Eminar

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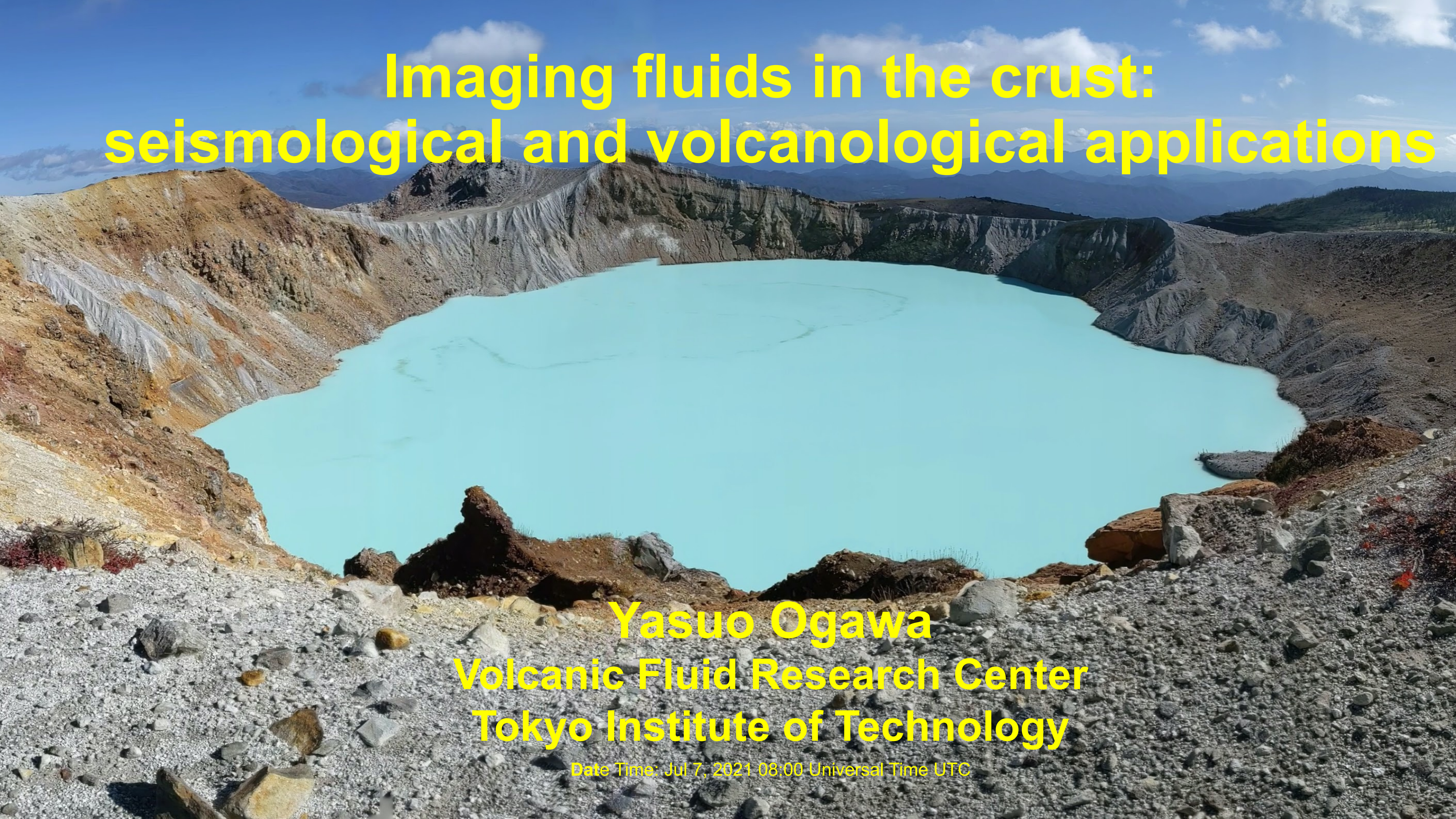
07 July 2021	08:00	R	Prof. Yasuo Ogawa Tokyo Institute of Technology	Imaging fluids in the crust: seismological and volcanological applications	Registration link

July 7th, 17:00 Japanese Local Time



Imaging fluids in the crust: seismological and volcanological applications

Yasuo Ogawa

Volcanic Fluid Research Center

Tokyo Institute of Technology

Date Time: Jul 7, 2021 08:00 Universal Time UTC

Outline

- Review on our magnetotelluric studies

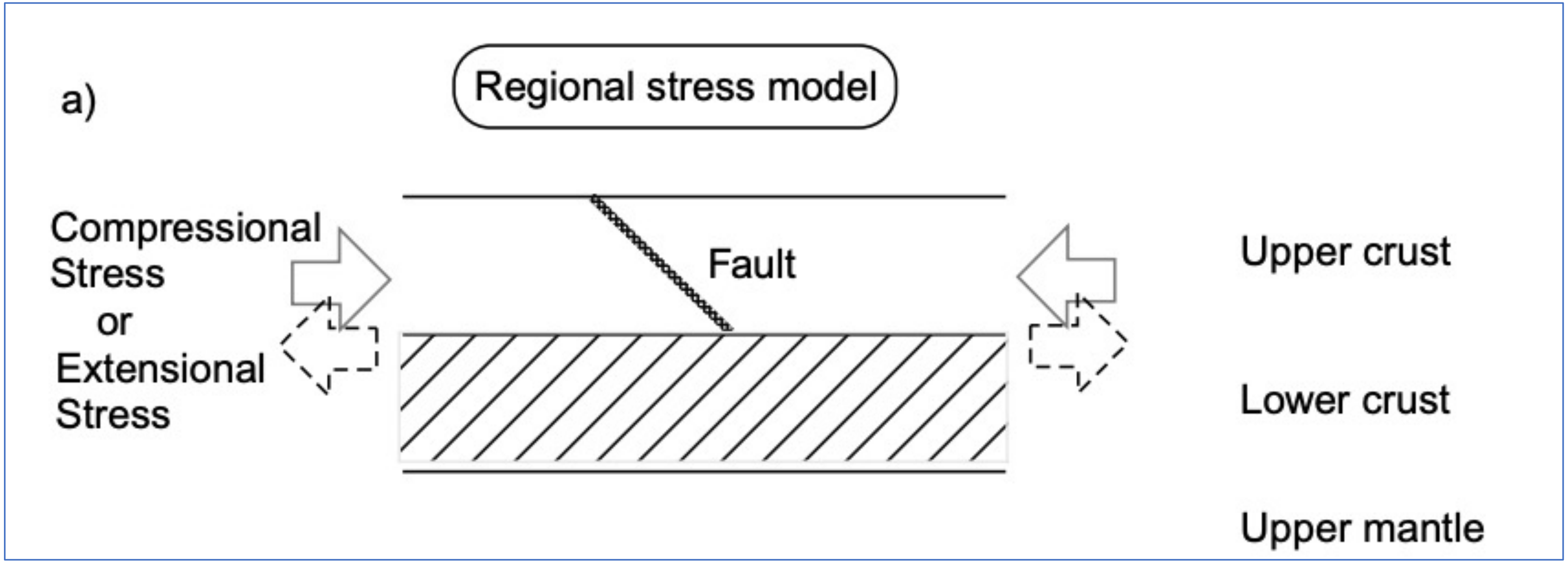
- Seismology targets
  - Intraplate earthquakes
  - Plate interface at subduction zones

