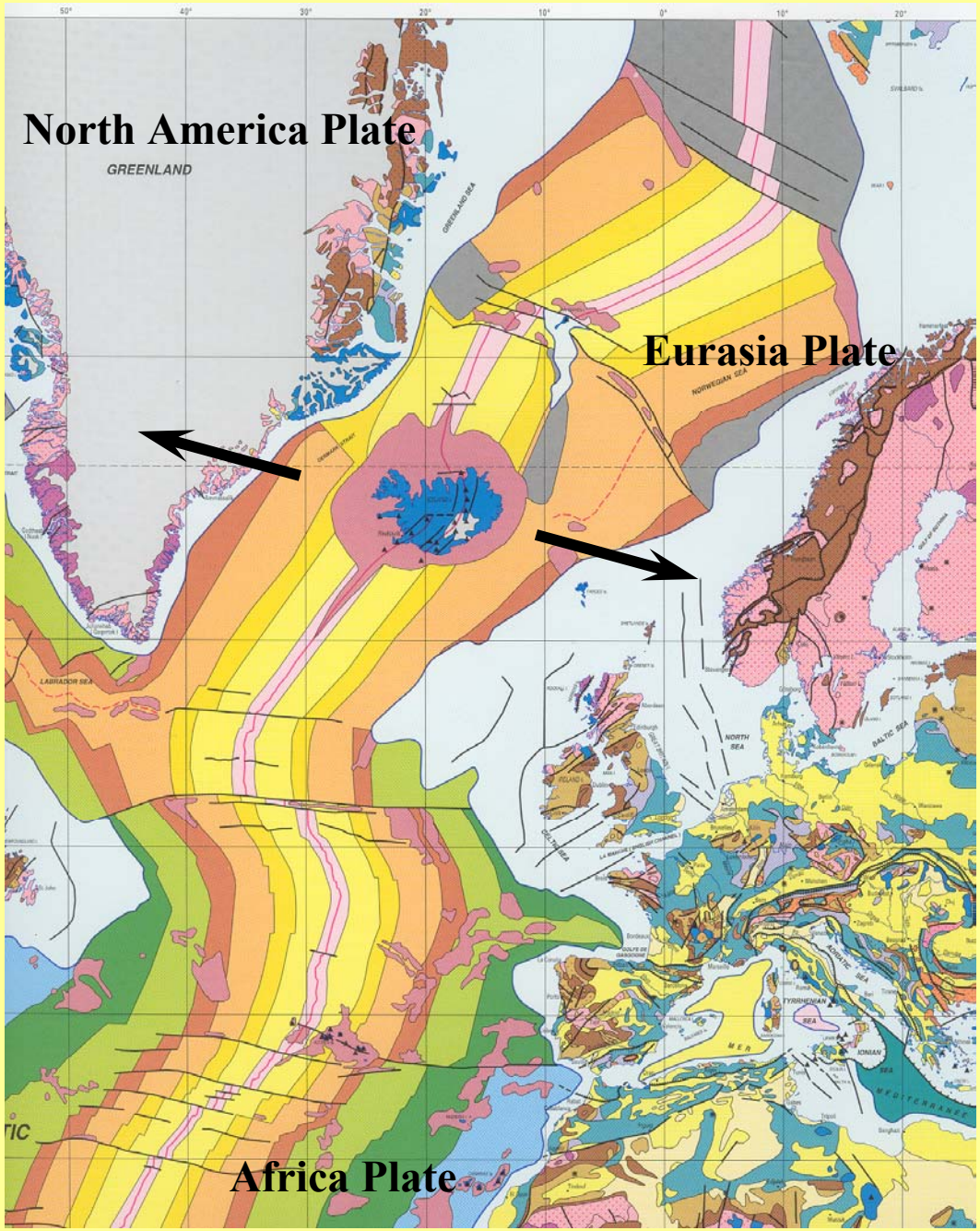
Geodynamics and crustal movements in Iceland

Páll Einarsson, Freysteinn Sigmundsson

Institute of Earth Sciences, University of Iceland

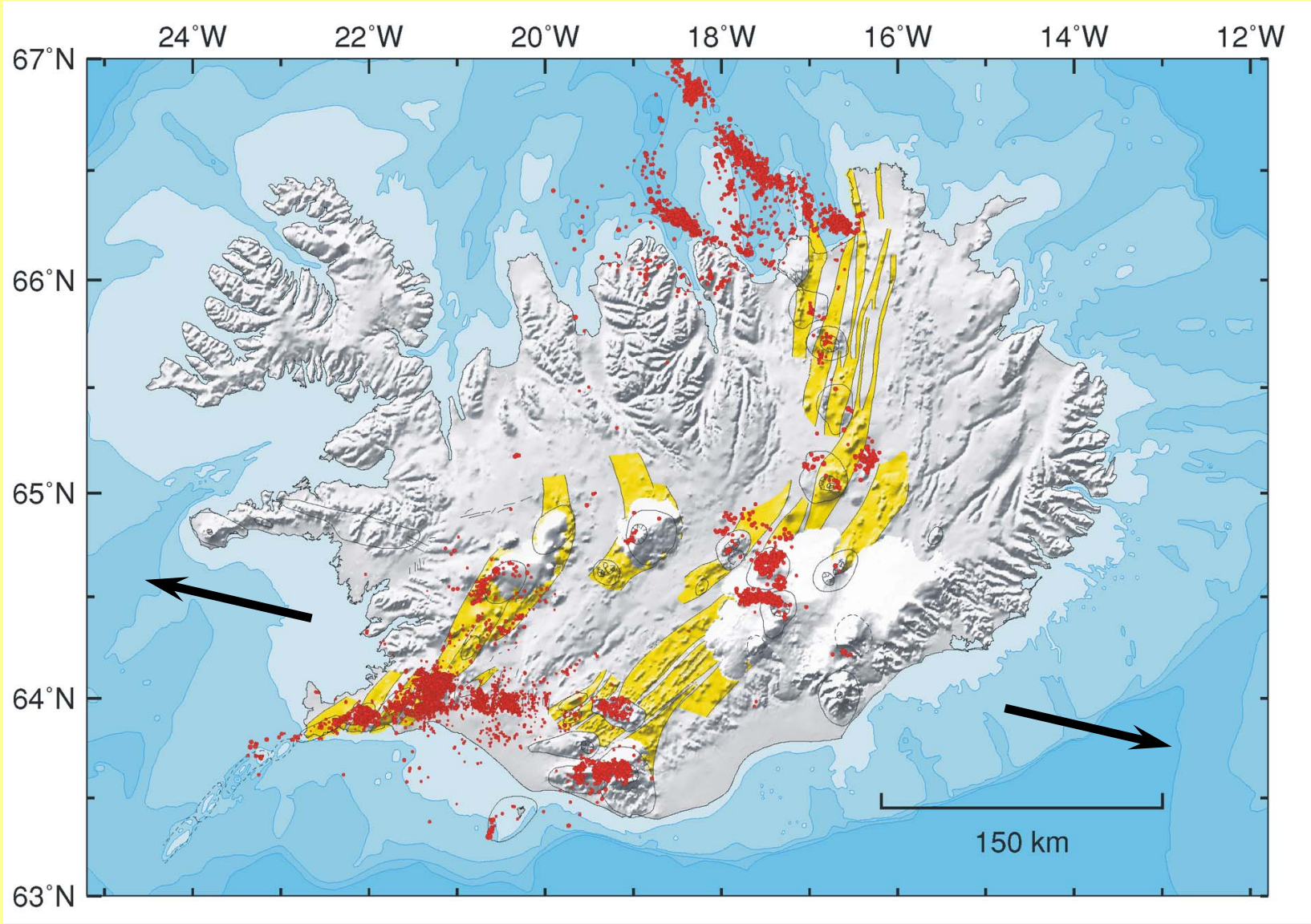
With material from Halldór Geirsson, Erik Sturkell, Pete La Femina, Tim Dixon, Christof Völksen, Þóra Árnadóttir, and many others



Spreading in the Iceland area:

Spreading direction: 104-105°
Well constrained by the azimuth of adjacent long fracture zones, Charlie-Gibbs FZ and Jan Mayen FZ

Full spreading rate: 1.85-1.95 cm/year
Well constrained by magnetic anomalies on adjacent ridges



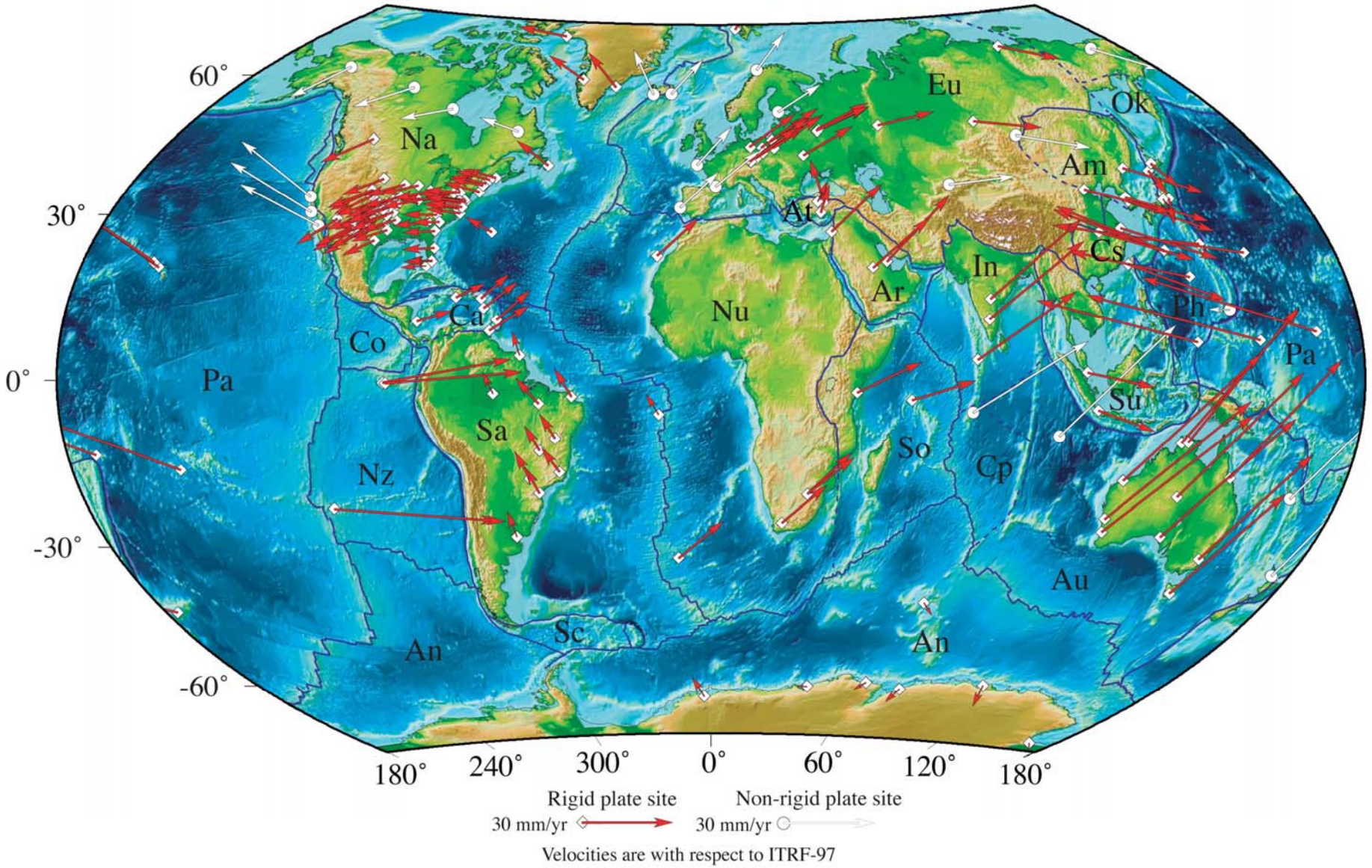
Iceland: Volcanic systems and epicenters 1994-97

Epicenters from the Icelandic Meteorological Office

Crustal movements - Processes

- Plate movements
- Plate cooling
- Plate boundary deformation
- Volcano deformation
- Crustal loading-unloading, isostasy

