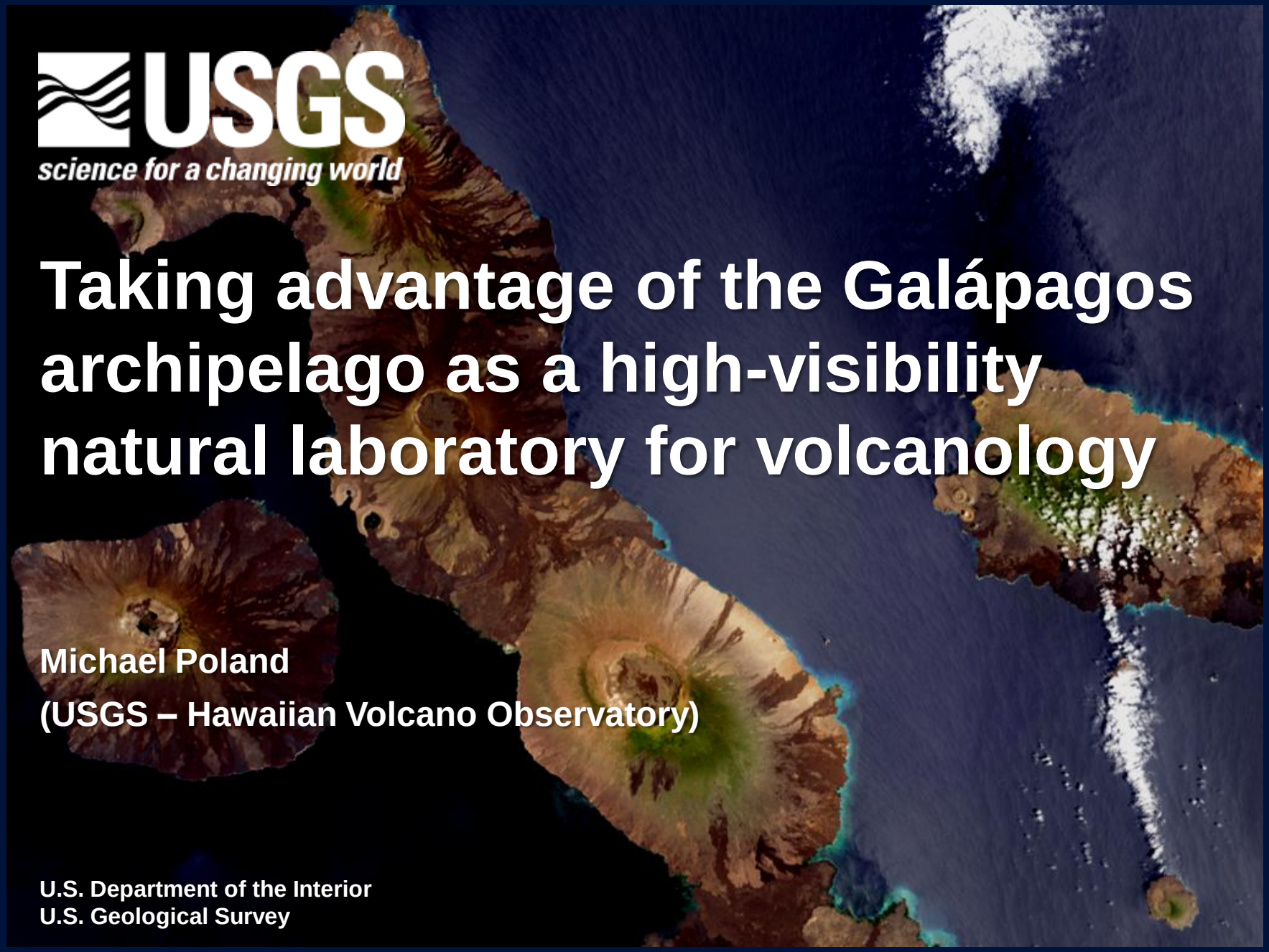


Taking advantage of the Galápagos archipelago as a high-visibility natural laboratory for volcanology

Michael Poland

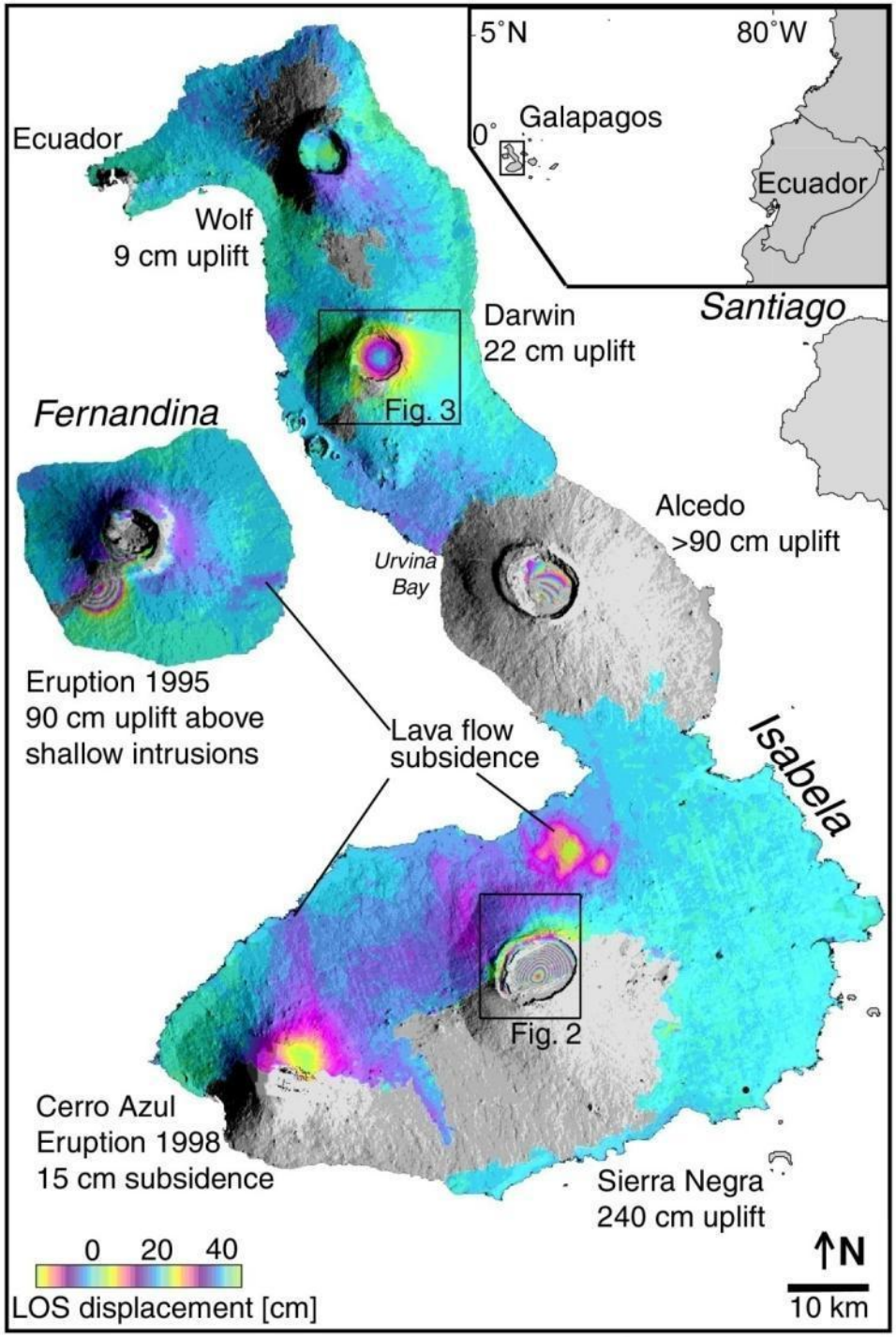
(USGS – Hawaiian Volcano Observatory)

U.S. Department of the Interior
U.S. Geological Survey


Journal of Volcanology and Geothermal Research, 26 (1985) 173–177
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands
Letter Section
THE GALAPAGOS VOLCANO ALCEDO: A UNIQUE OCEAN CALDERA
A.R. McBIRNEY, A.B. CULLEN, D. GEIST, E.P. VICENZI, R.A. DUNCAN, M.L. HALL and M. ESTRELLA
(Received July 10, 1985)
The caldera of Volcan Fernandina: a remote sensing study of its structure and recent activity
Scott K. Rowland and Duncan C. Munro
Bull Volcanol (1992) 55:97–106
Volcanology
© Springer-Verlag 1992
31 July 1970, Volume 169, Number 3944
SCIENCE
Caldera Collapse in the Galápagos Islands, 1968
Tom Simkin and Keith A. Howard
BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 57, PP. 215-234, 4 FIGS., 4 PLS.
FEBRUARY 1946
GEOLOGY OF ISABELA (ALBEMARLE) ISLAND, ARCHIPELAGO DE COLON (GALAPAGOS)
By A. F. Banfield, Chas. H. Hedge, Jr., and David St. Clair
Bull Volcanol (2000) 61:497–514
© Springer-Verlag 2000
ORIGINAL PAPER
T. Naumann · D. Geist
Physical volcanology and structural development of Cerro Azul Volcano, Isabela Island, Galápagos: implications for the development of Galápagos-type shield volcanoes
Received: 24 September 1998 / Accepted: 7 August 1999
Illegitimate magmas of the Galápagos: Insights into mantle mixing and magma transport
Dennis Geist*
William White
Terry Naumann
Robert Reynolds
ELSEVIER
Journal of Volcanology and Geothermal Research 66 (1995) 37–52
Mechanical modeling of circumferential and radial dike intrusion on Galapagos volcanoes
W.W. Chadwick Jr. a, J.H. Dieterich b
Received 27 December 1991; accepted 7 July 1994

USGS

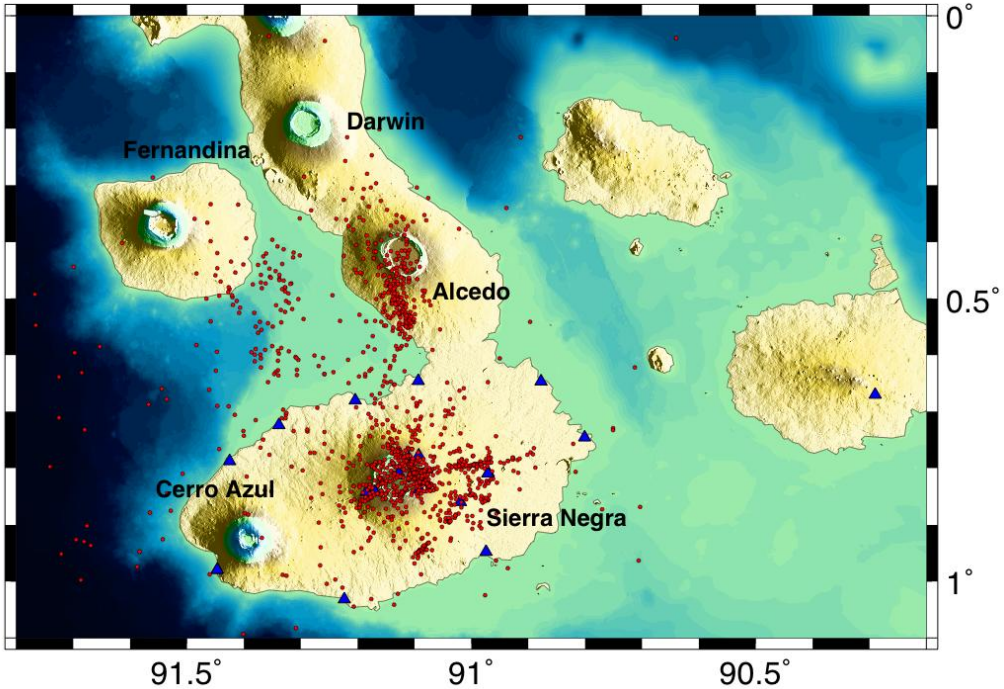
A revolution…



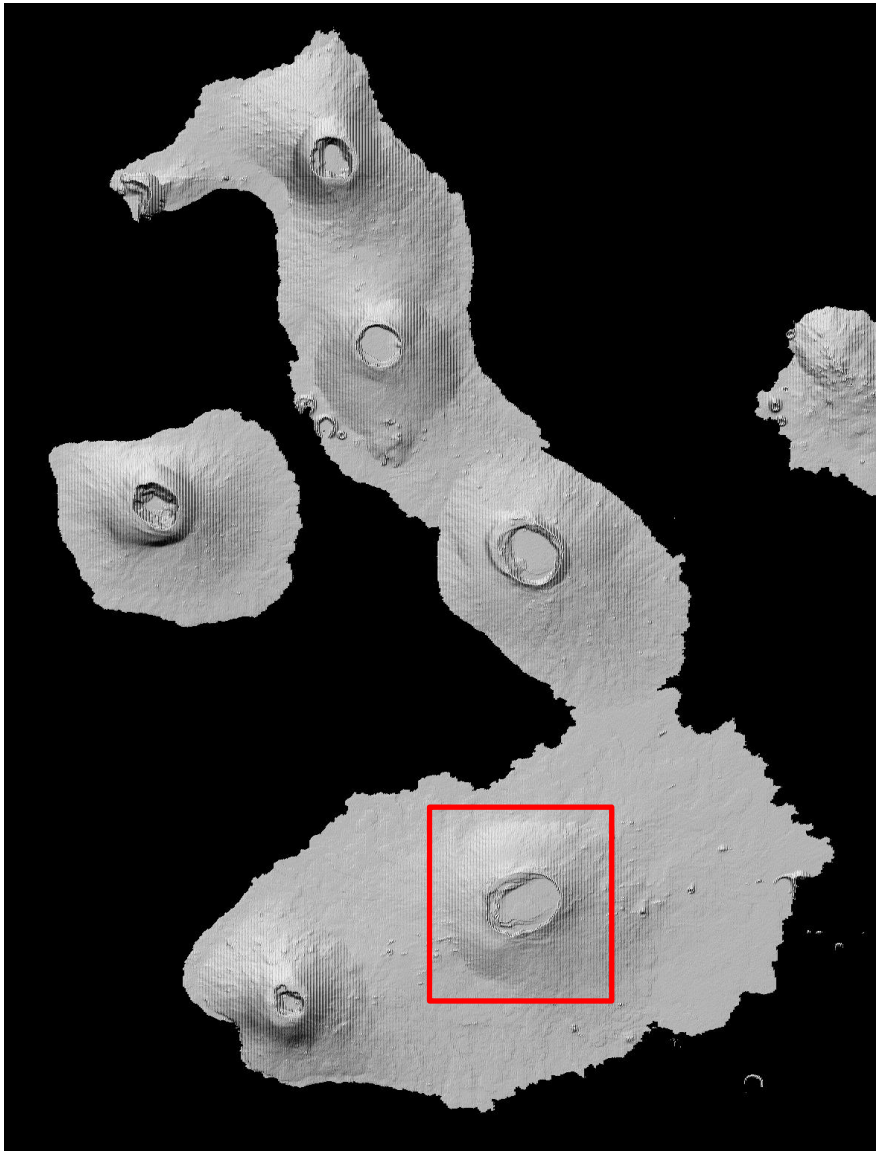
USGS

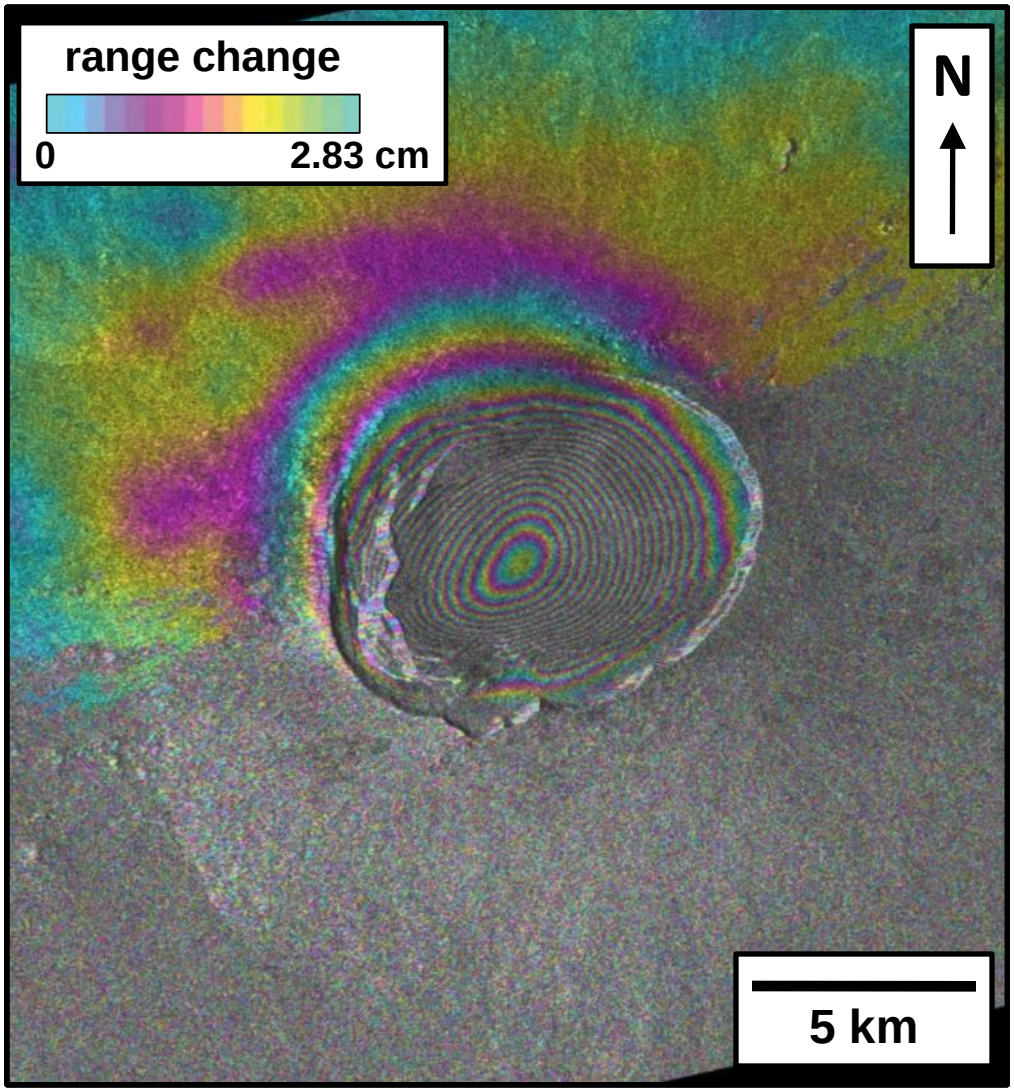
Amelung et al., 2000

Inspiration!



