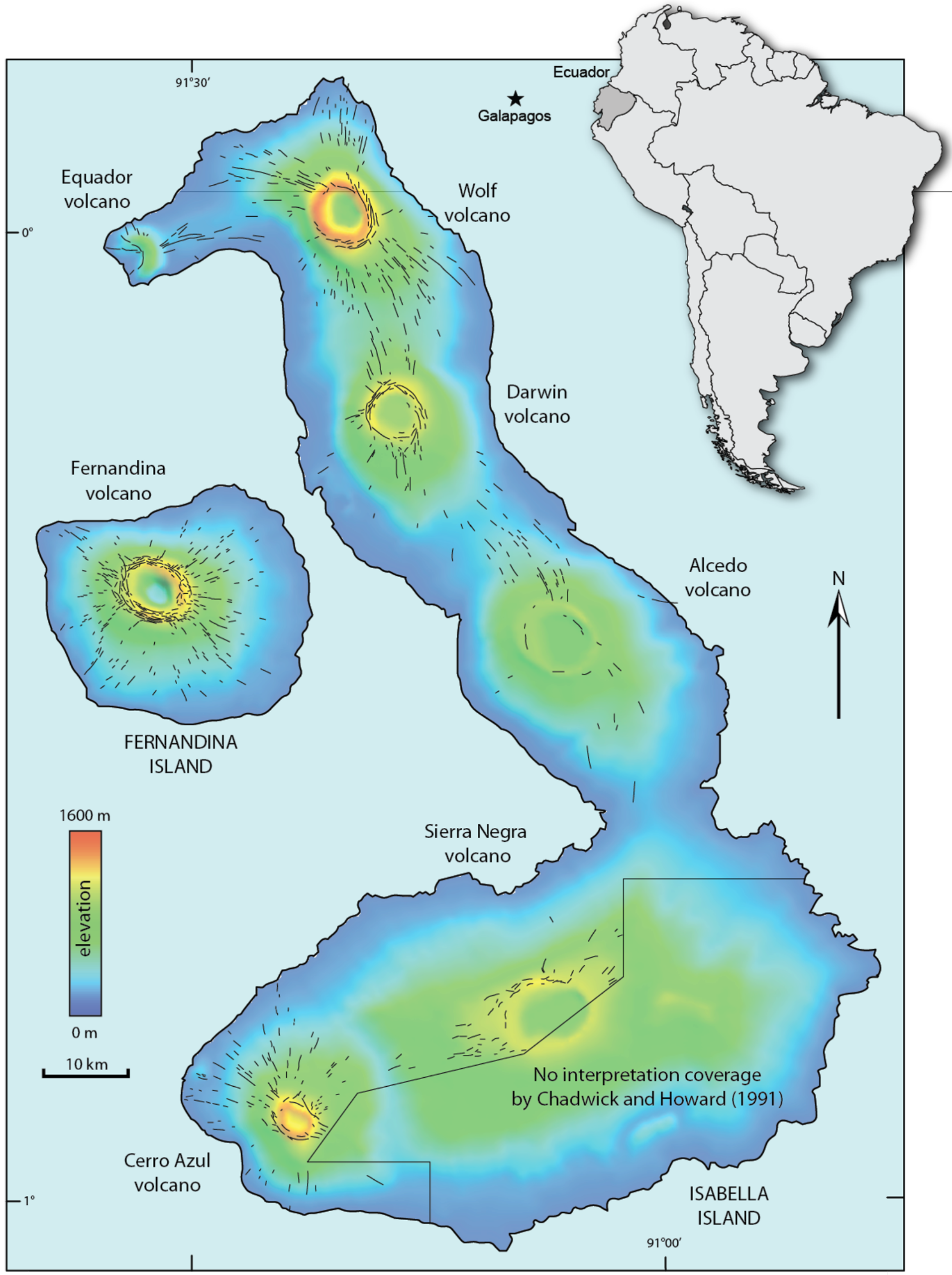
Method: Arch – 3D geomechanical modeling

Principle

- <u>3D</u> boundary element method (BEM)
- Only boundary surfaces are modeled as triangulated surfaces of any shape (fractures, faults, <u>magma chambers</u>, salt bodies, cavities, etc.)
- Heterogeneous <u>elastic</u> medium
- 3D remote stress or strain
- Computed displacements, strains and stresses anywhere in space

