From permanent flank sliding to catastrophic collapse and explosive eruptions at basaltic volcanoes: the role of shallow intrusive magma bodies

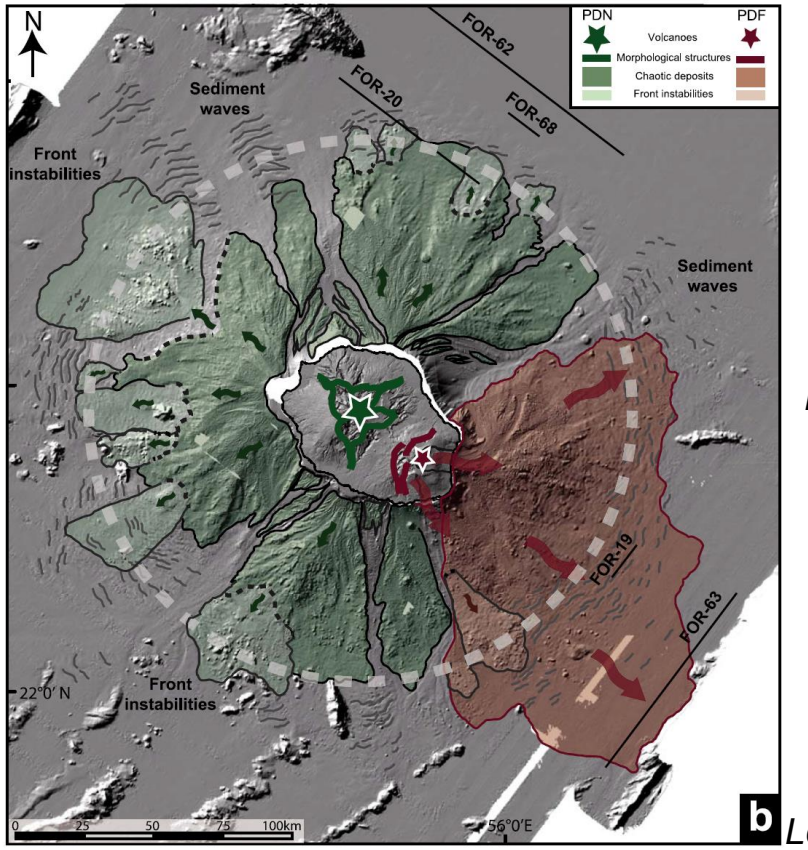
Andrea DI MURO, Fabian SCHWARZLMÜLLER, Ulrich KUEPPERS, Michael HEAP and Donald DINGWELL

the virtual EGU 2021 conference

Deformation and collapse of intraplate basaltic volcanoes

La Réunion – Indian ocean

Piton des Neiges – quiescent



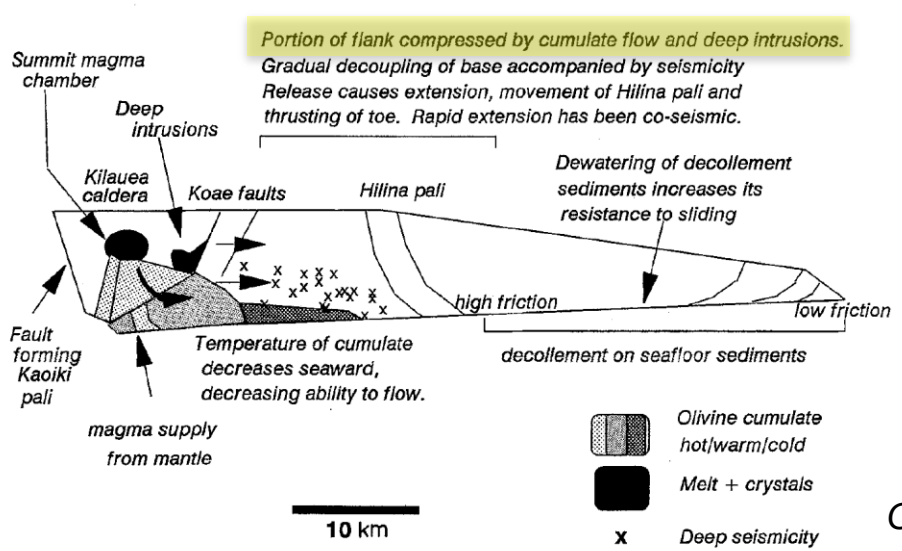
Piton de la Fournaise – active

Le Friant et al., GRL, 2011

Intraplate volcanoes are affected by a **range of mass movement processes**, ranging from near steady state spreading/sliding to large volume slumps to far-traveling catastrophic collapses.