USGS





USGS

Low-hanging fruit

I. **Magma supply**
   - Rate from hotspot
   - Partitioning between volcanoes

II. **Magma storage and transport**
   - Geometry of magma storage
   - Getting from the source to the surface

III. **Structural evolution of basaltic shields**
   - Interactions (volcano and tectonic)
   - Rift zones, calderas, flank instability

IV. **Volcanic eruptions**
   - Explosive basaltic volcanism
   - Eruption cycles (24 eruptions in last 50 years!)

USGS

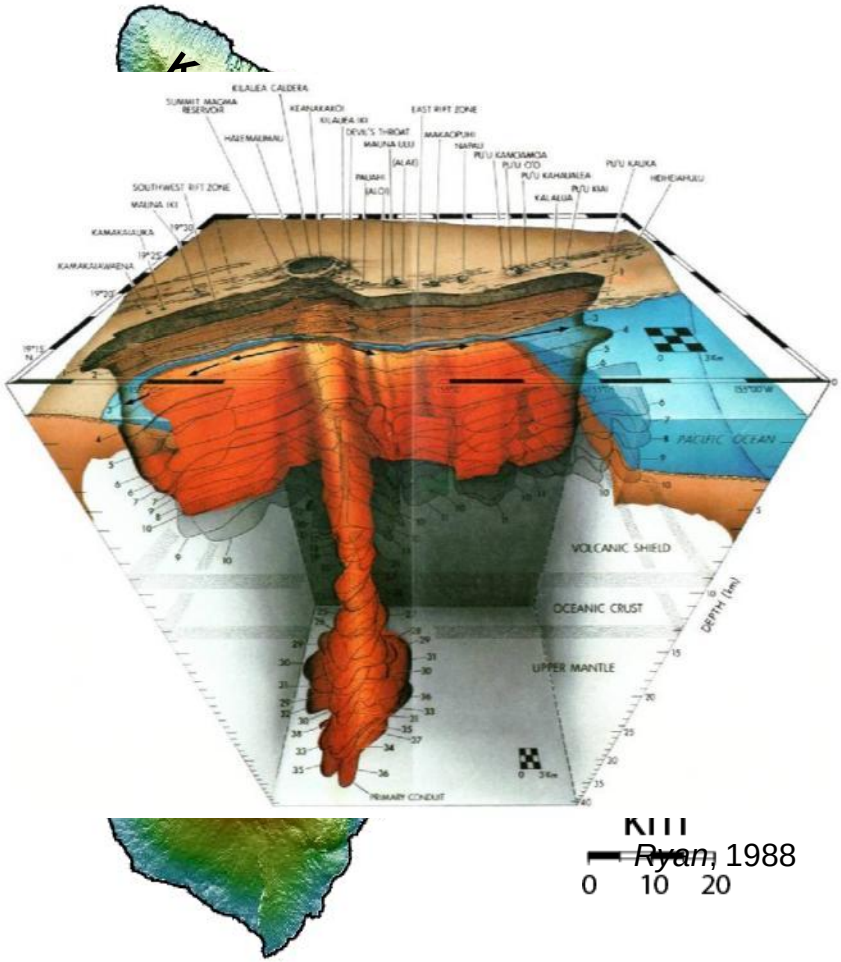
I. MAGMA SUPPLY

- What is the rate of magma supply to the Galápagos volcanoes?
- How is magma supply partitioned between volcanoes?
- Is the rate of magma supply constant?
- How does magma supply relate to volcanic activity?

USGS

Magma supply to Kīlauea, Hawai‘i

Time period	Supply (km³/yr)	Method	Reference
1918–1979	0.08	Ratio between repose times and erupted volumes	*Klein*, 1982
1919–1990	0.09	Effusion rate of several sustained eruptions	*Dvorak and Dzurisin*, 1993
1952–1971	0.11	Effusion rate of three sustained eruptions	*Swanson*, 1972
1956–1983	0.09	Average summit and rift deformation and eruption volumes	*Dzurisin et al.*, 1984
1959–1990	0.06	Average based on deformation and eruption volumes	*Dvorak and Dzurisin*, 1993
1960–1967	0.02–0.18	Deformation-inferred refilling of summit reservoir	*Dvorak and Dzurisin*, 1993
1966–1970	0.07	Deformation and eruption volumes	*Dvorak et al.*, 1983
1967-1975	0.05–0.18	Deformation and eruption volumes	*Wright and Klein*, 2008
1971–1972	0.08	Deformation and erupted volumes	*Duffield et al.*, 1982
1975–1977	0.07–0.16	Microgravity and deformation	*Dzurisin et al.*, 1980
1983–1984	0.12	First 20 episodes of Pu`u `O`o eruption	*Wolfe et al.*, 1987
1983–2002	0.12	Pu`u `O`o eruption volumes	*Heliker et al.*, 2003
1983–2002	0.13	SO_2 emissions from ERZ	*Sutton et al.*, 2003
1991	0.08	Deformation and effusion rates	*Denlinger*, 1997



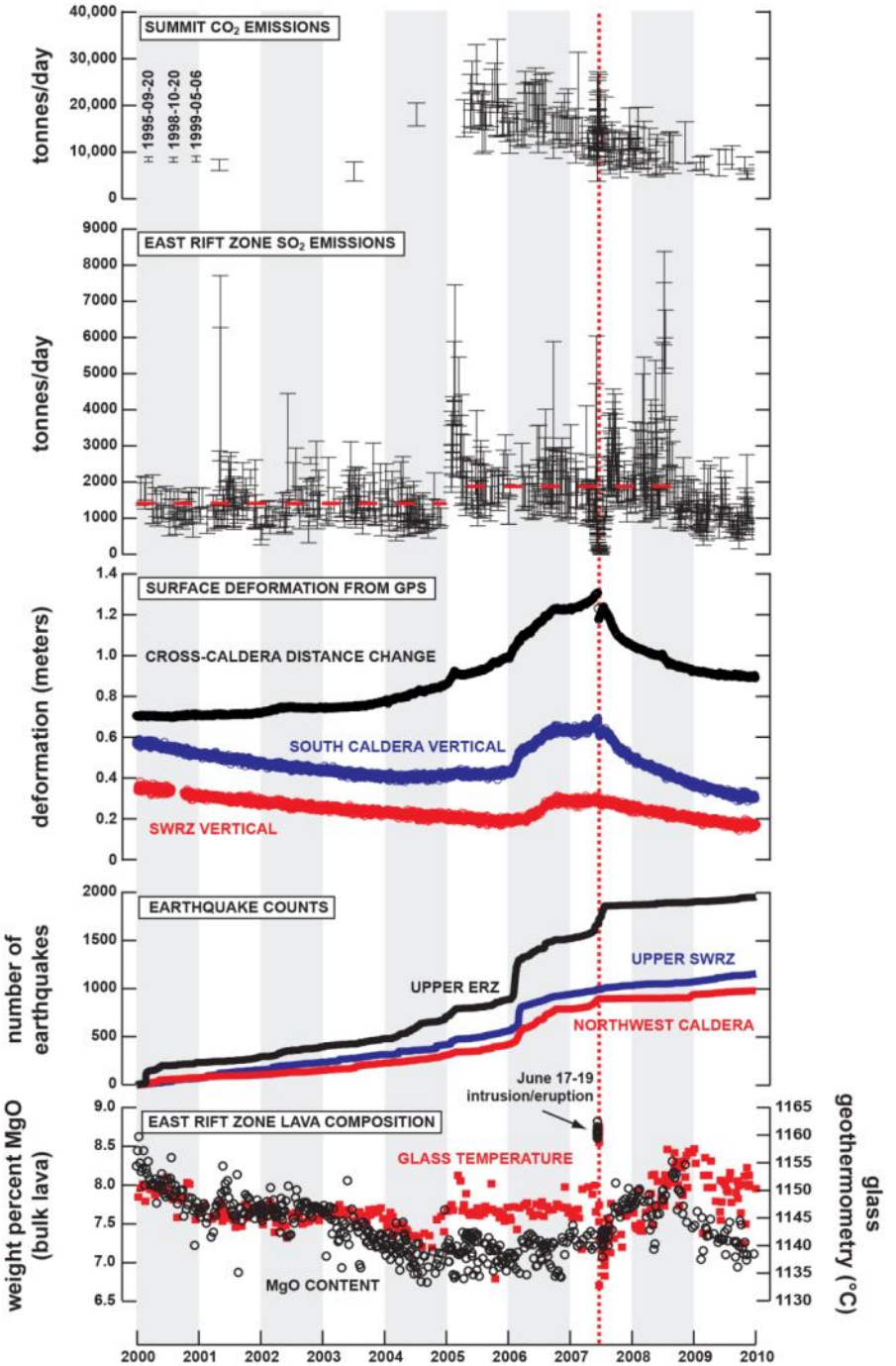
Ryan, 1988

Average supply rate: ~0.1 km³/yr

USGS

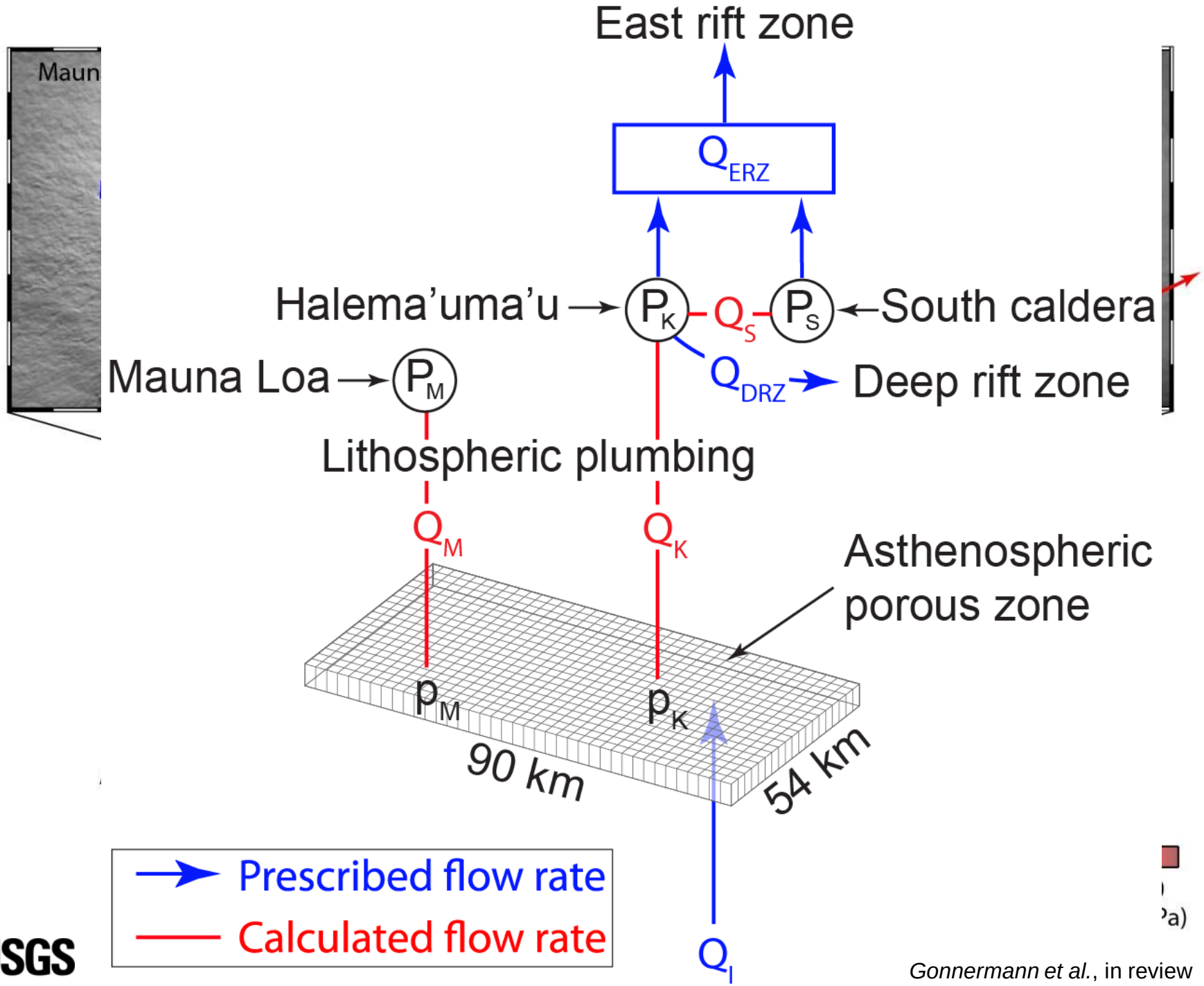
A change in magma supply

- CO_2 emissions increased by 2.5x in 2003–2004
- SO_2 emissions indicated higher lava effusion rates
- Summit inflation
- Increased summit earthquake rates
- Introduction of primitive magma to Kīlauea
- SURGE IN SUPPLY FROM MANTLE IN 2003-2007