- Volcanology targets
  - Imaging Geothermal system
  - Temporal resistivity changes

Seismology targets

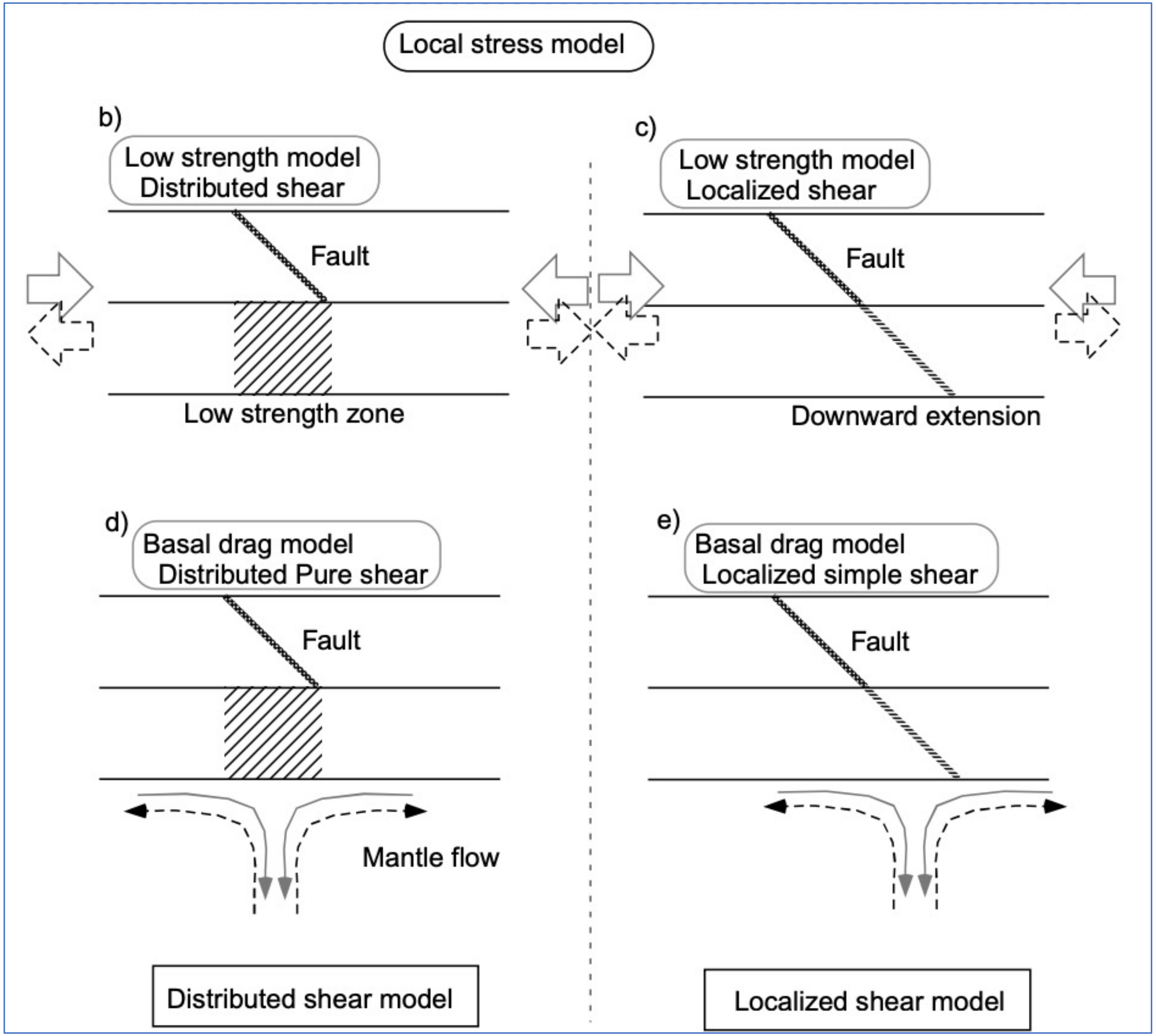
- Intraplate earthquakes
  - Active faults, shear zones, fluid reservoir, deformation
  - NE-Japan
  - North Anatolian Fault(NAF)
  - NZ
  - Volcano-Earthquake link
- Plate interface at subduction zones
  - NZ
  - SW Japan

Iio-Kobayashi Model (2002)



Iio & Kobayashi (2002, EPS)

Iio-Kobayashi Model (2002)



Iio & Kobayashi (2002, EPS)

Fault Valve model

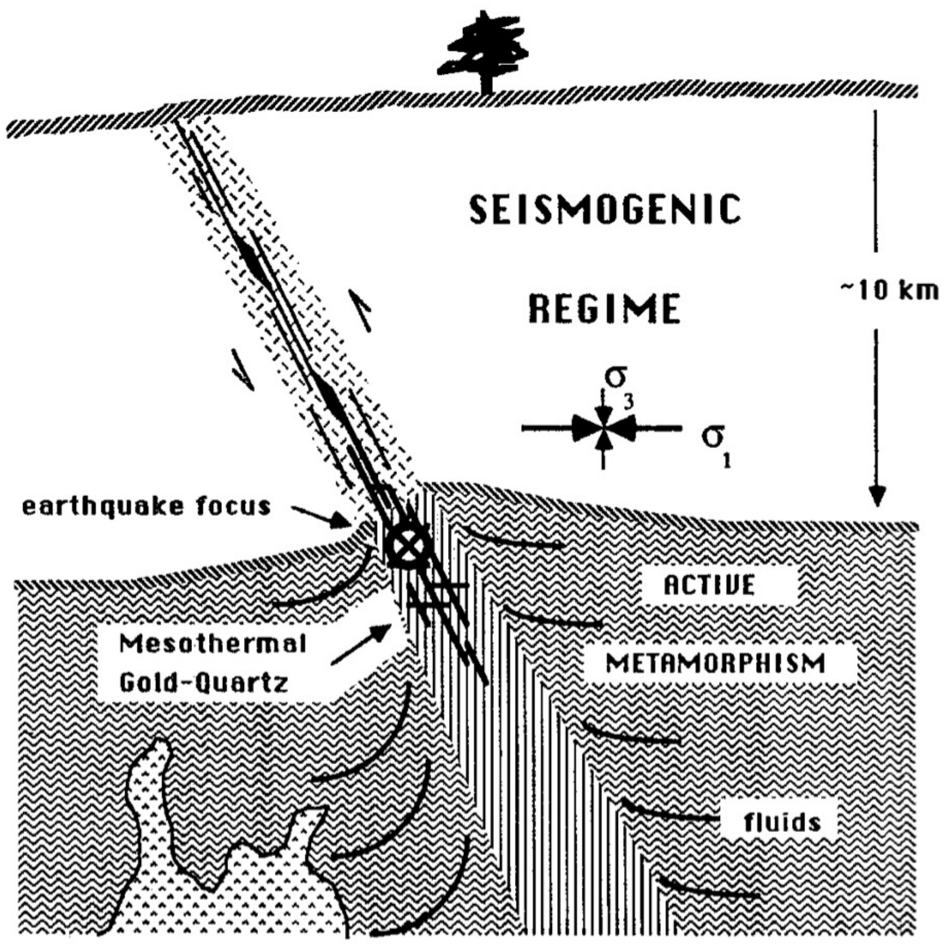
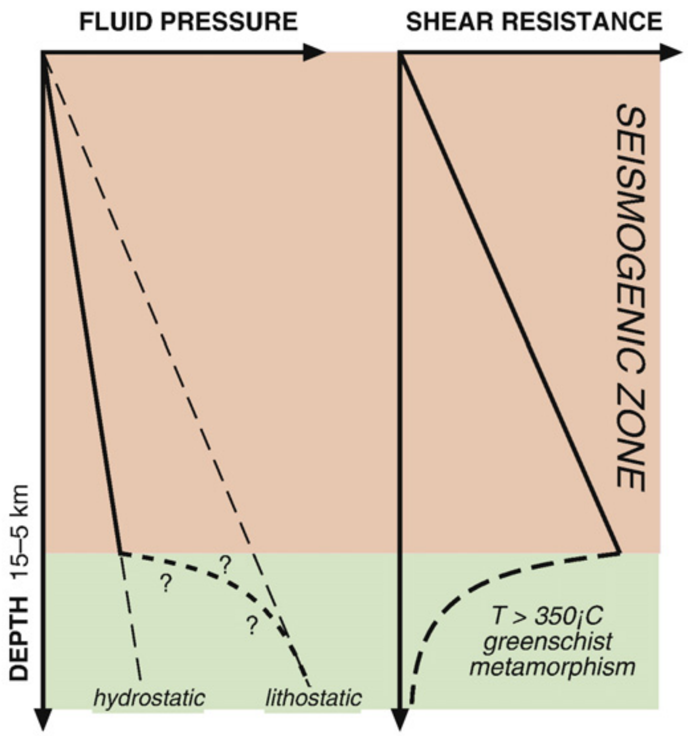


