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"7th Workshop on Three-Dimensional Modelling
of Seismic Waves Generation and their Propagation"

25 October - 5 November 2004

Study of Seismic Swarms Associated with Fluid Intrusions

T. Dahm
Institüt für Geophysik
Universität Hamburg

strada costiera, 11 - 34014 trieste italy - tel. +39 040 2240111 fax +39 040 224163 - sci_info@ictp.trieste.it - www.ictp.trieste.it

Study of seismic swarms associated with fluid intrusions

ICTP Course 2004 Trieste

Torsten Dahm

dahm@dkrz.de

Institut für Geophysik, Universität Hamburg

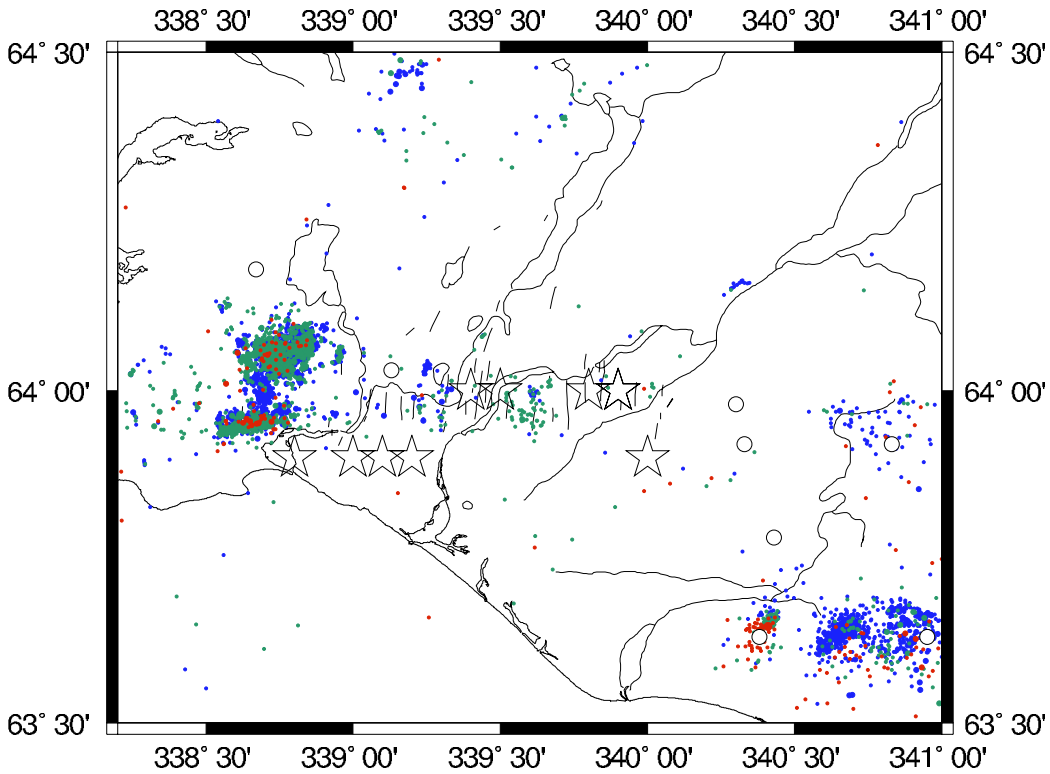
Content

1. Physics of fluid intrusions and earthquake swarm models
2. study of seismic swarms
3. Practical: relative moment tensor inversion

fluid-induced swarms - observations

- Typically in volcanic / geothermal regions
- long activity with possible key events or bursts, $M < 4$
- large b-values ($b > 1$), e.g. up to 2.5
- no typical Omori law decay
- possible hypocenter migration
- often large double-couple components, partly positive isotropic component, rarely pure tensile events
- accompanied by long-period or tremor events, ground deformation or degassing