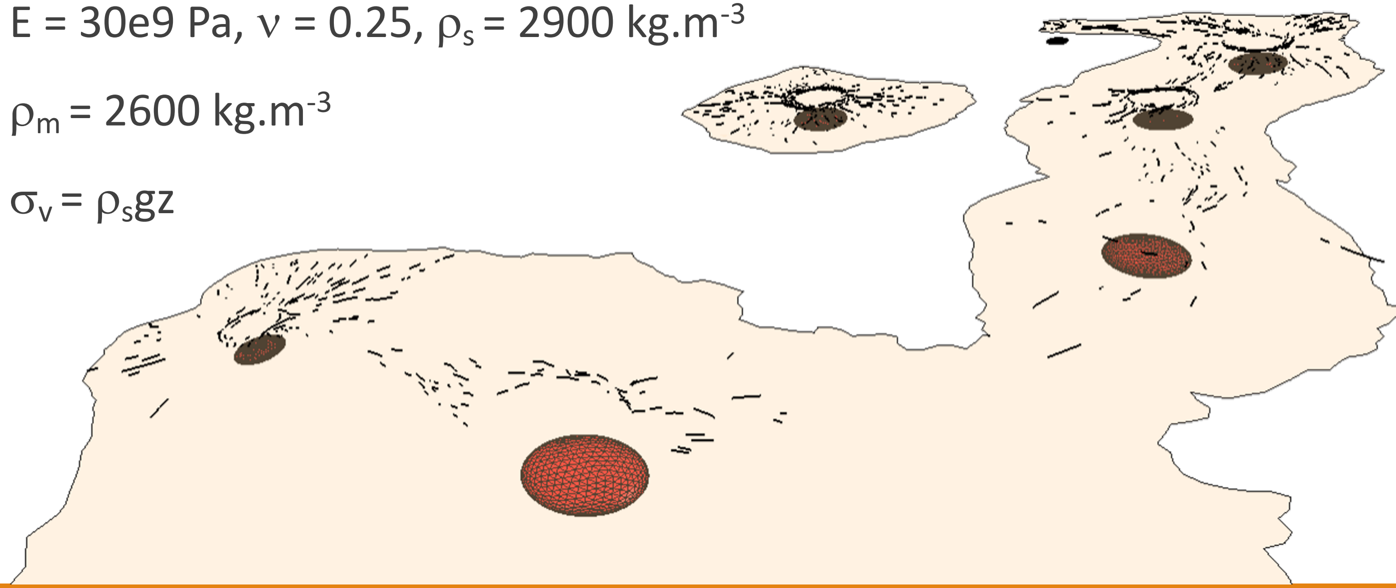
Boundary element method (BEM)