Figure 2. Synoptic diagram (not to scale) of inferred tectonic setting for mesothermal gold-quartz vein system in relation to continental seismogenic regime.

Sibson et al (1988, Geology)

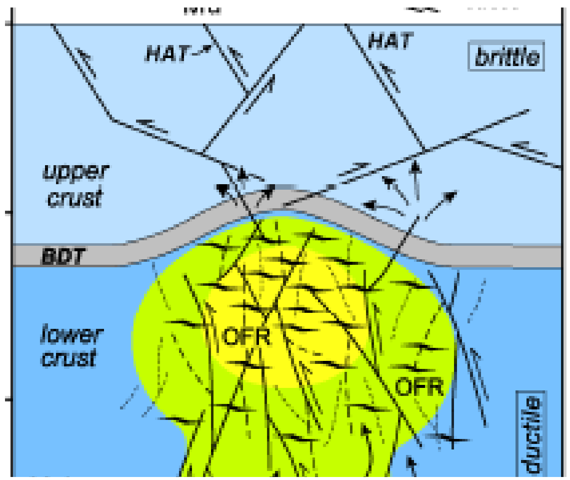


Sibson (2009, Tectonophysics)

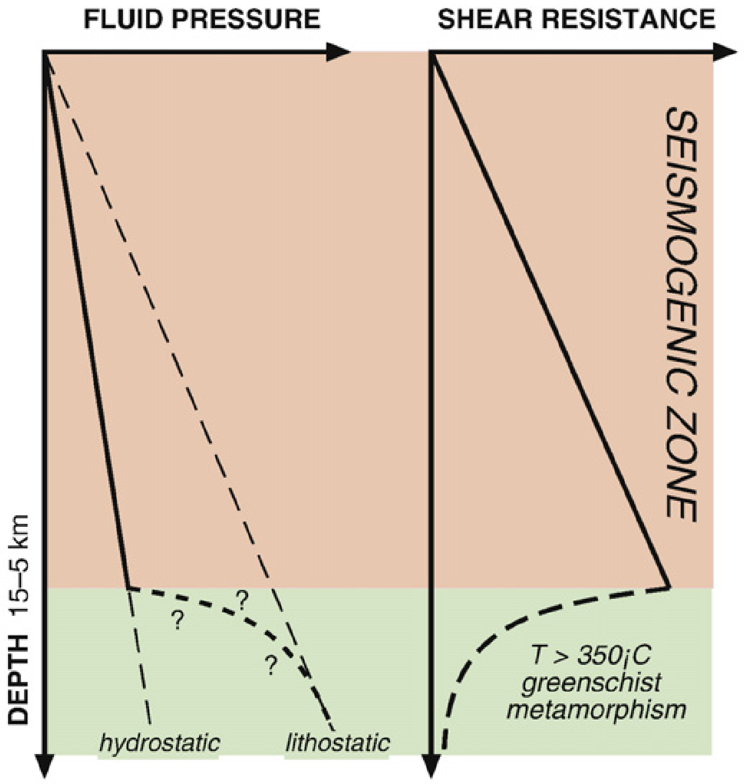
Pore pressure, Rheological properties
at the Brittle-Ductile Transition

BDT

Sealed by Silica
solubility breakdown @400 deg C
(Saishu et al, 2014, Terra Nova)