South Iceland Seismic Zone



○ volcanos

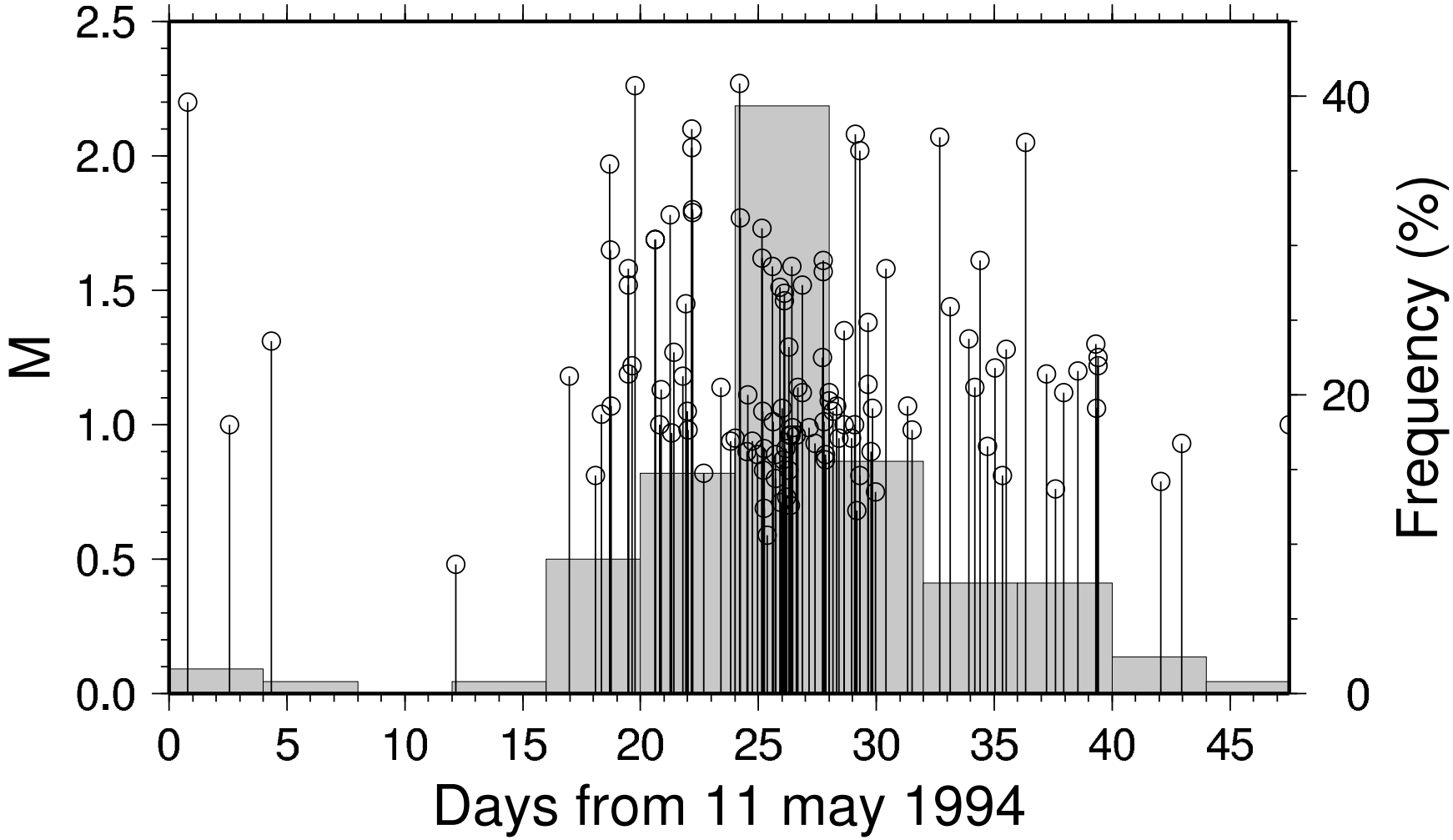
☆ M ≥ 6 earthquakes since 1700

○ 0 - 5 km

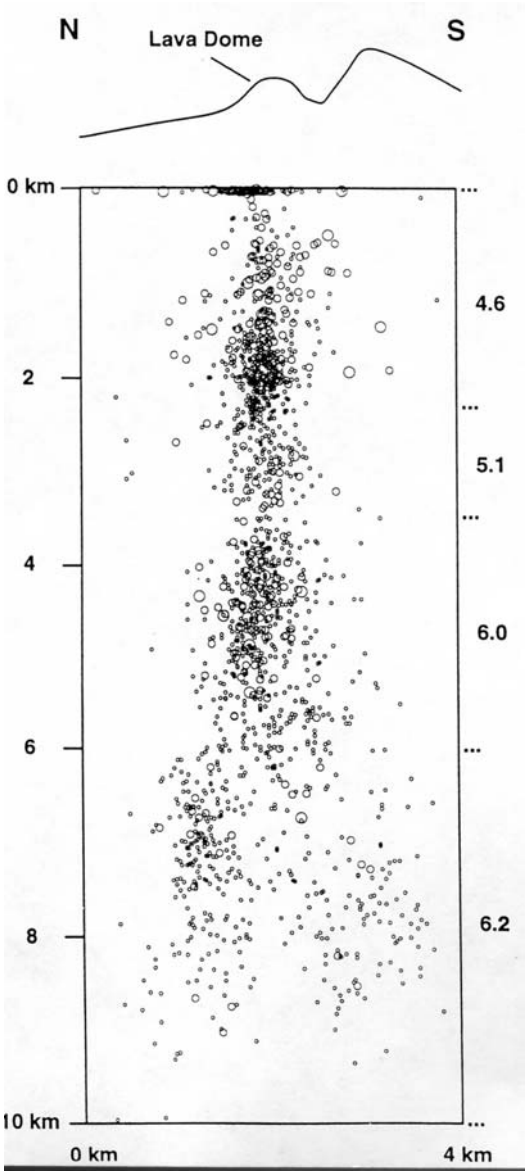
○ 5 - 10 km } micro-earthquakes

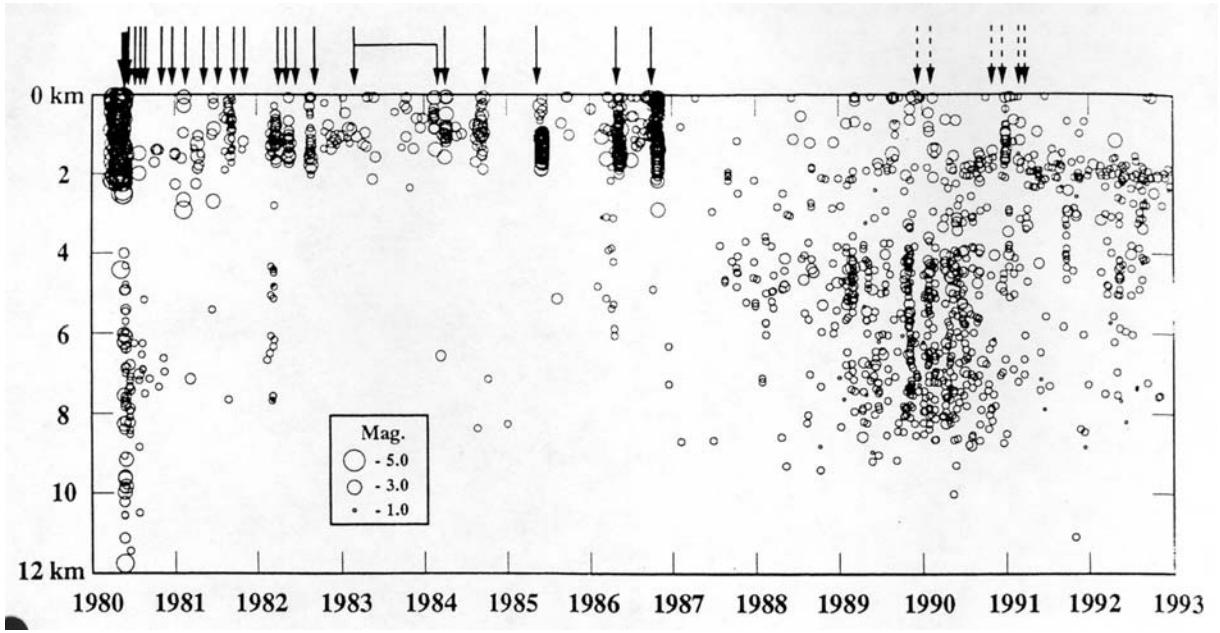
○ ≥ 10 km

Eyjafjallajoekull 1994 dike intrusion

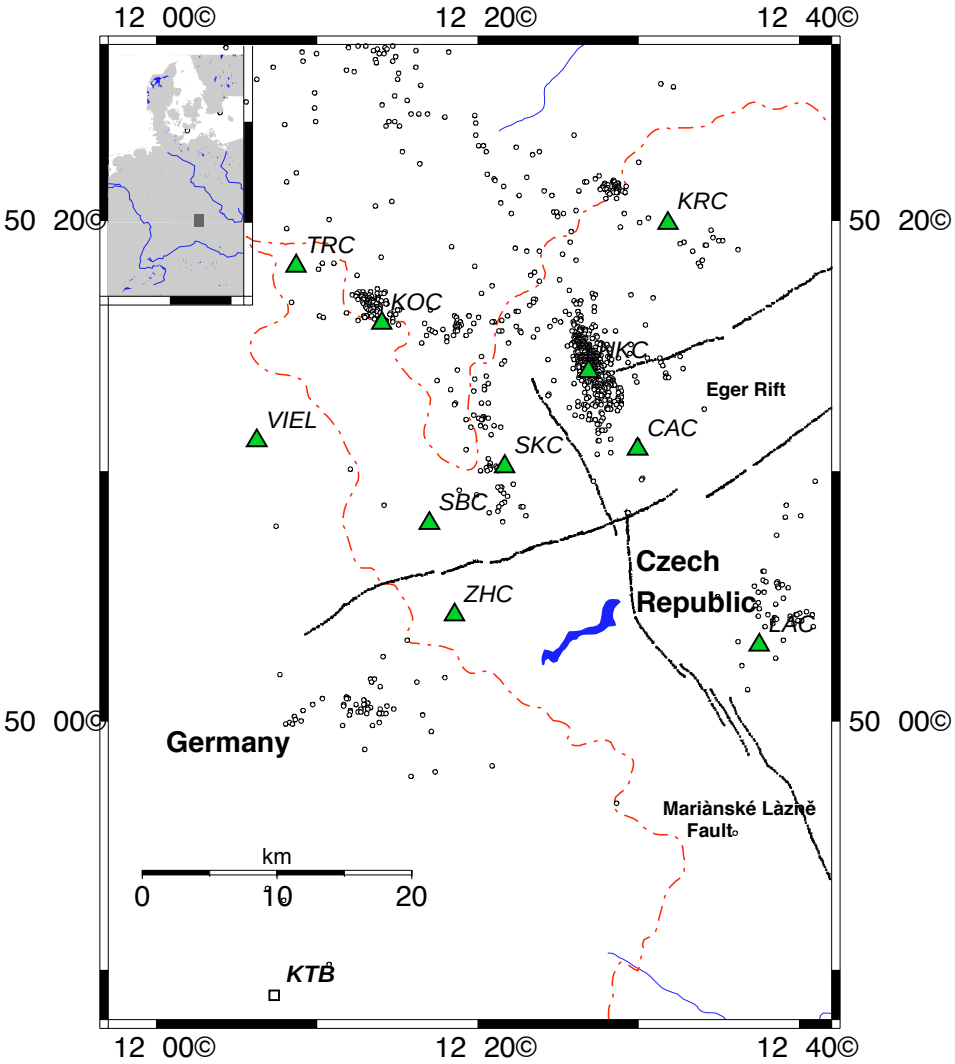


Mt St. Helens

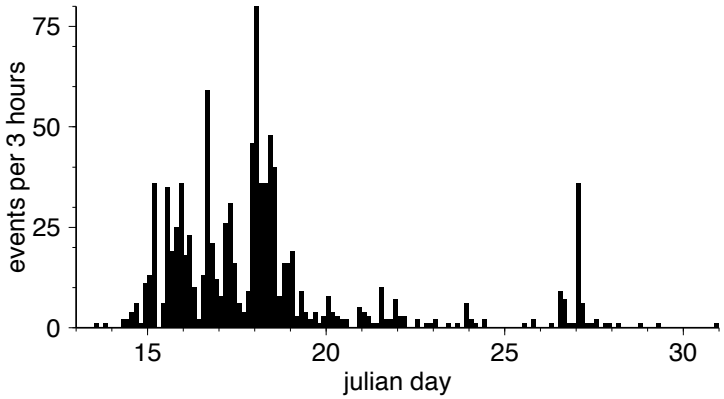

N
Lava Dome
S
0 km
2
4
6
8
10 km
0 km
4 km
4.6
5.1
6.0
6.2


0 km
2
4
6
8
10
12 km
Mag.
- 5.0
- 3.0
- 1.0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993

The Vogtland swarm region



- ≈ 1800 events during two weeks
- $M_L \leq 3$
- tiny clustered source region

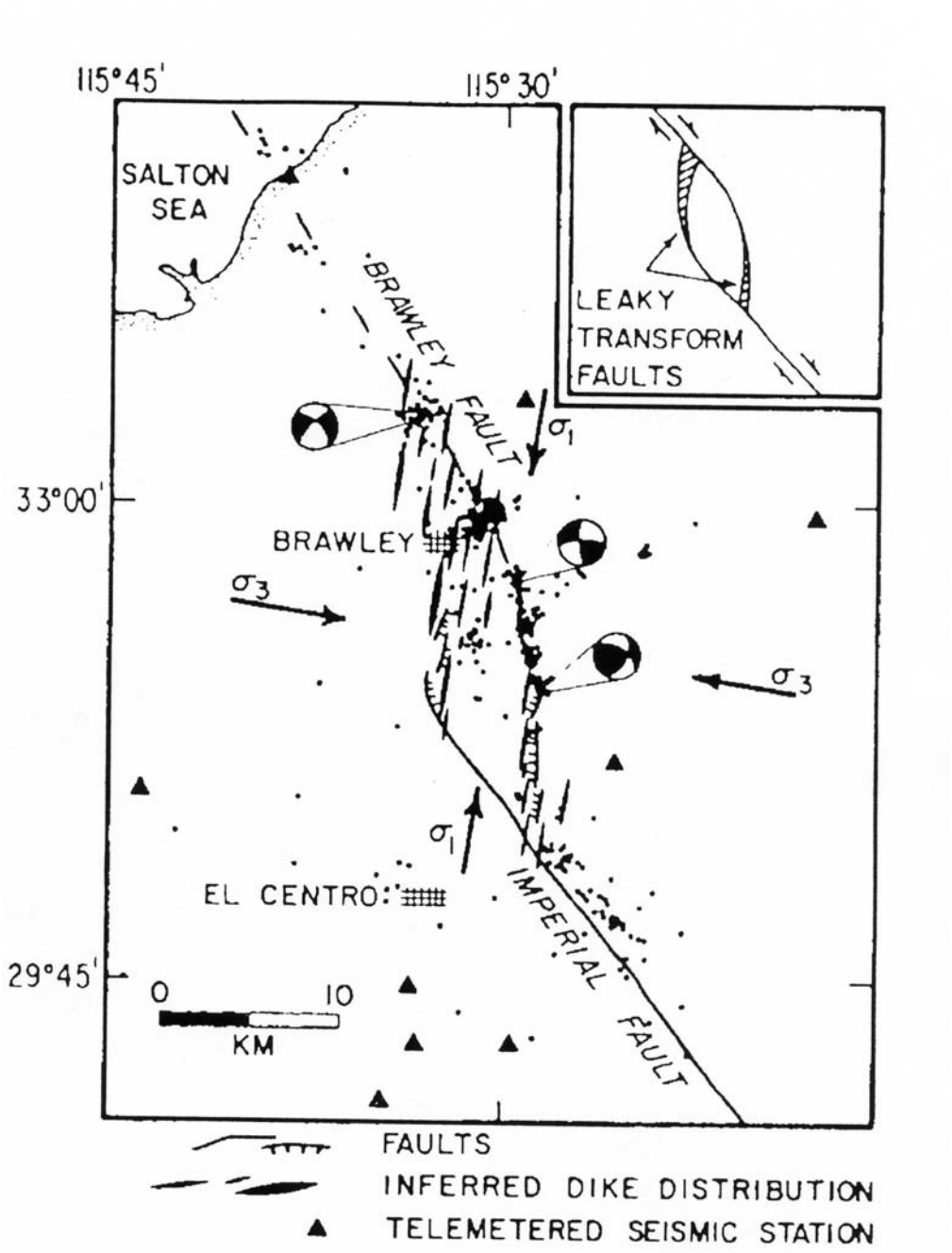


elements of swarm models

1. highly fractured media, without large, planar faults under shear
2. inhomogeneous stress fields and/or nonuniform loading
3. loading of cracks and faults by fluids