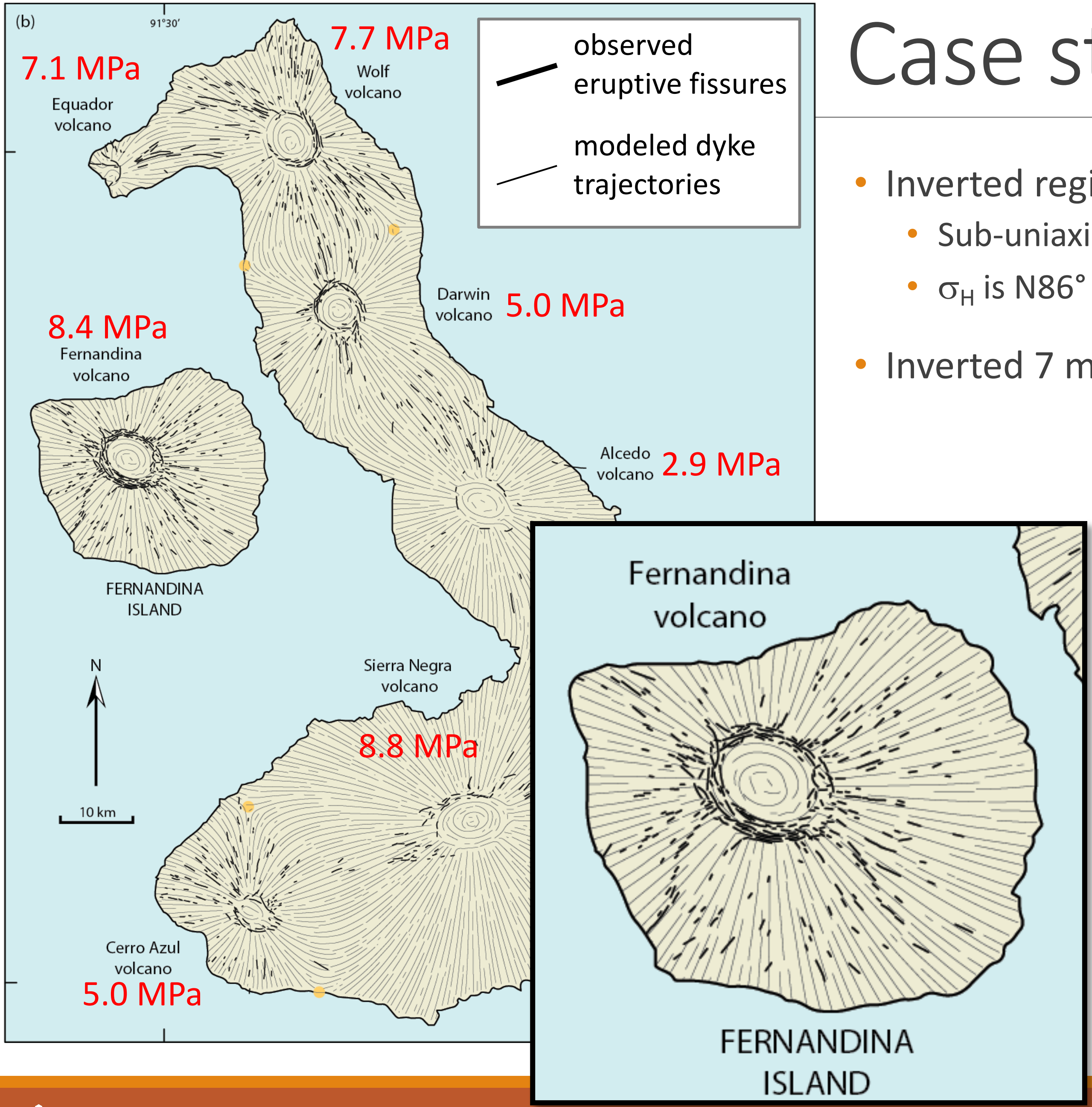




Case study: Galapagos Islands

- Observed traces of eruptive circumferential and radial fissures around volcanoes (*Chadwick and Howard, 1991*)
- Contemporaneous volcanoes at geological scale (*Chadwick & Dieterich, 1995*)
- Ellipsoidal magma chambers, top depth -2000 m (*Chestler & Grosfils, 2013*)
- Invert for 7 different volcano magma pressures
- Invert for regional stresses
- $E = 30e9$ Pa, $\nu = 0.25$, $\rho_s = 2900$ kg.m^{-3}
- $\rho_m = 2600$ kg.m^{-3}
- $\sigma_v = \rho_s g z$

