Ten years of extensometry at Soufrière of Guadeloupe: New constraints on the hydrothermal system

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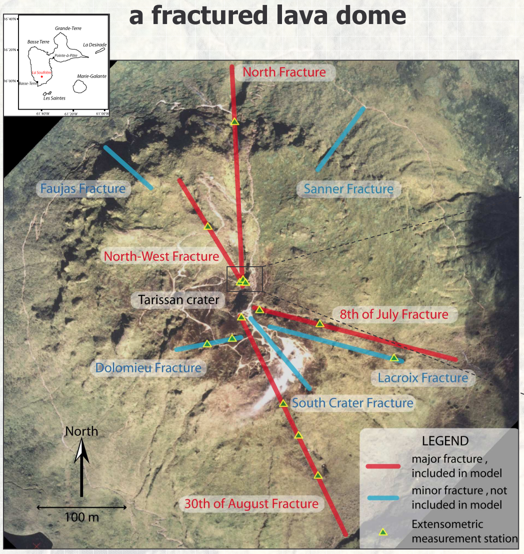
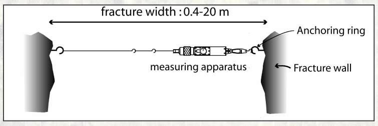
Abstract

Since 1995, the displacement field has been monitored on the lava dome's fractures at Soufrière of Guadeloupe volcano, using manual extensometry on 12 sites and five main radial fractures. In this study we analyse the data on four of the most important fractures: the North-west fracture, the North fracture, the 30th of August fracture and the 8th of July fracture, totalizing 7 stations. Three main trends are observed: (1) a period of extension from 1995 to 1999, (2) a period of contraction from 1999 to 2004, and (3) a new period of extension from 2004 until present. Given the small scale of these displacements, less than 2 cm, and given the real three dimensional context, we have used for modelling an elastostatic boundary elements code that takes into account 3-D topography, fractures and complex pressure source geometry: the mixed boundary element method (MBEM). Based on the hydrothermal activity of the volcano and recent results in electrical tomography, main source of displacements can be accounted by a hydrothermal reservoir undertaking pressure changes. Source overpressure value, geometry and location are inverted to simulate the complex observed deformation pattern. The best fit model for periods of extensions yields a shallow pressure source of ellipsoidal shape centered within the lava dome, at about 100-m depth, undergoing an overpressure rate of 0.21 and 0.48 MPa/yr for the two periods of extension respectively. At this given rate, if the extension trend remains constant in the future, the pressure in the superficial reservoir will exceed lithostatic pressure in less than ten years.

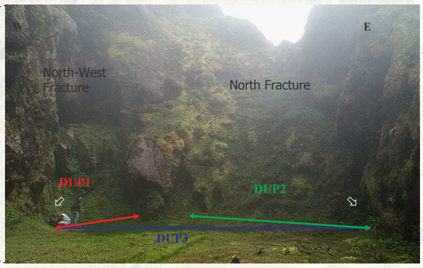
Soufrière of Guadeloupe Volcano: a fractured lava dome



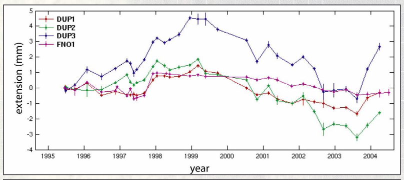
Extensometry: a way to quantify fracture opening

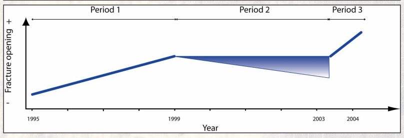


Convex extensometer. The measurement method consists in a simple rubber connected to a spring with a constant tension. The reading precision is 5.10^{-5} m whereas standard error on displacements is about 10^{-4} m for measured lengths up to 20 m.



Extensometer monitoring network. It has been set up on La Soufrière in 1995 [*David*, 1998] and consists presently in 17 stations on the main fractures of the lava dome. Measurements take a full day in the field with two operators and are repeated every 3 months.