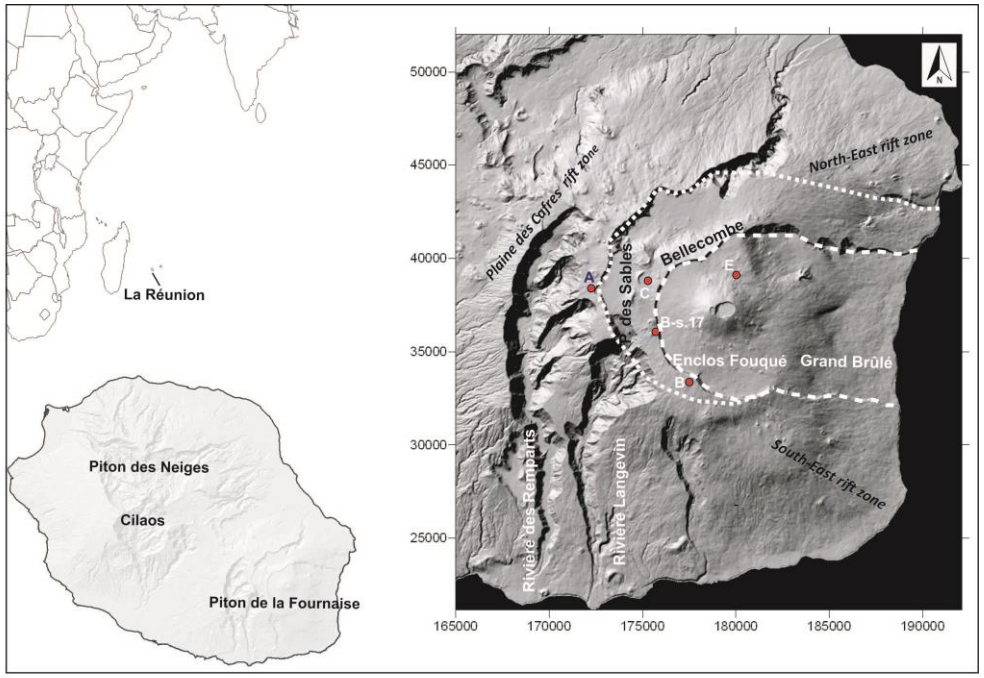
Processes leading to the collapse of Hawaiian volcanoes

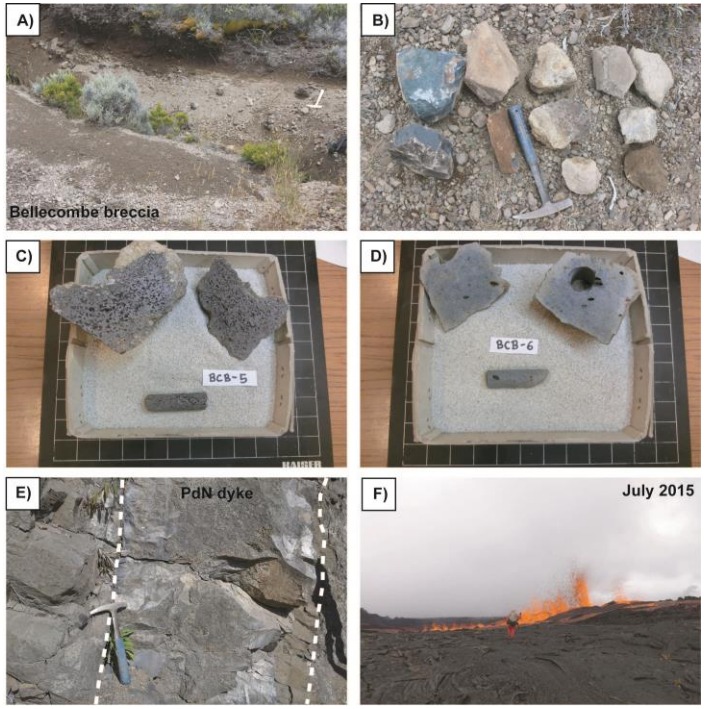
- The majority of **material** recovered from slumps of Hawaiian volcanoes was **erupted above sea level**.
- A link is observed between **phases of high eruption/intrusion** and lava accumulation rates and deformation
- Several possible **ductile layers**: sediments on oceanic plate, hydrothermally altered lavas, **dense dunite bodies**
- **Question**: is there a general link between magma storage and transfer and volcano instabilities?



Clague and Denlinger, BV, 1994

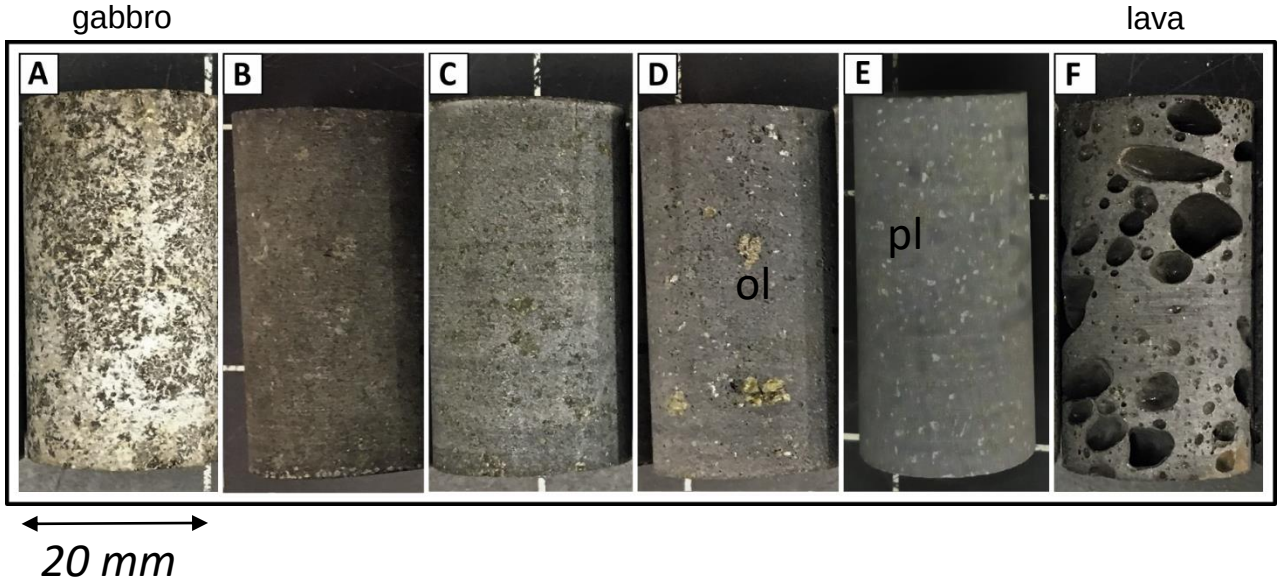
Sampling of PdF caldera-related explosive breccias