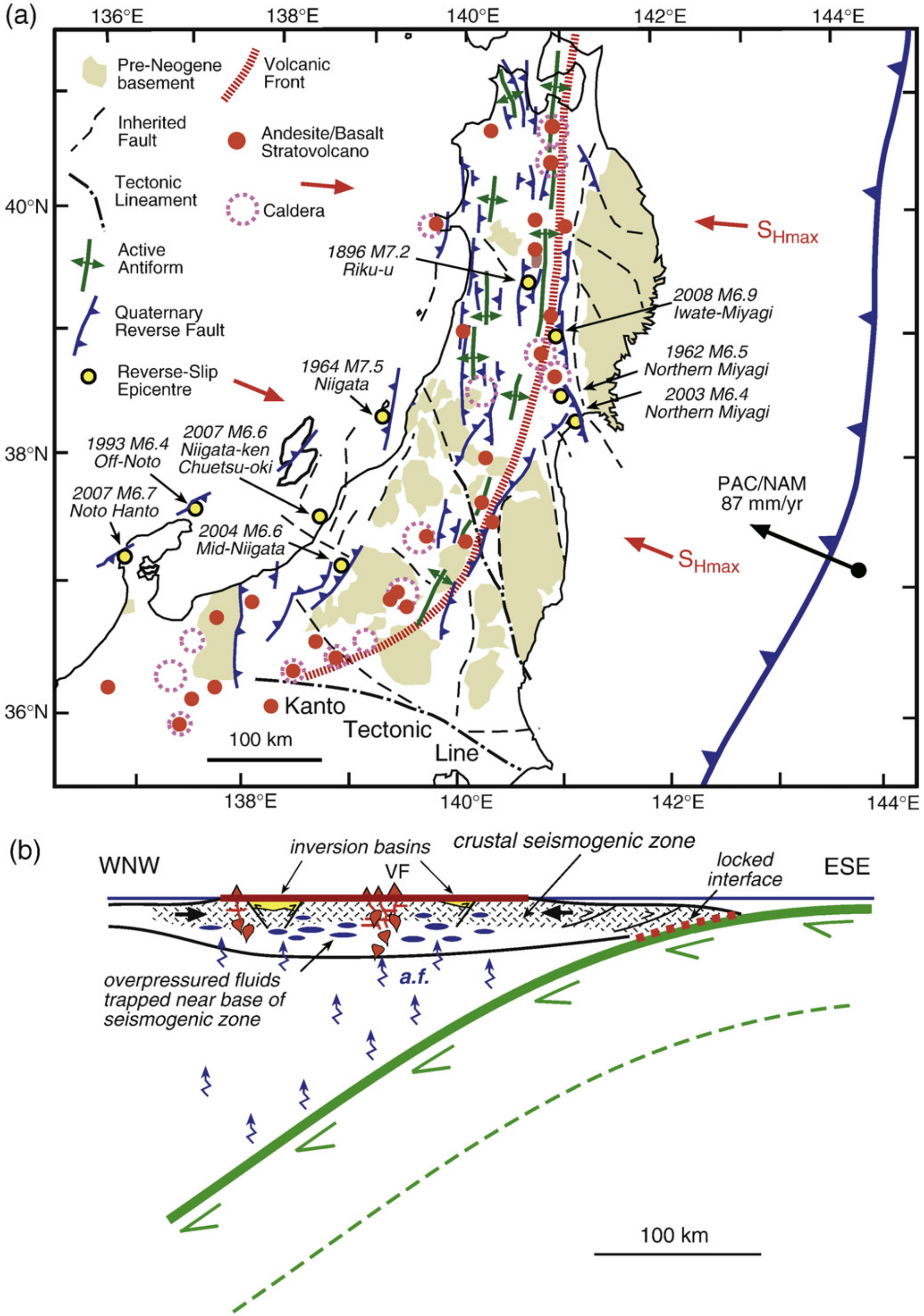


Wannamaker et al
(2009, Nature)



Sibson
(2009, Tectonophysics)

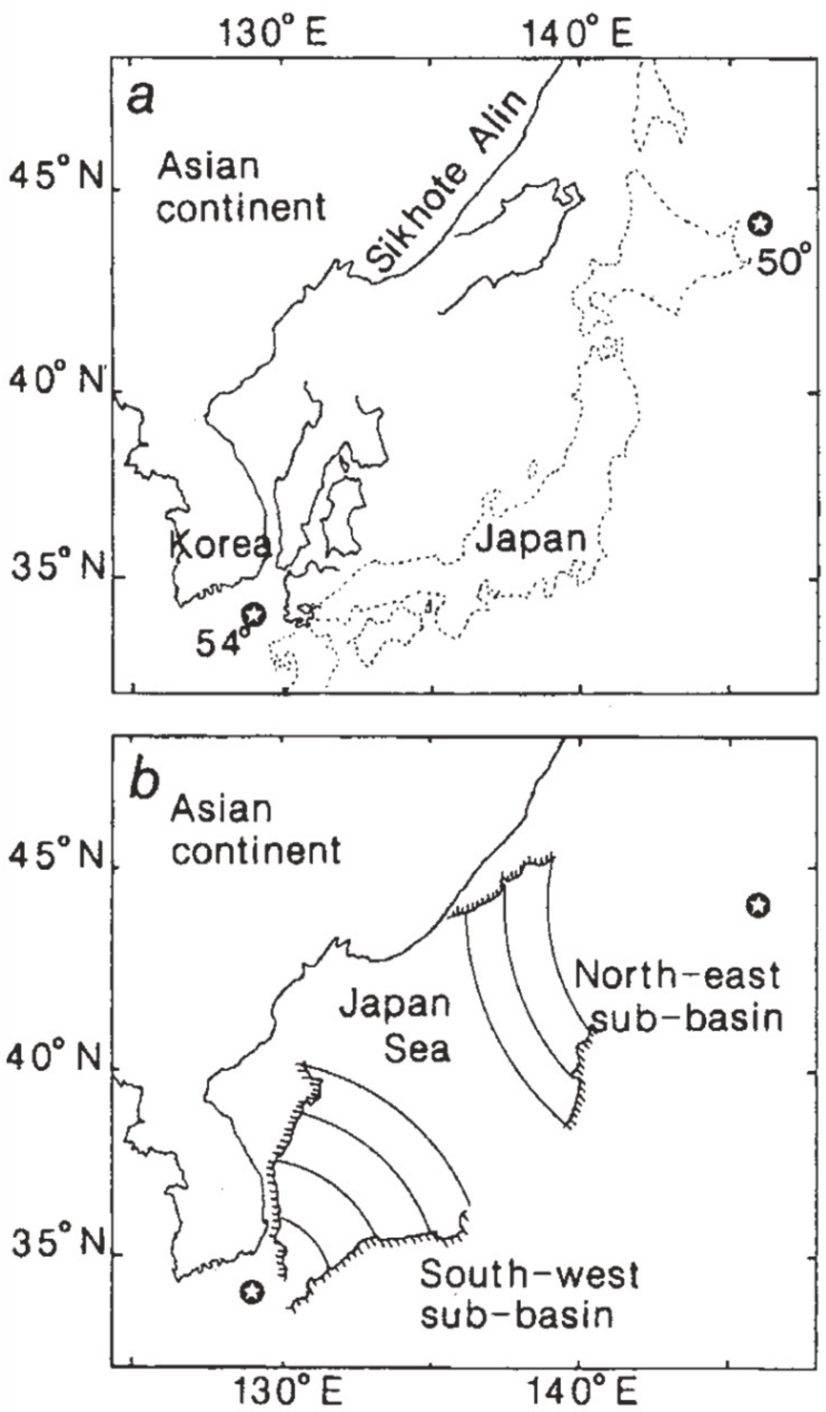
NE Japan



- Volcanic arc
- Reactivated fault
- Flow supply from the slab

Sibson (2009, Tectonophysics)

Japan Sea Rifting @Miocene 14Ma



Rifting
Normal Fault system

Ofofuji et al. (1985, Nature)