REVEL-2000



Sella, Dixon, and Mao J. Geophys. Res., 107, 10.1029/2000JB000033, 2002

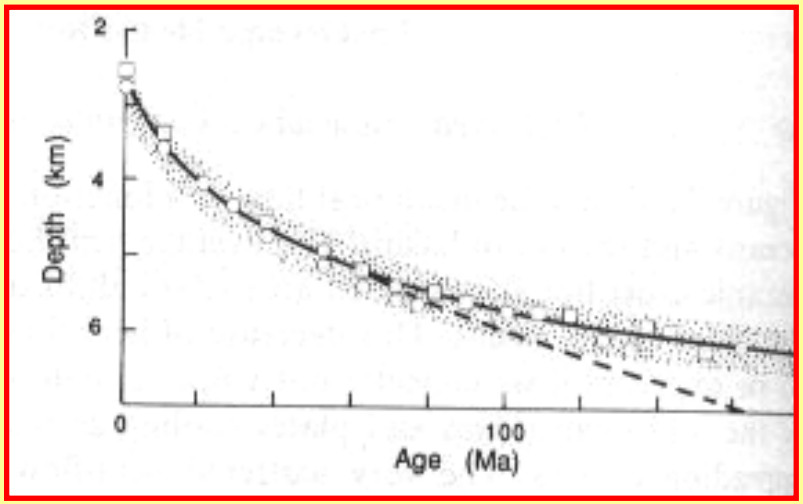
Plate divergence in Iceland

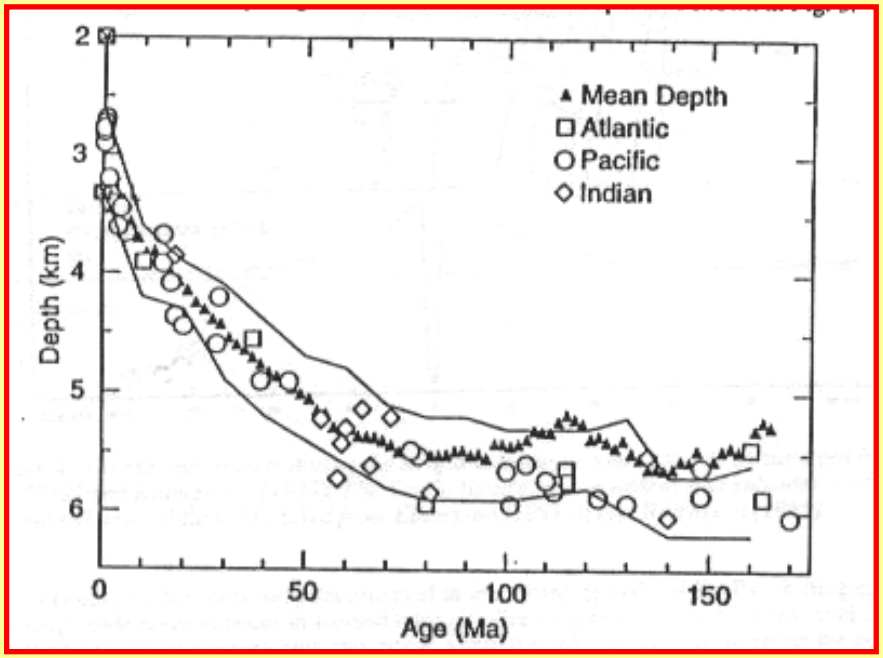
Two major plates: North America Plate,
Eurasia Plate

One microplate: Hreppar Microplate

Spreading rates between major plates:

- Geological time scale, 1-10 My:
  NUVEL-1A (18.3 mm/yr @ N105°E)
- Space geodesy, time scale of a decade:
  REVEL (19.7 mm/yr @ N103°E)
- Instantaneous: Continuous GPS



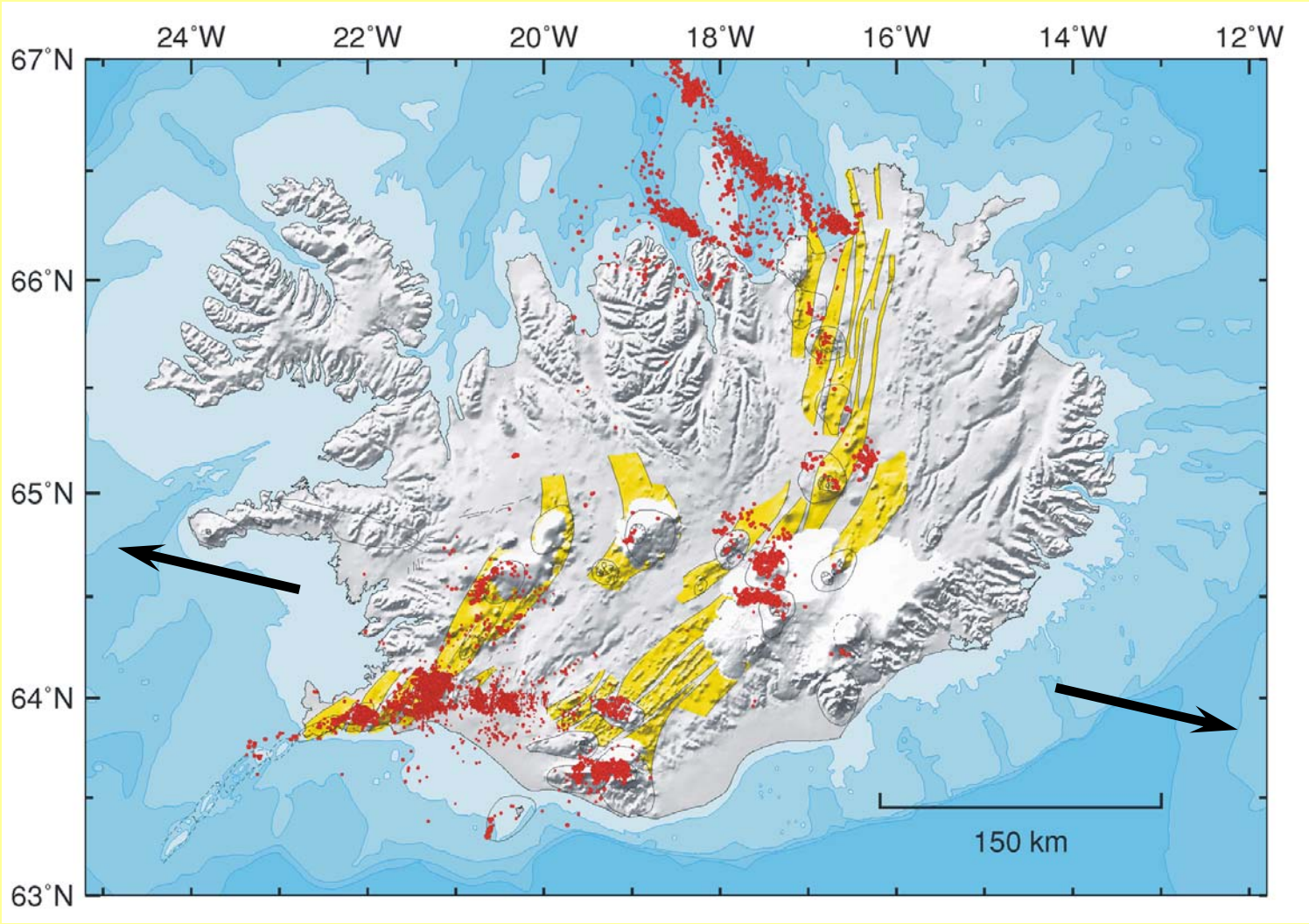


Lithosphere cooling

Ocean depth depends on the age of the lithosphere:

$$D = 2.5 + 0.35\ t^{1/2}$$

Plate boundary deformation: Volcanic rift zones



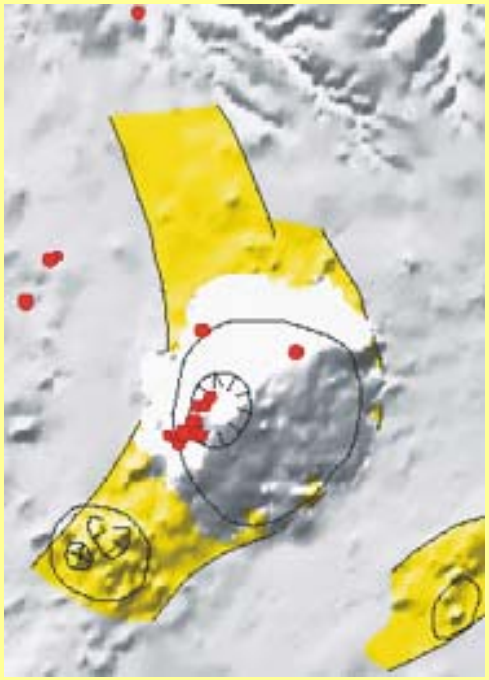
Iceland: Volcanic systems and epicenters 1994-97

Epicenters from the Icelandic Meteorological Office

The basic structural and petrological element of the rift zone is the **volcanic system.**

Each segment of the rift zone consists of several volcanic systems.

The systems may be arranged side-by-side or en echelon, depending on the degree of obliqueness of spreading.



A **volcanic system** has some of the following characteristics:

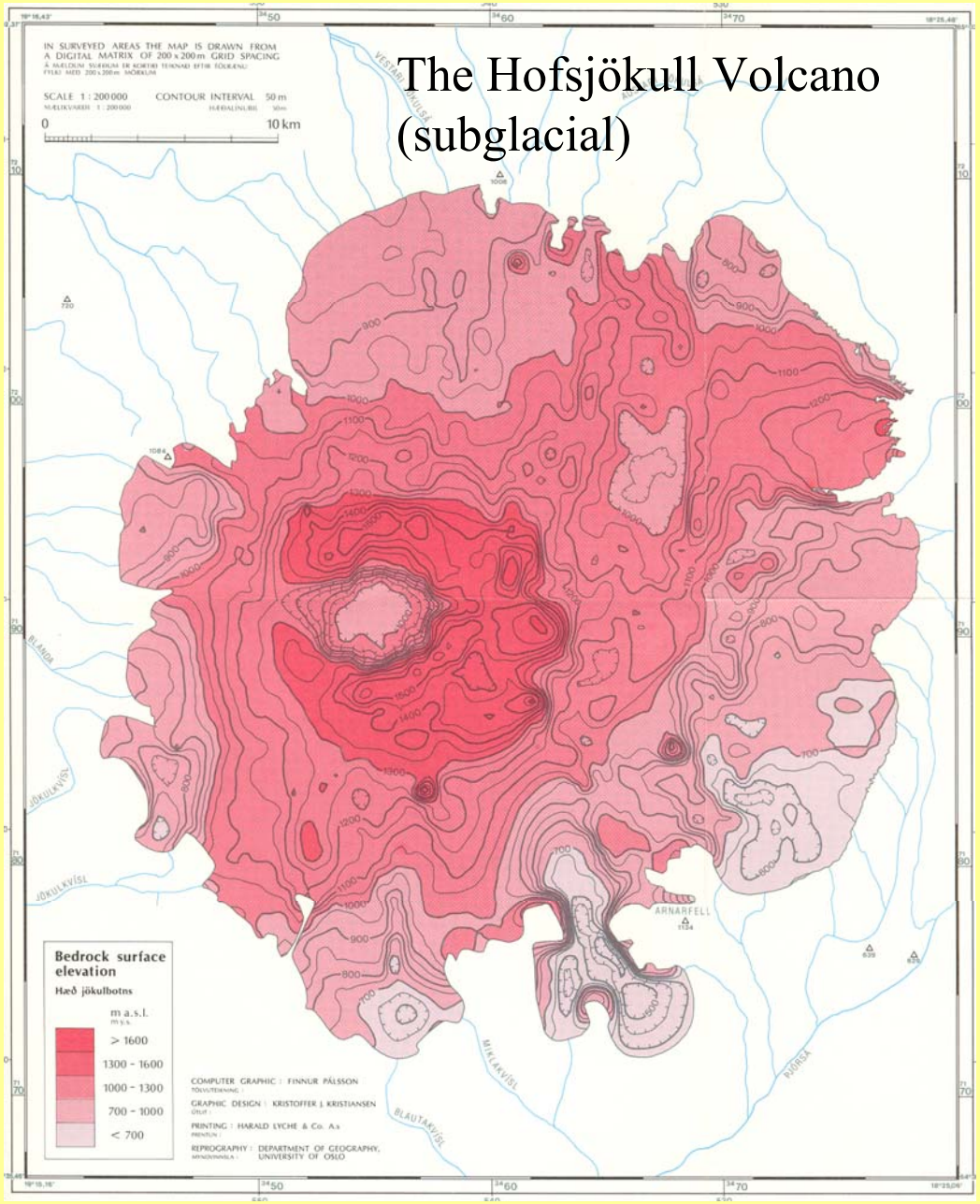
1. A central volcano or a center of production

2. A consistent petrological signature

3. A transecting fissure swarm

4. Caldera

5. Geothermal system



Map by Helgi Björnsson

Central volcanoes:

Centers of production

Calderas

Acidic rocks occur

Subdued topography due to subsidence

The highest ones are covered by glaciers

Askja Central Volcano

Photo: Oddur Sigurðsson

TM image

The Western Volcanic Rift Zone

Main rift since 6-7 Ma

No significant activity since the settlement

Lava shields

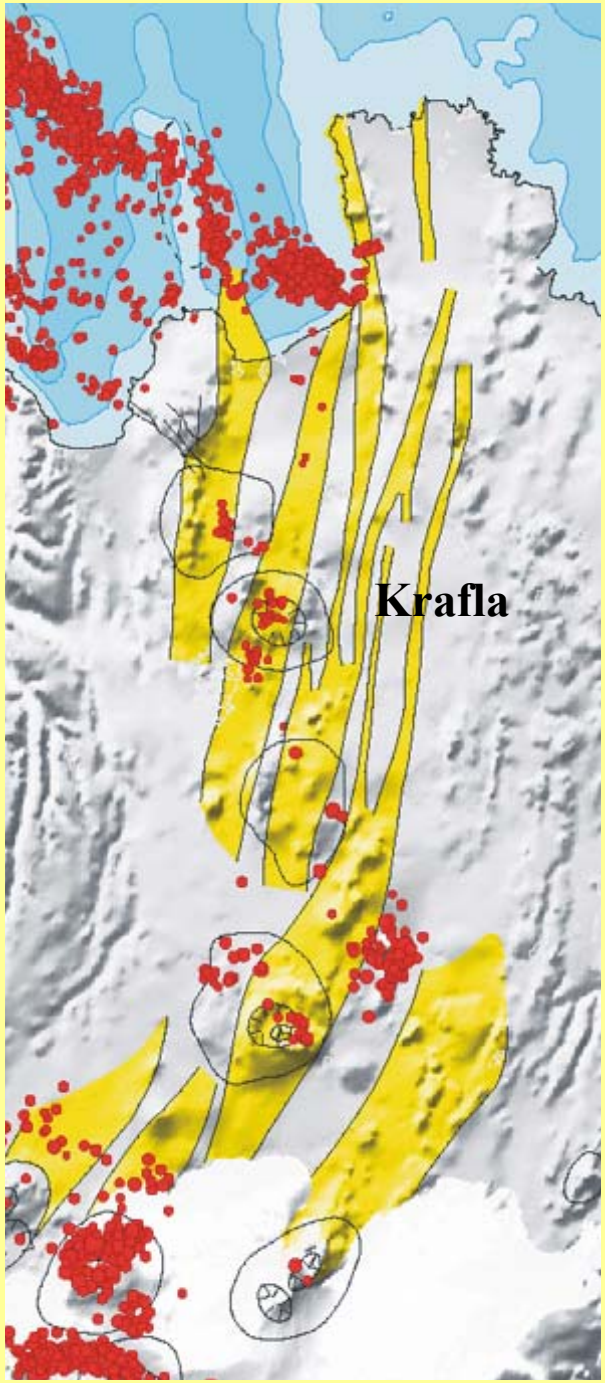
No en echelon arrangement of volcanic systems