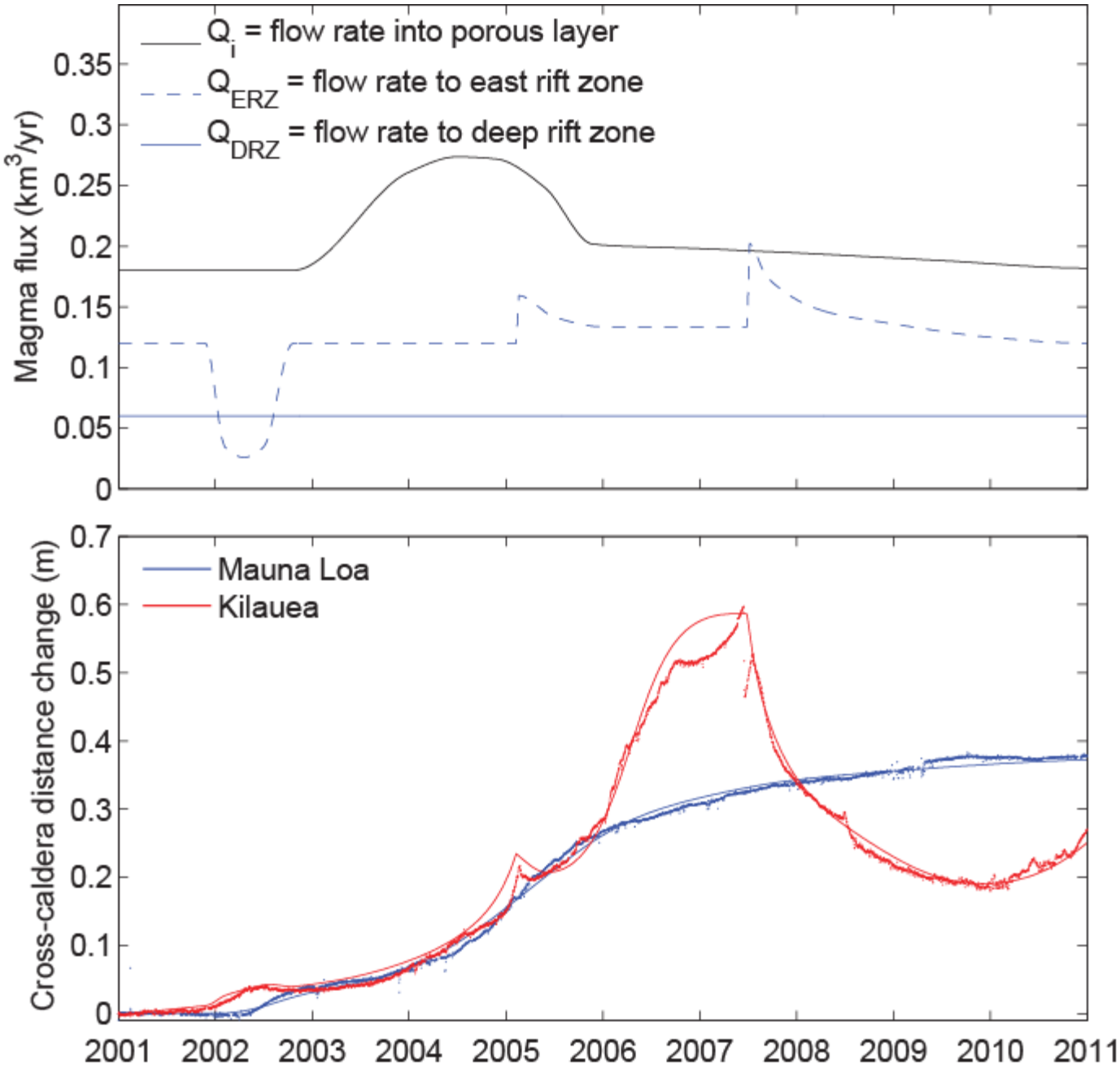
Poland et al., in review

USGS



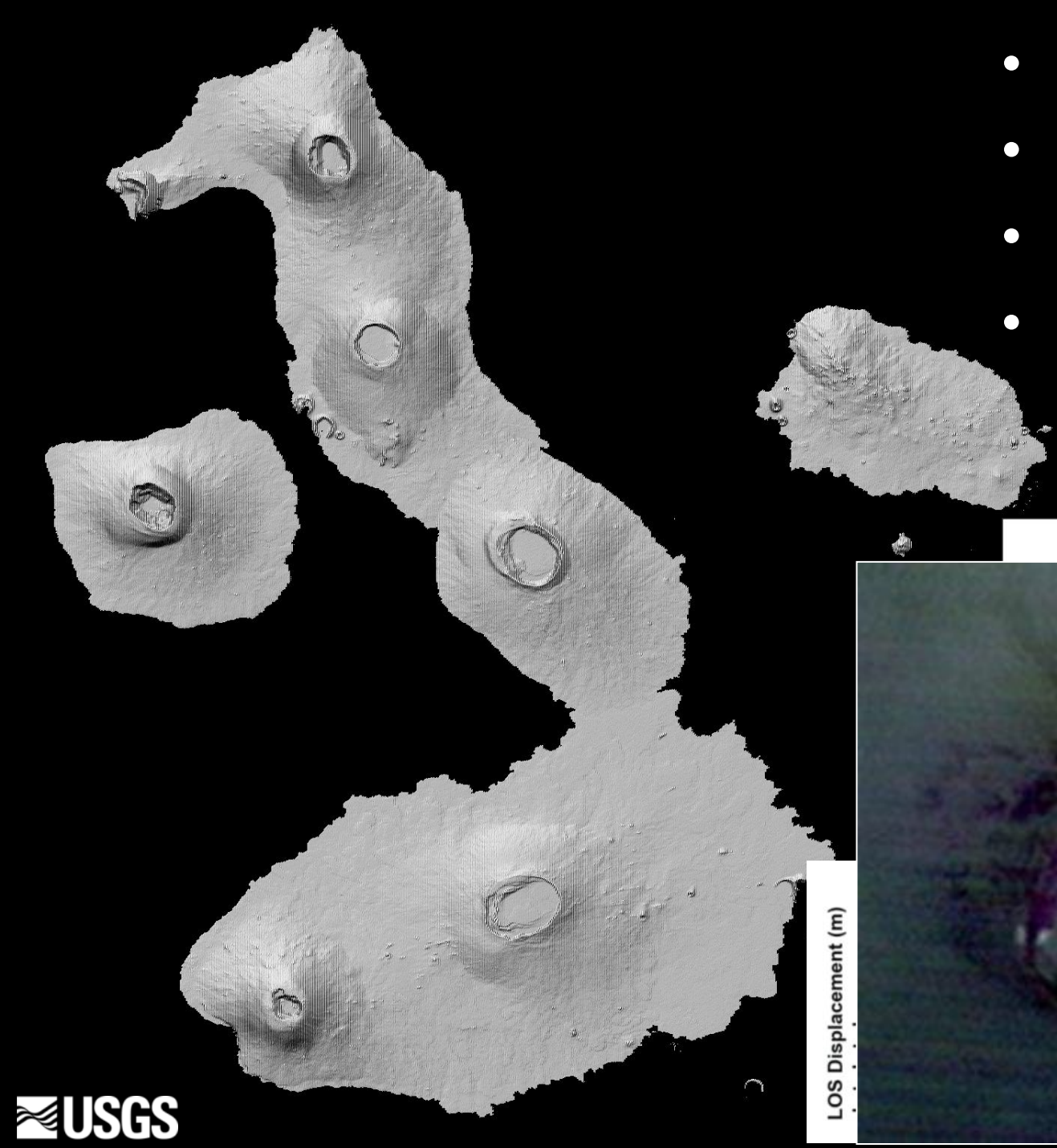
USGS

Gonnermann et al., in review



USGS

Gonnermann et al., in review



- **Eruption data**
- **Deformation**
- **Seismicity**
- **Gas emissions**

Figure courtesy of

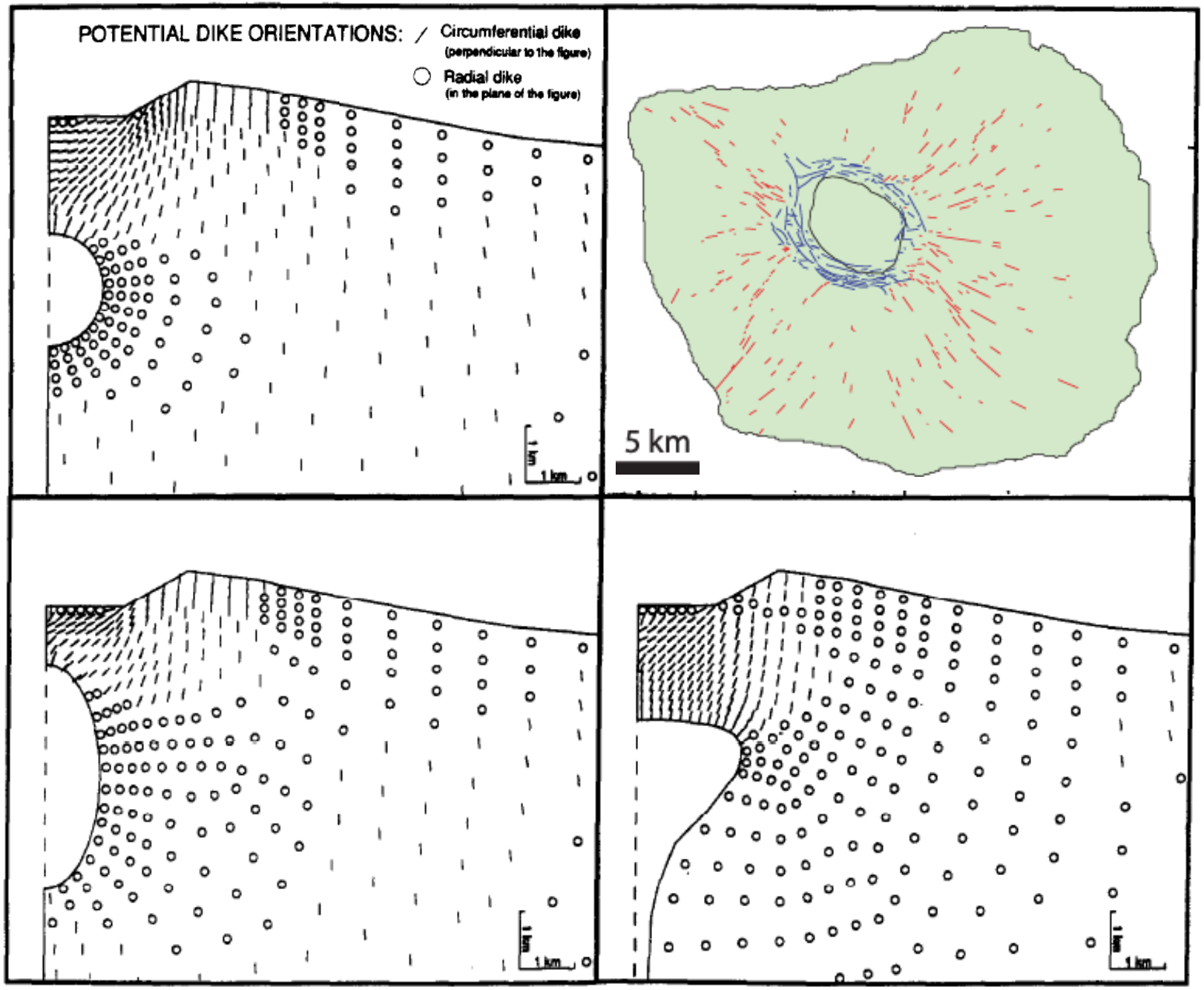
LOS Displacement (m)

USGS

II. MAGMA STORAGE AND TRANSPORT

- What is the geometry and depth of magma storage beneath Galapagos volcanoes?
- How is magma transported between storage reservoirs and the surface?

USGS



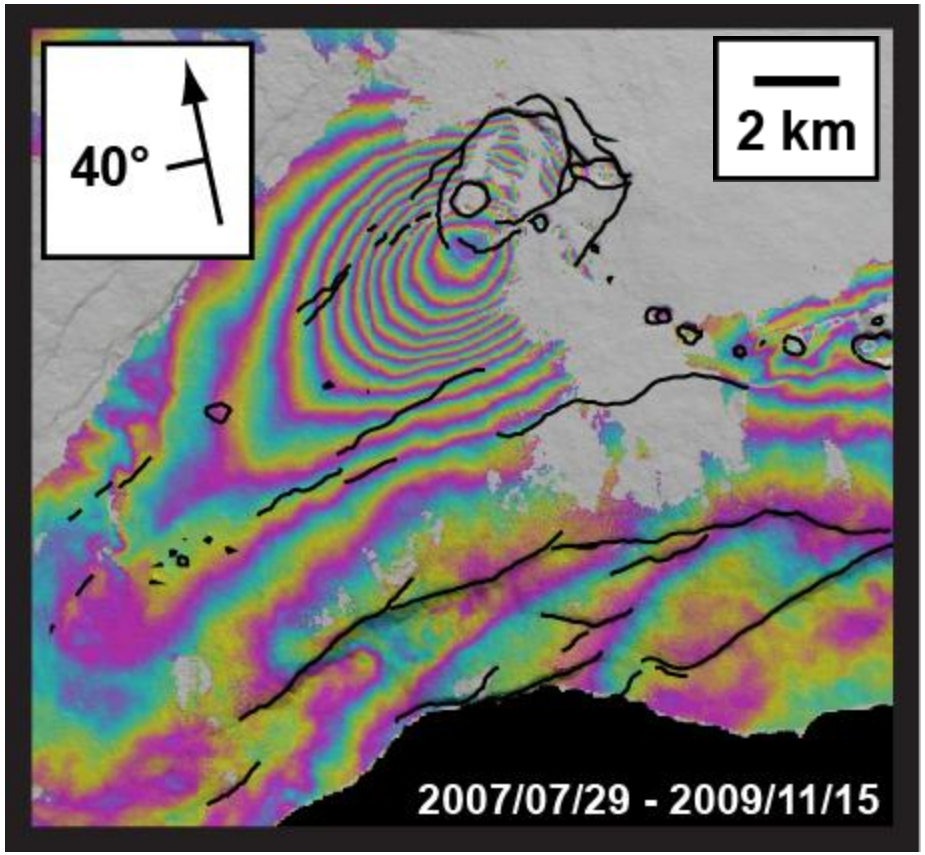
USGS

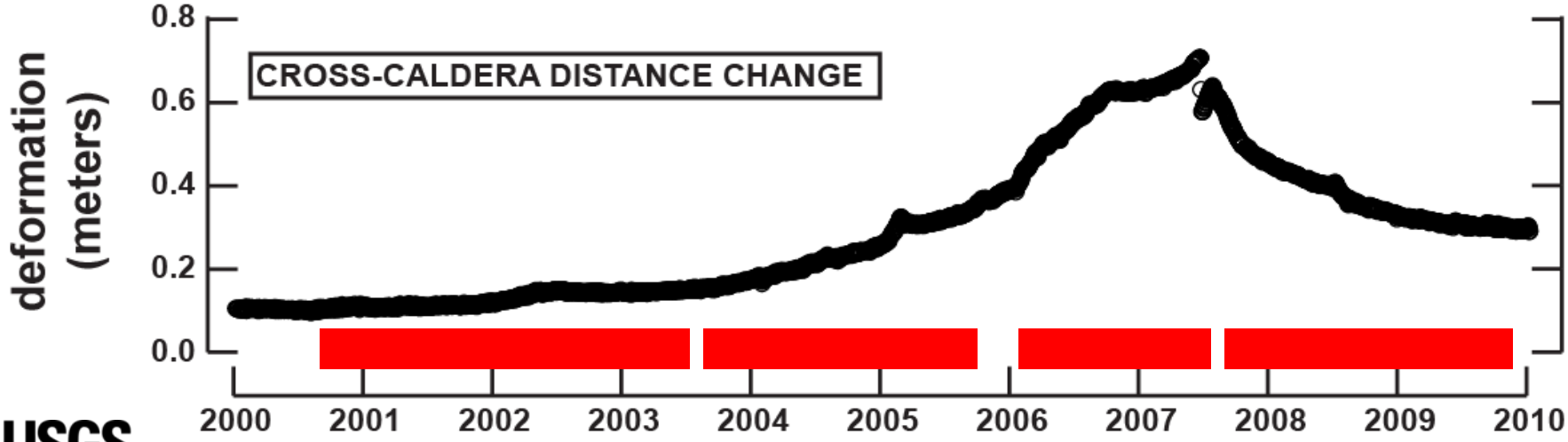
Geist et al., 2006; *Chadwick and Dieterich*, 1995

Kīlauea

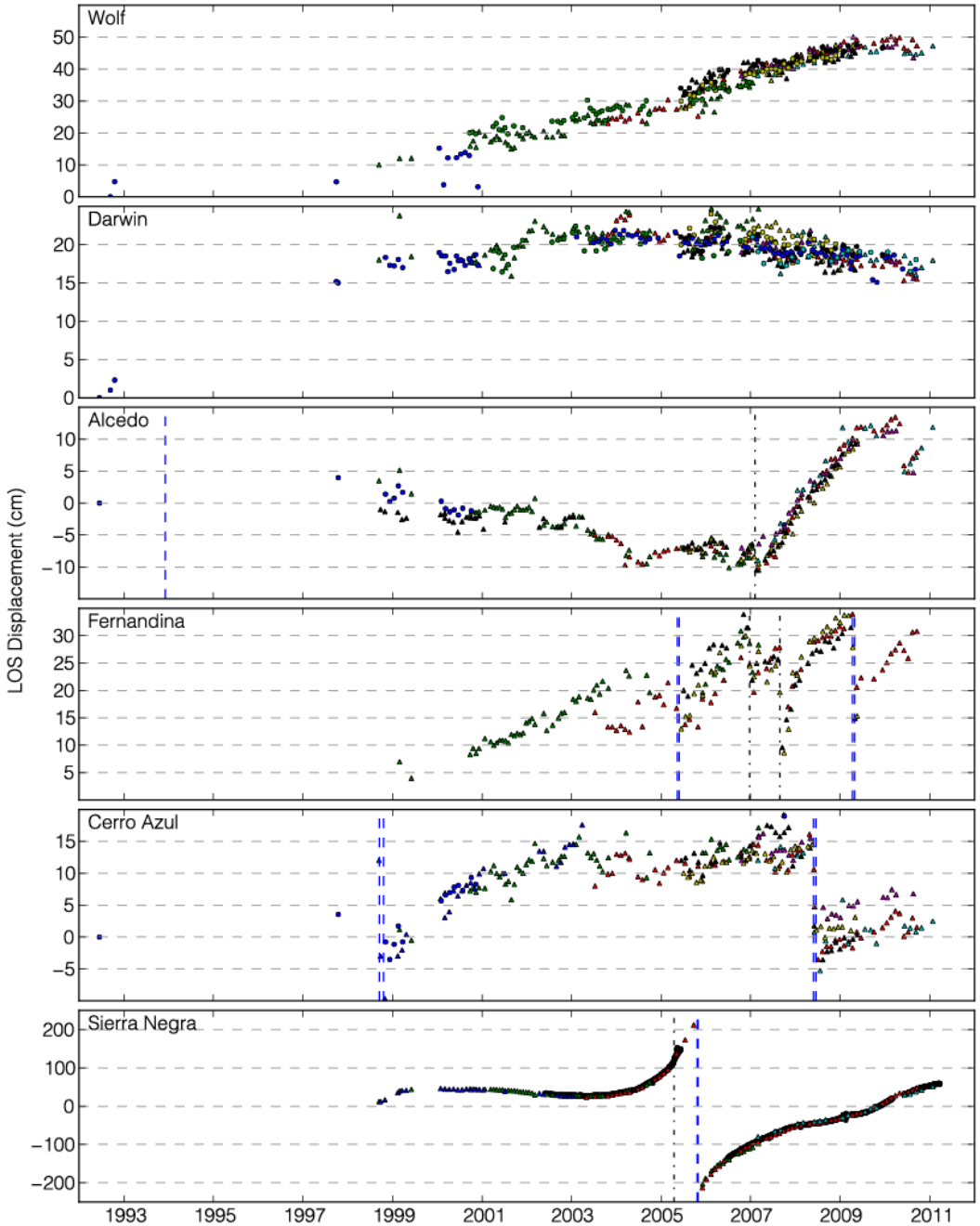
Deflation, instantaneous collapse

Inflation, intrusion, dike emplacement





Poland et al., in review



Oct 2005 – Sep 2010 (average displacements)