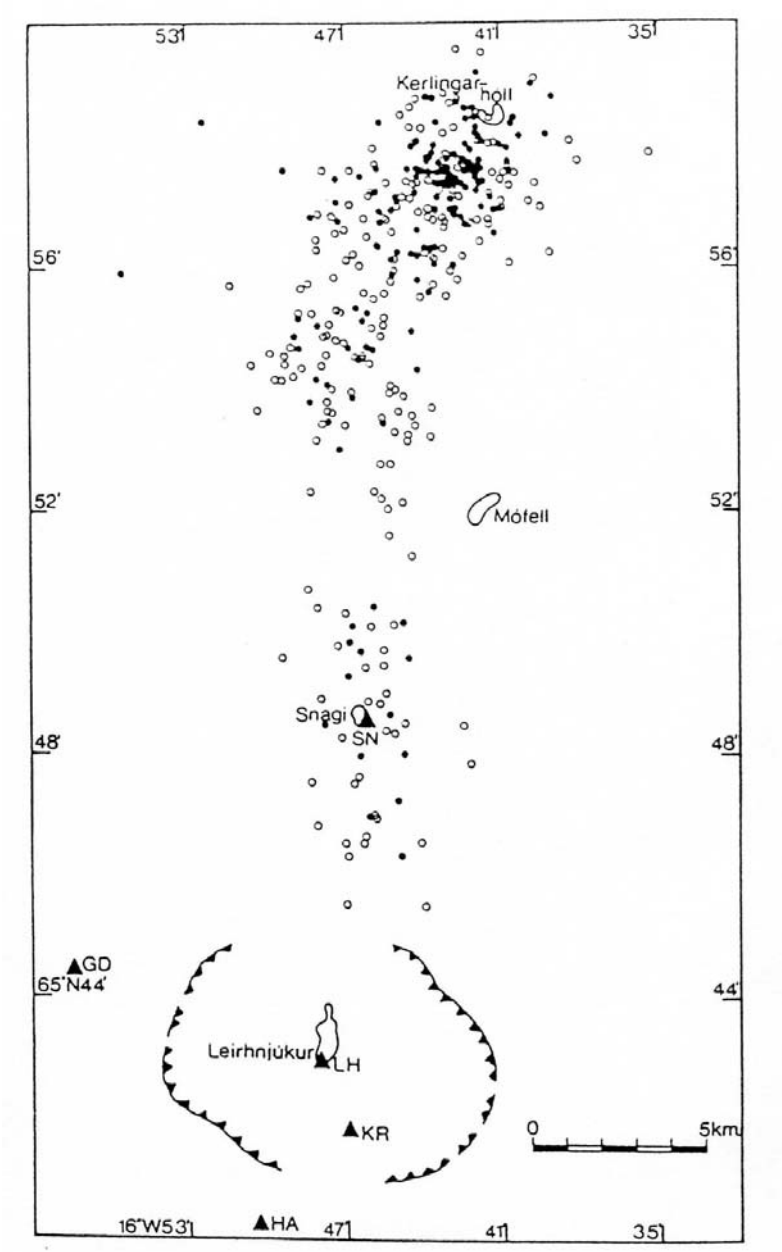
e.g. Mogi, 1963; Sammis & Julian, 1987; Rubin & Gillard, 1998

Hills model

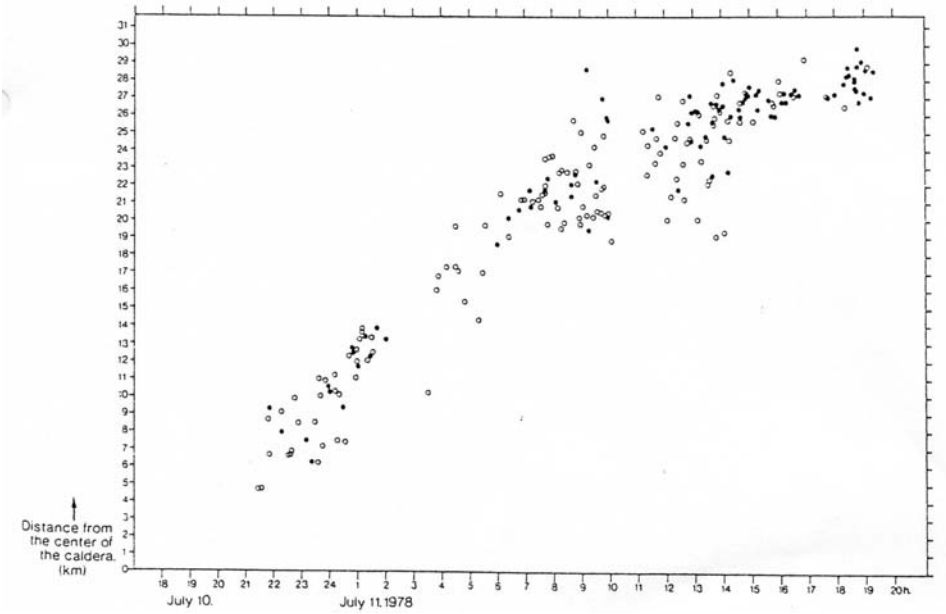


swarms are caused by stress loading (e.g. by dikes) in the extensional field of leaky transform faults.
Dikes and shear cracks use different faults.

Intrusion-induced swarms



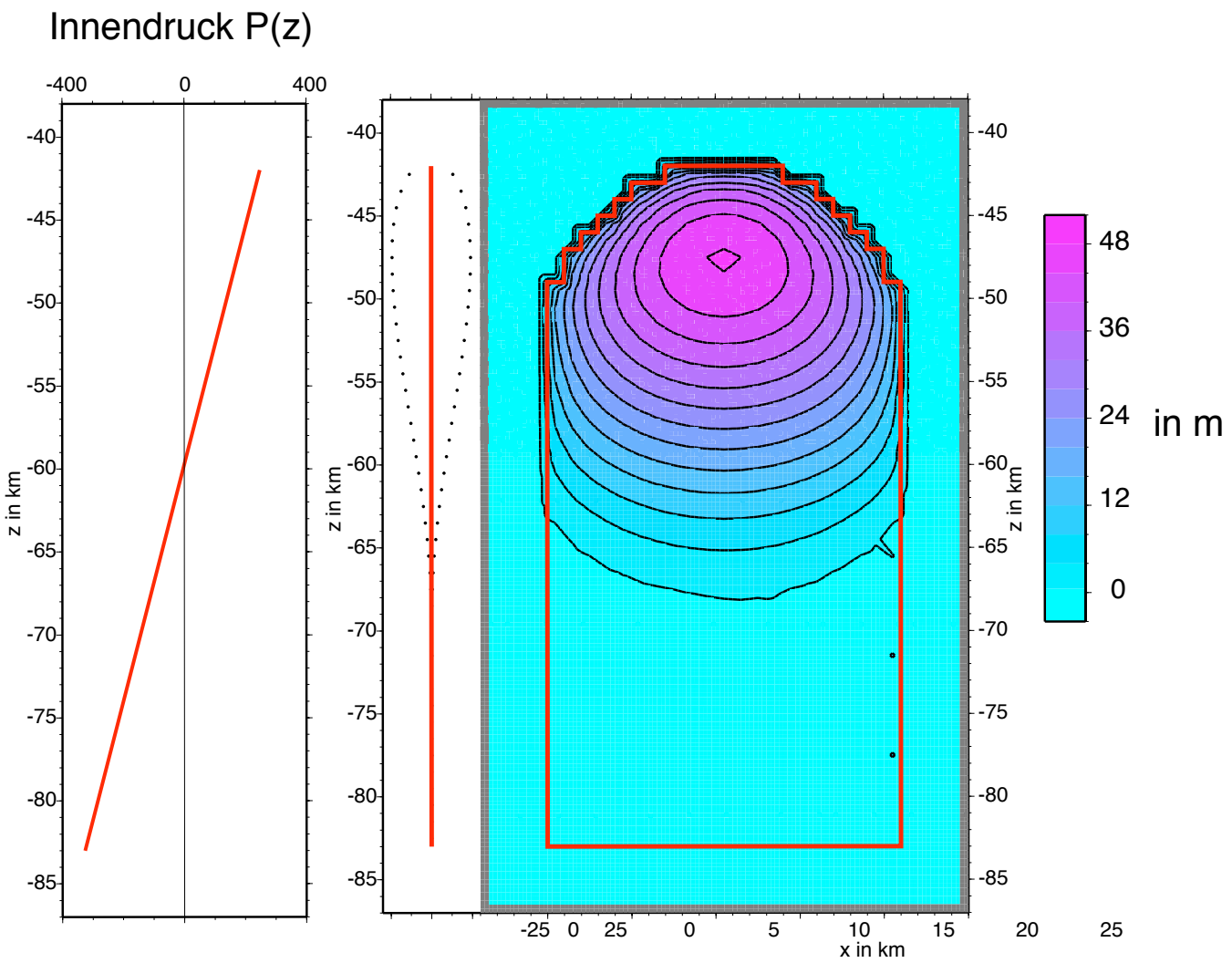
Krafla 1978 swarm induced by lateral intrusion