Low productivity

Normal faulting prominent

Kaldidalur, WVZ: Normal faulting

Photo: U. Münzer



The Northern Volcanic Rift Zone

En echelon, overlapping fissure swarms

Central volcanoes mark plate boundary

Lava shields prominent

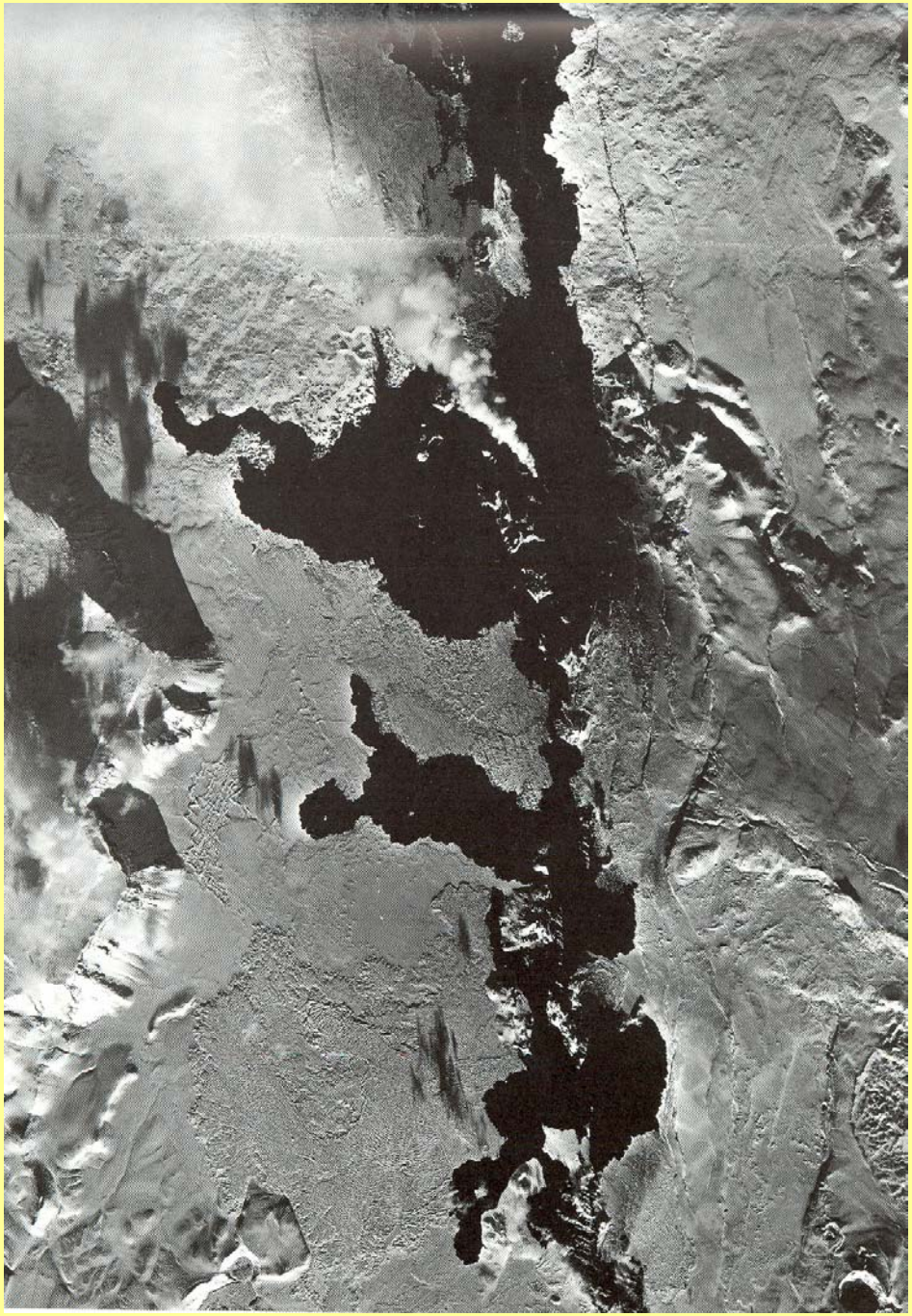
Spreading slightly oblique

Spreading episodes

Krafla episodes 1724-46, 1975-84
Inflation, deflation, rifting, transform faulting, eruptions

Krafla eruption of November 1981.

The Krafla 1975-84 episode consisted of 22 injection events, of which 9 reached the surface in eruptions. The eruptions lasted from less than one hour to 14 days.

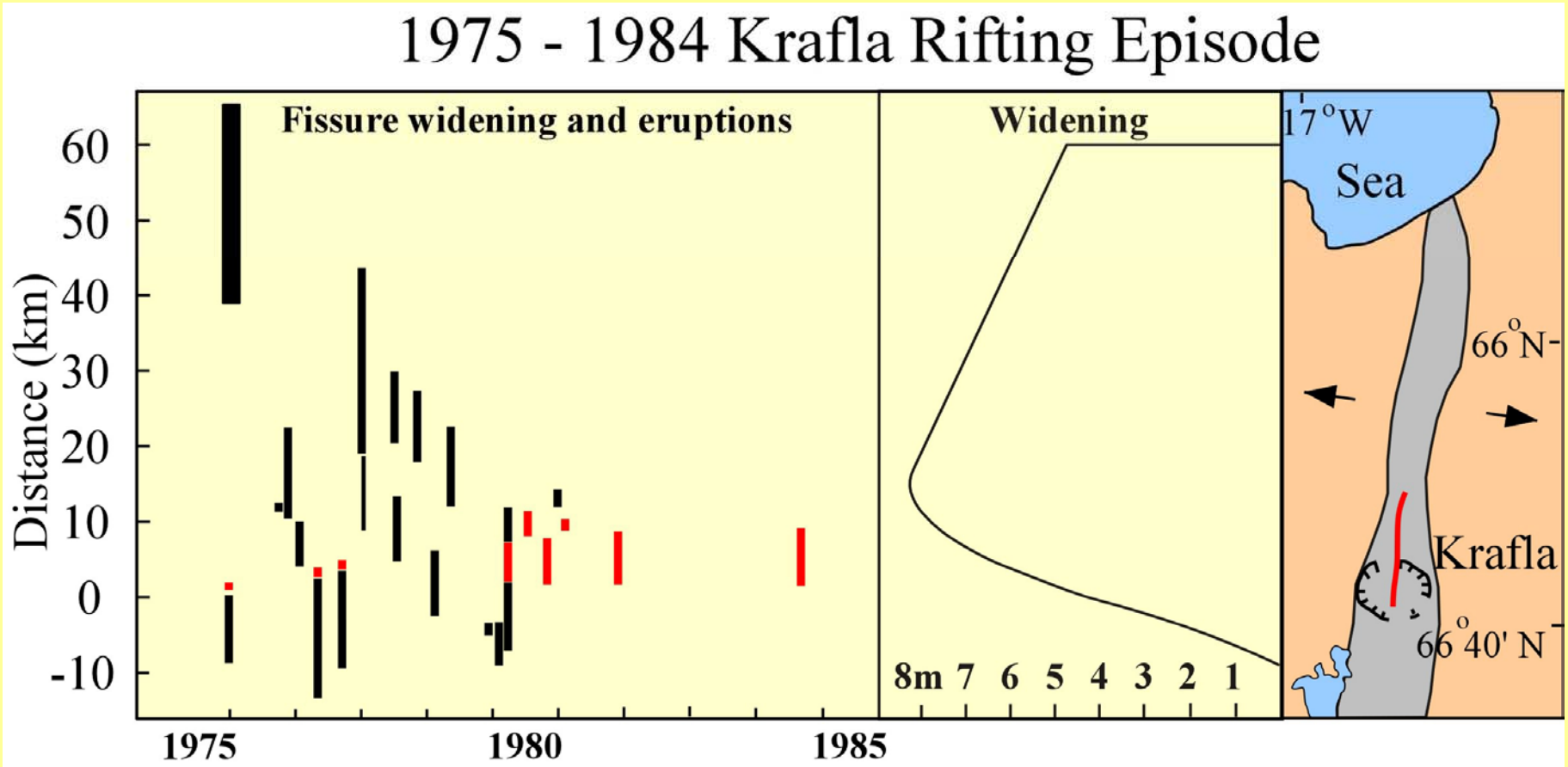


Krafla eruption of November 1981

The eruption lasted 5 days

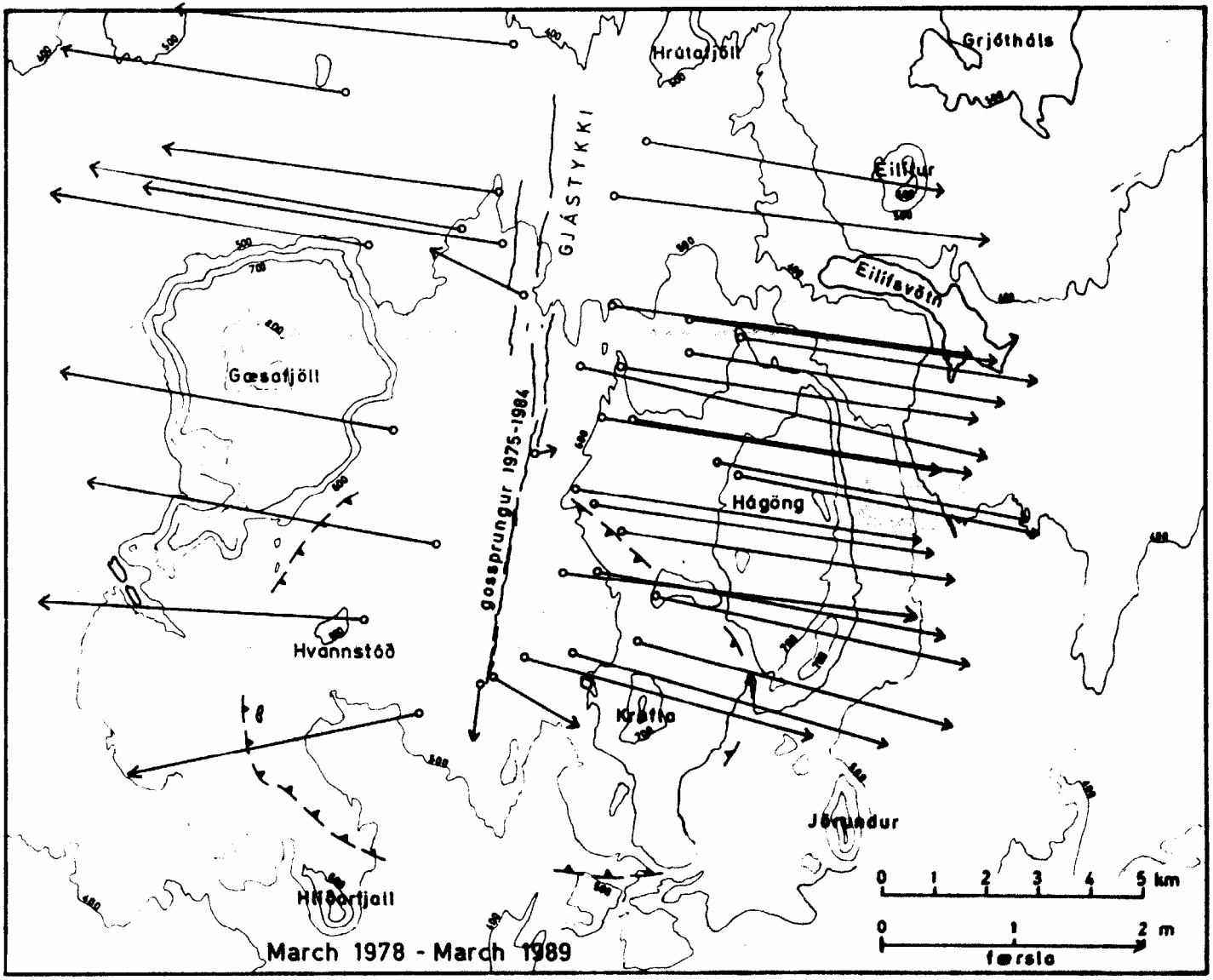
The discontinuous eruptive fissure was 8 km long