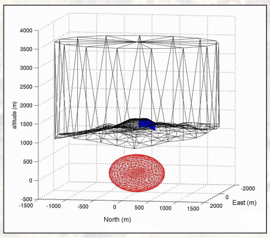




Example of displacement data from the North Fracture and general trend applying to all major fractures since 1995: (1) extension from 1995-1999, (2) neutral state to compression from 1999 to 2003, extension from 2003 to present. The two extensional periods yield similar deformation patterns, whereas the compression period does not.

Numerical modelling of the displacement field

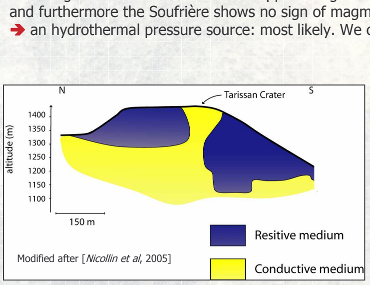
For modelling, we use the **Mixed Boundary Elements Method** [*Cayol & Cornet*, 1997], based on a combination of Displacements Discontinuity and Direct methods in infinite elastic medium. The code allows to solve 3-D problems with massive structures (as complex pressure source geometry), free surfaces (topography), and fractures together, without the constraints of complex meshing of finite elements. This approach optimises time computation.



Deformation style is **elastic** : this is coherent with the small time and displacement scale – less then 2 cm – of the observed deformation.

What type of pressure source can account for the observed deformation?

➔ a magmatic chamber source? Not applicable given the small and localized deformation, and furthermore the Soufrière shows no sign of magmatic activity,
➔ an hydrothermal pressure source: most likely. We choose to test this hypothesis.



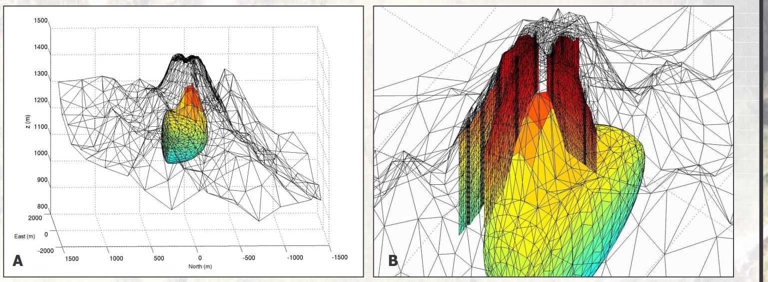
Modified after [*Nicollin et al*, 2005]

Evidence for a hydrothermal pressure source

There are active and past fumaroles on the volcano. Recent electrical tomography [*Nicollin et al*, 2005] clearly shows a high conductivity area within the dome. This area may contain the pressurized reservoir. The last major crisis was a phreatic eruption (1976-1977).

➔ **Our aim is to test parameters of the hydrothermal reservoir's geometry, location and pressure value which best accounts for the complex observed deformation pattern.**

Results: best fit model for the periods of extension

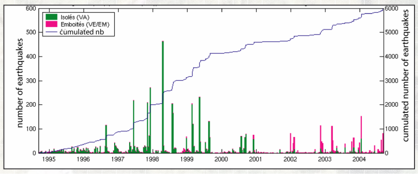


Geometry and location of the best fit hydrothermal overpressure source, constrained by the conductive volume determined from electrical tomography results. Fractures are not represented in A for an enhanced visualisation. Our model yields an overpressure rate in the reservoir of 0.21 and 0.48 MPa/y for the two periods of extension, respectively. Comparing these overpressure rates with the lithostatic pressure applied on the reservoir may help us to forecast when a crisis might happen, if these rates remain constant. We are not able to reproduce the deformation pattern for the period of contraction with the same reservoir.

What are the Soufrière's dome deformations correlated with ?

➔ Volcanic seismicity: the rate of volcanic earthquakes seems to be correlated with the dome's deformations,

➔ Rainfall: there isn't any direct correlation between rainfall and deformation.



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▪ **Cayol, V. and F.H. Cornet, 1997.** 3D mixed boundary elements for elastostatic deformation field analysis, *Int. J. Rock Mech. Min. Sci.*, **34**, 275–287.
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▪ **Nicollin F., D. Gibert, F. Beauducel, G. Boudon, J.-C. Komorowski, 2005.** Electrical Tomography of La Soufrière of Guadeloupe Volcano: Field Experiments, 1D Inversion and Qualitative Interpretation. *Submitted to Earth Planetary Science Letters.*