how do vertical intrusions look

numerical 3D buoyant dike

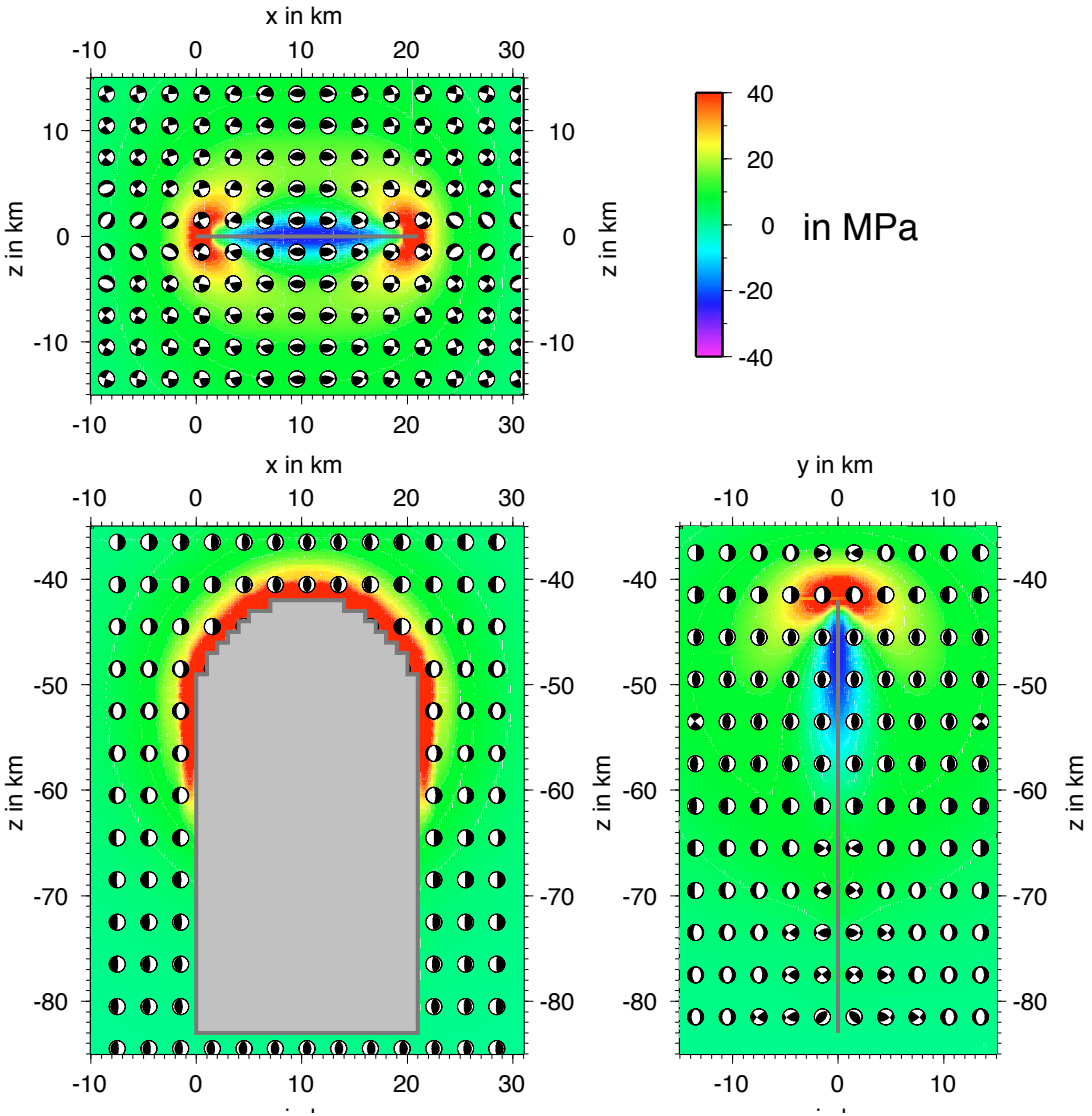
fluid-filled crack



stress loading by buoyant diking

Change of the Coulombstress

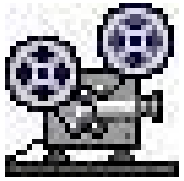
$$\Delta\sigma_C = \Delta\tau - \mu\,\Delta\sigma_n$$



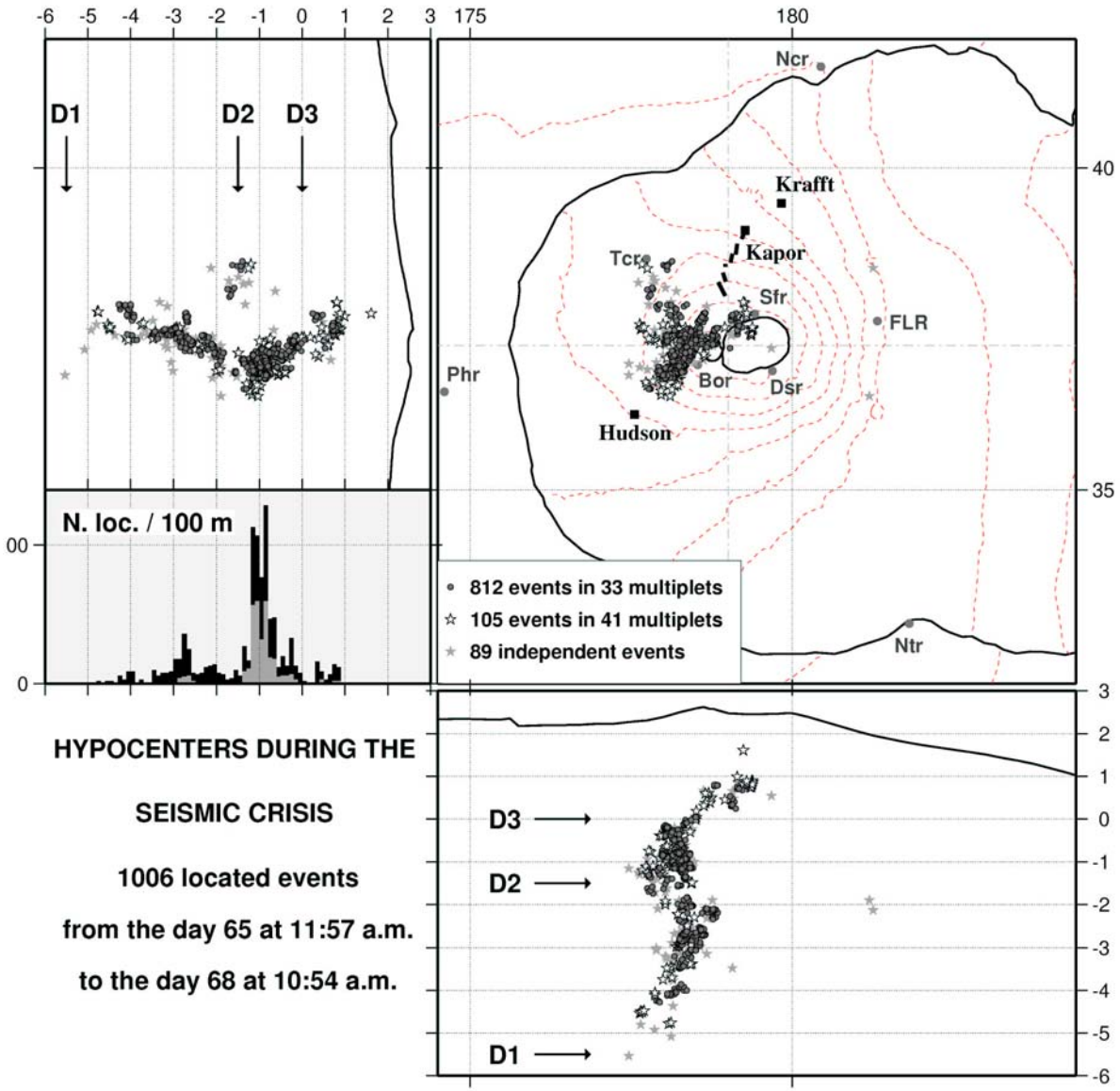
Gelatine experiments

click

- 3% gelatine, brittle, transparent
- air is injected with a syringe
- characteristic length of cracks in the order of some cm