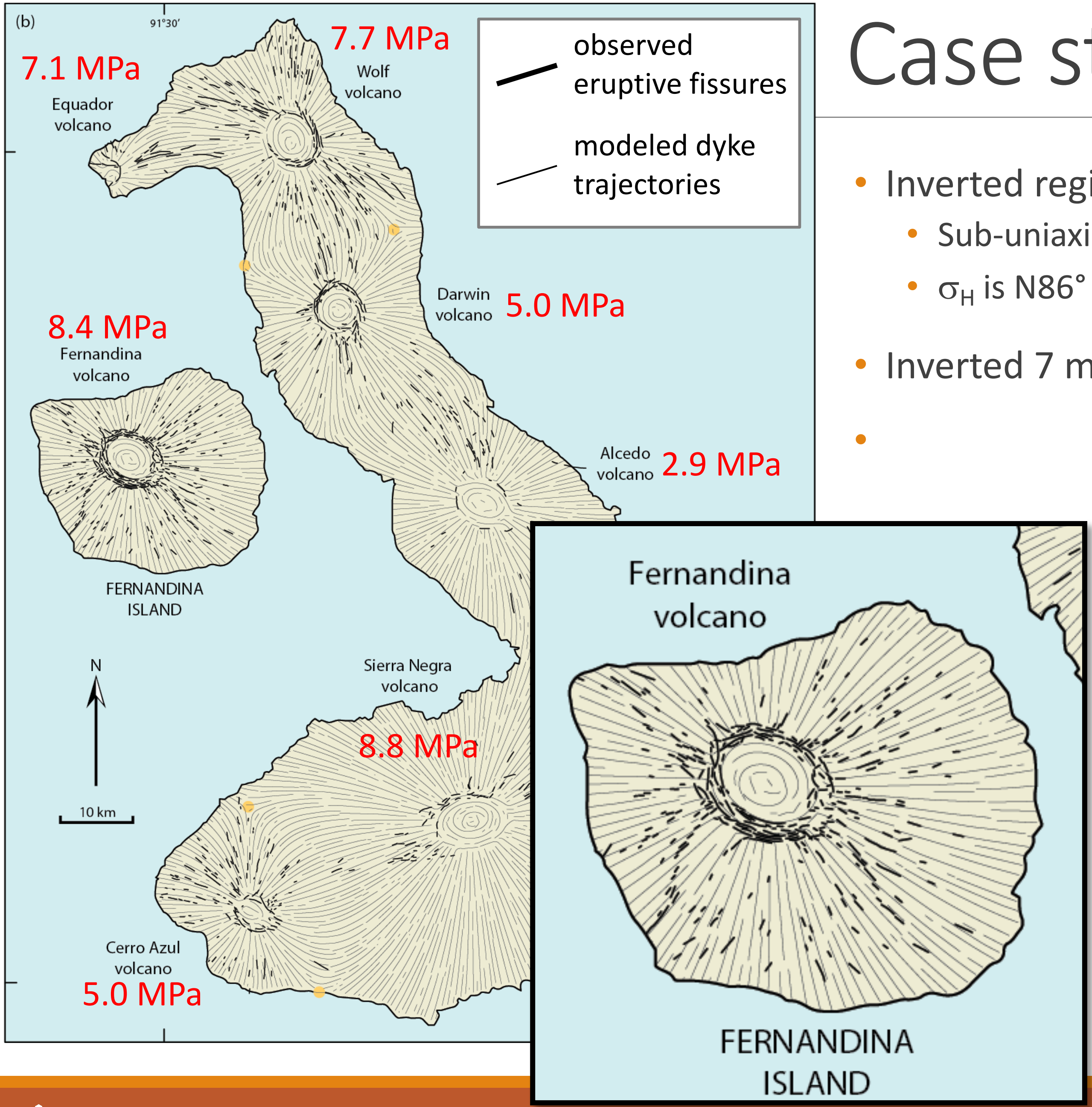




Case study: Galapagos Islands

- Inverted regional stresses:
  - Sub-uniaxial normal stress regime ($\sigma_h \approx \sigma_H$)
  - σ_H is N86°
- Inverted 7 magma pressures (see figure)

Computation time:
12mn



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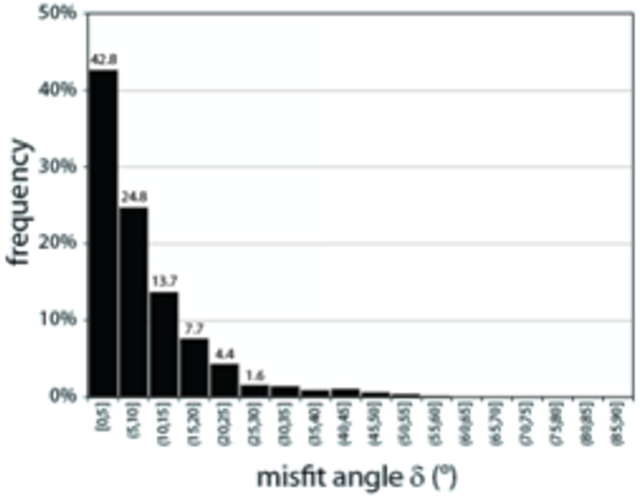
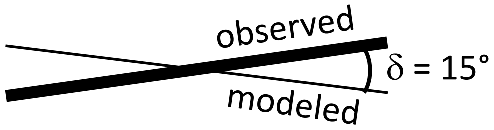


Misfit angle (δ)



- 81% ($\delta < 15°$) of the observed eruptive fissures can be geomechanically explained with the inverted parameters

Conclusions

- Method inverts for both the far field stress (past or present) and multiple pressures and densities.
- Any type of data can be used and combined to constrain the inversion (fractures, GPS, InSAR, focal mechanism, in-situ stress, …).
- Models are simple to build (only 3D triangulated surfaces).
- Method is based on 3D geomechanical modeling.
- Method is as fast as classical stress inversion methods.

Thank you

- **Maerten, F.**, 2010. *Geomechanics to solve geological structure issues: forward, inverse and restoration modeling* (Doctoral dissertation, UNIVERSITE MONTPELLIER II SCIENCES ET TECHNIQUES DU LANGUEDOC).
- **Maerten, F., Madden, E.H., Pollard, D.D. and Maerten, L.**, 2016. *Incorporating fault mechanics into inversions of aftershock data for the regional remote stress, with application to the 1992 Landers, California earthquake*. Tectonophysics, 674, pp.52-64.
- **Maerten, L., Maerten, F., Lejri, M. and Gillespie, P.**, 2016. *Geomechanical paleostress inversion using fracture data*. Journal of structural Geology, 89, pp.197-213.
- **Maerten, F., Maerten, L., Plateaux, R., Cornard, P.,** 2022, *Joint inversion of tectonic stress and magma pressures using dyke trajectories. Submitted in Geological Magazine*