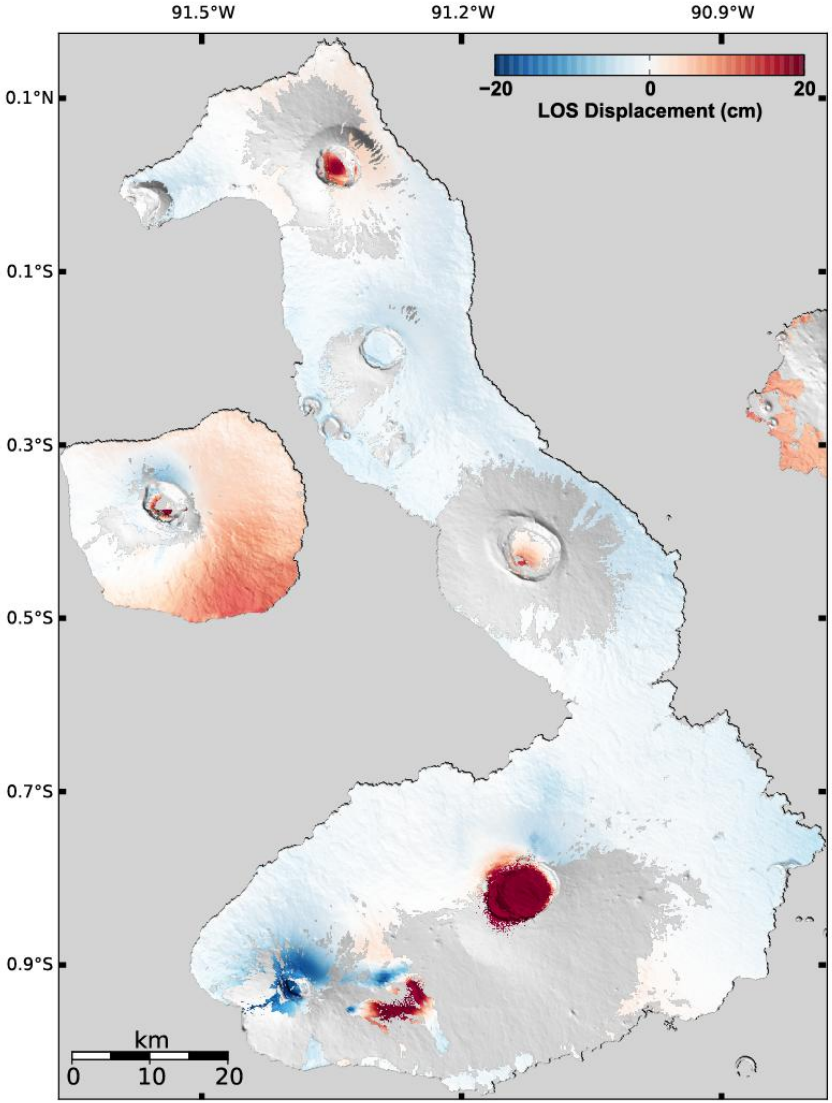
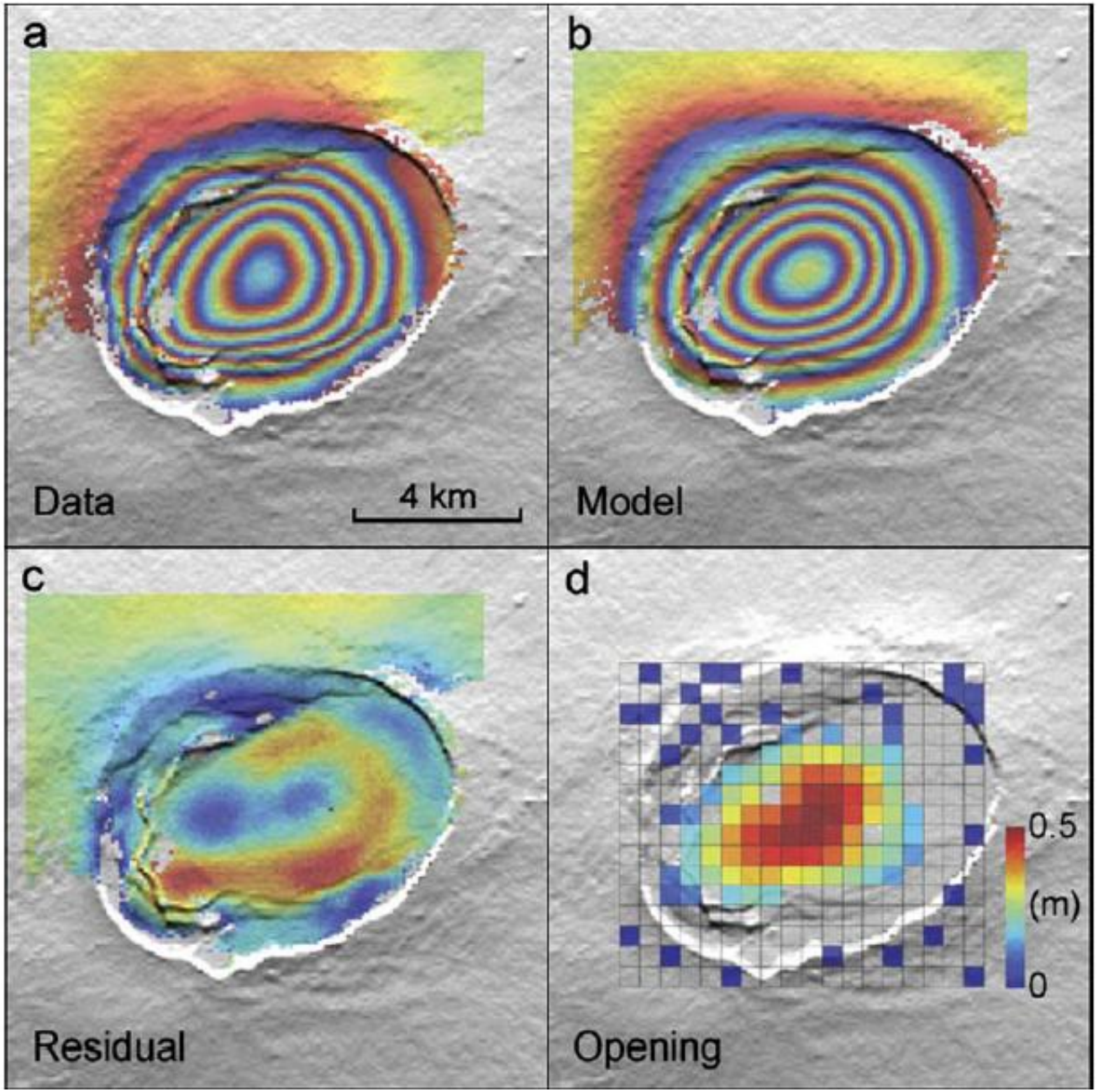


Figure courtesy of *Scott Baker* and *Marco Bagnardi*

USGS

Sill-like reservoir at 2 km depth beneath Sierra Negra.

Cannot distinguish between a sill and a diapir, however.

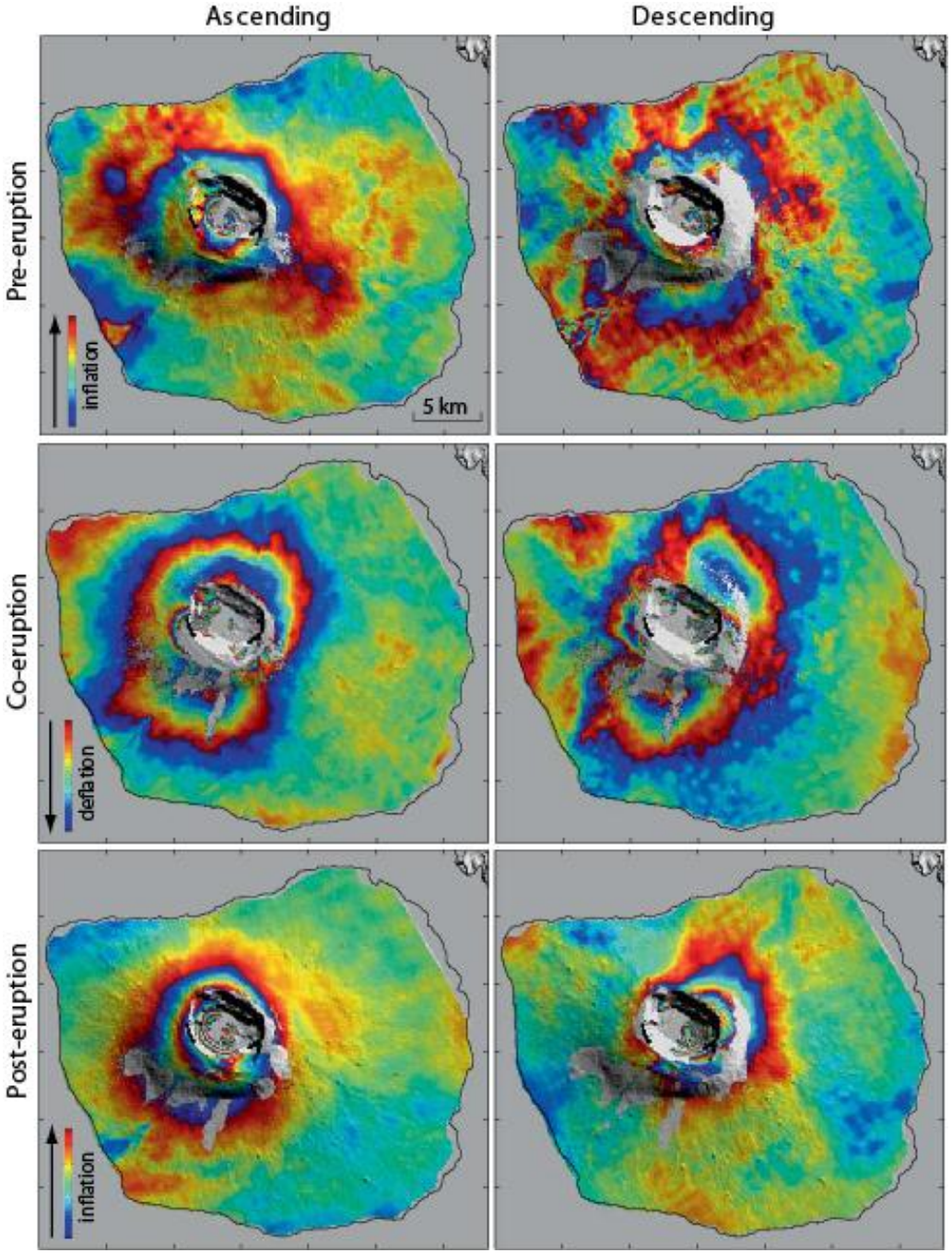


USGS

Yun et al., 2006

Fernandina — 2005 eruption

Circumferential eruptive fissure on southwest flank



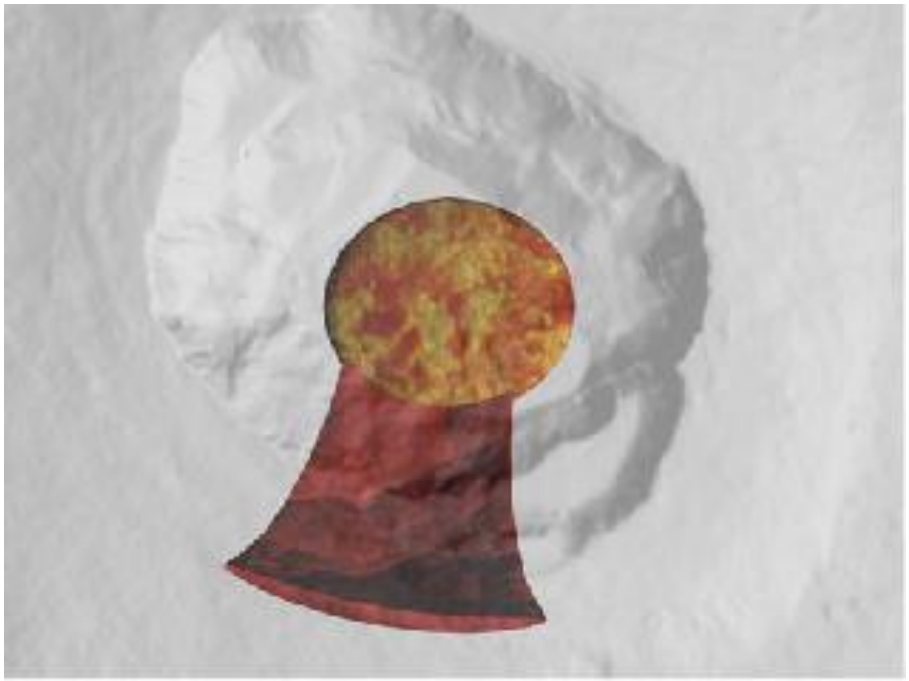
Chadwick et al., 2011

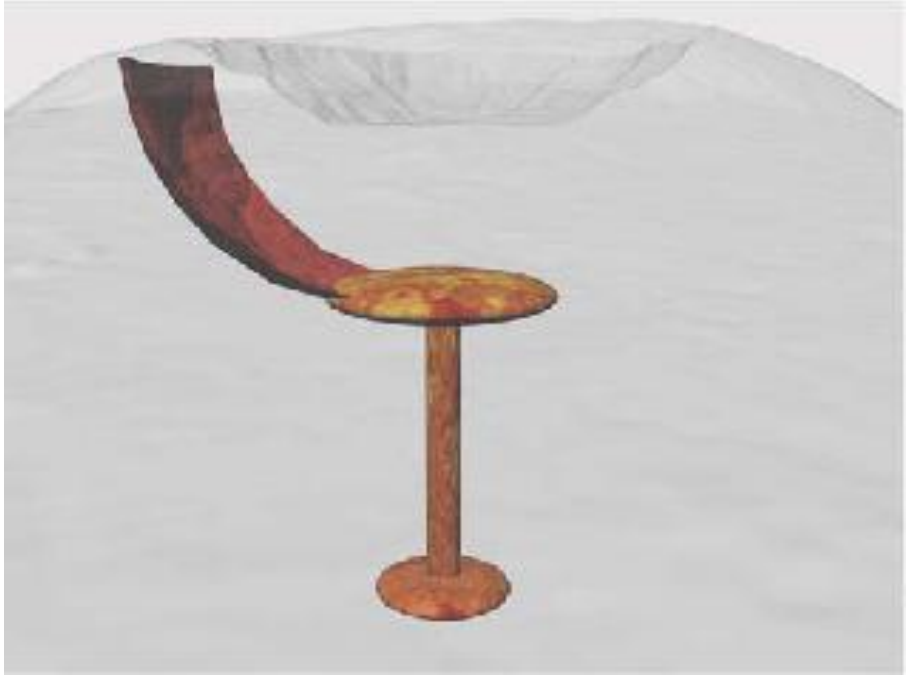
USGS

Fernandina — 2005 eruption

Co-eruptive deformation indicates magma storage at ~1 and ~5 km depths.