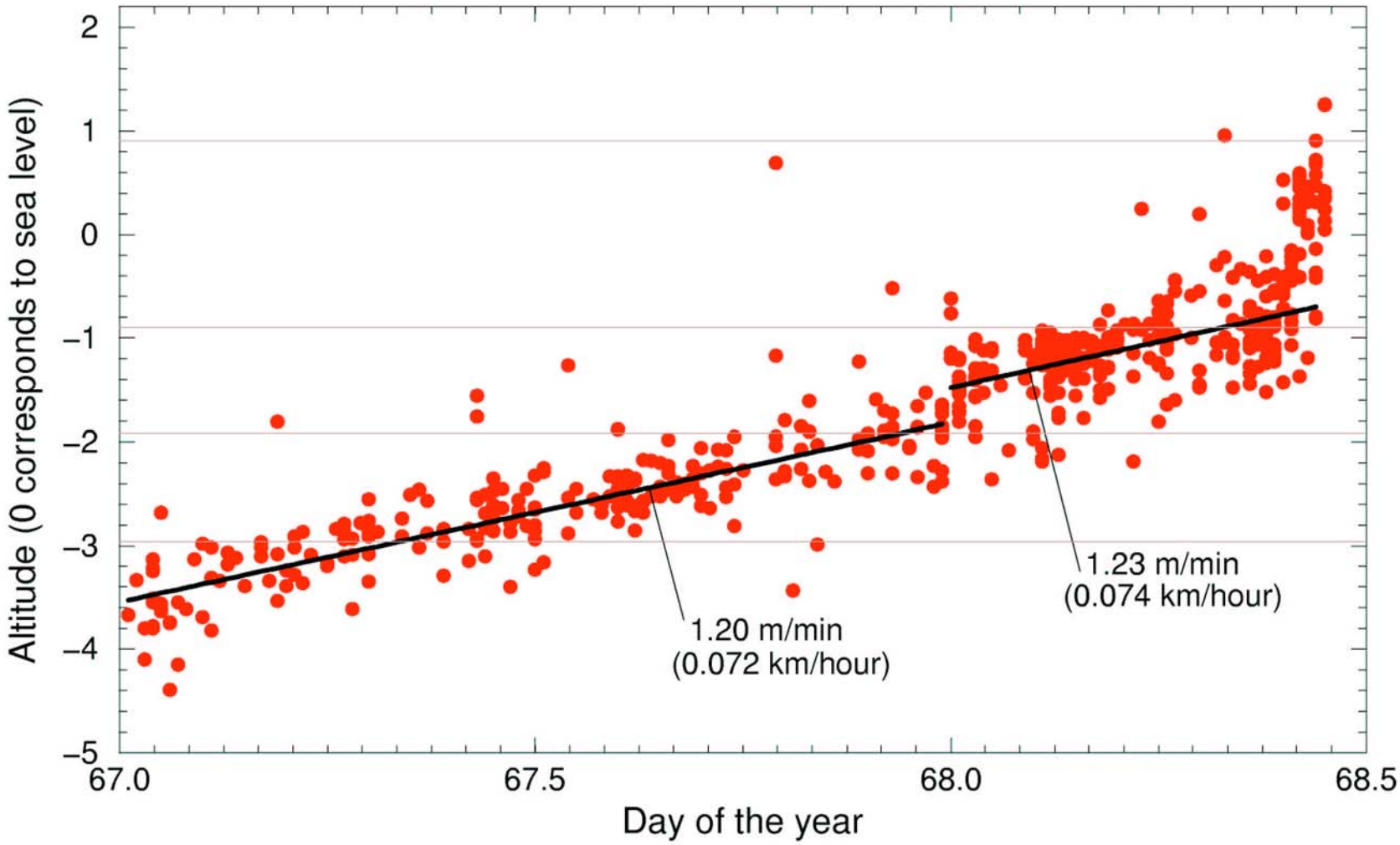
click  speed of the movie: $25\times$

1998 Piton de la Fournaise eruption



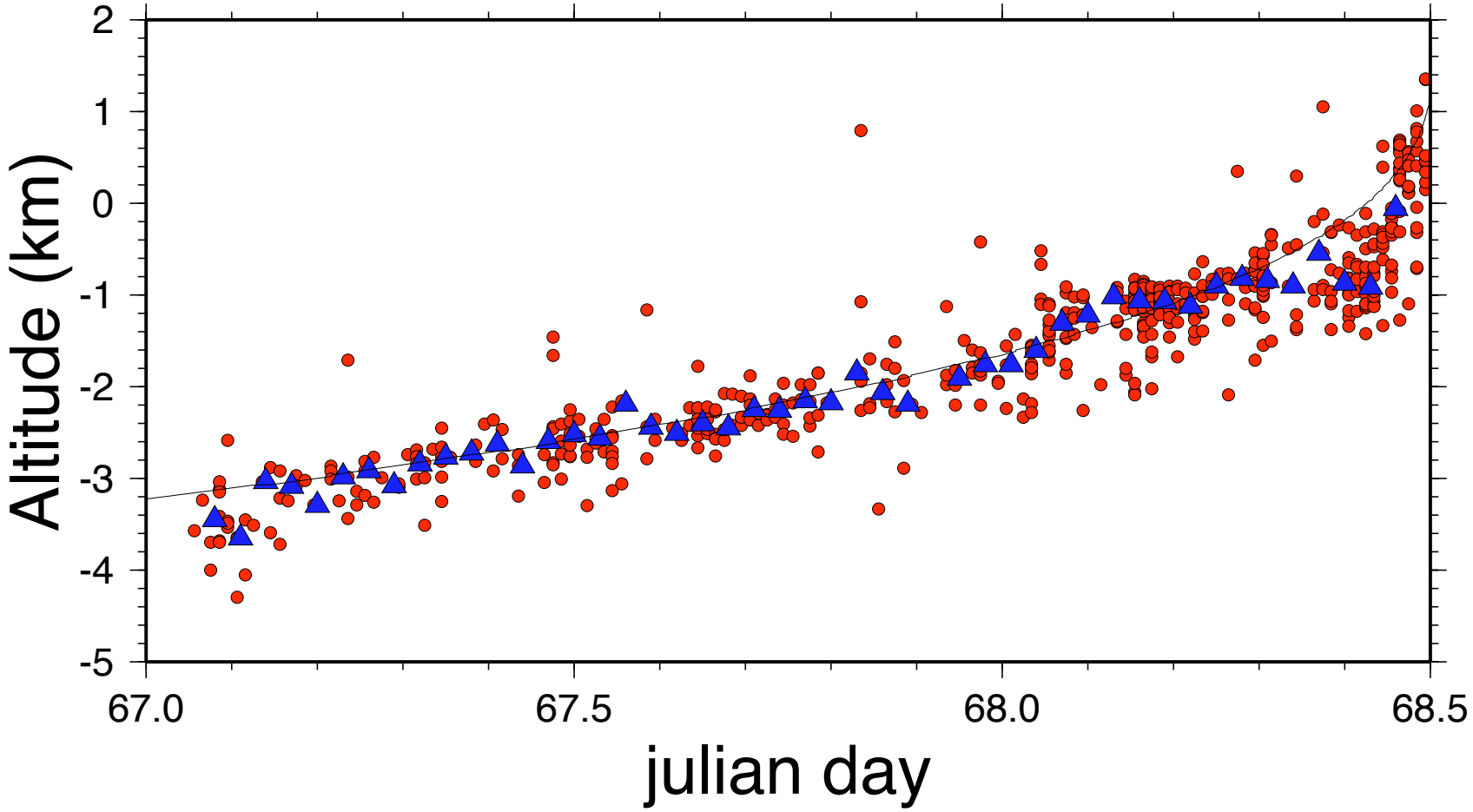
Battaglia (2001)

Migration of earthquake focal depths



from Battaglia (2001)