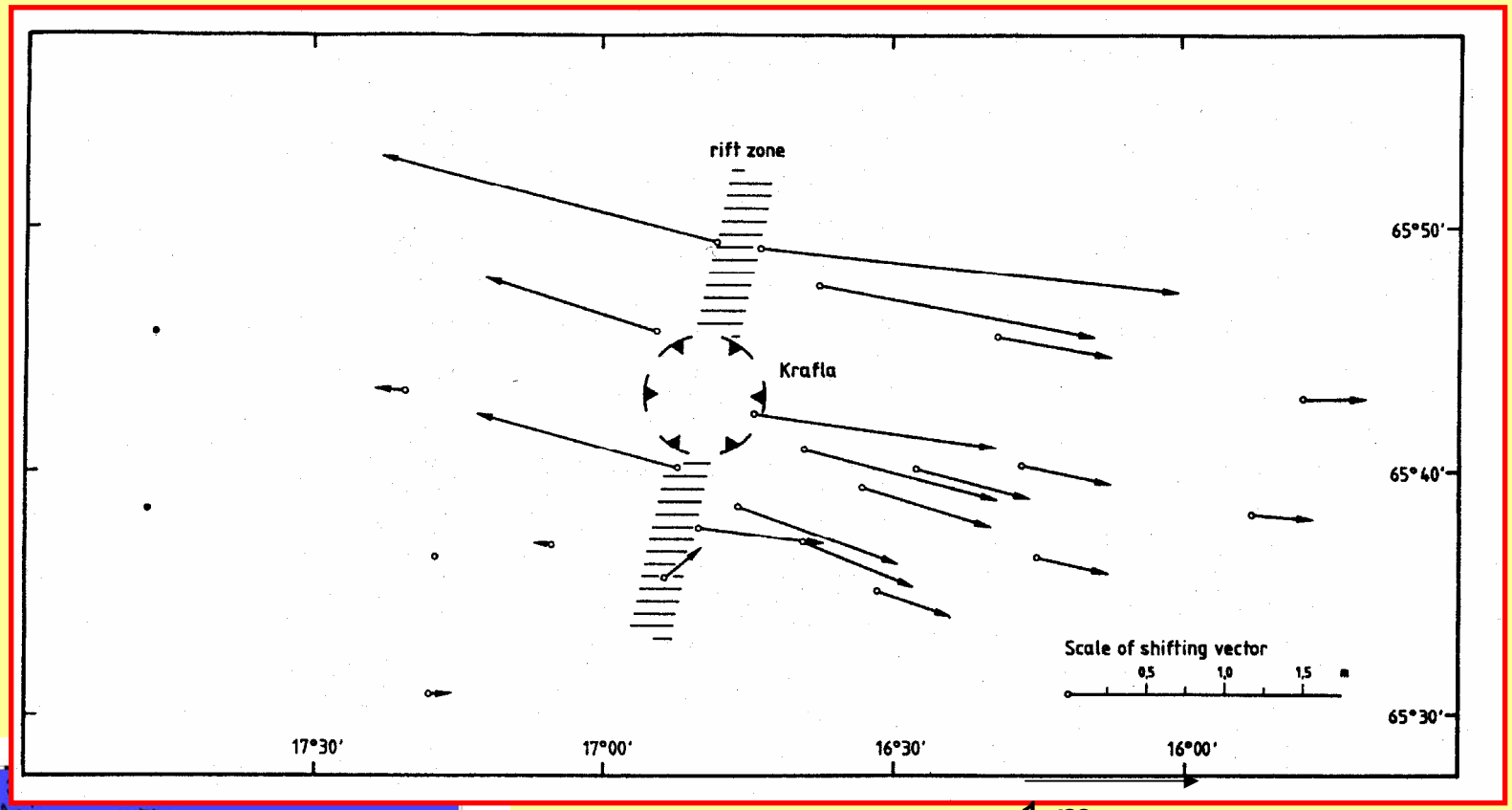
The lava flow was 17 km^2

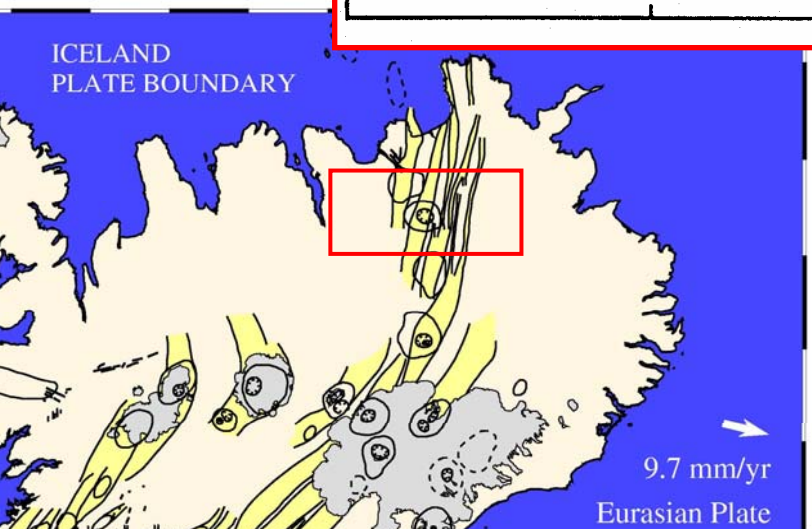


Páll Einarsson - Eysteinn Tryggvason

Krafla rifting: 1978-1989 (Eysteinn Tryggvason)

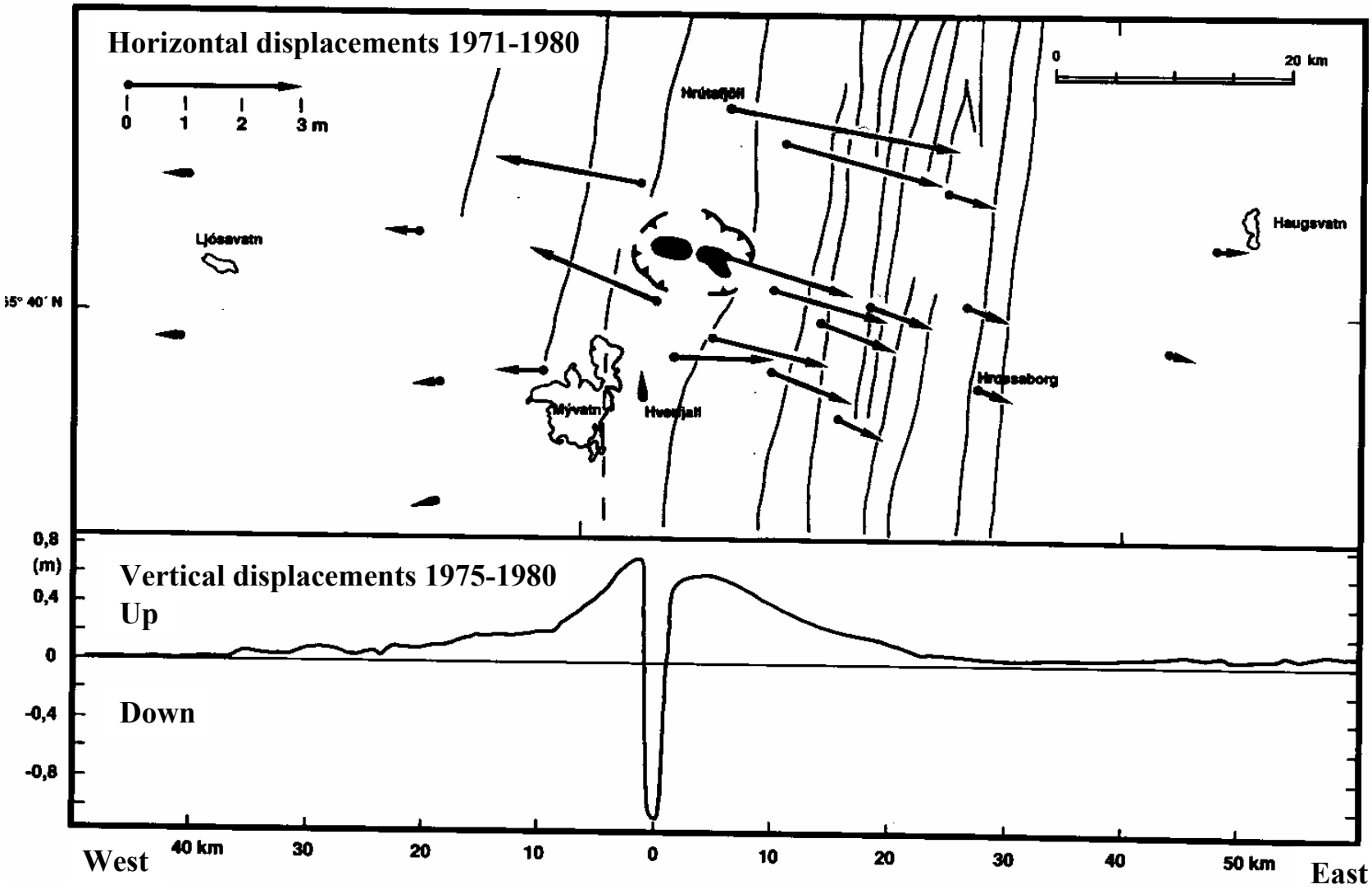




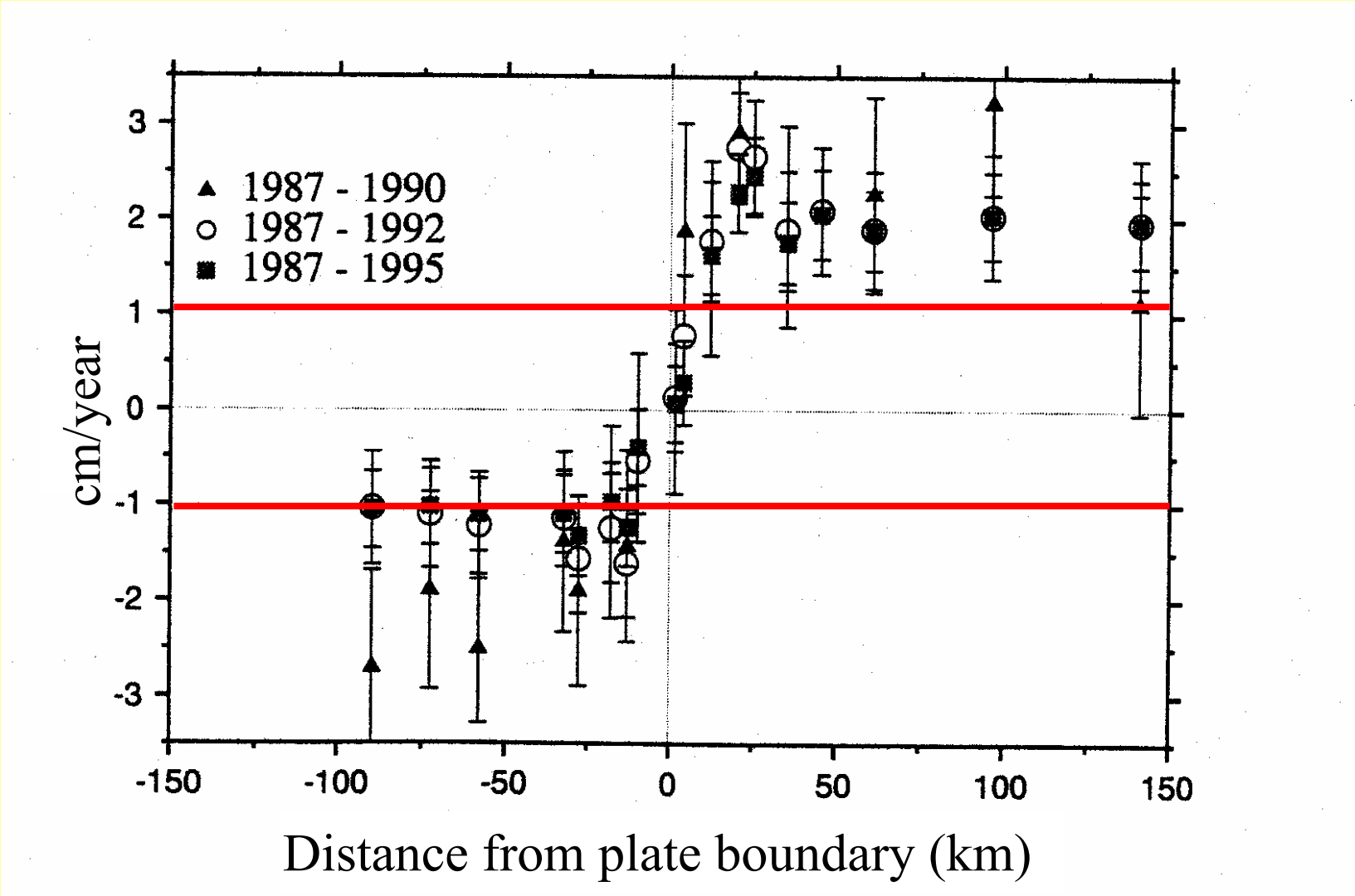


Krafla rifting: 1977-1980 (Wendt et al., 1985)