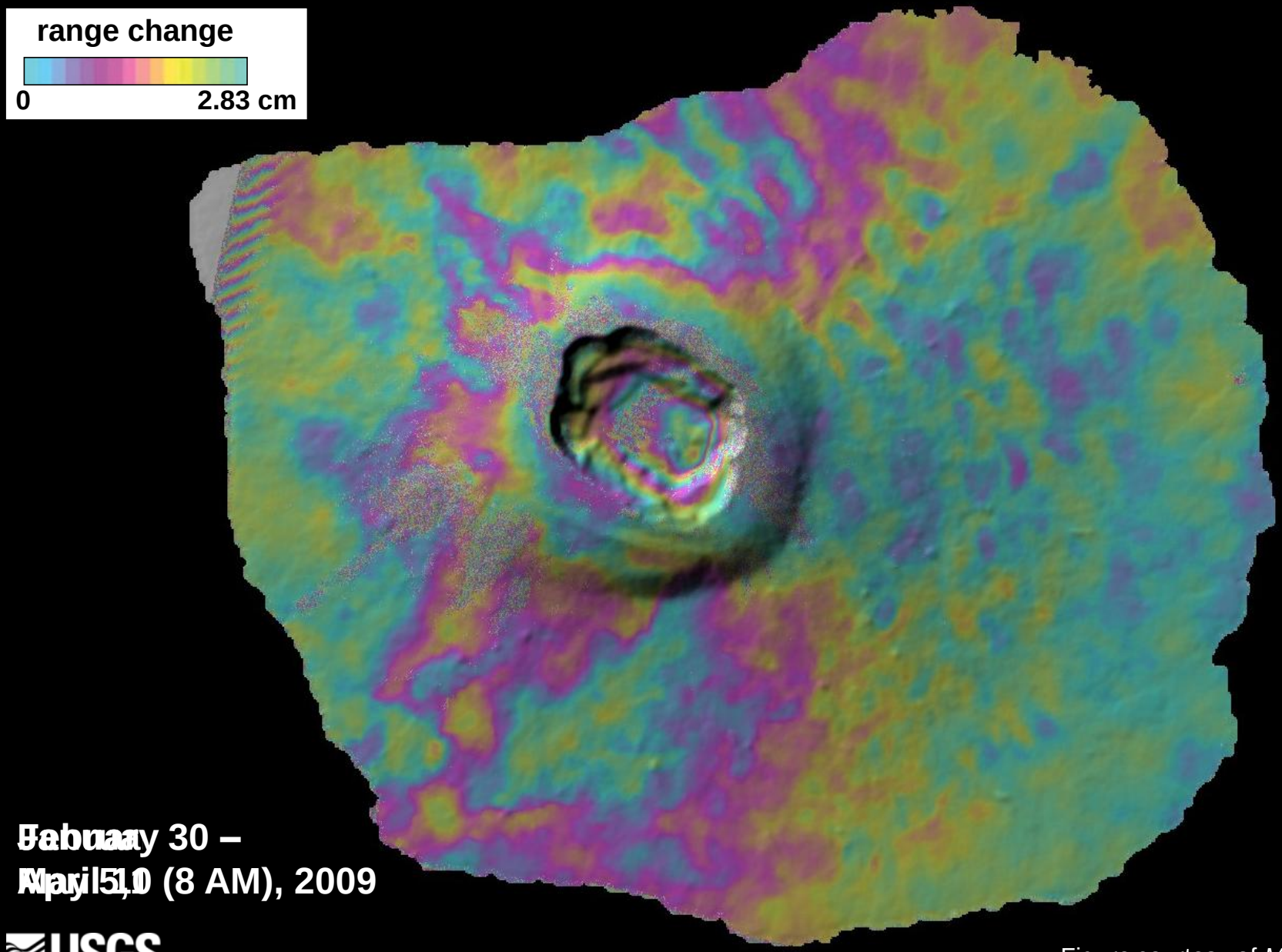
Circumferential eruptive fissure propagated upward from shallow magma storage area.





Chadwick et al., 2011

Fernandina — 2009 eruption

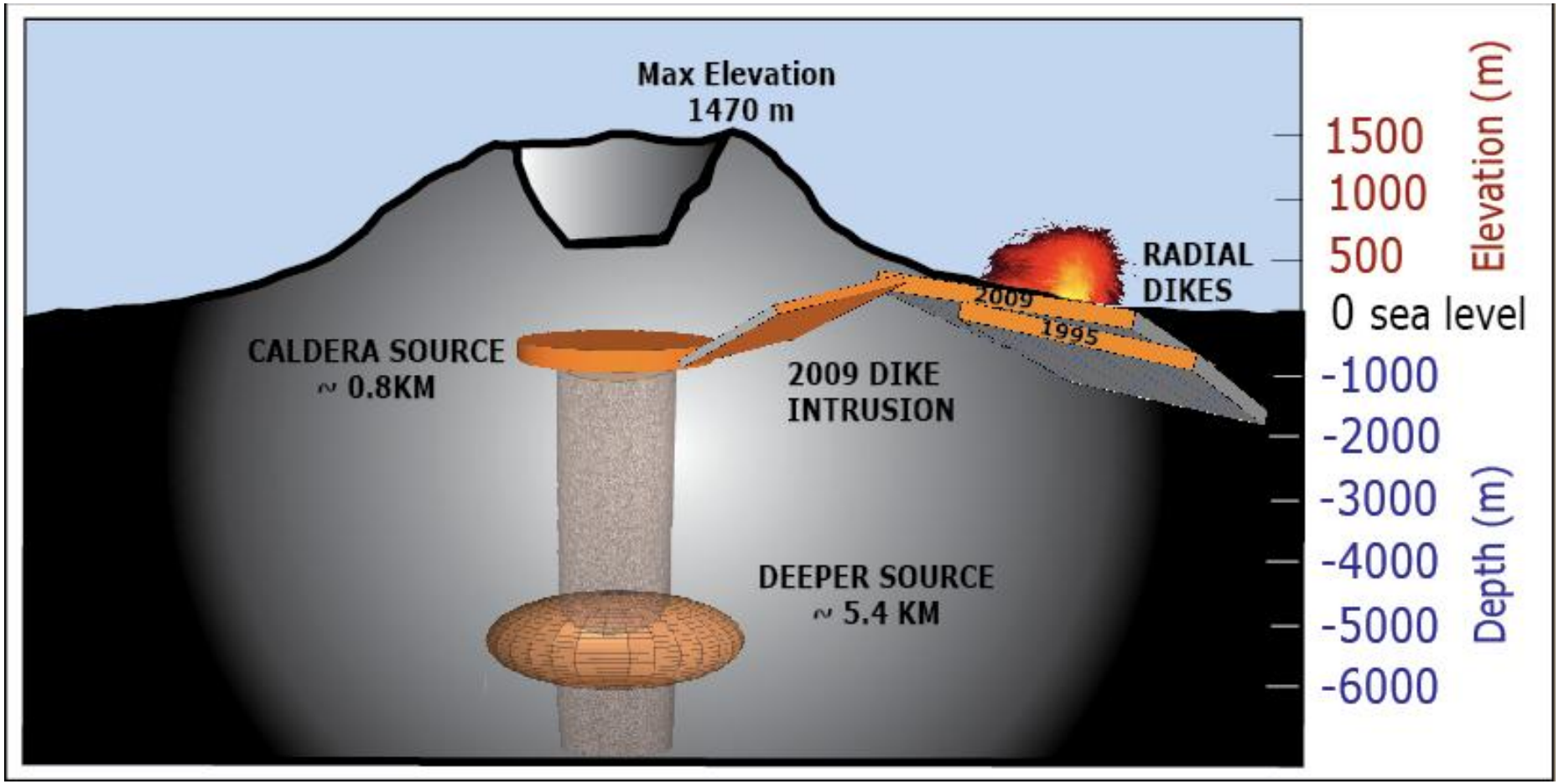


February 30 –
April 10 (8 AM), 2009

USGS

Figure courtesy of *Marco Bagnardi*

Fernandina — 2009 eruption



Same stacked reservoir geometry and sill-like initiation, but, like 1995, a shallow-dipping dike feeding the fissure.

USGS

Figure courtesy of *Marco Bagnardi*

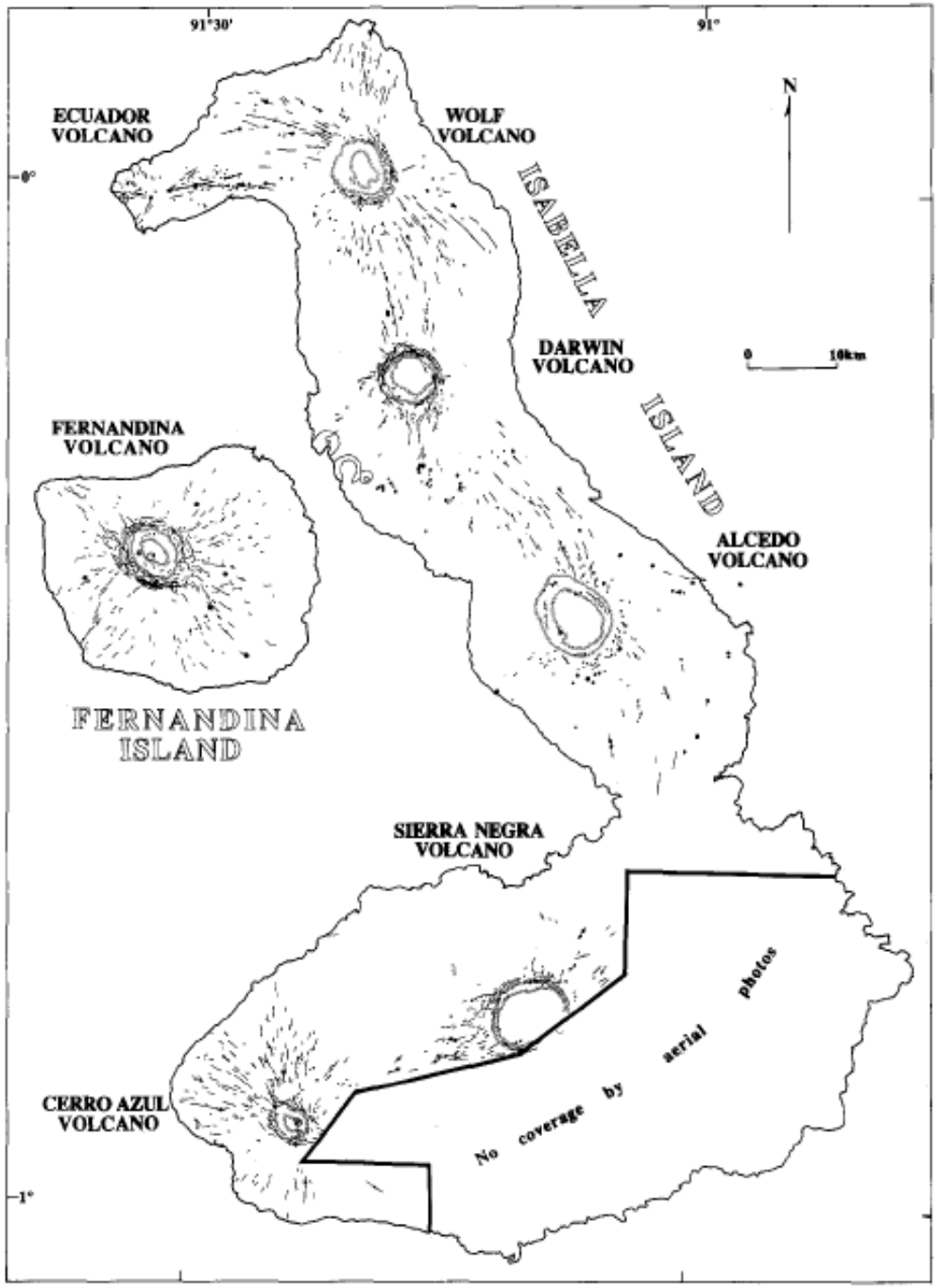
III. EVOLUTION OF BASALTIC SHIELDS

- What causes the pattern of radial and circumferential eruptive fissures?
- Where are the rift zones?
- Is there any sign of flank instability?
- How do neighboring volcanoes interact?
- What are the causes and consequences of volcano-tectonic interactions?
- How do basaltic calderas develop?