Crack tip predicted by gelatine model

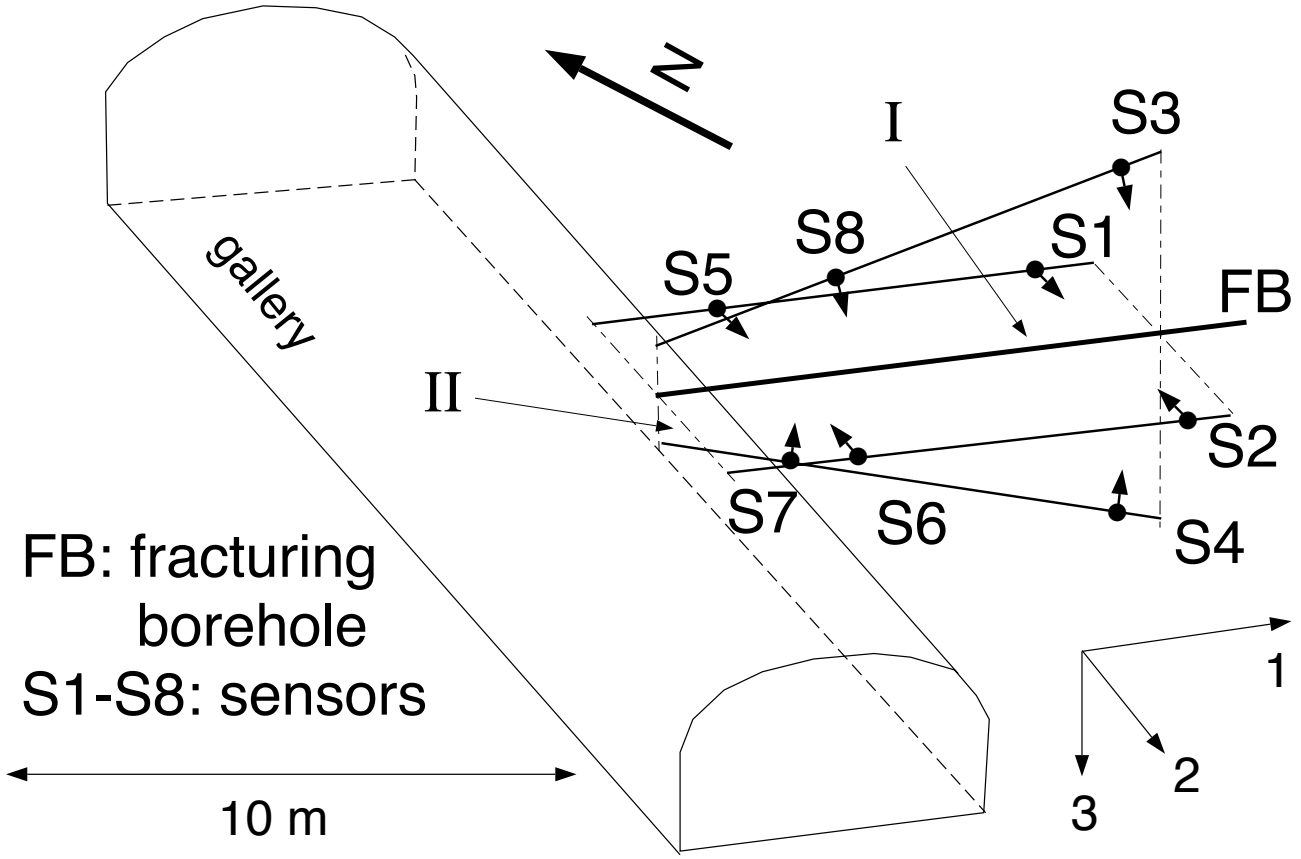


Rivalta & Dahm, submitted to GJI

non-buoyant intrusion

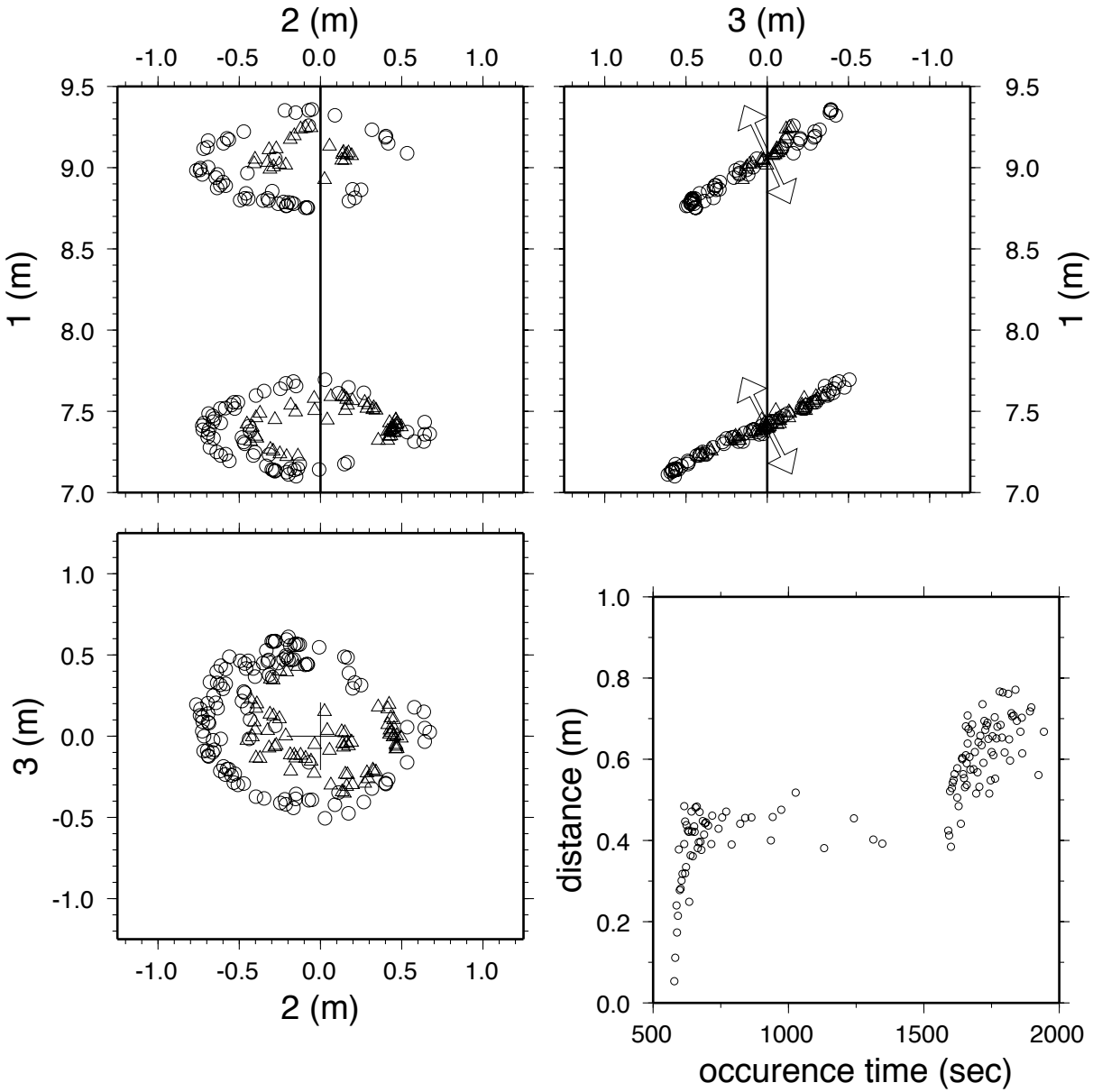
- Hydrofrac in Plexiglas: experiment by Prof. Rummel
- animated gif to follow incremental growth of sub-events

Example: Hydrofrac in a salt mine



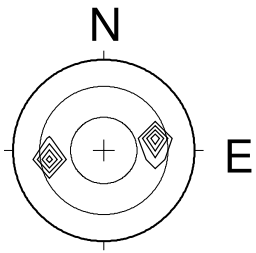
Dahm, Manthei & Eisenblätter (1999), Dahm (2001)

hypocenter follow penny shape crack

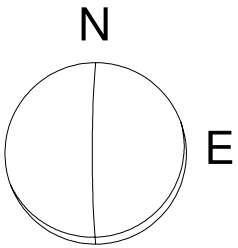


moment tensor solutions

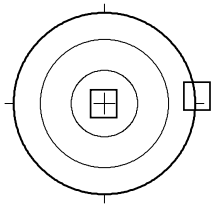
summed distribution
of P and T axis from
180 studied events