NE Japan

Tectonic background

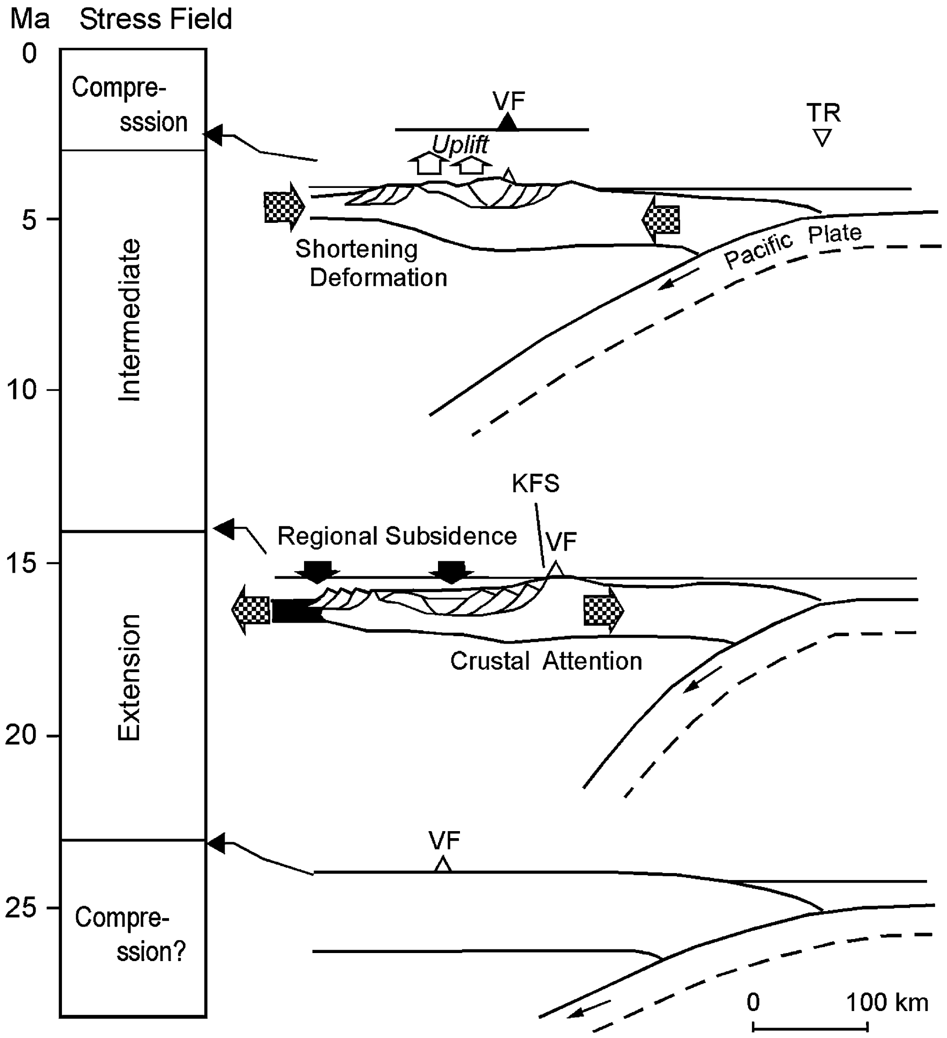


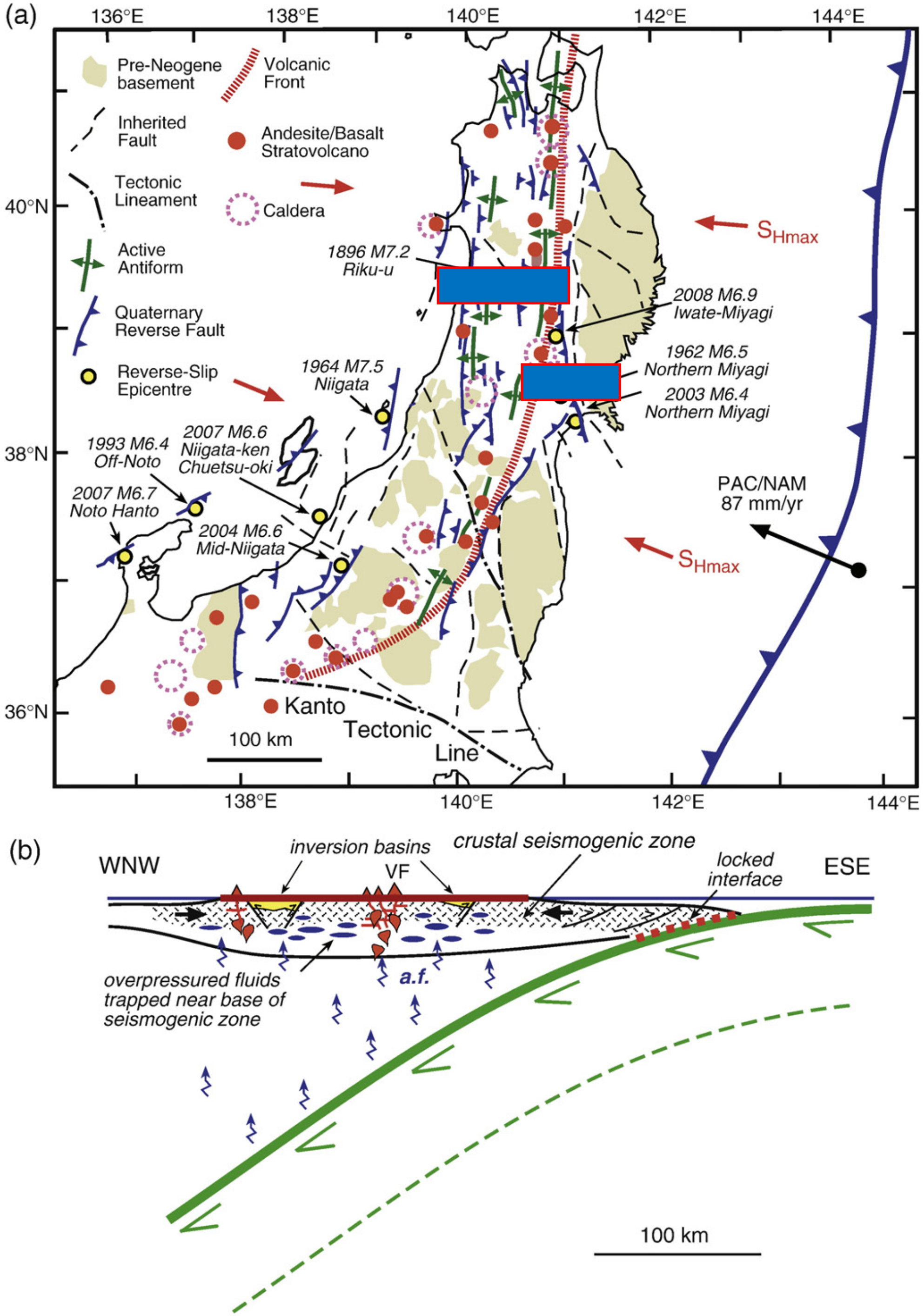
Fig. 2. Neogene tectonic evolution of Northern Honshu modified after Sato and Amano (1991). VF: volcanic front, TR: trench axis, KFS: Kitakami fault system.