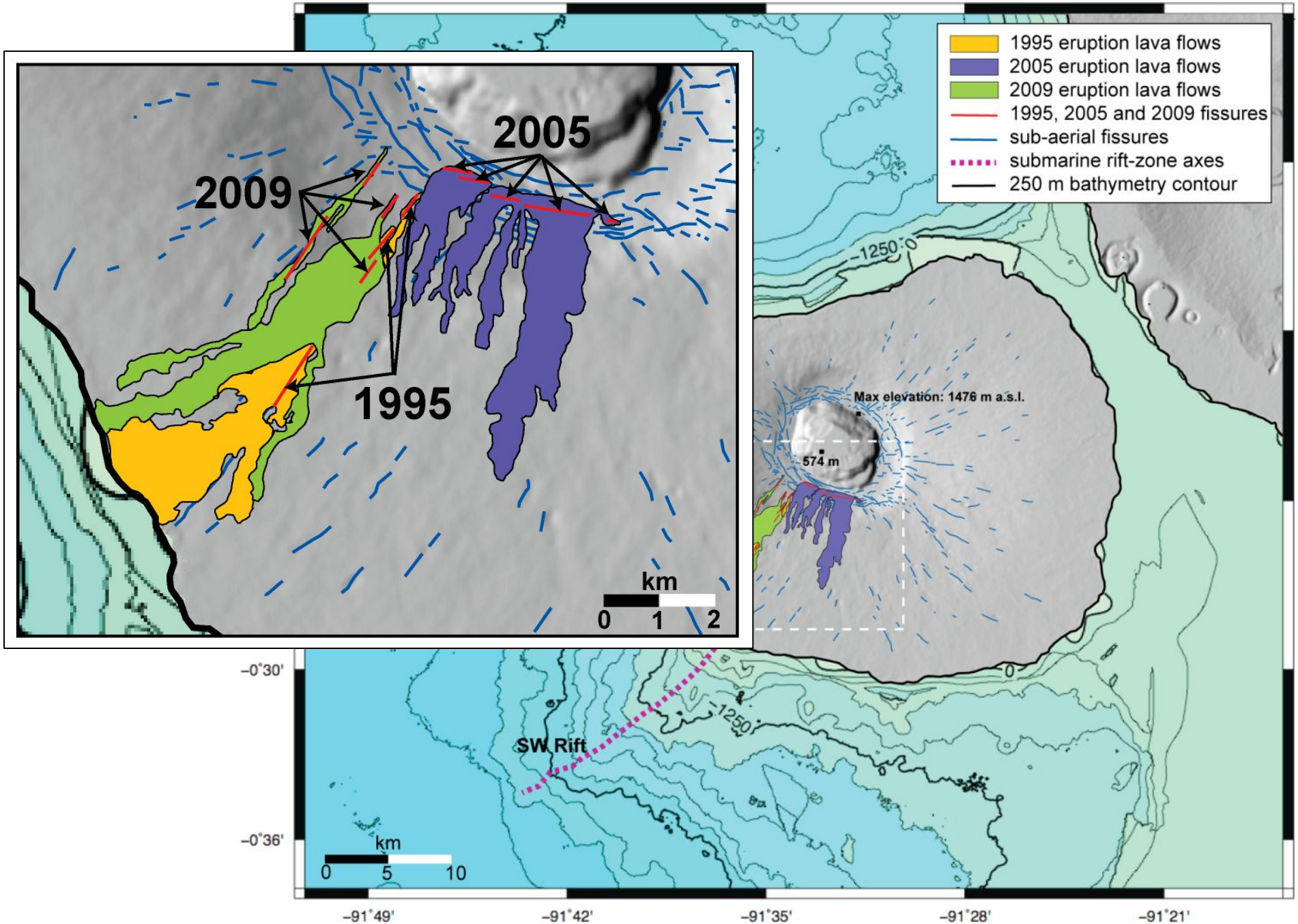
USGS

A curious pattern

radial vs. circumferential eruptive fissures



Chadwick and Howard, 1991

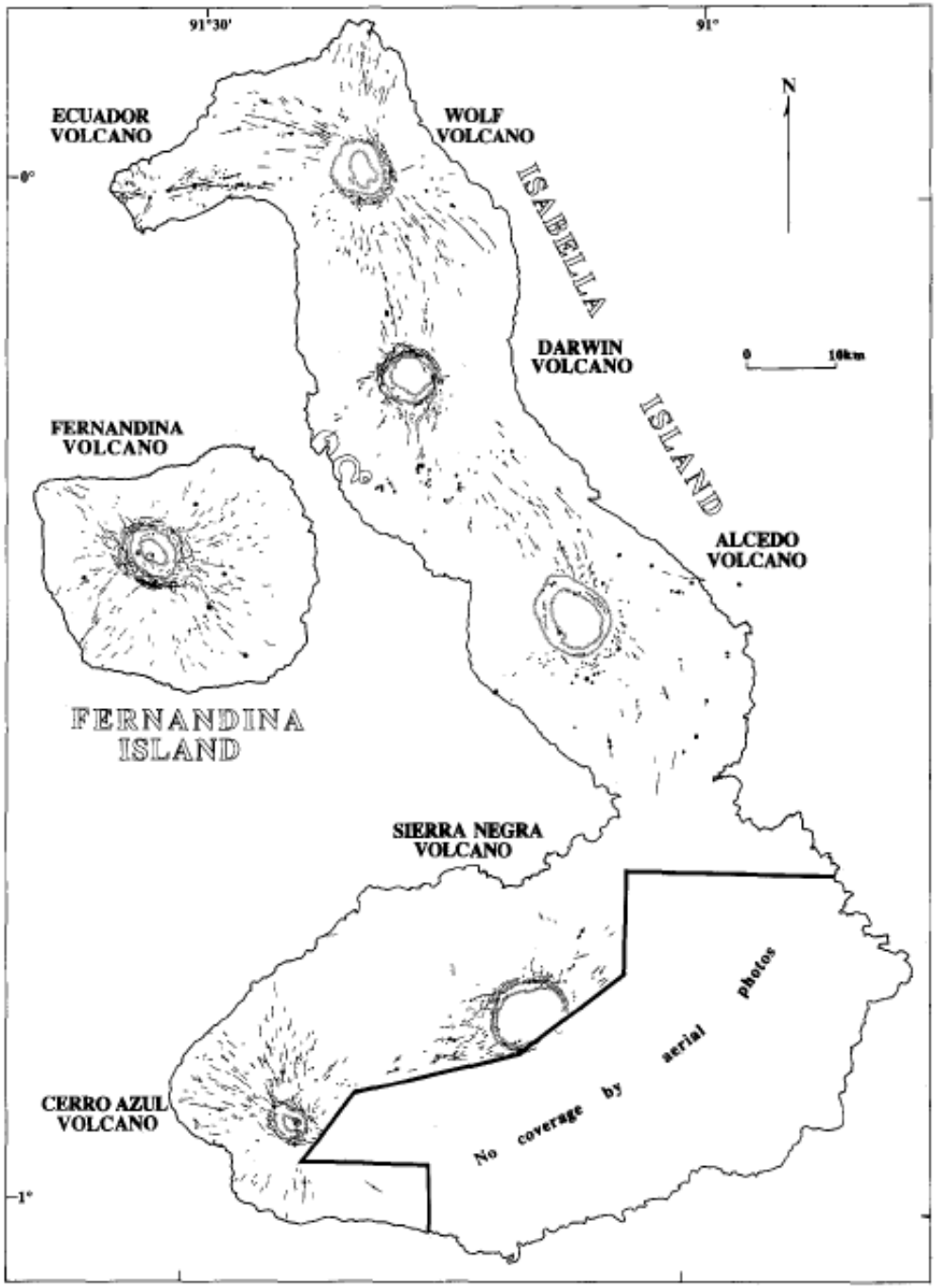


USGS

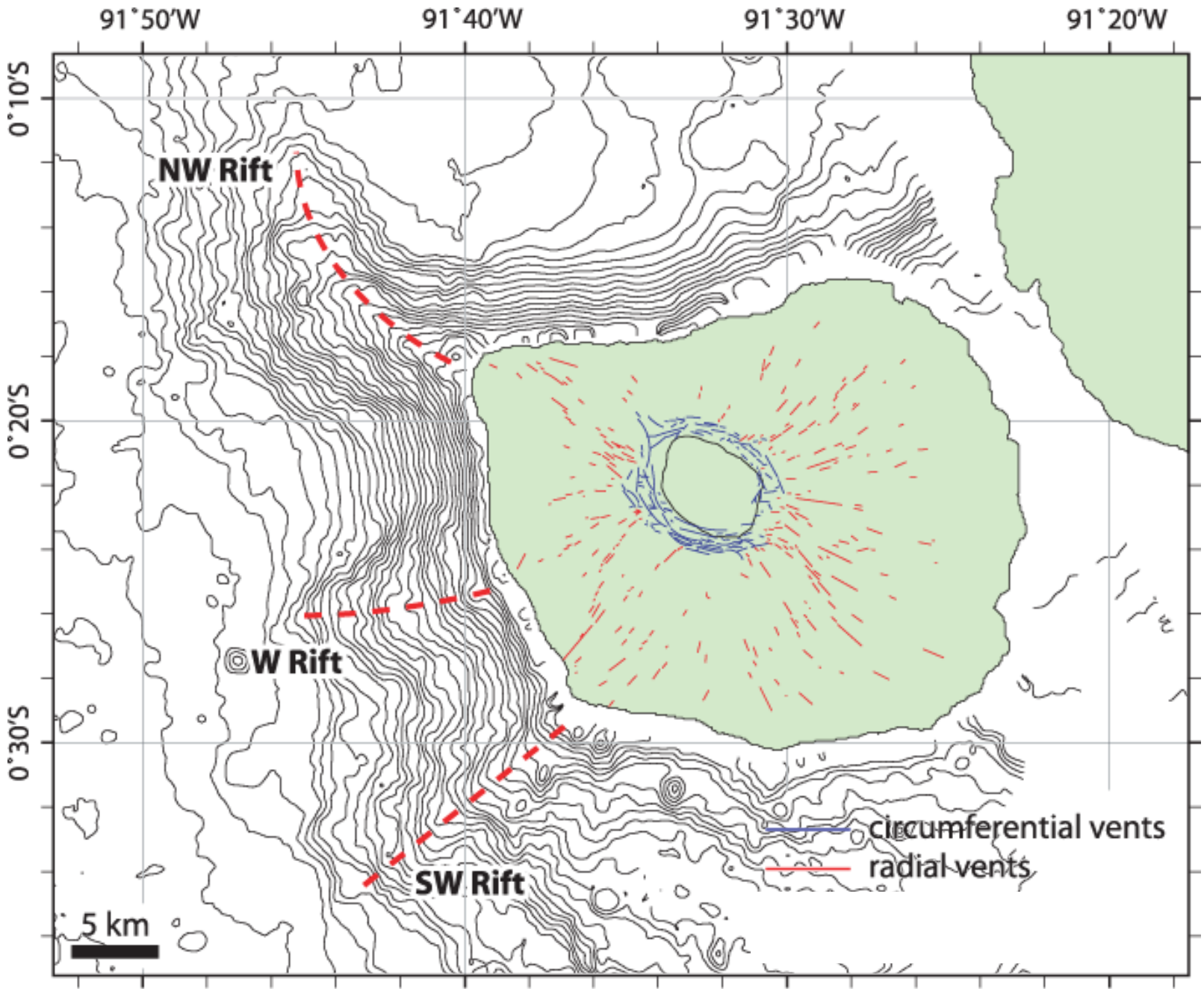
Figure courtesy of *Marco Bagnardi*

Rift Zones

Where are they?



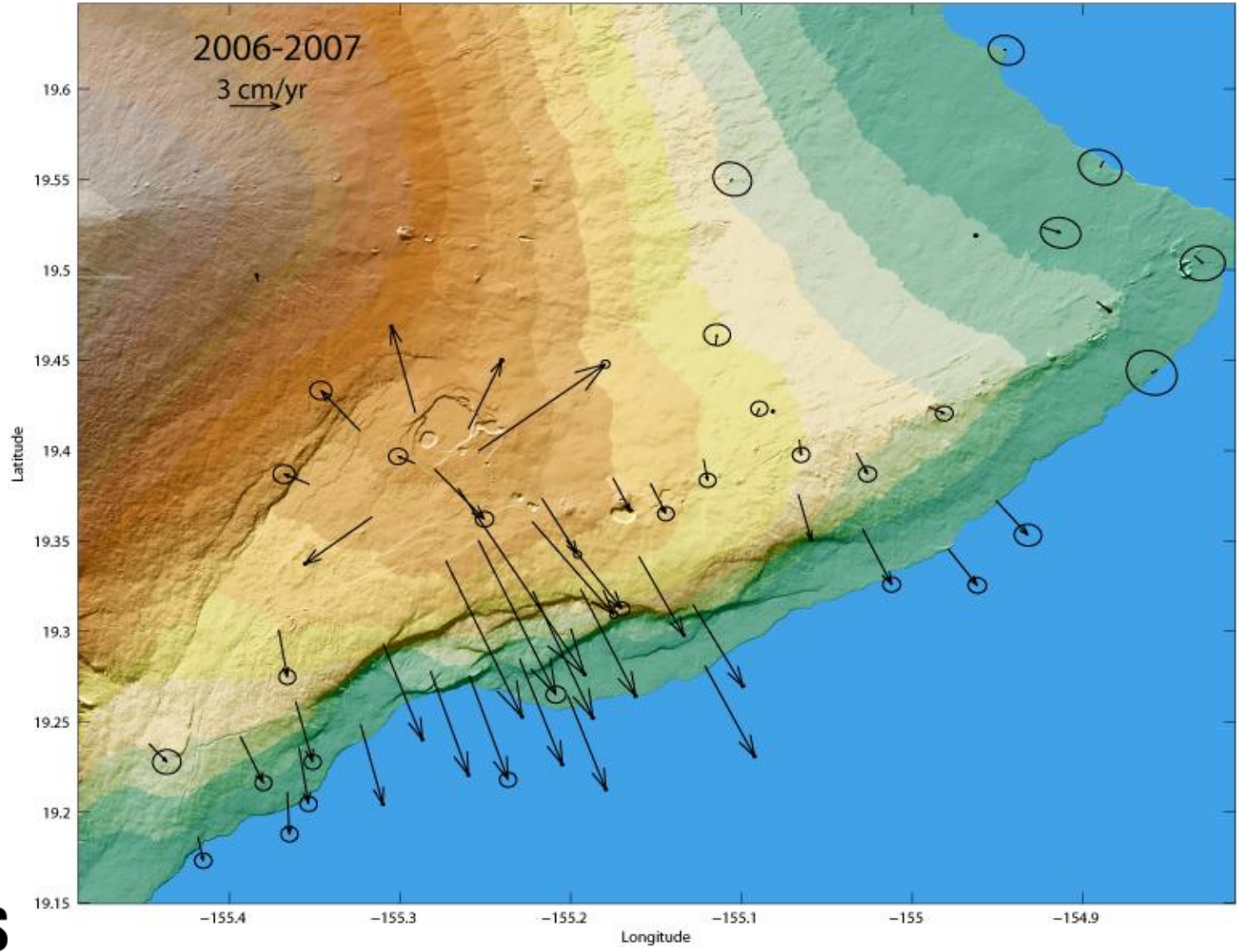
Chadwick and Howard, 1991



USGS

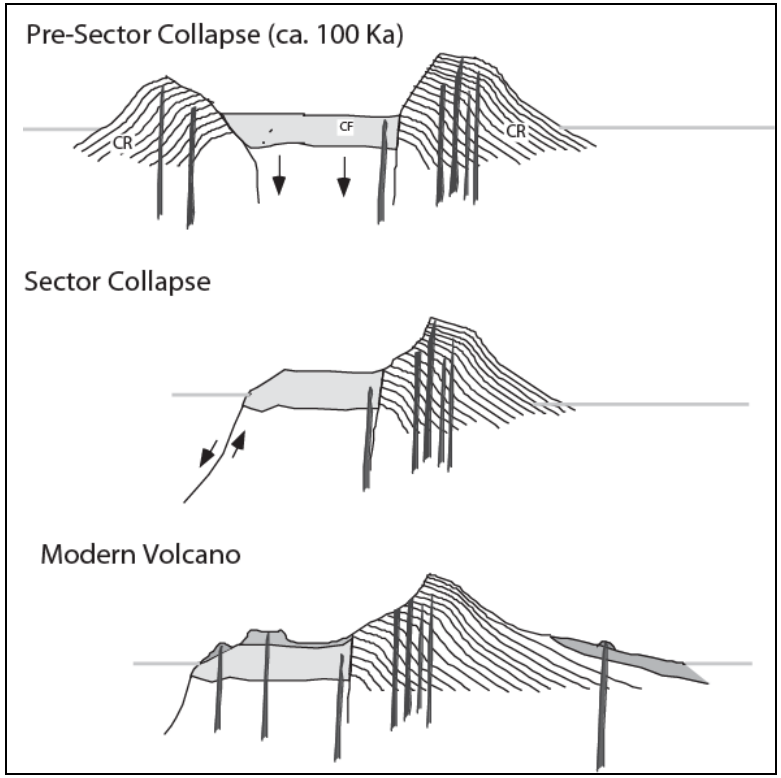
Geist et al., 2006

Flank instability

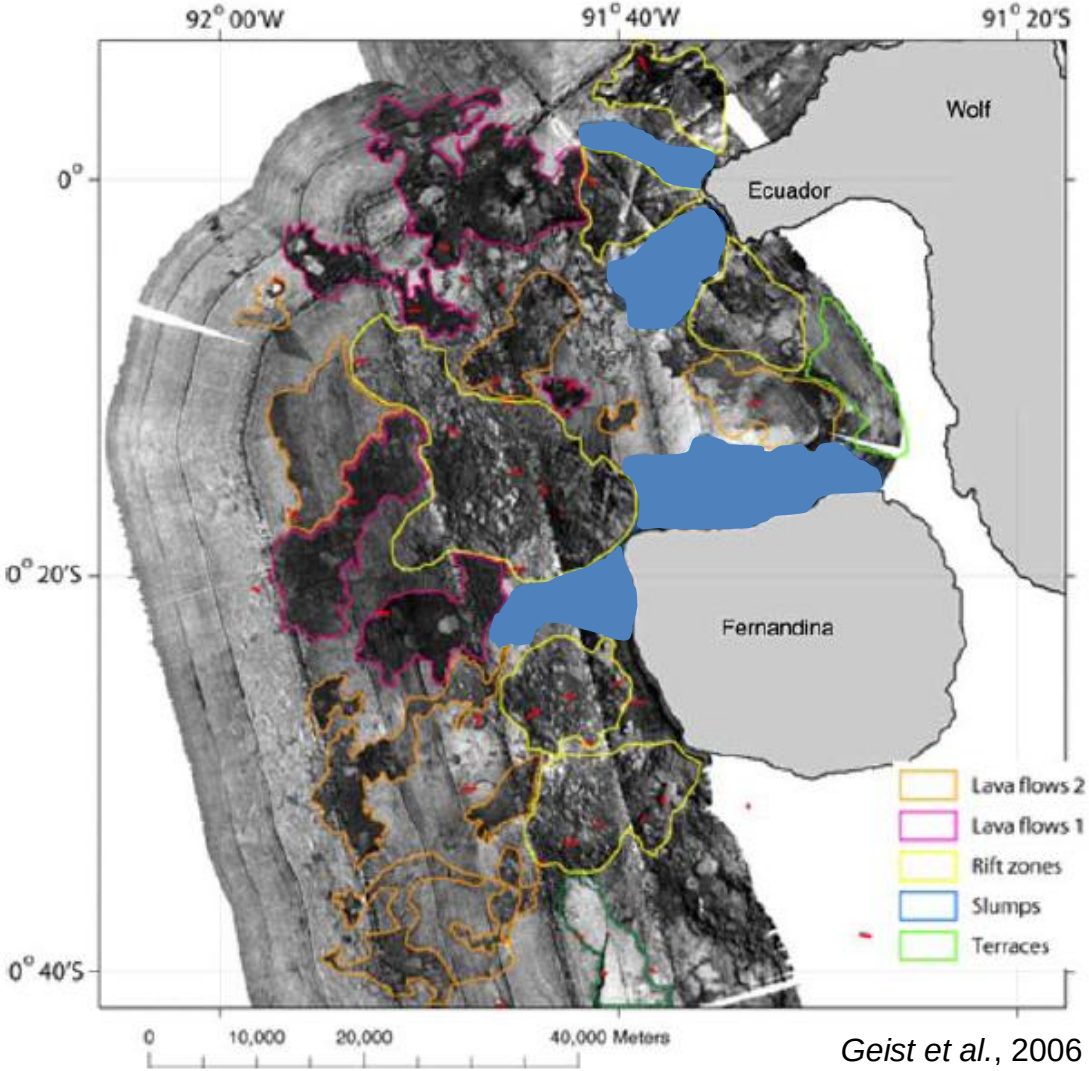


USGS

There is geologic evidence for flank instability, but nothing from deformation measurements (yet?). So how does flank instability develop at ocean island volcanoes?



Geist et al., 2002



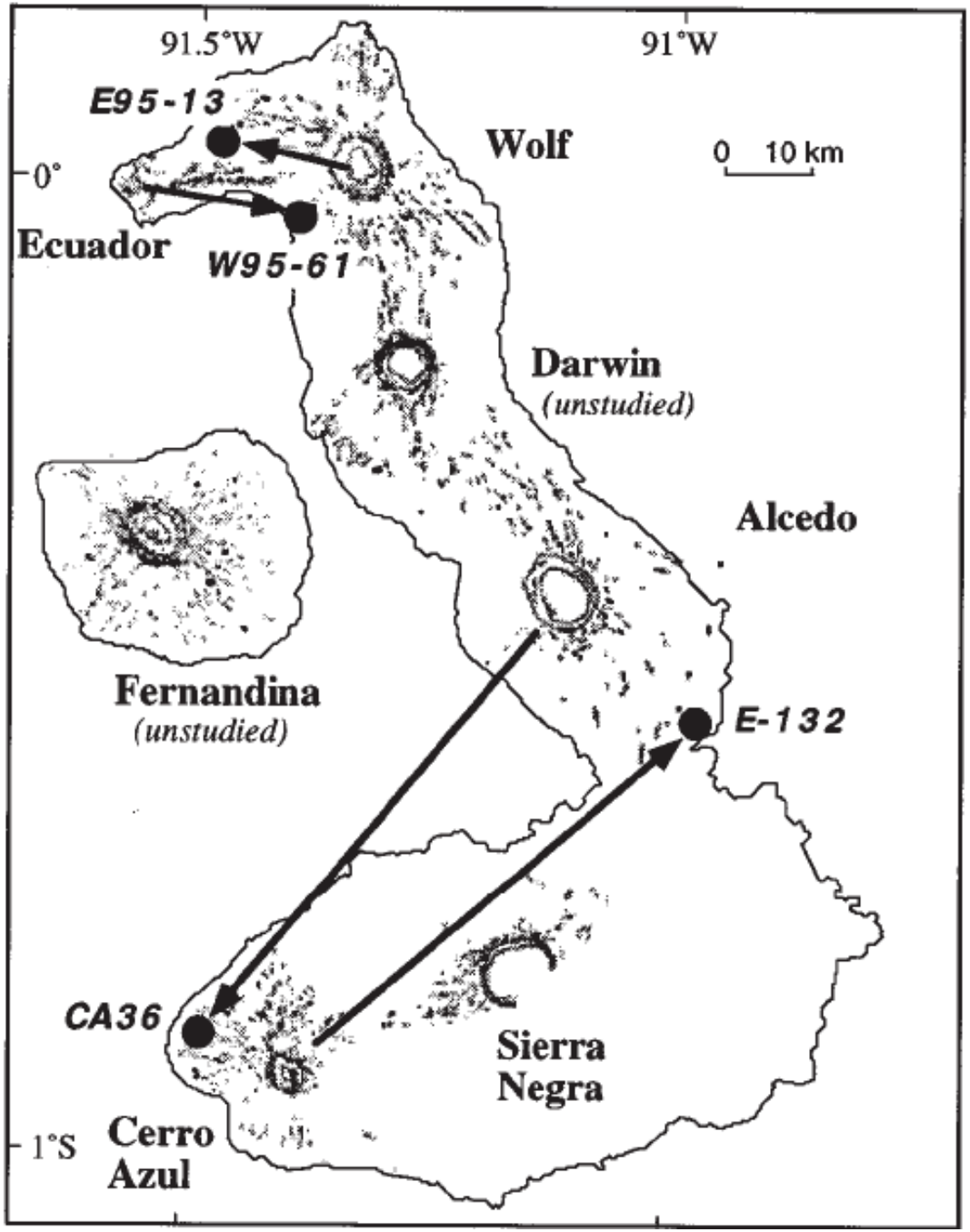
Geist et al., 2006

USGS

Volcano-volcano interactions

- Eight active volcanoes within 130 x 130 km area
- Volcano growth is contemporaneous
- Do the volcanoes interact?