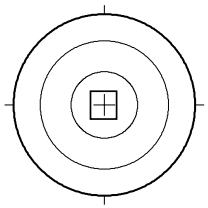
best double couple
of typical solution



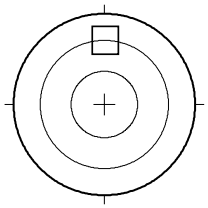
poles of typical nodal plane



poles of horizontal layers

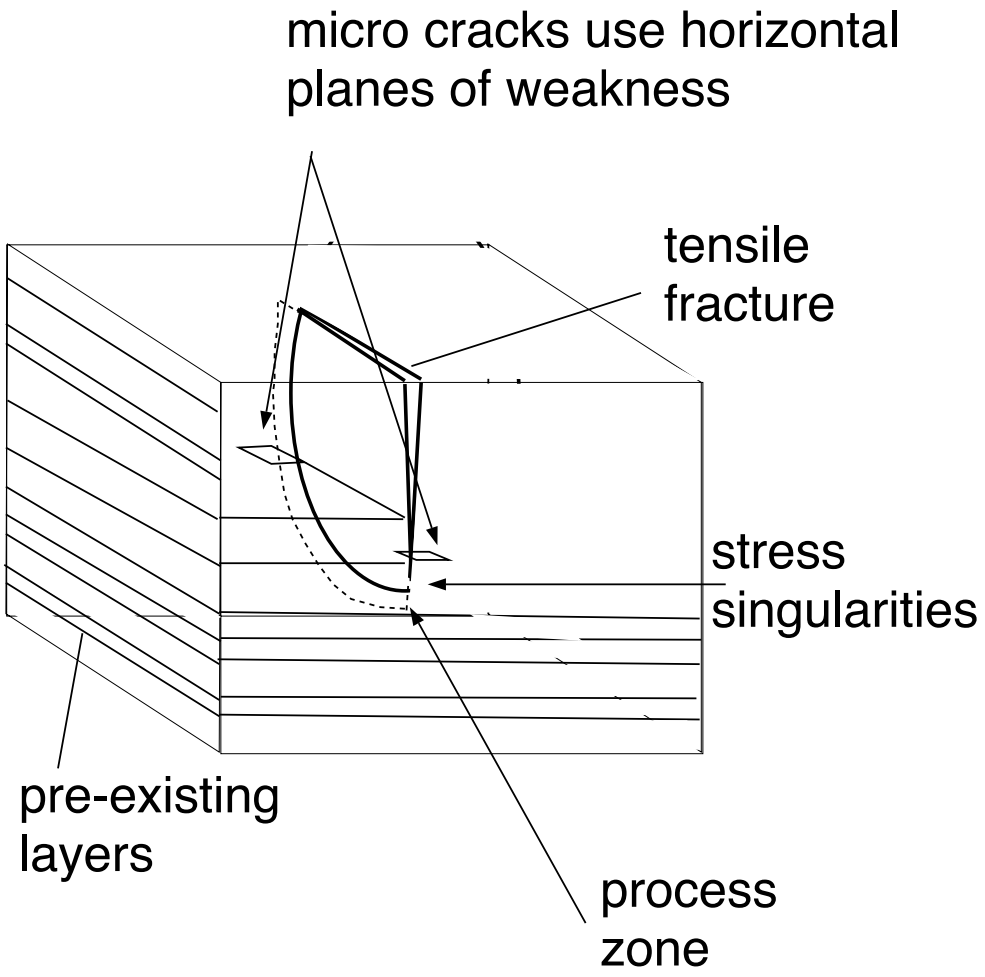


pole of fluid-filled fracture
plane

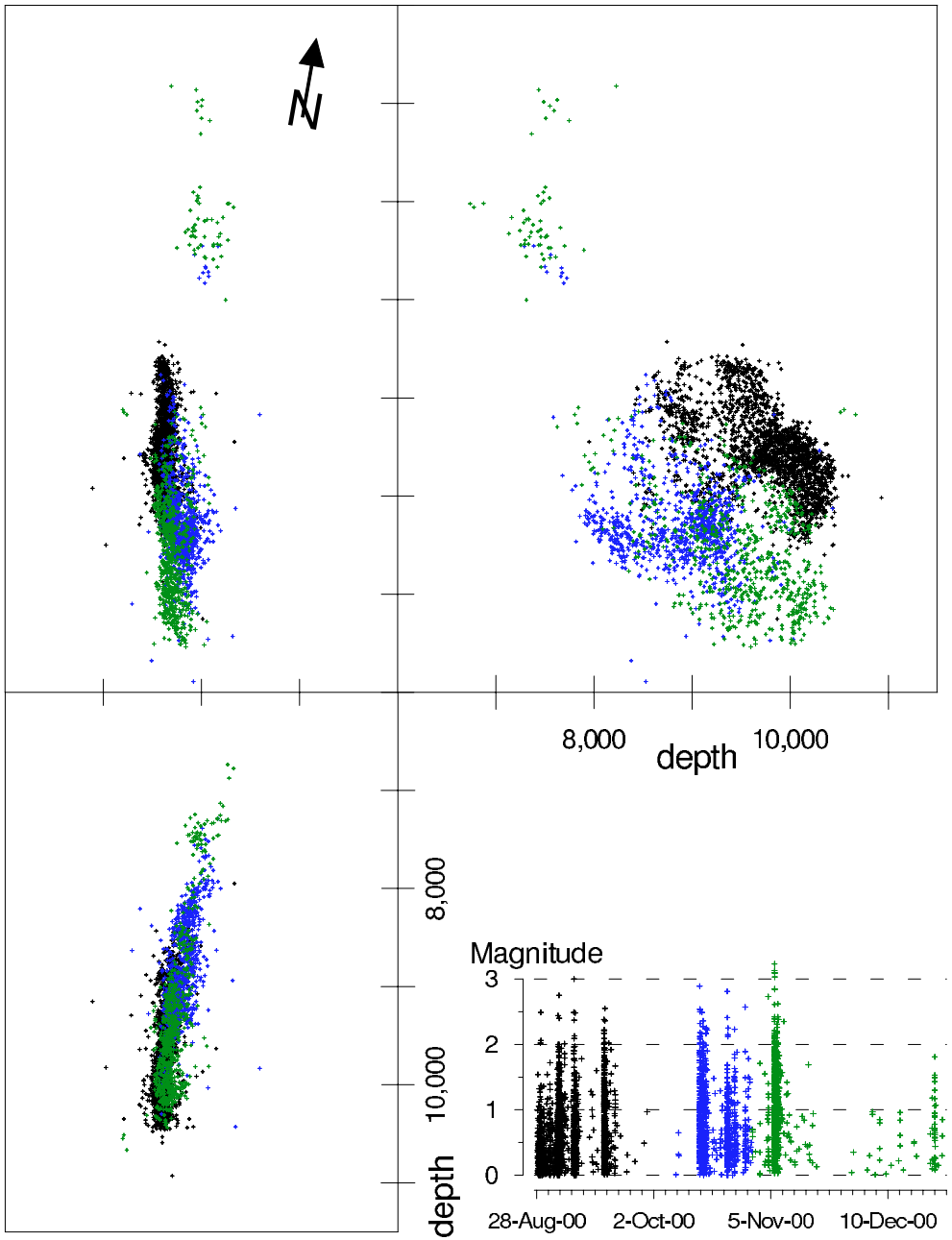


- shear cracks
- horizontal fault planes

Interpretation

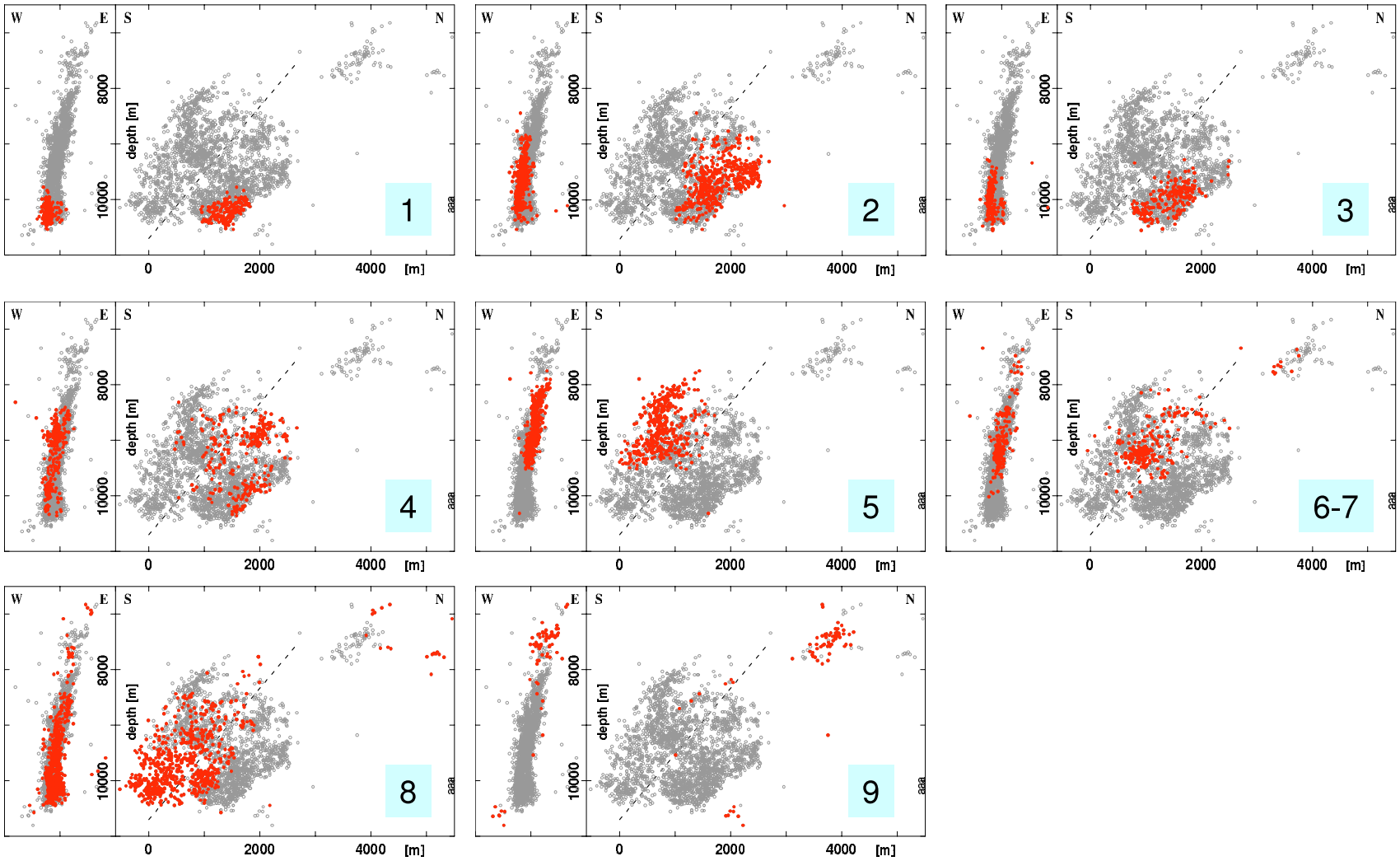


Example: Vogtland 2000 swarm

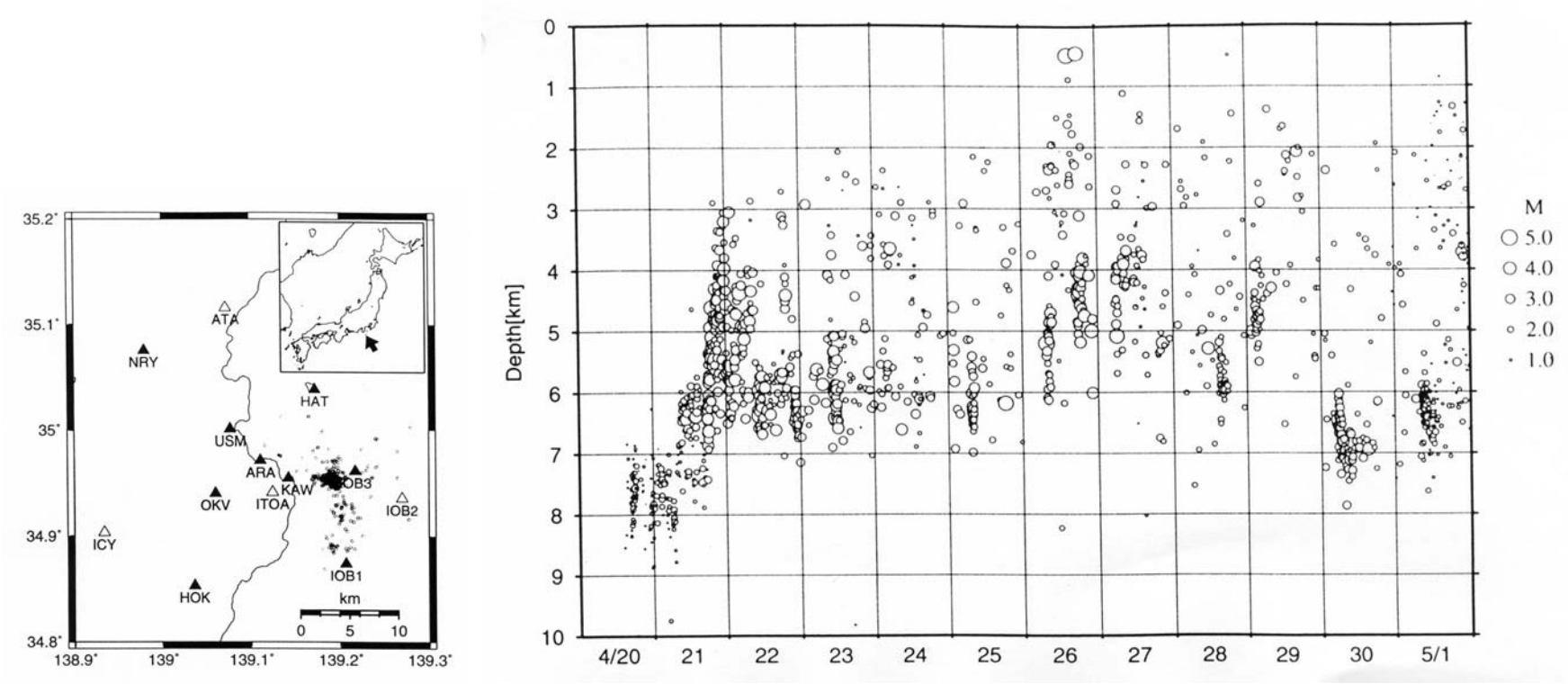


Fischer (2002)