Reverse faulting
Using the existing faults

Inversion tectonics

Normal faulting
Japan Sea Opening in Miocene

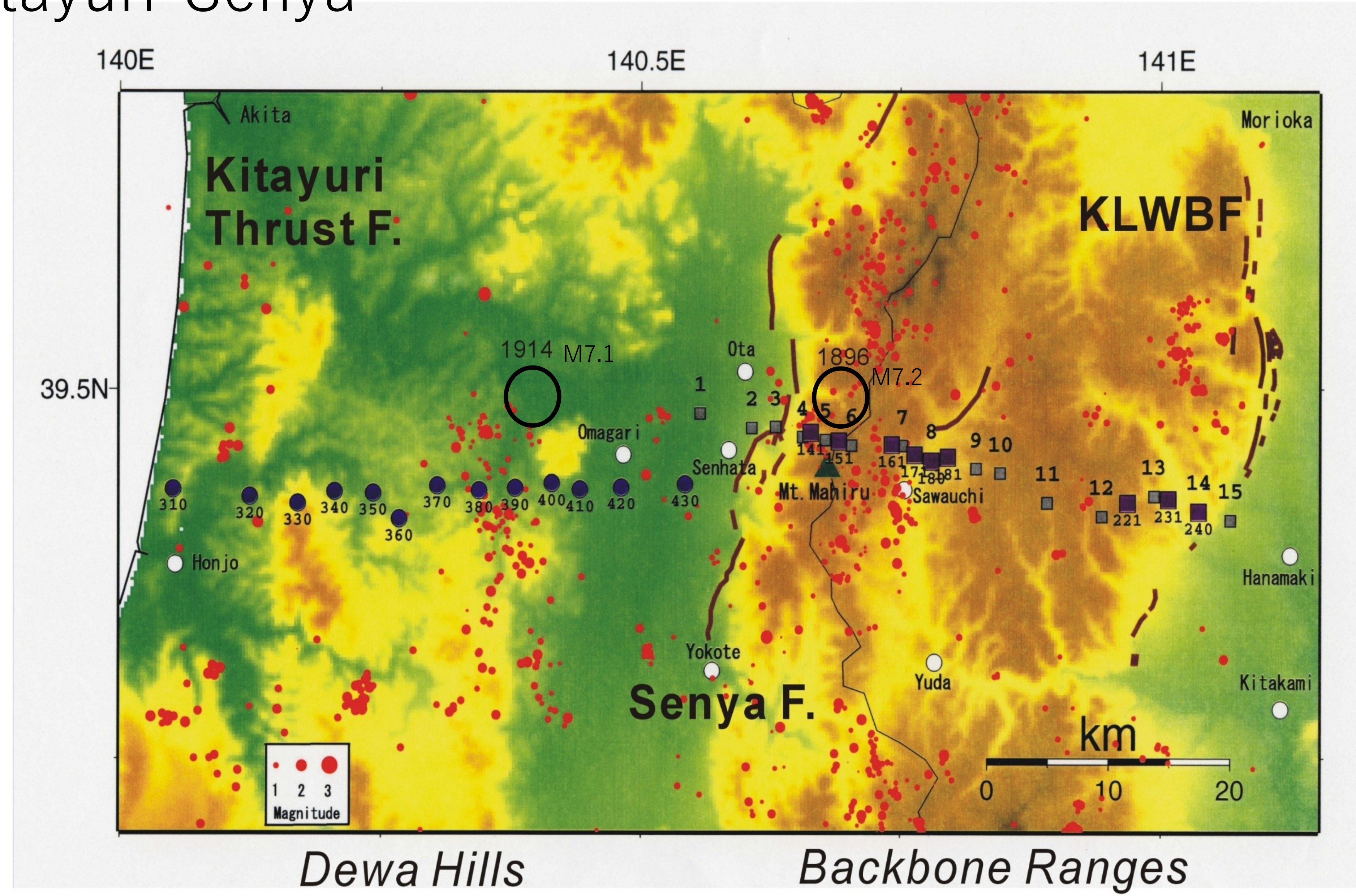
NE Japan



- Volcanic arc
- Reactivated fault
- Flow supply from the slab

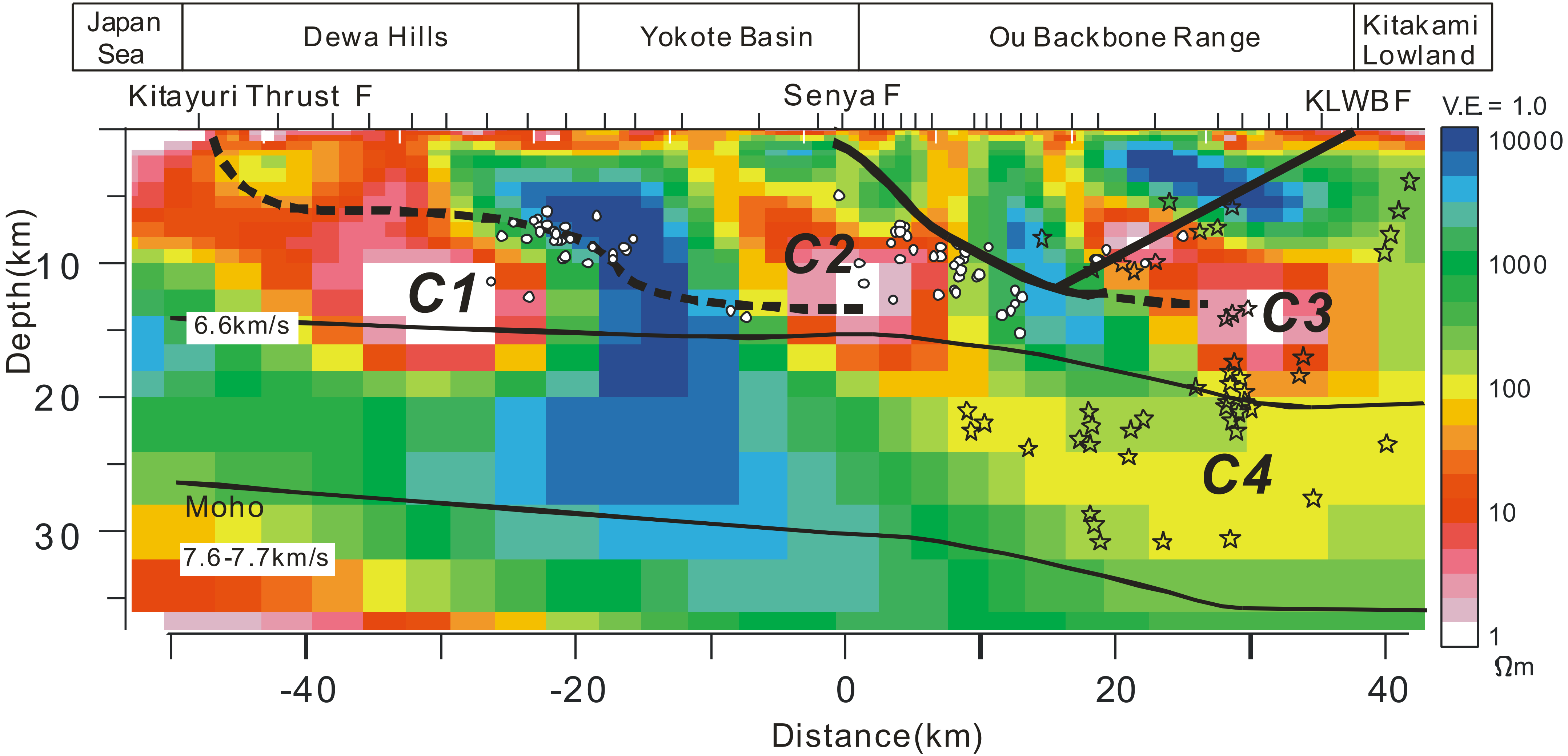
Sibson (2009, Tectonophysics)

NE Japan (1) Kitayuri-Senya



(Ogawa et al.,2001,GRL)