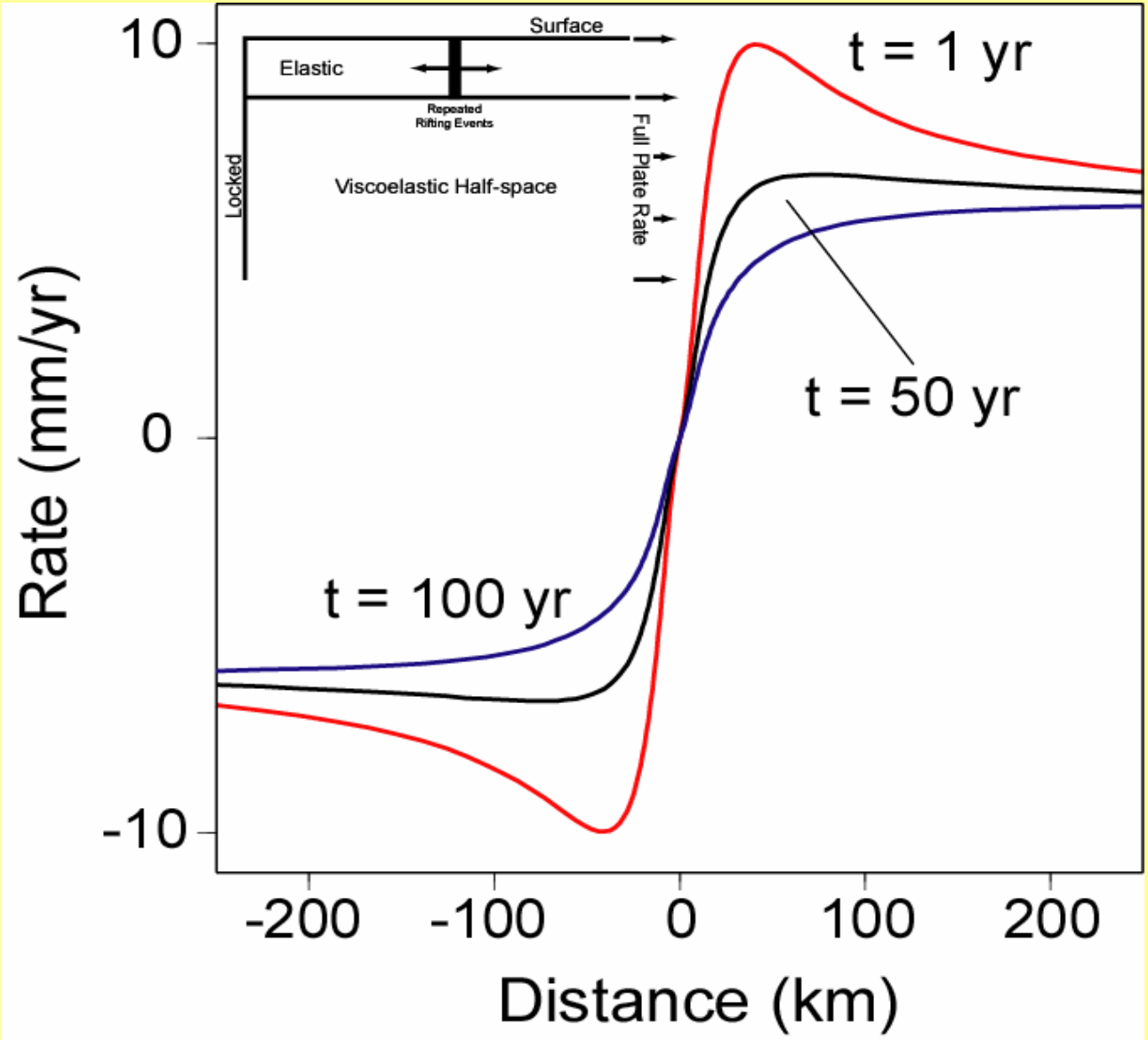
Krafla - Displacements



North Iceland: Post-rifting relaxation after Krafla 1975-1984



(Völksen, 2000)



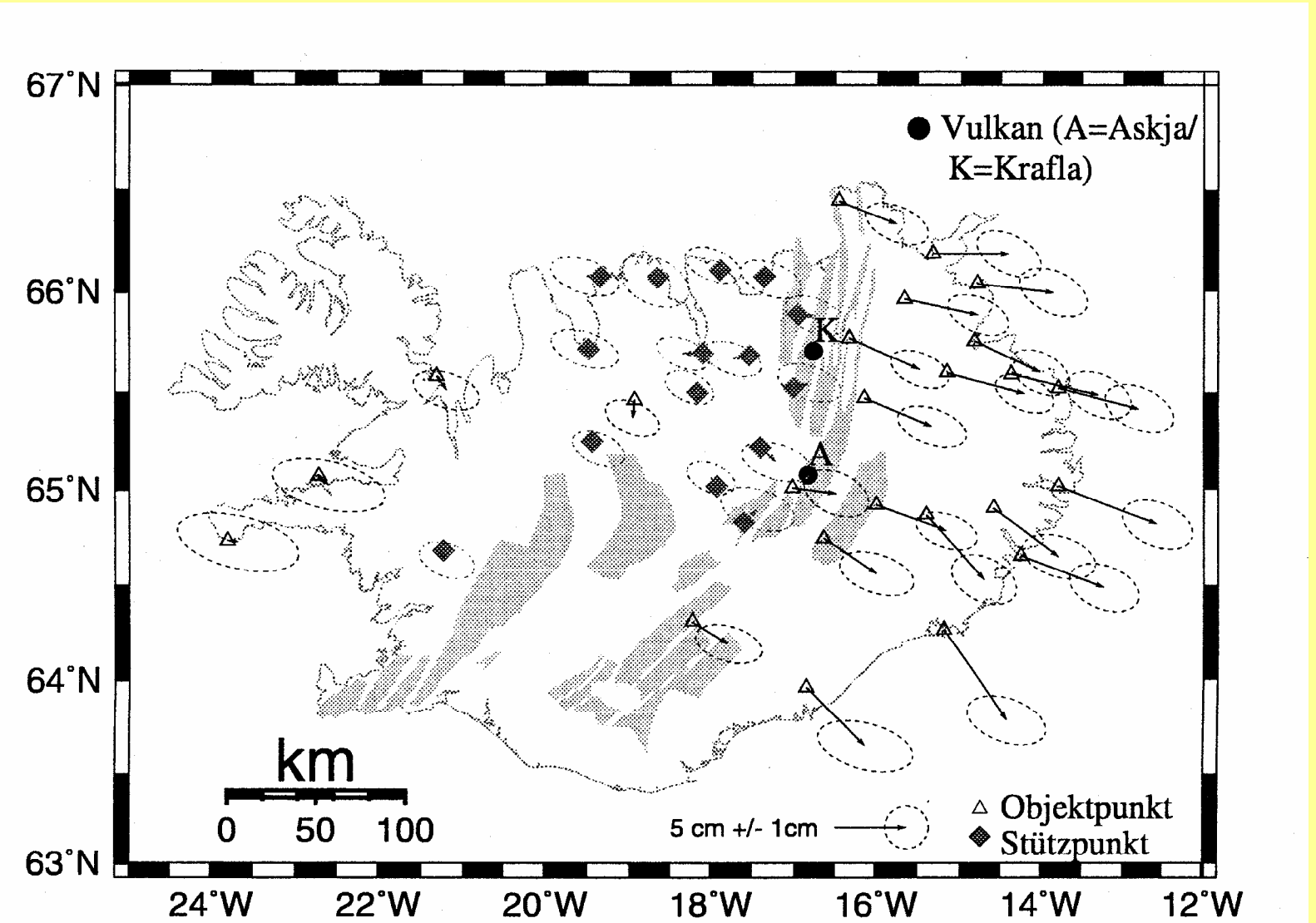
1D visco-elastic model
Eastern Volcanic Zone:

3.0 m wide dike
every 250 years:
(12 mm/year spreading)

Elastic layer = 10 km.
Young's Modulus 30 GPa.
Viscosity = 2x10^19Pa s.