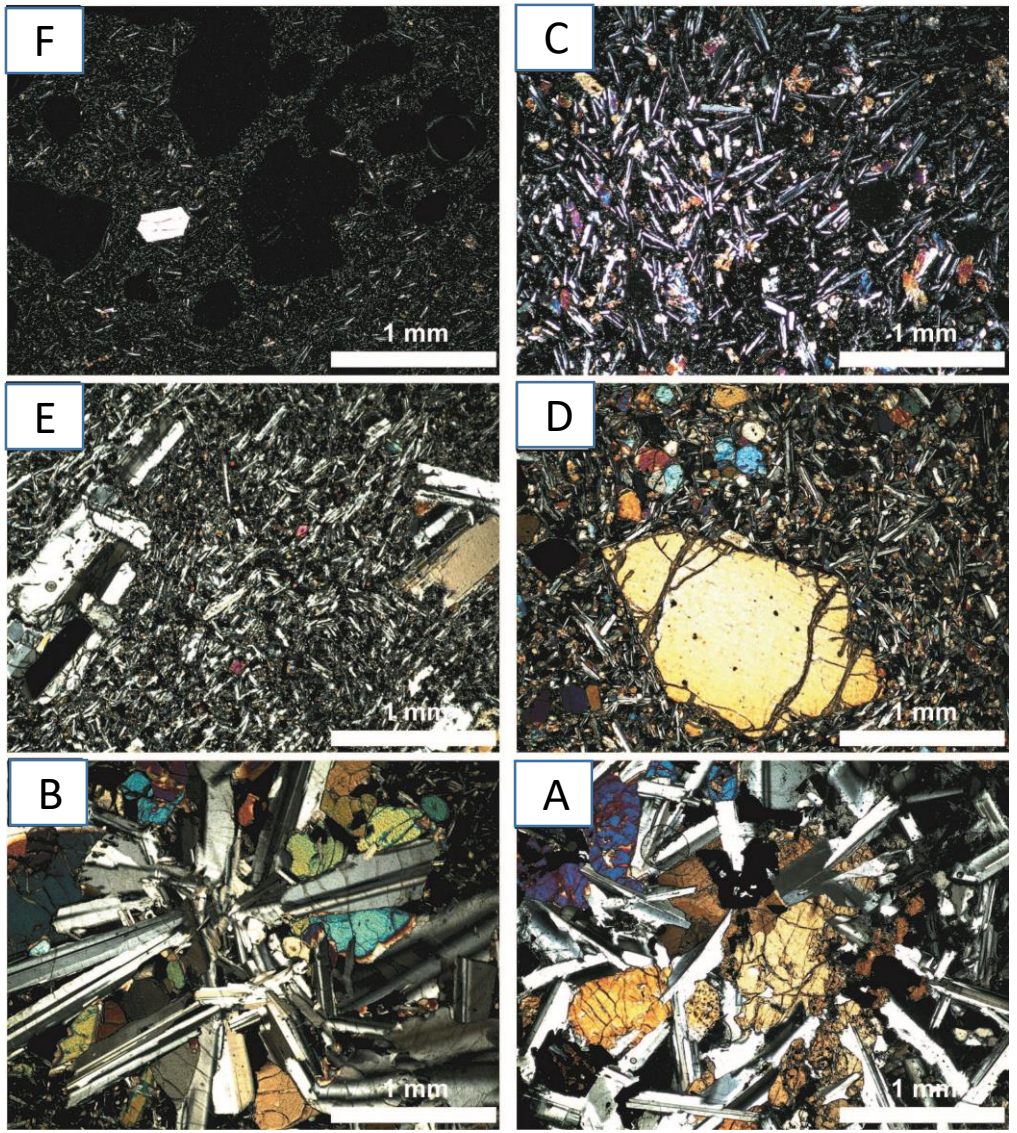




- Dm-sized basaltic blocks from the **most recent breccias** (Bellecombe-5kyrs; Plaine des Sables-65kyrs);
- Focus on **unaltered samples** (low proportion of altered clasts in the breccia);
- **Reference samples** from exposed dykes and modern lavas;