migration of events

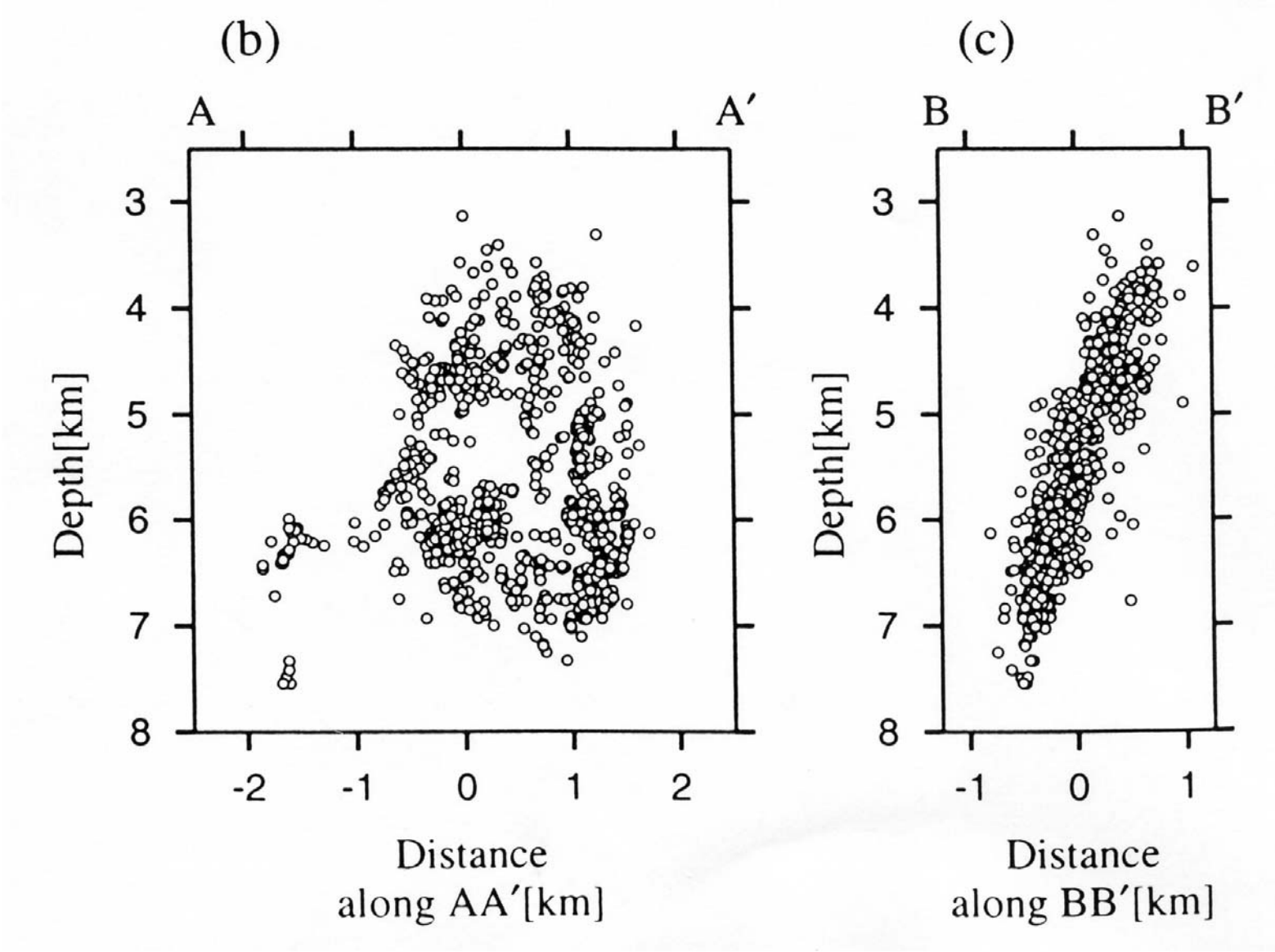


Example: Izu Bonin intrusion 2000

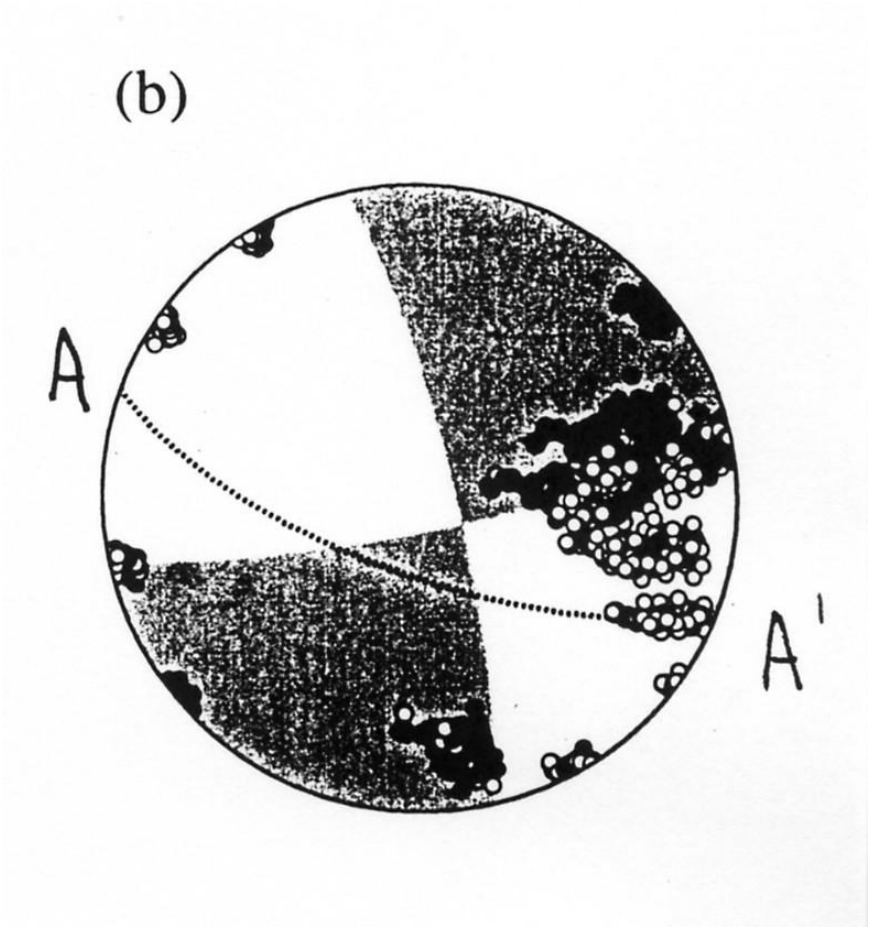


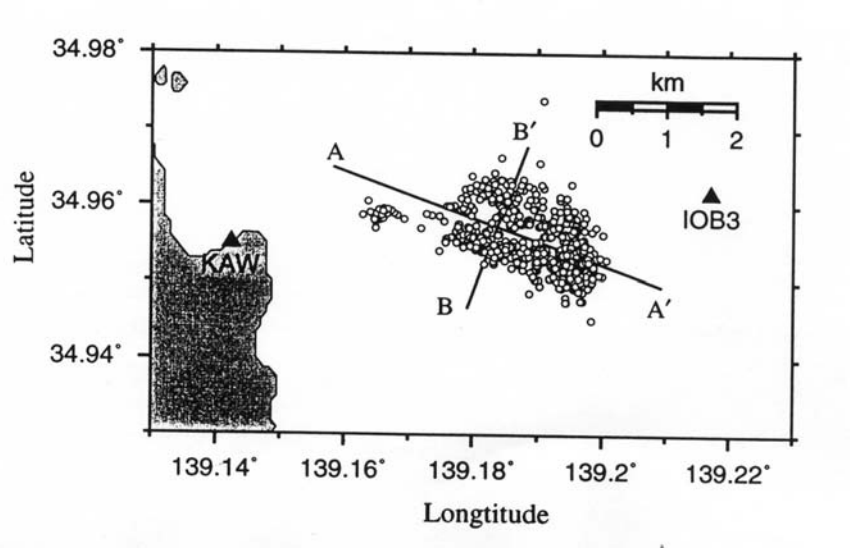
Hayashi & Morita, GJI, 2002: A magma intrusion process inferred from hypocenter migration of earthquake swarm

Izu Bonin


(b)
A
A′
Depth[km]
3
4
5
6
7
8
-2
-1
0
1
2
Distance
along AA′[km]
(c)
B
B′
Depth[km]
3
4
5
6
7
8
-1
0
1
Distance
along BB′[km]

Source mechanism study





Composite focal solution of similar events indicate that shear cracks are induced outside the dike volume

Summary

1. high-precision relative location shows migration of events and can reveal intrusion history
2. (relative) moment tensor are important to understand intrusion physics
3. intrusion-induced earthquakes are usually (off-plane) shear events. They may have small volume expansion components