NE Japan (1) Kitayuri-Senya

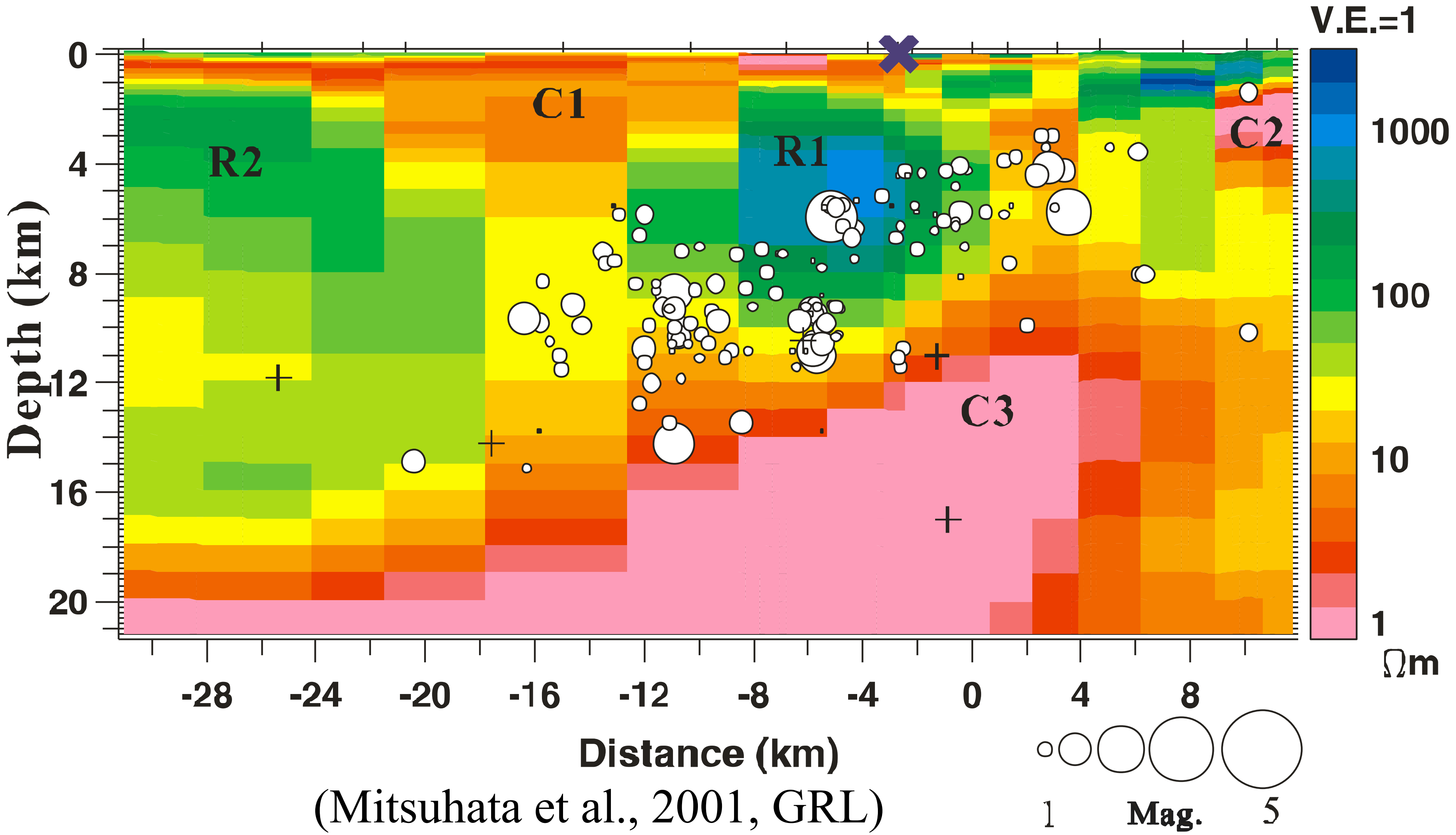


High seismicity at the rim of the mid-crustal conductors
Starts: Seismic reflectors

(Ogawa et al., 2001,GRL)

NE Japan (2) Northern Miyagi

Hypocenter region of
1962 Northern-Miyagi Earthquake

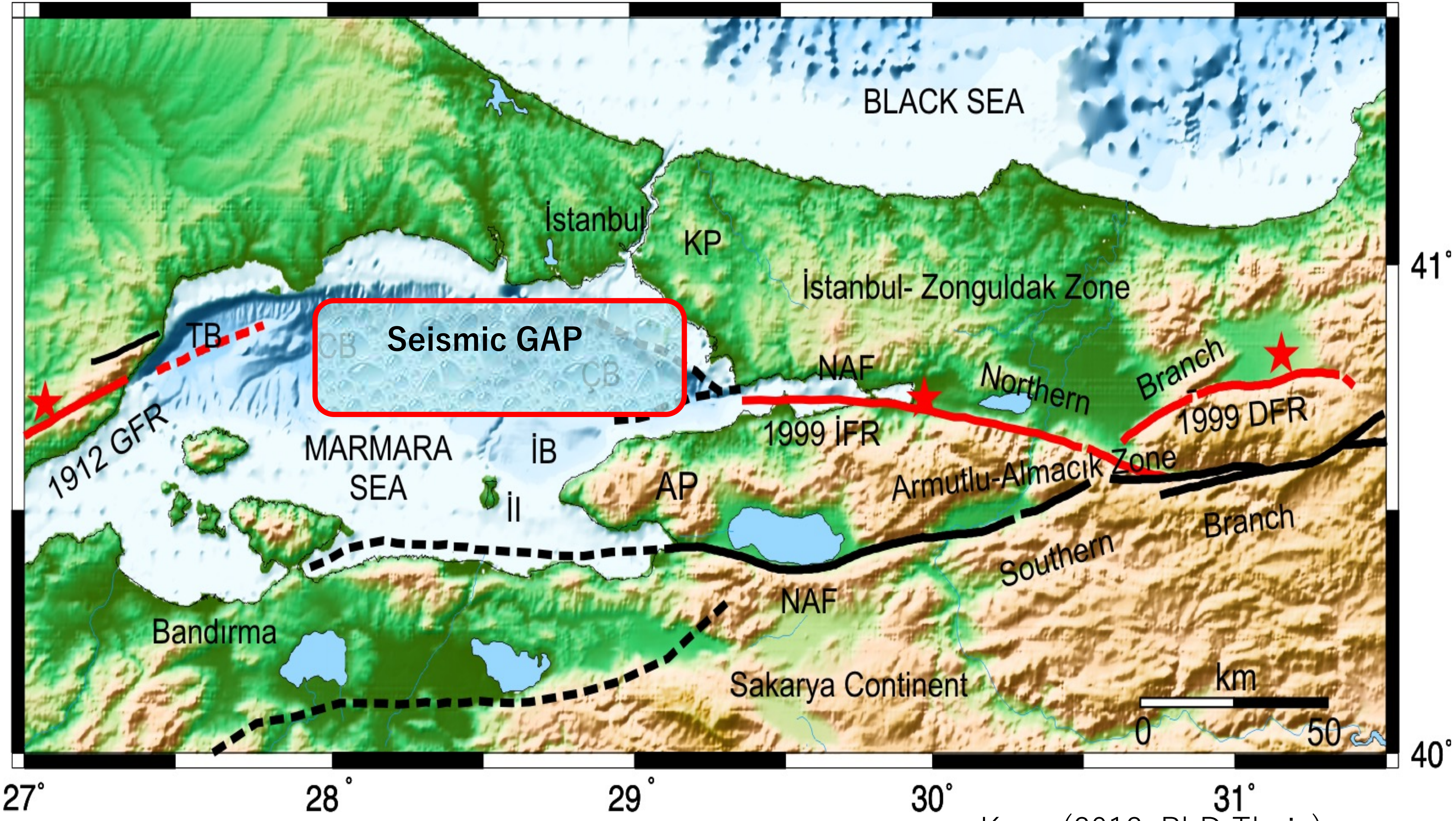


(Mitsuhata et al., 2001, GRL)