Large petrological heterogeneity of caldera-related explosive breccias





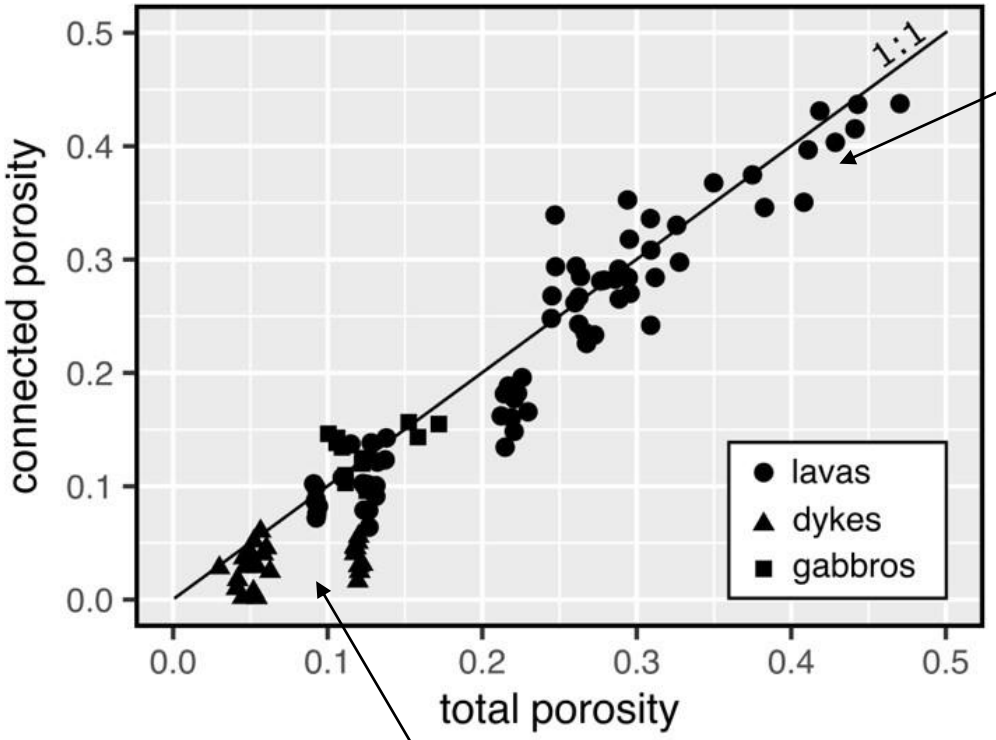
effusive

- Aphyric and cotectic (ol+cpx+pl) vesicular lavas
- Porphyritic dense lavas (ol; pl +/- cpx)

intrusive

- **Dolerites (ol-pl variolitic micro-troctolite)**
- **Fine-grained gabbros (ol-cpx)**
- **Minor dunite**

Large physical heterogeneity of caldera related explosive breccias

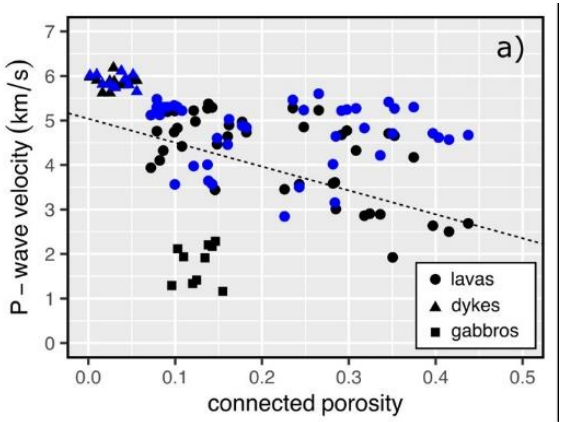


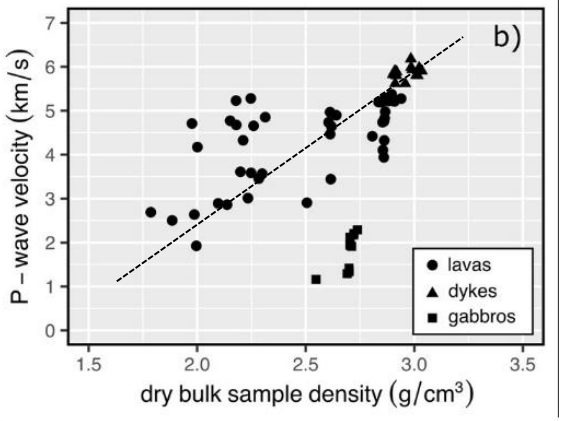
Typical range of modern lavas: vesicles

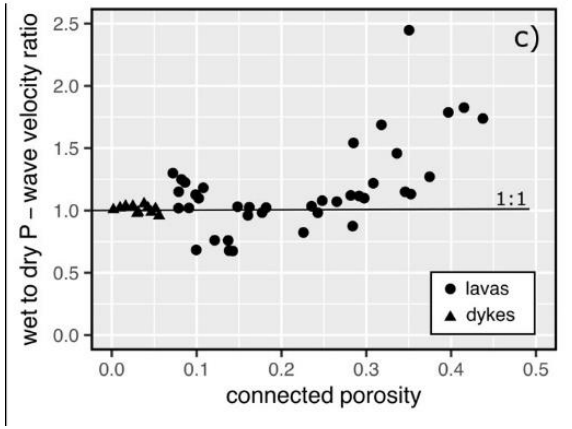
- **Breccias permit to document the full range of rock porosity produced by effusive and intrusive activity.**