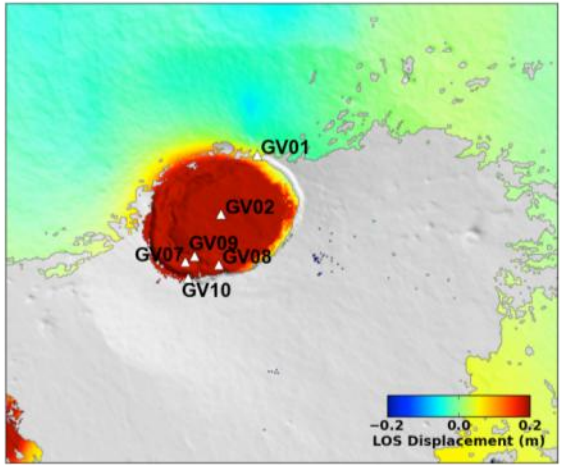
- Illegitimate (bastard) magmas

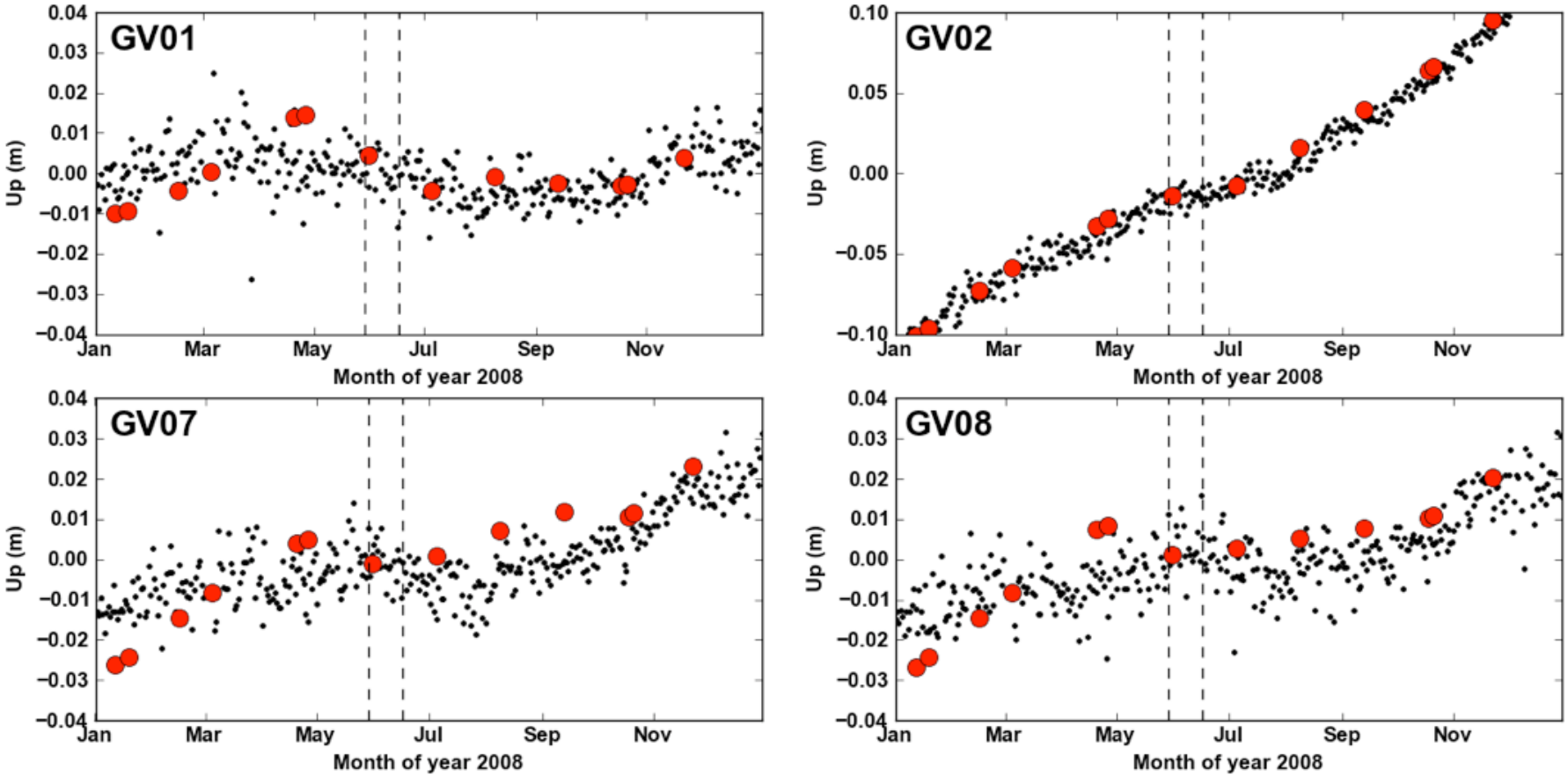


Geist et al., 1999

USGS

Sierra Negra subsidence brackets the 2008 eruption of Cerro Azul.





USGS

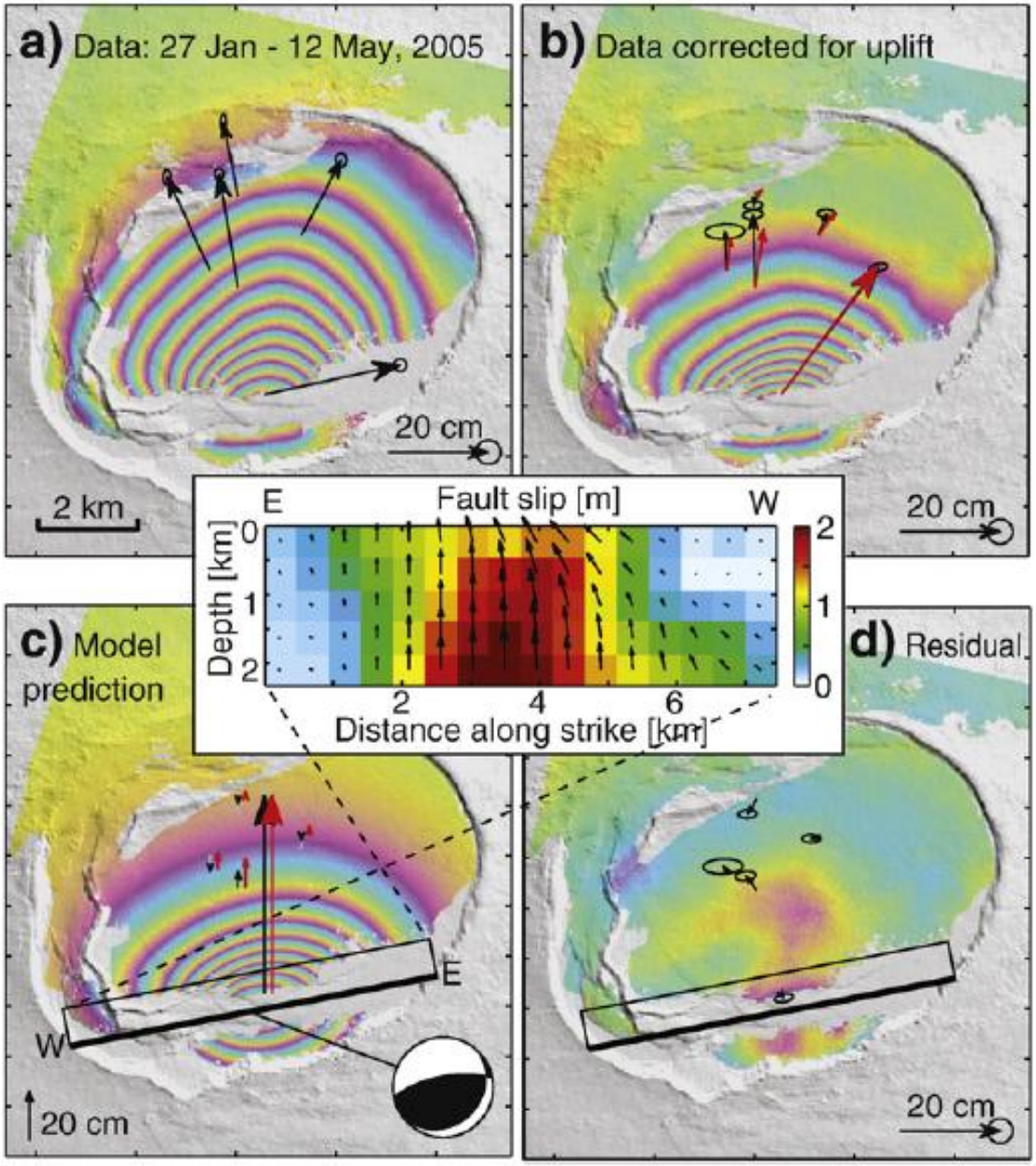
Figure courtesy of *Scott Baker*

Photo by *U.S. Air Force*, 1946

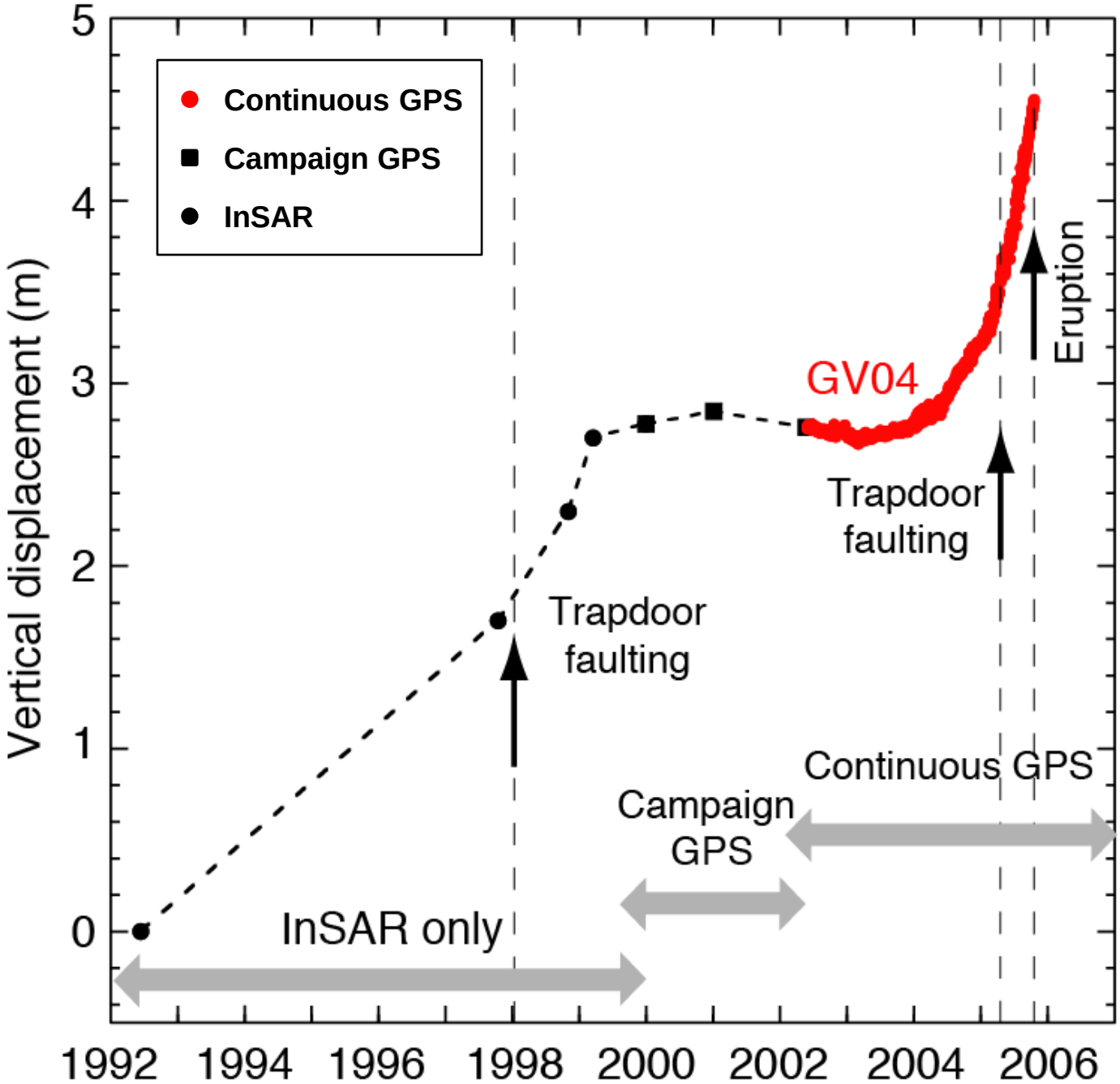
Volcano-tectonic interactions

Photo by *P. Ramon*, 2005

- **Trapdoor faulting at Sierra Negra in 1998 and 2005**
- **Inflation promotes faulting**
- **Faulting encourages dike emplacement to the north**
- **Faulting allows for more inflation without eruption**



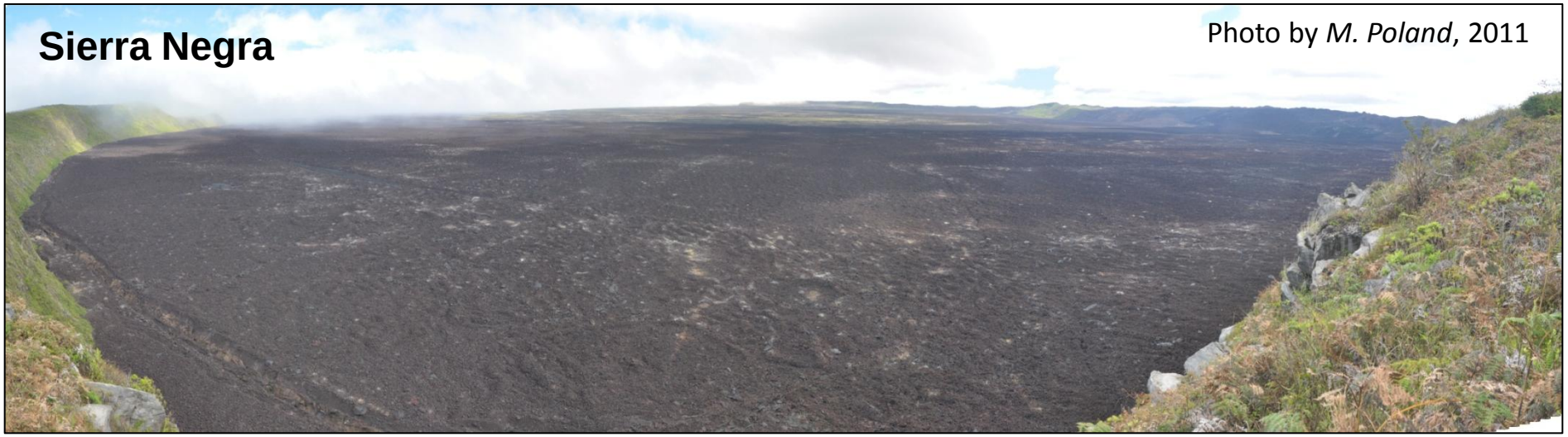
Jónsson, 2009



Chadwick et al., 2006

Calderas

- **Formation**
- **Morphology**



USGS

IV. VOLCANIC ERUPTIONS

- **What are the characteristics and causal mechanisms of explosive basaltic eruptions?**

- **What characterizes the stages of a basaltic volcano's eruption cycle?**

USGS

Explosive basaltic eruptions

- **Basaltic volcanoes are effusive, right?**
- **Work at Kīlauea indicates otherwise and demonstrates the extreme hazard**
- **So where can one study explosive basaltic volcanoes?**