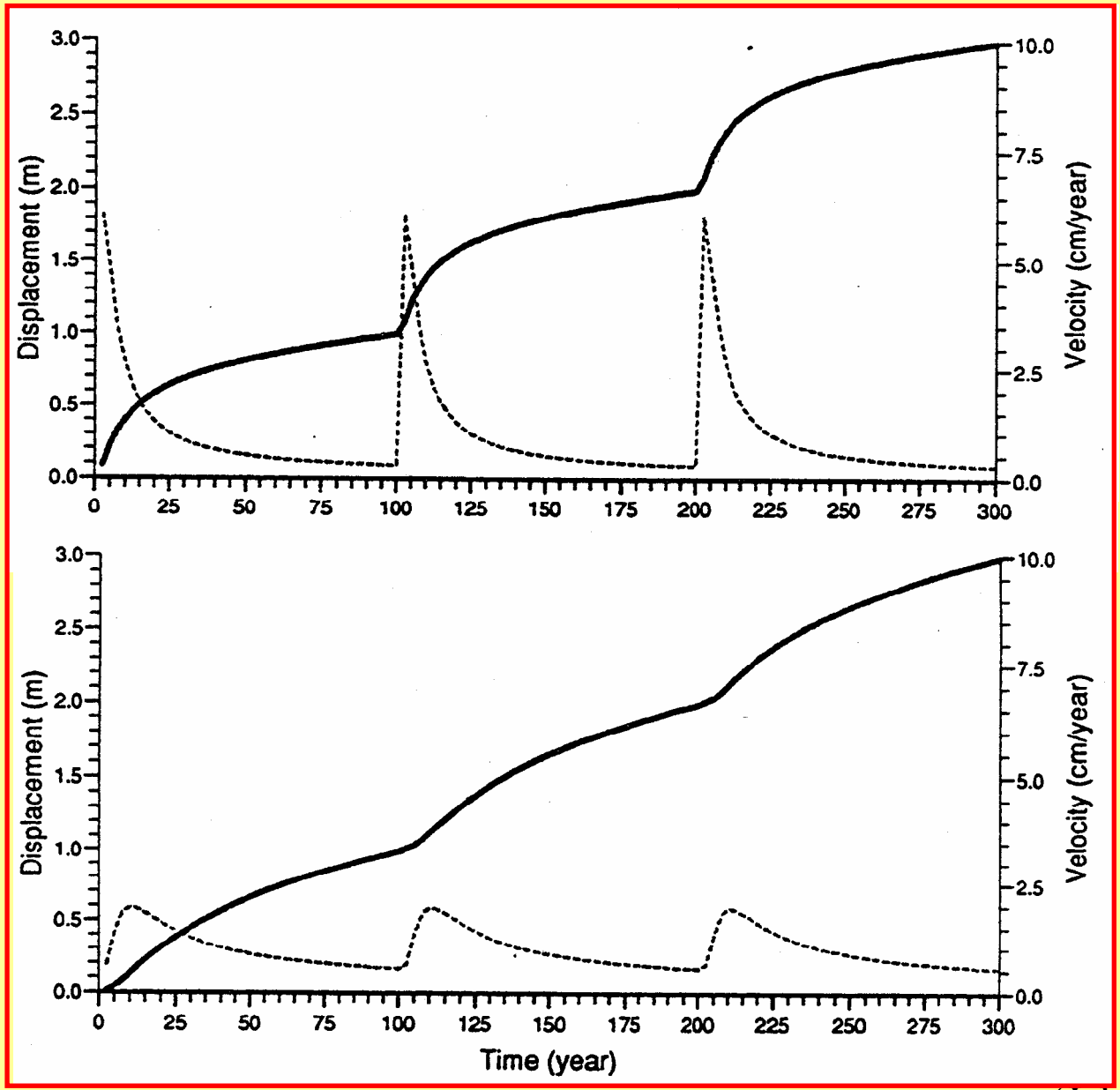
Pete La Femina et al. 2005

1993-1995: 2.1 cm/yr @ N115°E



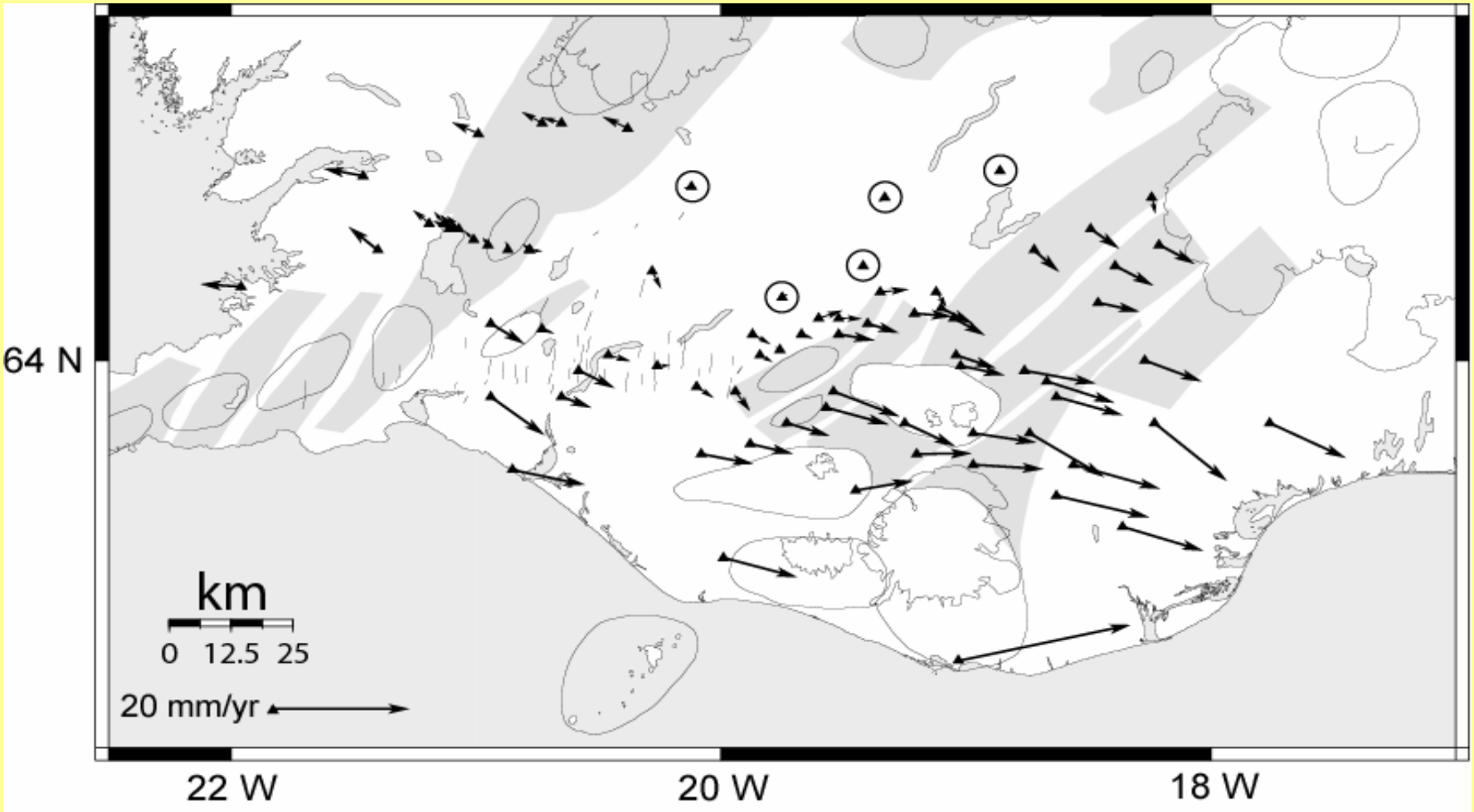
(Völksen, 2000)

Plate boundary: Displacement/Velocity at 50 and 100 km distance from rift axis

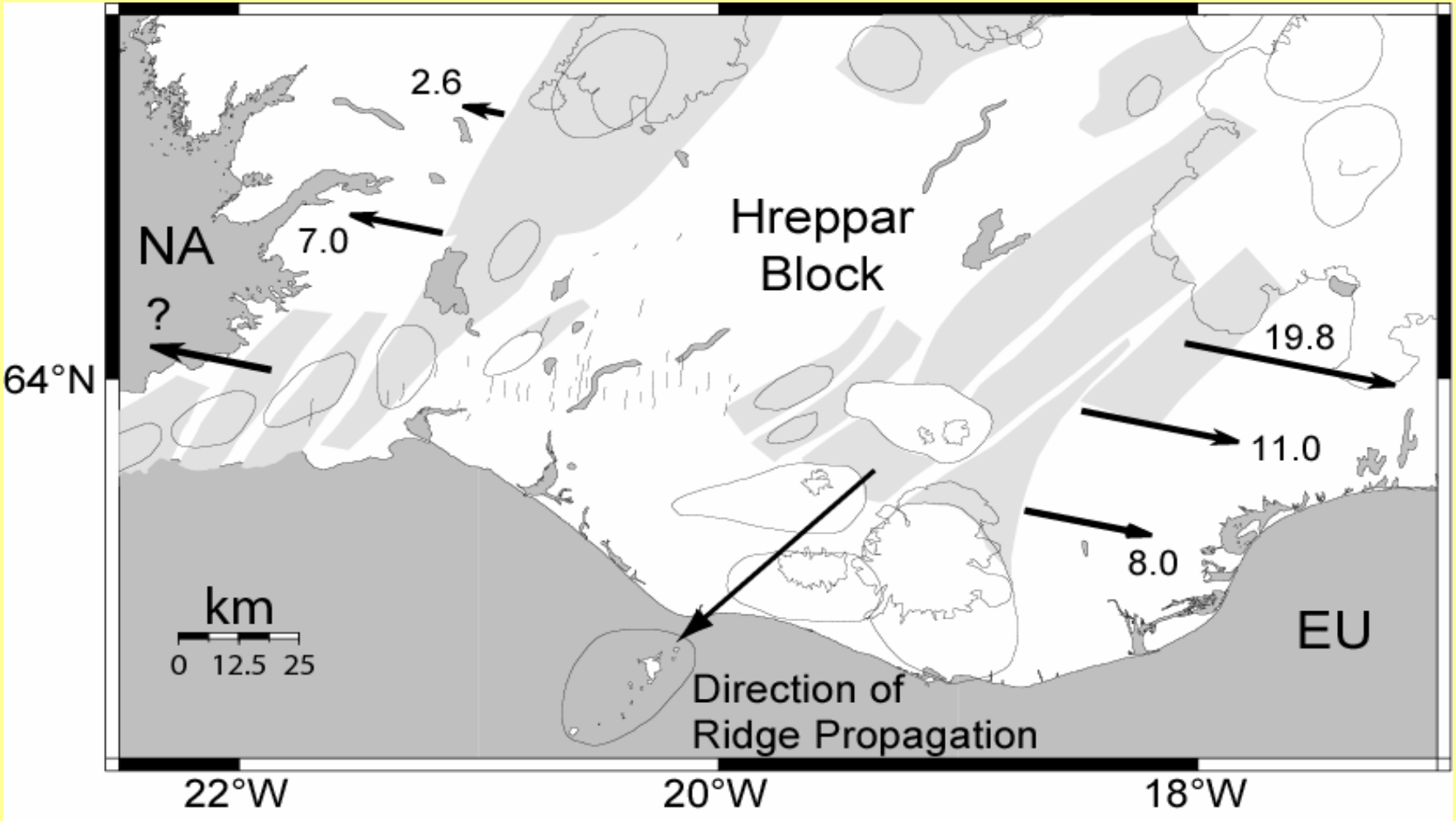


(Jahn, 1992)

Secular velocity field in South Iceland (1994-2004 GPS data)



La Femina, P. C., Dixon, T. H., Malservisi, R., Arnadottir, Th., Sturkell, E., Sigmundsson, F., and Einarsson, P., Strain partitioning and accumulation in a propagating ridge system: Geodetic GPS measurements in South Iceland, submitted to *J. Geopys. Res*.



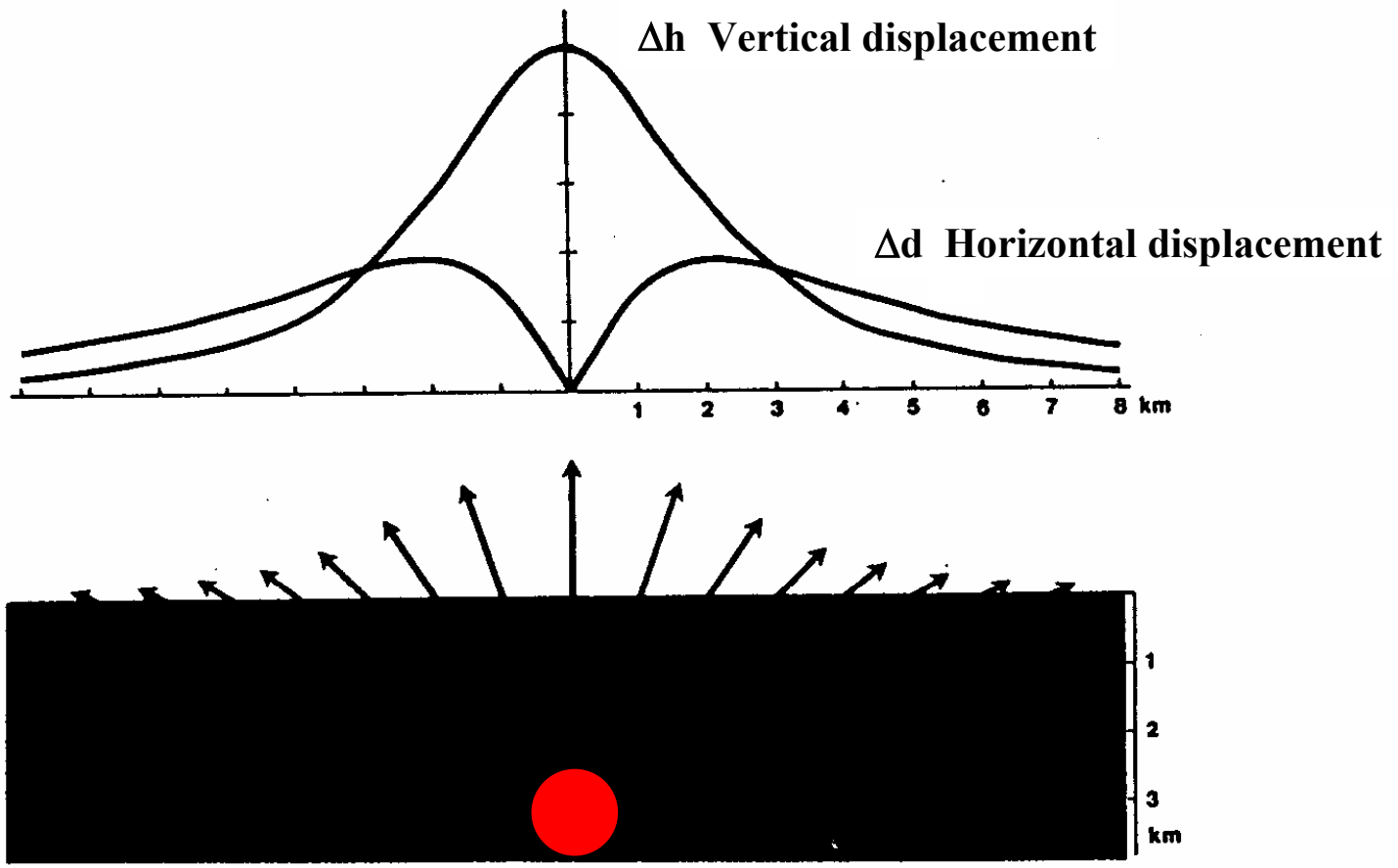
Pete La Femina et al. 2005

Photo: Gísli Óskarsson

Photo: Sigurjón Sindrason

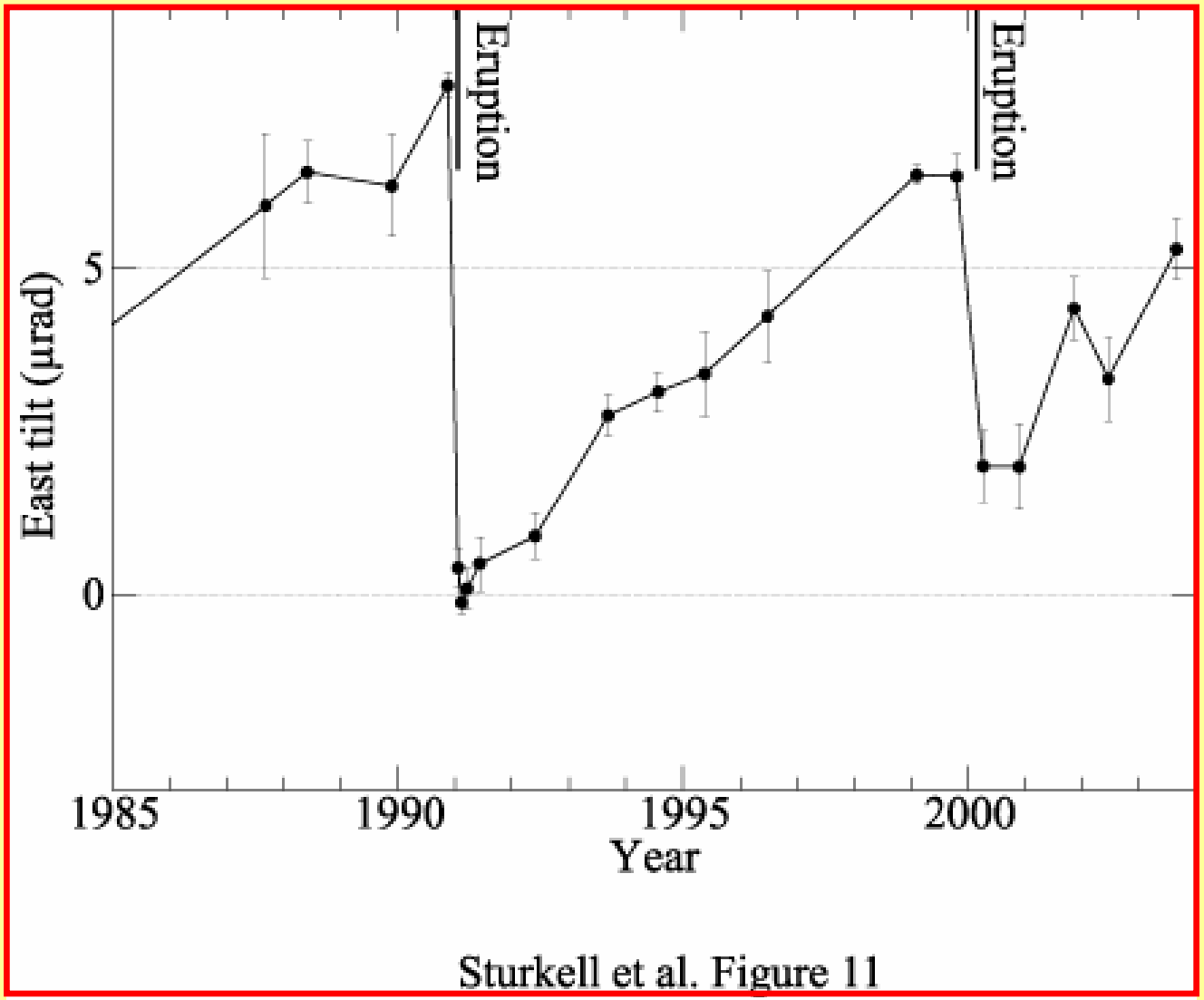
Photo: Erik Sturkell

Volcano deformation

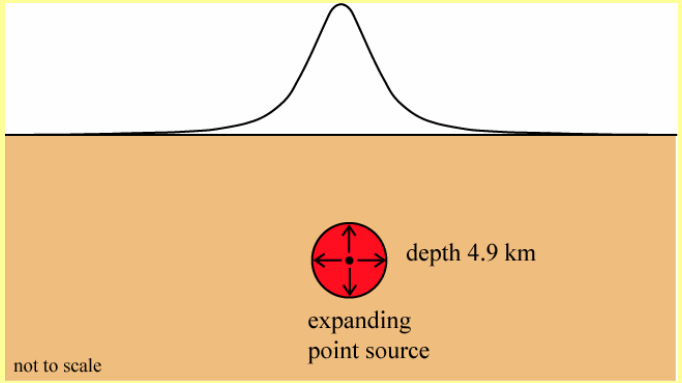


An expanding spherical volume at depth in the crust produces a characteristic pattern of uplift and outward movements at the surface above it (the Mogi-model)