Dense shallow intrusives (dolerite; gabbro): microcracks

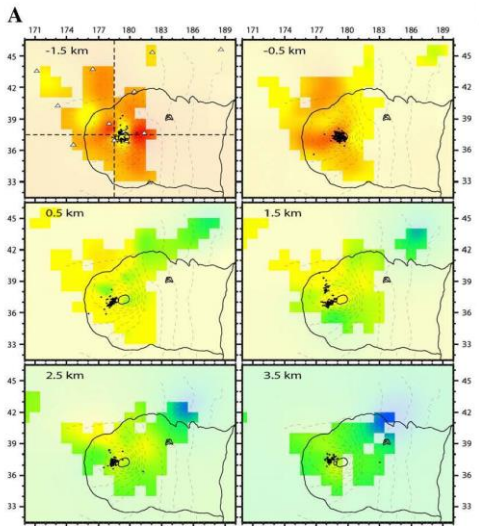
Wet and dry P-wave velocity

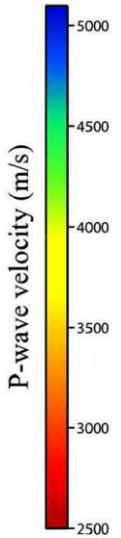


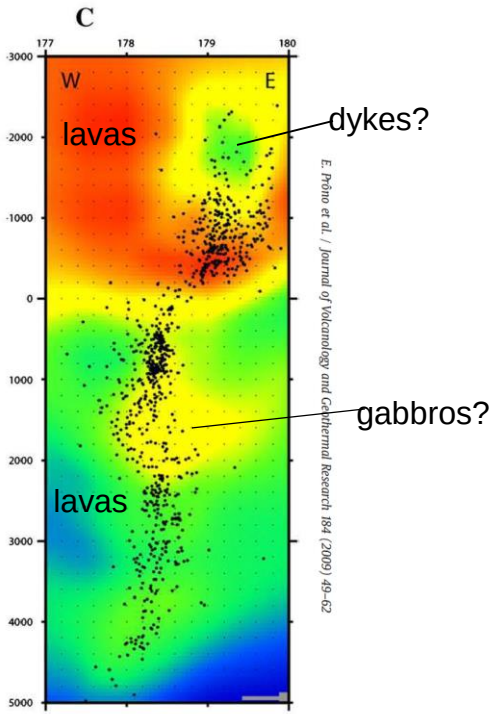




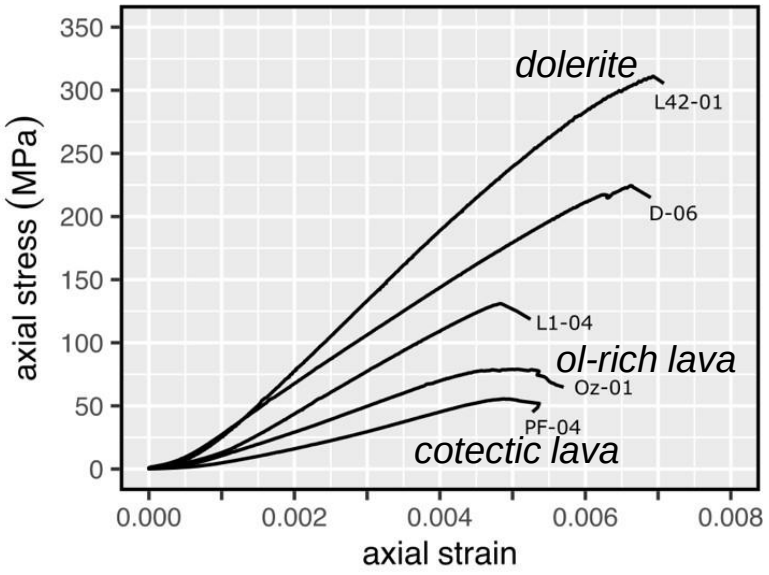
- P-wave velocity increases from vesicular aphyric lavas to dense ol-rich lavas to fine-grained dense dolerites;
- Scattering in vesicular lavas poorly correlated with modal mineralogy;
- **Water saturation increases P-wave velocity in vesicular lavas (>0.25);**
- **Low seismic velocity of our gabbros;**