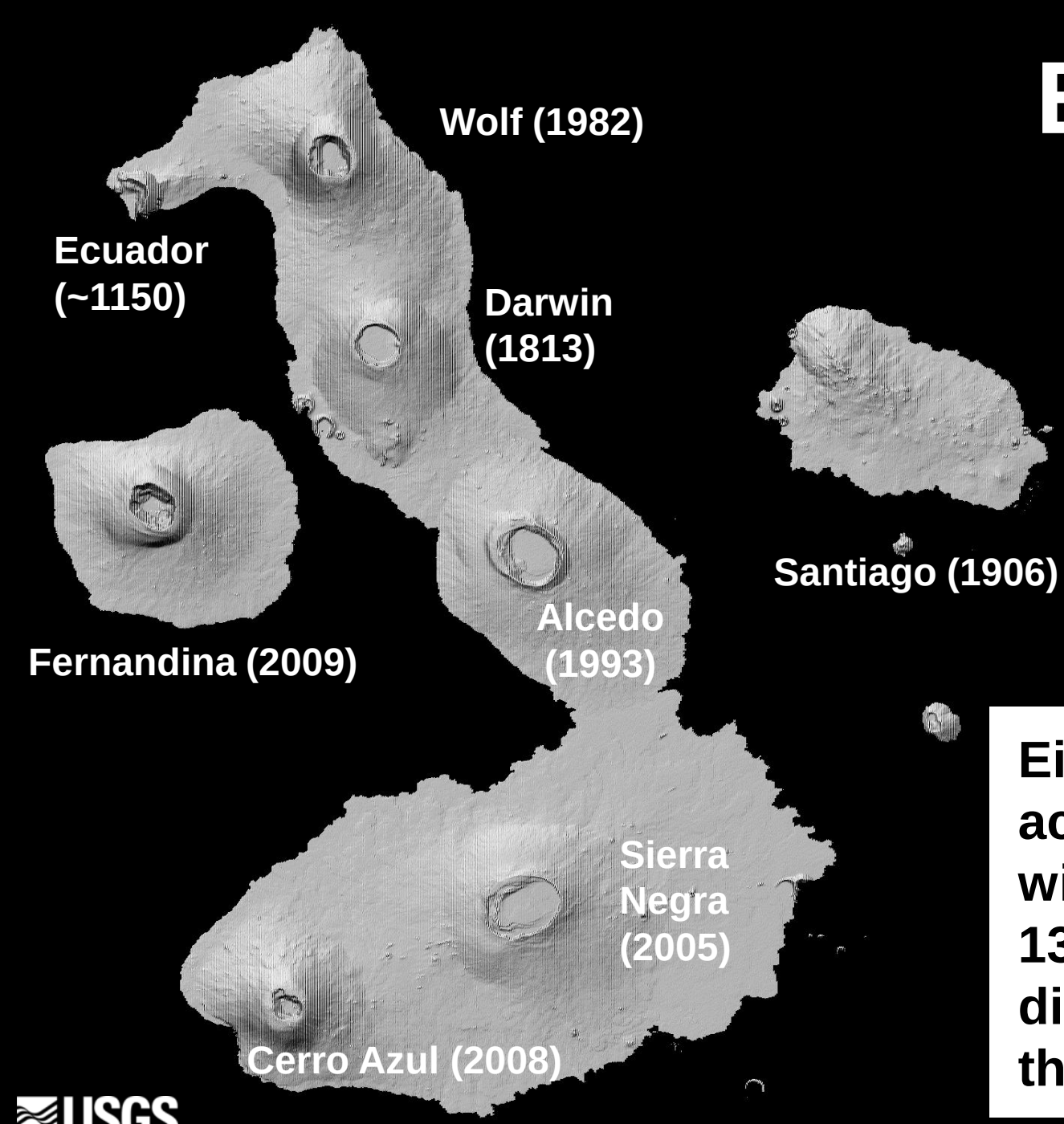

Photo by *D. Geist*
USGS


Photo by *T. Simkin*, 1968

Fernandina 1968


Photo by *J. Harte*, 1968

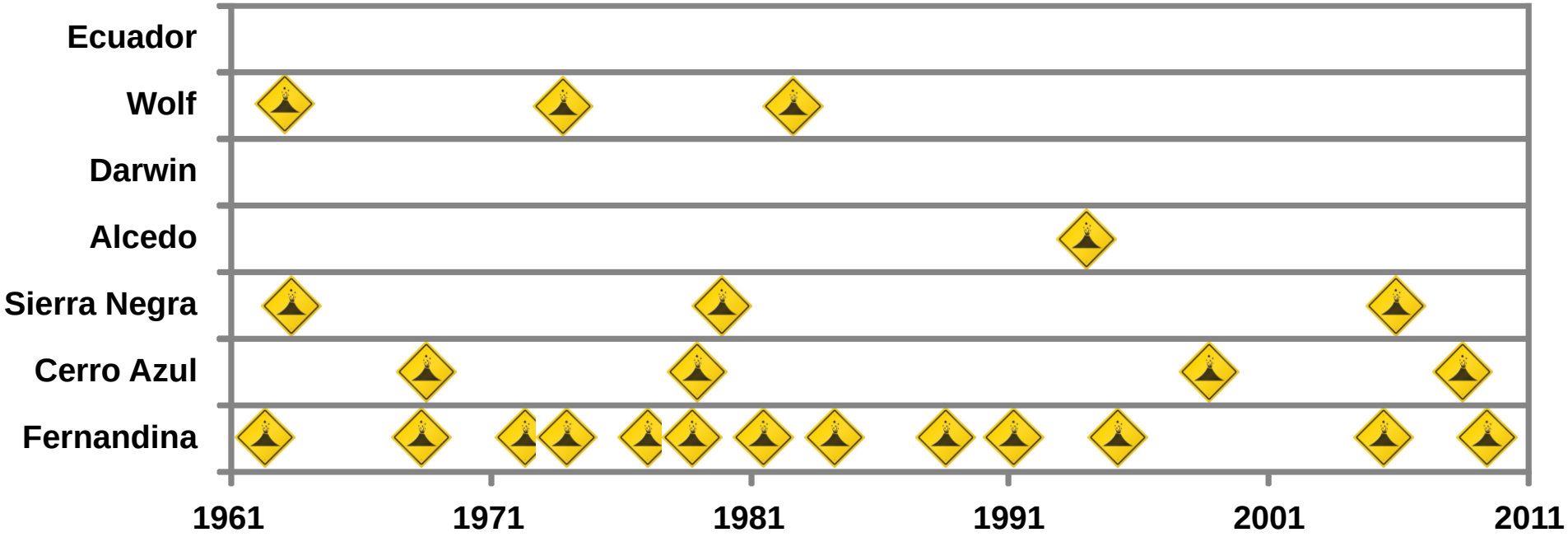
Eruption Cycle



Eight recently active volcanoes within a 130 km x 130 km area, all in different stages of the eruption cycle

USGS

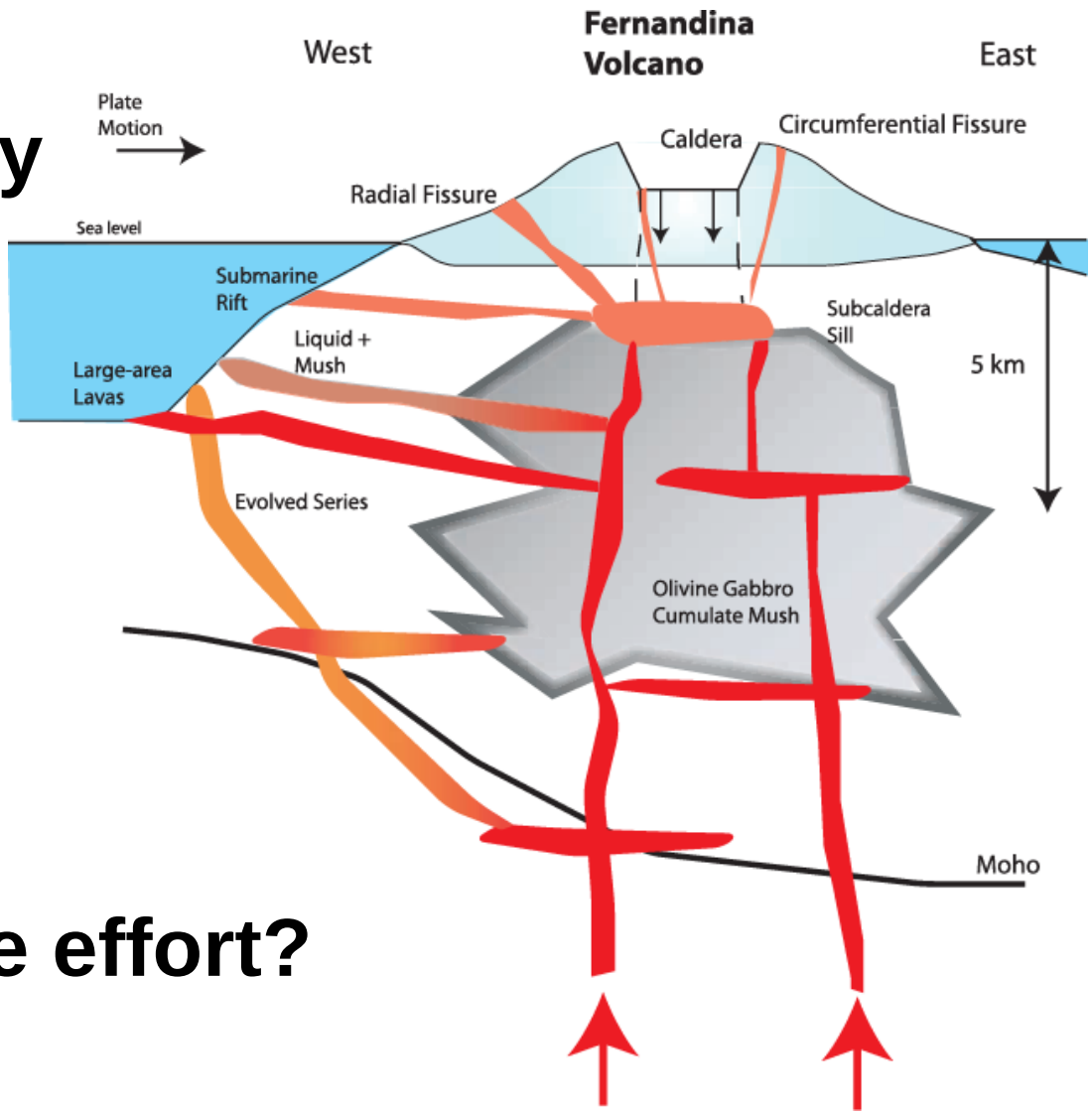
Galápagos volcanoes erupt more often than we might appreciate (24 times in past 50 years). A great place to observe basaltic eruptions!



USGS

Summary

- **Natural laboratory**
  - I. **Magma supply**
  - II. **Magma storage and transport**
  - III. **Evolution of basaltic shields**
  - IV. **Volcanic eruptions**
- **But is it worth the effort?**

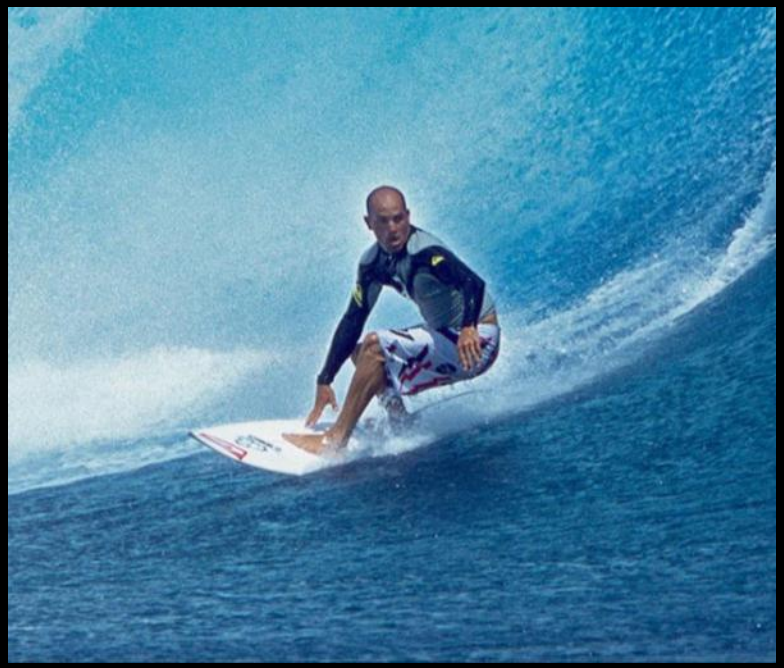


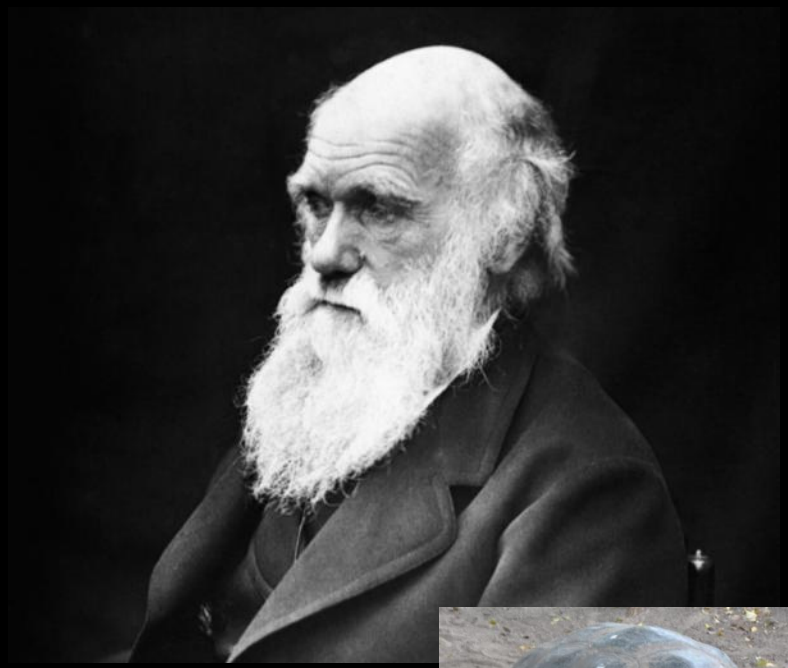
USGS

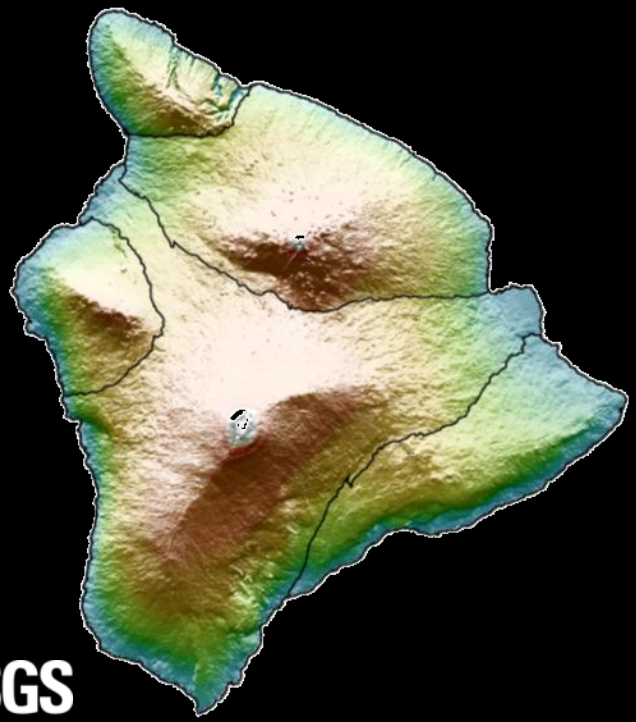
Geist et al., 2006

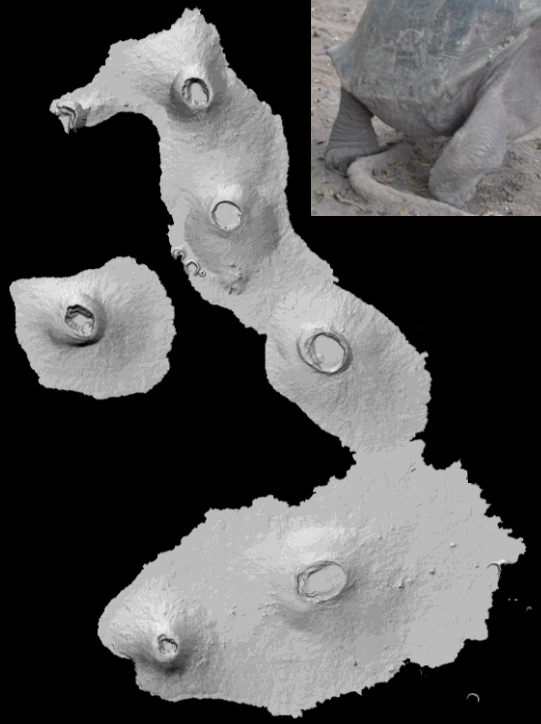
Downers	Uppers
• Remoteness of location	• Exceptional volcanic activity
• Lack of infrastructure	• New technology and satellites
• Working in a National Park	• Public visibility and notoriety

USGS









USGS