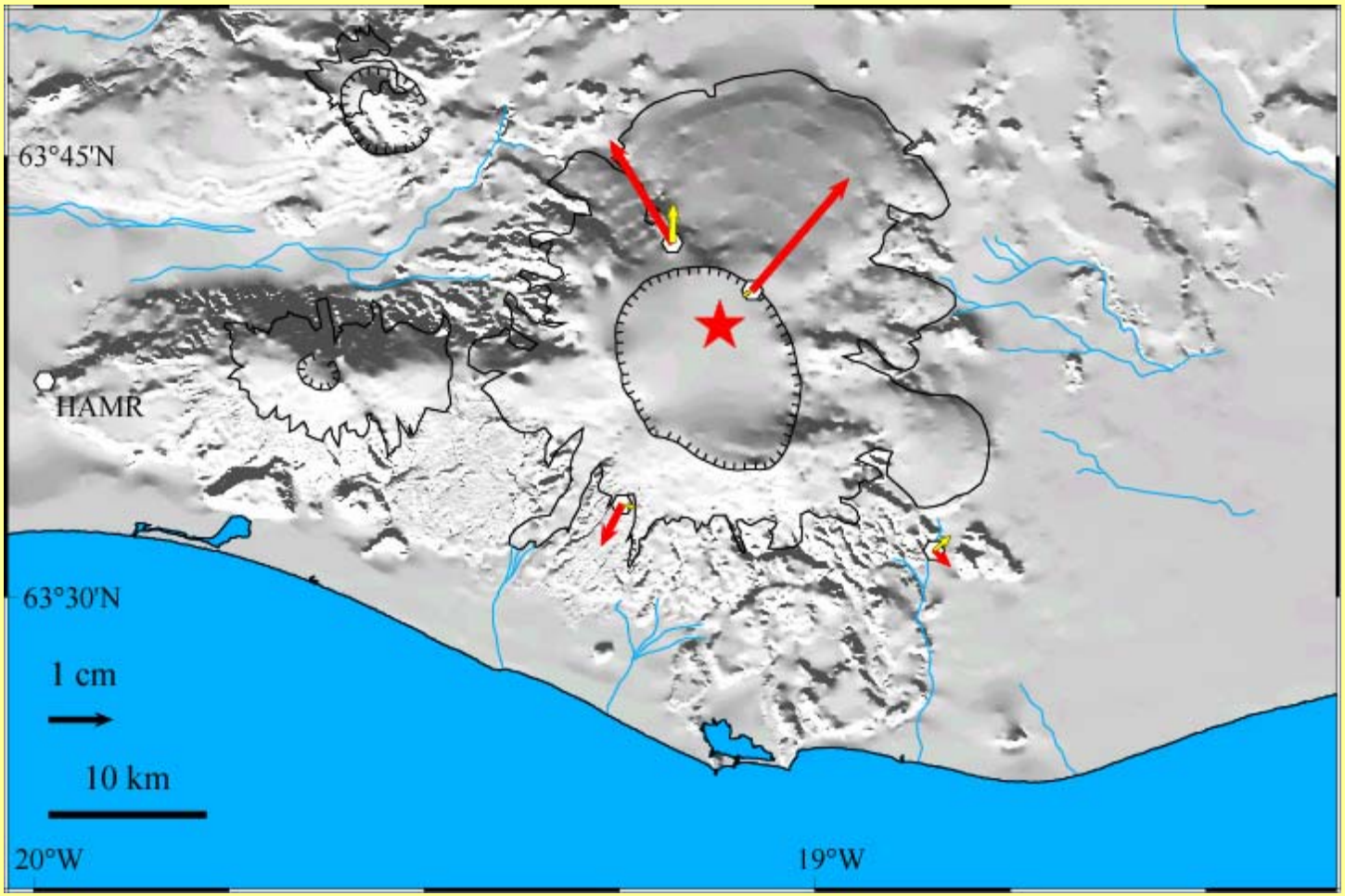
Tilt changes west of Hekla show pressure variations in its roots:



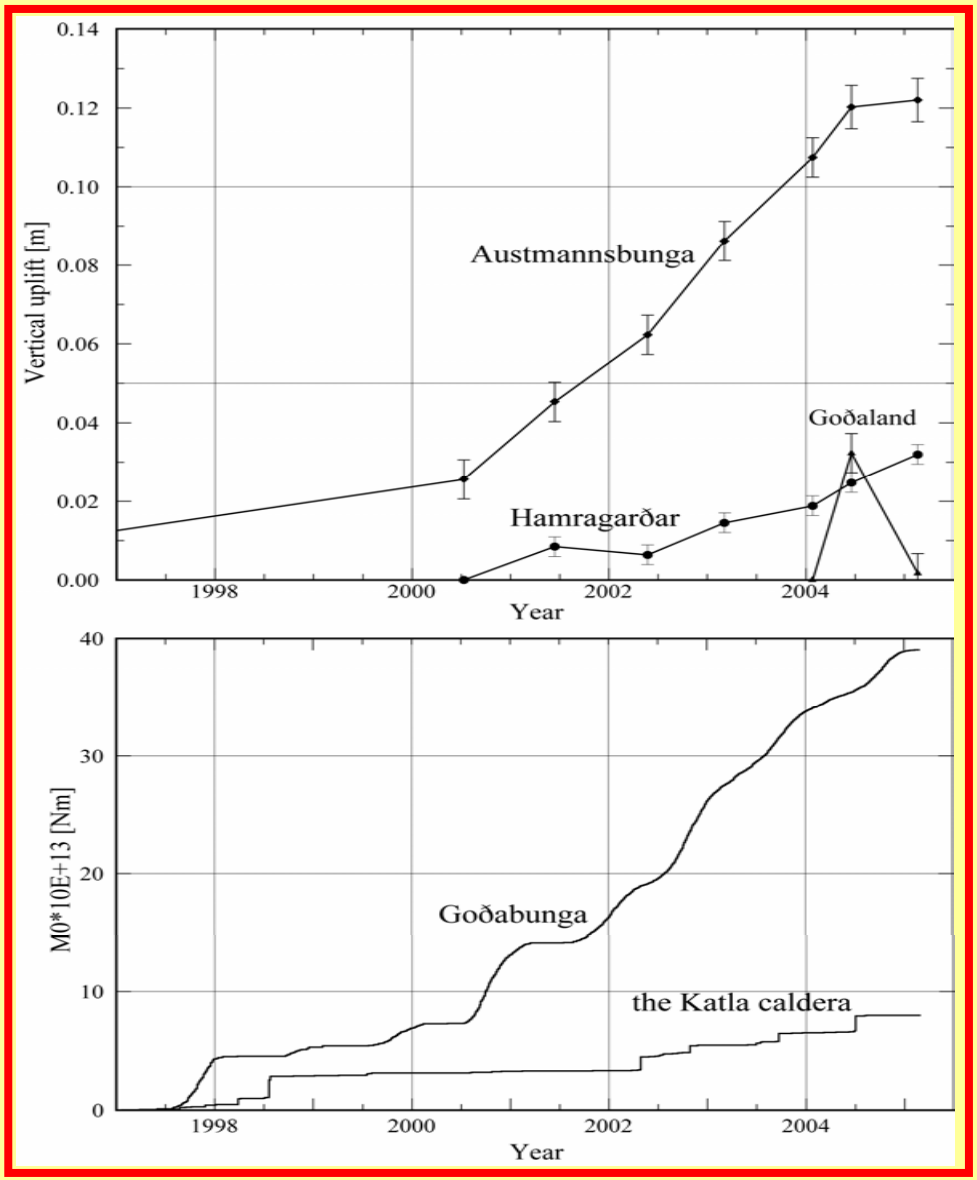
Sturkell et al. Figure 11

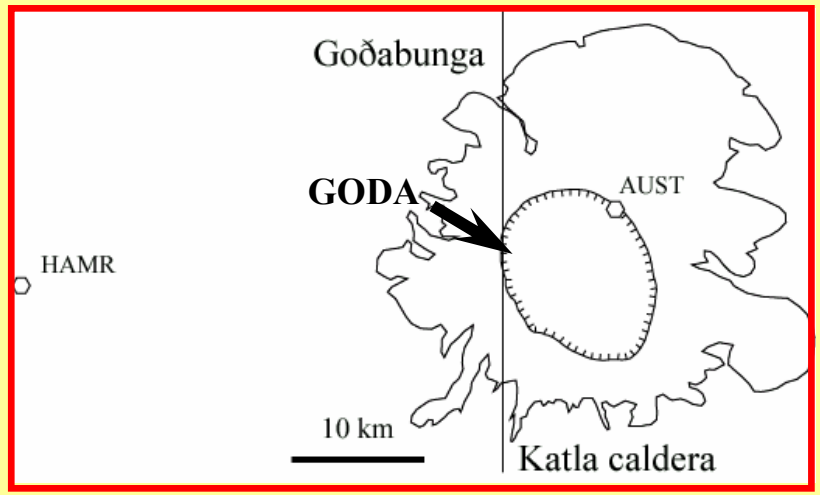


Horizontal movements radiate away from the Katla caldera, interpreted as result of inflation of a magma chamber at 5 km depth beneath the caldera (star).
(Fig. from Erik Sturkell et al.)



Inflation and cumulative seismic moment in Katla since 1997 as a function of time





Inflation at the survey points AUST and HAMR compared to Reykjavík.