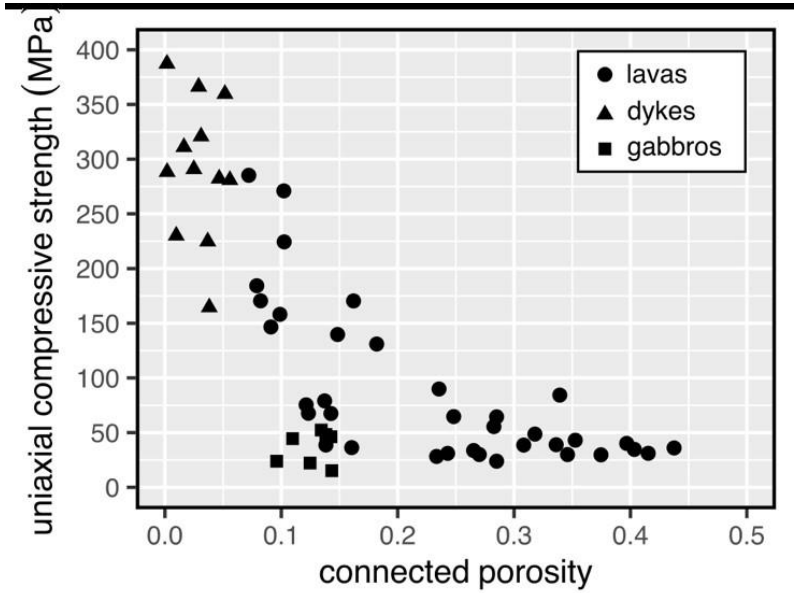






Uniaxial compressive strength (UCS)

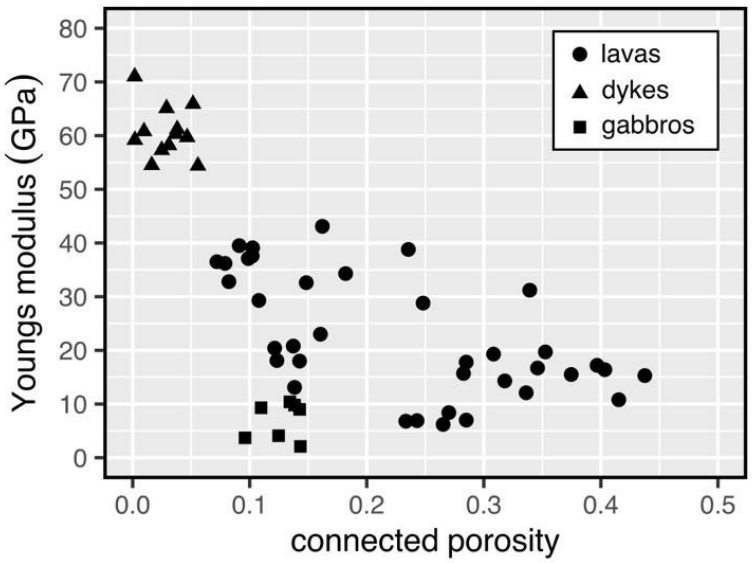




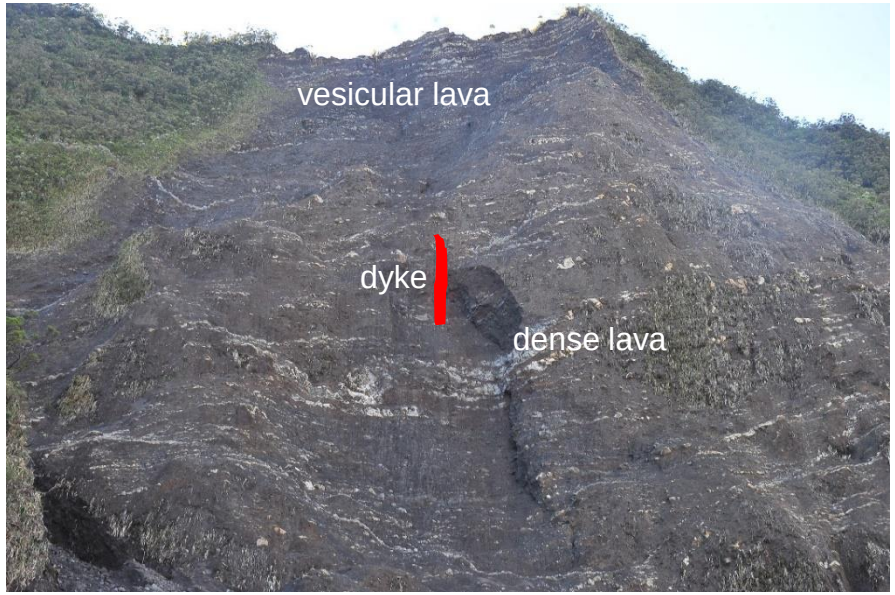
- Very large range in UCS;
- UCS decreases with increasing vesicularity from fine-grained dolerite dykes to vesicular lavas;
- **Unexpected low UCS in gabbros (abundant micro-cracks and cpx-pl cleavages)**;

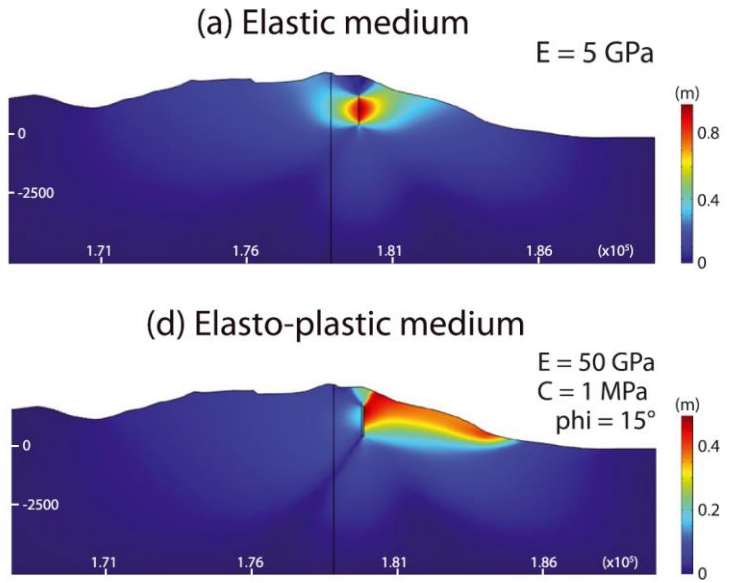
Consistent with properties of gabbro slowly heated to 1000°C (Keshavarz et al., P.A.G, 2010)

