The Galápagos style: space-geodetic observations of intrusions and eruptions at Fernandina and other Galápagos volcanoes

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April 2009 eruption at Fernandina Volcano, Galápagos. Photo by Paulo Martel
Hawai’i

Western Galápagos

2 natural laboratories

7,300 km
2 natural laboratories

Hawai‘i

Western Galápagos

7,300 km
Hawai‘i

10,432 km²

Kohala

Mauna Kea

Hualalai

Mauna Loa

Kilauea

Since 1980: 2

Western Galápagos

642 km² + 4,640 km² = 5282 km²

Ecuador

Wolf

Isabela Island

Darwin

Fernandina

Alcedo

Sierra Negra

Cerro Azúl

Since 1980: 5
Hawai’i

10,432 km²

Kohala

Mauna Kea

Hualalai

Mauna Loa

Kilauea

Since 1980: 2
Since 1992: 1

Western Galápagos

642 km² + 4,640 km² = 5282 km²

Isabela Island

Ecuador

Wolf

Fernandina

Alcedo

Sierra Negra

Since 1980: 5
Since 1992: 4 (3F - 2CA - 1SN – 1A?)
Amelung et al., 2000

“Six volcanoes are deforming ...”
InSAR (> 550 SAR images)

ERS-1/2

Envisat

JERS-1

Radarsat-1

ALOS

TerraSAR-X

GPS (10 stations)

Sierra Negra

Continuous-GPS network
Spatial and temporal variations

**Baker et al., in prep.**

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Deformation modeling

Yun et al., 2006

Jónsson, 2009

Chadwick et al., 2011

Bagnardi & Amelung, in review
Spatial and temporal variations

Baker et al., in prep.

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2003-2010

Vertical displacement (m)

Los Displacement (cm)

km

20

Galapagos Islands

Wolf

Darwin

Fernandina

Alcedo

Cerro Azul

Sierra Negra

Baker et al., in prep.
Eruptive fissures in the Galápagos

Modified after Chadwick and Howard, 1991

Chadwick and Howard, 1991
**FERNANDINA**

Latest eruptions:

1982 (C) [Rowland and Munro, 1992]
1995 (R) [Jónsson et al., 1999]
2005 (C) [Chadwick et al., 2010]
2009 (R) [Bagnardi et al., in prep.]

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1995 eruption lava flows
2005 eruption lava flows
2009 eruption lava flows
1995, 2005 and 2009 fissures
sub-aerial fissures

*Chadwick and Dieterich, 1995*
April 10th 2009 eruption (11 PM LT): **pre-eruptive deformation**

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**T412 Descending IS2**
16/12/2008 - 31/03/2009

**T54 Descending IS7**
06/03/2009 - 10/04/2009 8 AM

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**ERUPTION**

March 15  
March 31  
April 15  
April 30  
May 15

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cm LOS - displacement
April 2009 eruption – Phase 1
2 hours before eruption

Envisat IS2 (Asc.): 31/01/2009 – 10/04/2009

Unwrapped

cm LOS - displacement

-2.8 -1.4 0 1.4 2.8

cm LOS - displacement

-0.10 -0.05 0 0.05 0.10

March 15

March 31

April 15

April 30

May 15
April 2009 eruption – Phase 1

Envisat IS2 (Asc.): 31/01/2009 – 10/04/2009

Unwrapped

Planar dislocation [Okada, 1992]

Length: 2.3 km
Min depth: 0.95 km
Dip: 24° from horizontal

Width: 3.00 km
Max depth: 1.90 km
Strike: 153°
Phase 1

Sub-caldera reservoir
April 2009 eruption – Phase 2

Envisat IS2 (Desc.): 31/03/2009 – 05/05/2009

cm LOS - displacement
Planar dislocation [Okada, 1992]

Length: 5.60 km
Min depth: 0.0 km
Dip: 30° from horizontal

Width: 2.80 km
Max depth: 1.40 km
Strike: 215°
Phase 1

Sub-caldera reservoir

Case A

Phase 2
A Shallow-Dipping Dike fed the 1995 Flank Eruption at Fernandina Volcano, Galápagos, Observed by Satellite Radar Interferometry

Sigurjón Jónsson, Howard Zebker, Peter Cervelli, Paul Segall
Geophysics Department, Stanford University, California

Harold Garbeil, Peter Mougini-Mark, Scott Rowland
Hawaii Institute of Geophysics and Planetology, University of Hawaii, Honolulu

Planar dislocation [Okada, 1992]

Length: 3.8 km
Width: 2.3 km
Min depth: 0.00 km
Max depth: 1.50 km
**Dip: 34° from horizontal**
Strike: 227°
April 2009 eruption – Phase 2

Envisat IS2 (Desc.): 31/03/2009 – 05/05/2009

2 x Planar dislocation [Okada, 1992]

**Horizontal**
- $\sim 2.5 \times 4.5 \text{ km}$
- Strike: $211^\circ$
- Depth: $\sim 1.00 \text{ km}$

**Vertical**
- $\sim 4.30 \times 1.00 \text{ km}$
- Strike: $211^\circ$
- Depth: $\sim 0-1 \text{ km}$
Phase 1

Sub-caldera reservoir

Phase 2

Case A

Case B
Phase 1

Sub-caldera reservoir

Phase 2

Case A

Case B
Principal stresses – reservoir inflation
Conclusions

• Radial fissures seem to be fed by intrusive bodies that:
  - originate as shallow dipping sills
  - propagate as sub-horizontal sills within the flank
  - rotate into sub-vertical dikes in the upper 1 km of the edifice

• Inflation of a sill-type reservoir is able to create a state of stress compatible with the inferred geometry
  - however, circumferential dikes are not promoted
  - there is a need for a different process to promote circumferential diking (feedback from radial dikes?)
Thank you

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Envisat IS2 (Asc.): 31/01/2009 – 10/04/2009

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“Evidence for interactions between the Galápagos Islands volcanoes”

S. Baker, M. Bagnardi and F. Amelung

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