Seismicity data from Iceland Meteorological Office

Tertiary lavas tilt towards the rift that generated them

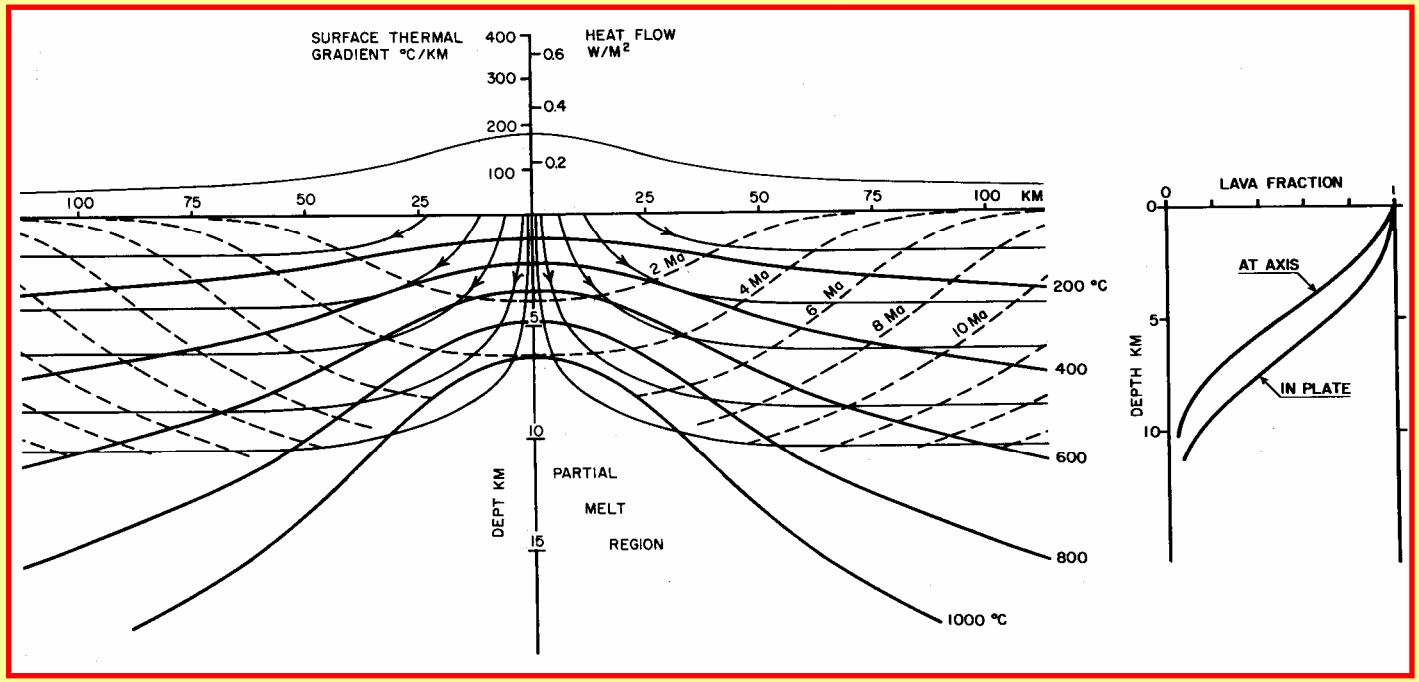
Ljósm: G. Biessy

Ljósm: G. Biessy

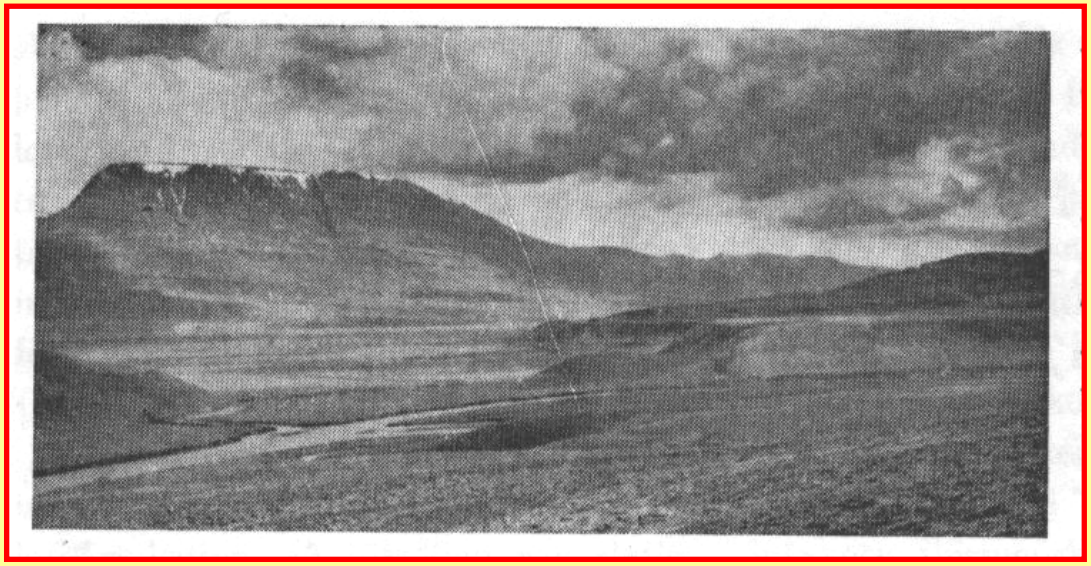
Geithellnadalur

The flanks of an Icelandic rift zone dip towards the rift center:

The Pálmason model: The crust is loaded by the products of volcanism and subsides, maintaining isostatic equilibrium

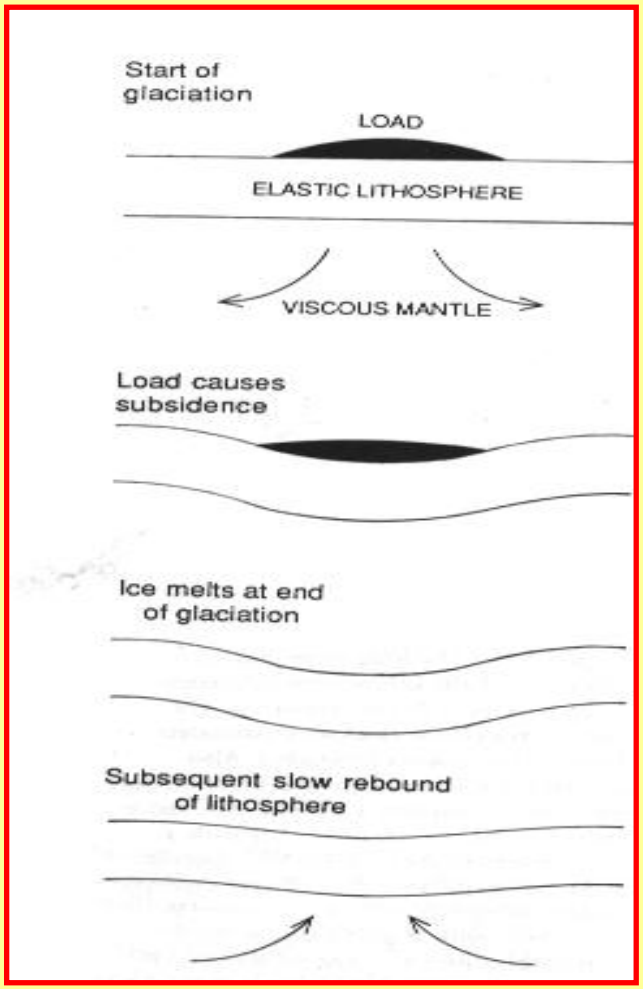


Changes in Post-glacial sea level



Þorleifur Einarsson

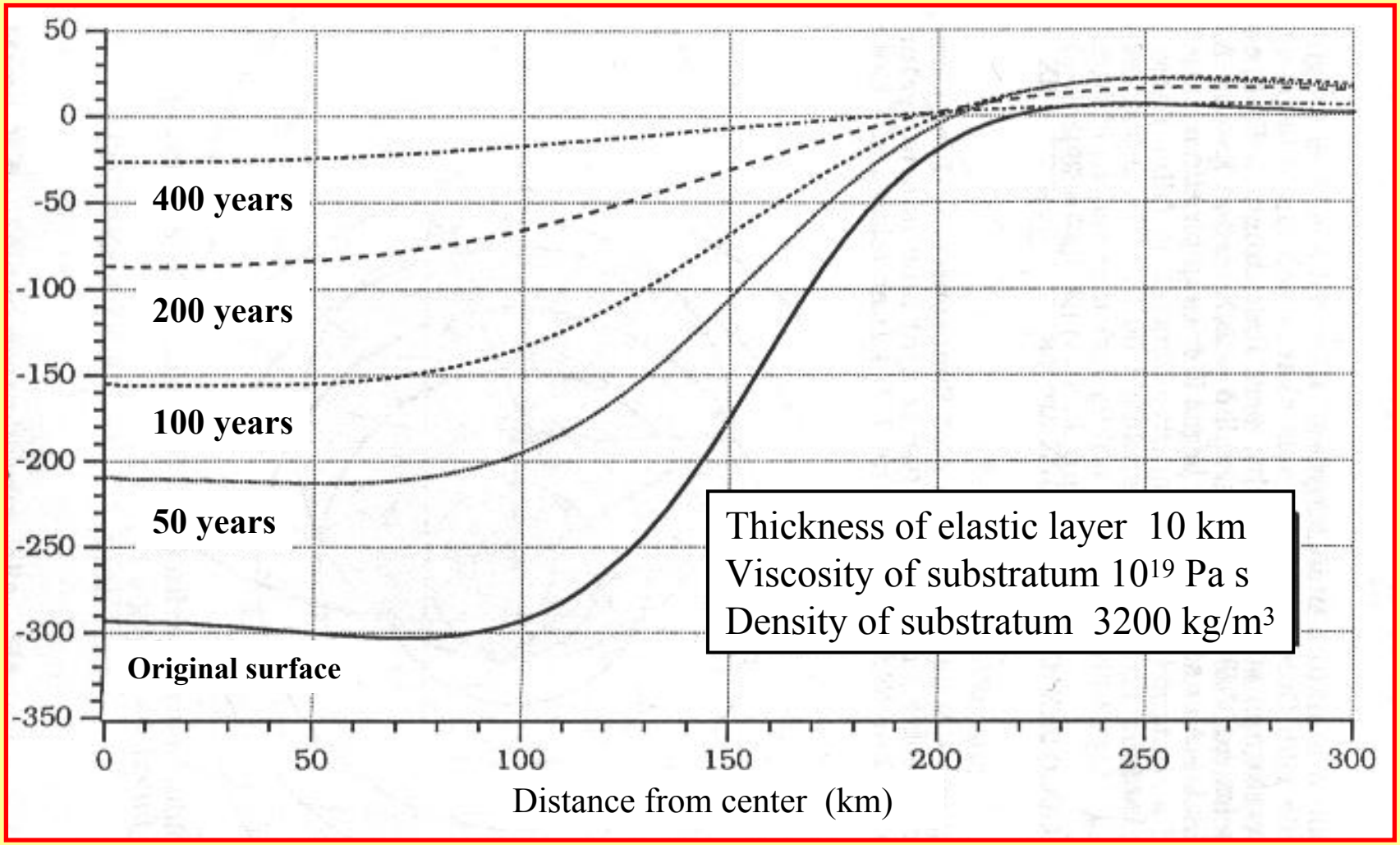
Guðmundur Kjartansson



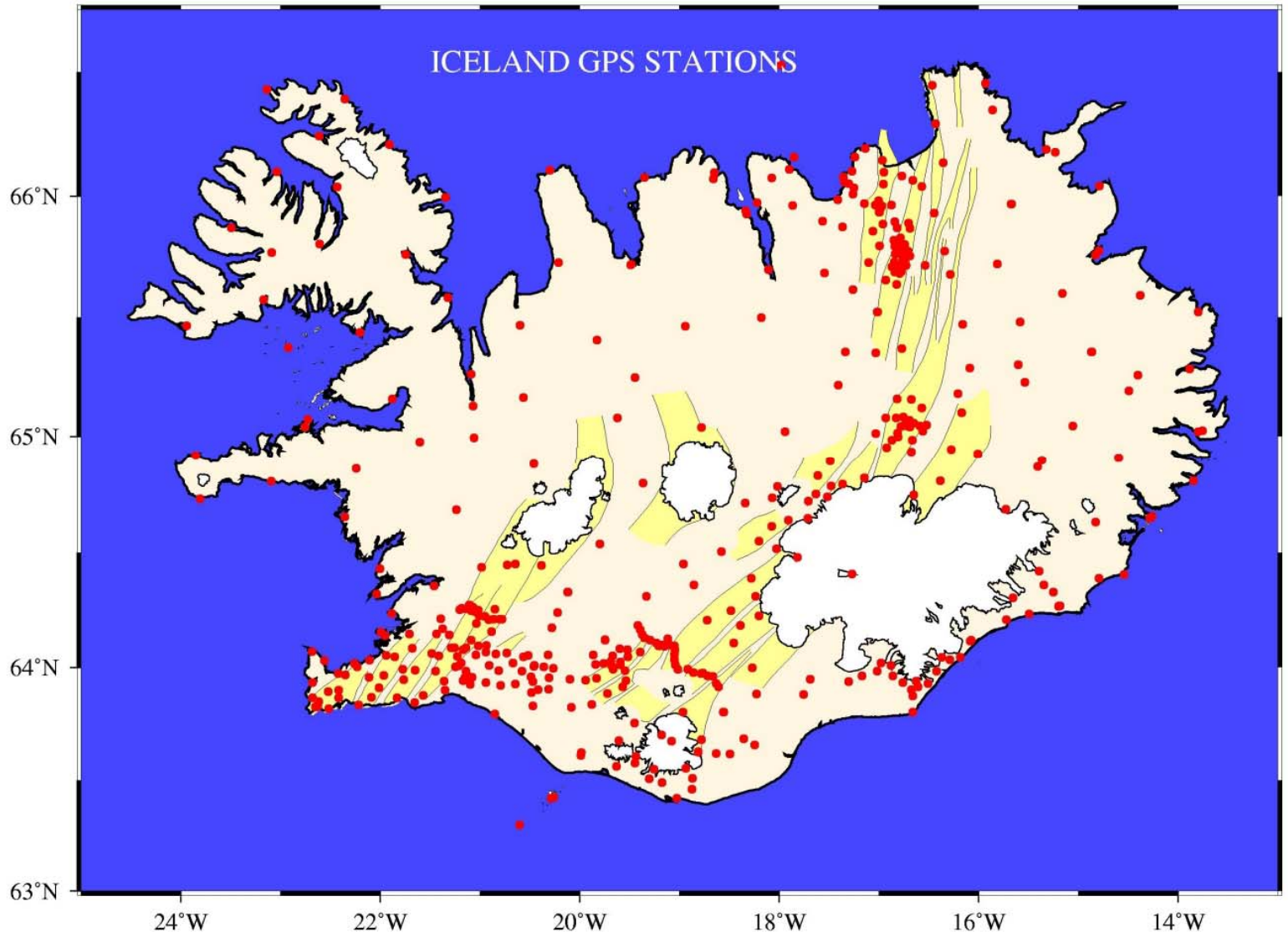
Úr Fowler

Post-glacial uplift in Iceland took place in less than 1000 years. The inferred viscosity of the lower crust and upper mantle is of the order of 10^{19} Pa s.

Height of surface (m)



Freysteinn Sigmundsson


ICELAND GPS STATIONS
66°N
65°N
64°N
63°N
24°W
22°W
20°W
18°W
16°W
14°W