Young's modulus



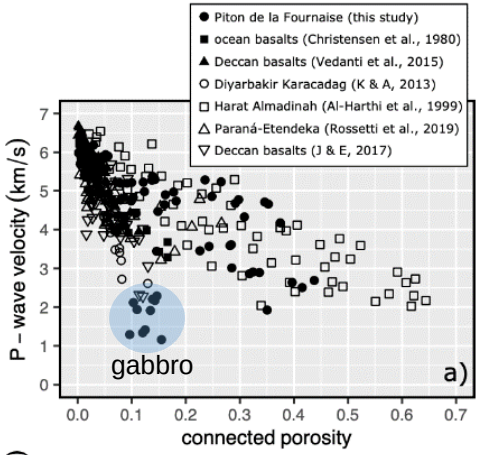
- Young's modulus decreases with increasing porosity;
- Seawards sliding PdF flank formed by alternation of vesicular and dense lavas + subvertical dense dykes (dolerites); drilling shows that the lava piles lies on a km-thick unit of layered gabbros;
- Medium properties range from elastic (low-Y) to elasto-plastic (high-Y) and can deform without collapsing;

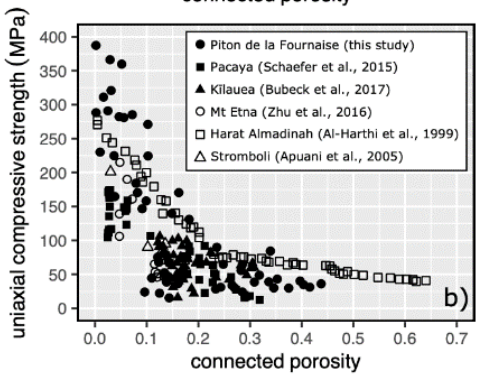


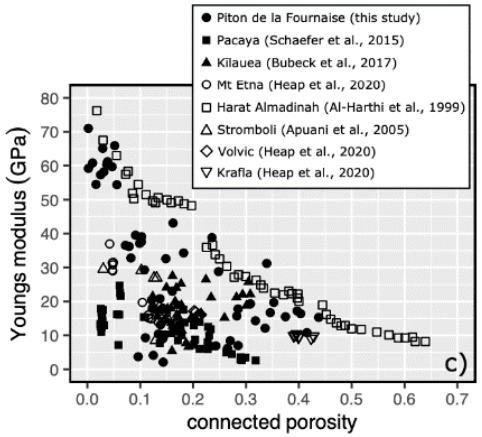


Got et al., JGR, 2013

Physical properties of basaltic volcanoes

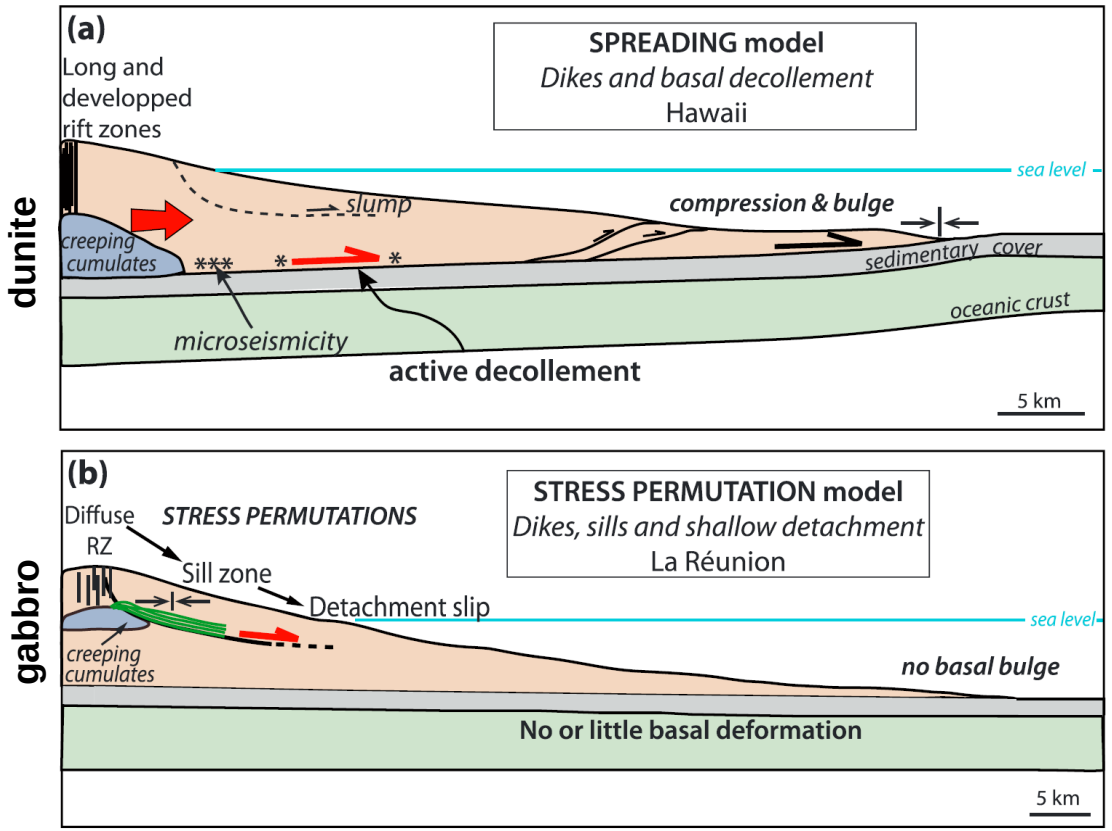






- **Large range in porosity** (from vesicular and dense lavas to dense dykes and gabbros) control the variability in basaltic rock properties;
- Complex link with modal lava composition and phenocryst size/content**;**
- **No need of extensive hydrothermal alteration to produce large heterogeneities and jump in physical properties in basaltic volcanoes**;
- **Unexpected weak behaviour** (low P-wave, low UCS, low Young modulus) **of shallow intrusive bodies (gabbros): influence of heating cycles on mineral oxydation, high micro-crack density and expansion of fluid inclusions;**

Sliding and collapse of intraplate basaltic volcanoes



Chaput et al., JGR, 2014

- Evolved basalt composition and **shallow magma storage** (close to sea level) **at Piton de la Fournaise**: gabbros instead of dunites (Hawaii);
- Dissected Piton des Neiges outcrops shows detachment related to **repeated sill injection on the gabbro-lava interface (jump in petro-physical properties)**;
- **Possible role of gabbro weakening in promoting transition from slow sliding to catastrophic collapse**;

THANK YOU FOR LISTENING!!

VOLCANICA

Petrophysical characterization of volcanic ejecta to constrain subsurface lithological heterogeneities: implications for edifice stability at basaltic volcanoes

Andrea Di Muro*[1,2], Fabian Schwarzlmueller[2,3], Ulrich Kueppers[3], Michael Heap[4], and Donald B. Dingwell[3]

[1]*Université de Paris, Institut de physique du globe de Paris, CNRS, F-75005 Paris, France*
[2]*Observatoire volcanologique du Piton de la Fournaise, Institut de physique du globe de Paris, F-97418 La Plaine des Cafres, France*
[3]*Department of Earth and Environmental Sciences, Ludwig-Maximilians-Universität München, Theresienstraße 41, 80333 Munich, Germany*
[4]*Université de Strasbourg, CNRS, ENGEES, Institut Terre et Environnement de Strasbourg, UMR 7063, 5 rue René Descartes, Strasbourg F-67084, France*

Abstract

Piton de la Fournaise (PdF) is an active basaltic volcano whose eruptive activity is predominantly characterized by frequent effusive to mildly explosive (Hawaiian-Strombolian) eruptions. The geologic record also preserves evidence of less frequent, major explosive eruptions, typically associated with the seaward sliding of the steep east flank. Such eruptions formed calderas that are several km in diameter and their products have been emplaced as proximal pyroclastic breccias and medial fall deposits dispersed over tens of km. Such rare yet recurrent highly explosive events at volcanoes exhibiting predominantly effusive behavior are accruing increasingly more attention. The breccias of PdF offer the unique opportunity to sample a wide range of different crustal lithologies covering most of the litho-stratigraphy of La Réunion edifice. In the framework of the national project "SlideVOLC", funded by the National Research Agency of France (ANR), a petrological and petrophysical characterization of 14 different effusive and intrusive lithologies has been conducted. Petrological analysis of samples from the Plaine des Sables and Bellecombe breccias (deposits relating to the main recent explosive events related to volcano destabilization) reveal a large range of fresh to weakly altered basaltic lithologies, encompassing plutonic (fine to medium grained gabbros), sub-volcanic (fine-grained dolerites emplaced in sills and dykes), and volcanic (lavas with variable vesicularity and porphyricity) units. Petrophysical measurements revealed a corresponding variability in density, porosity, P-wave velocity (dry and wet), and uniaxial compressive strength (UCS), confirming the petrophysical consequences of the lithological diversity of PdF. The large variation in P-wave velocity and UCS is interpreted to be the result of the wide ranges in texture (porosity/vesicularity) and lithology. Notably, some of the dense gabbroic units that have remained intact despite likely having experienced several natural cycles of reheating are comparatively weak. Different lithologies cannot simply be distinguished solely on the basis of their physical properties. We infer that volcano instability should not be interpreted solely in terms of altered (hydrothermalised) rock units. Rather, the large petrophysical heterogeneity of crustal rocks at PdF, and by inference likely at many other volcanoes, must be considered when interpreting monitoring data and assessing potential hazards related to volcano stability.

And thank you to ANR « SlideVolc » and CAS (LMU) for financial support