Seismicity above the conductor

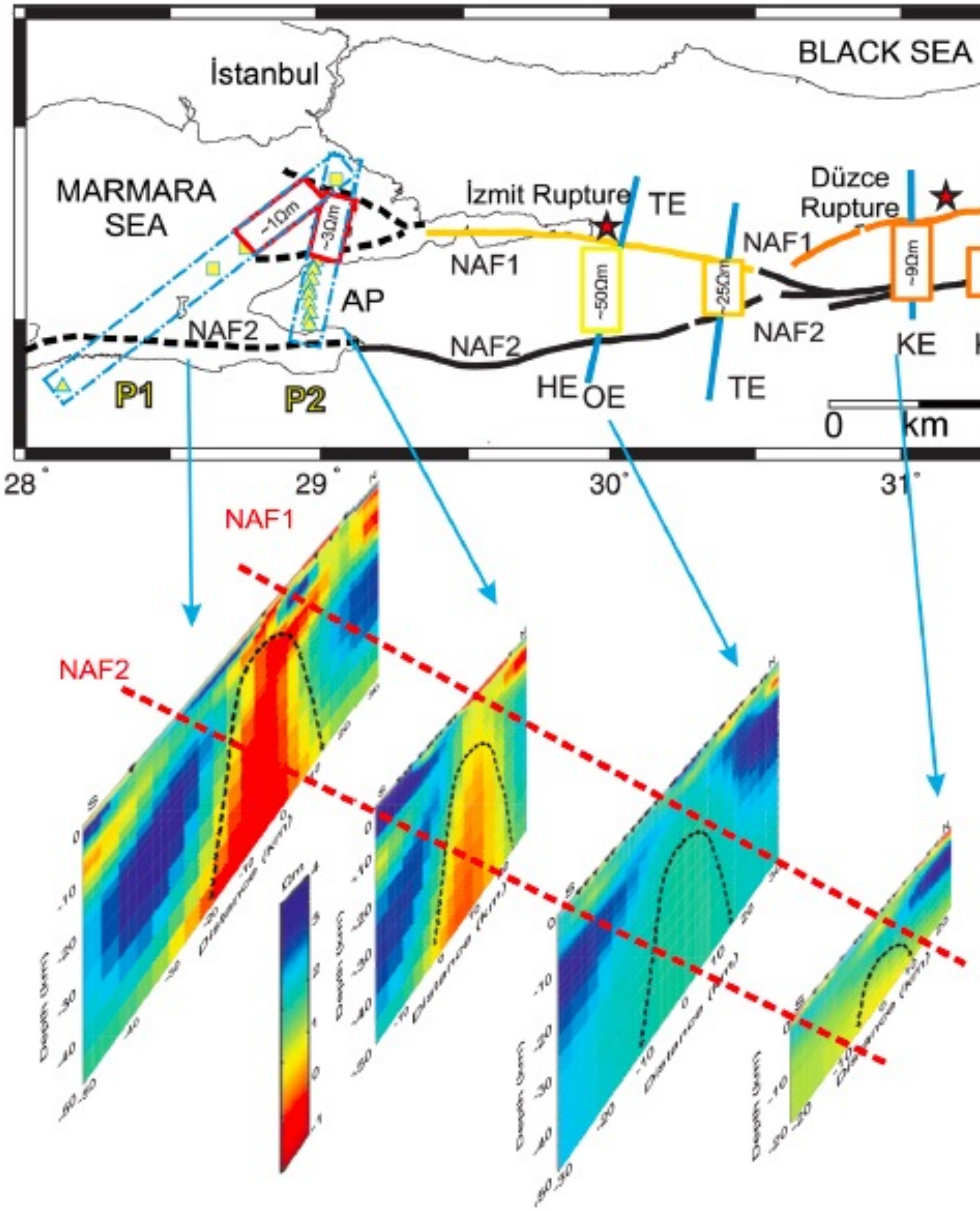
Cutoff depth of seismicity = top of conductor

North Anatolian Fault, Turkey



Kaya (2012, PhD Theis)

Compilation of NAF 2D profiles



Along strike variation

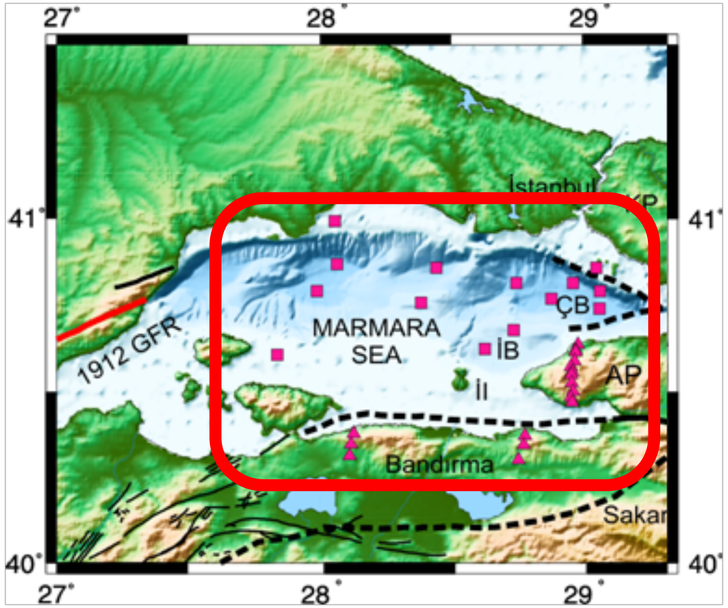
Segmentation

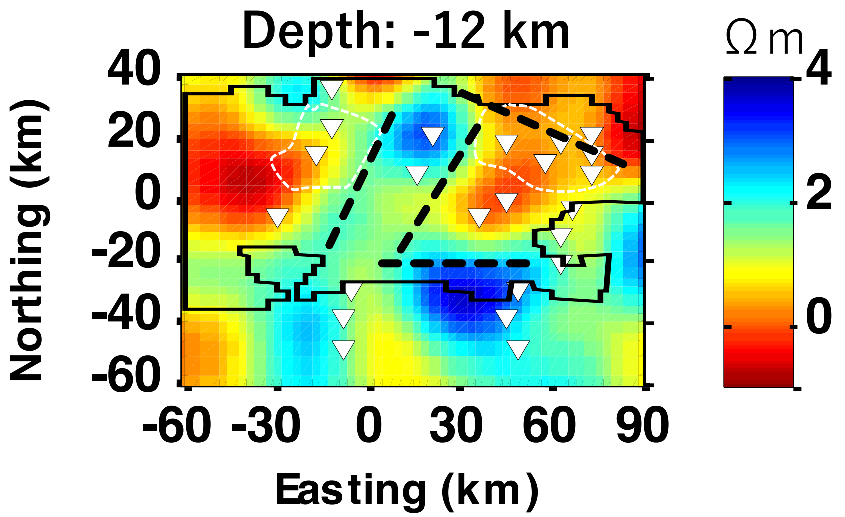
“Asperities” as “resistors”

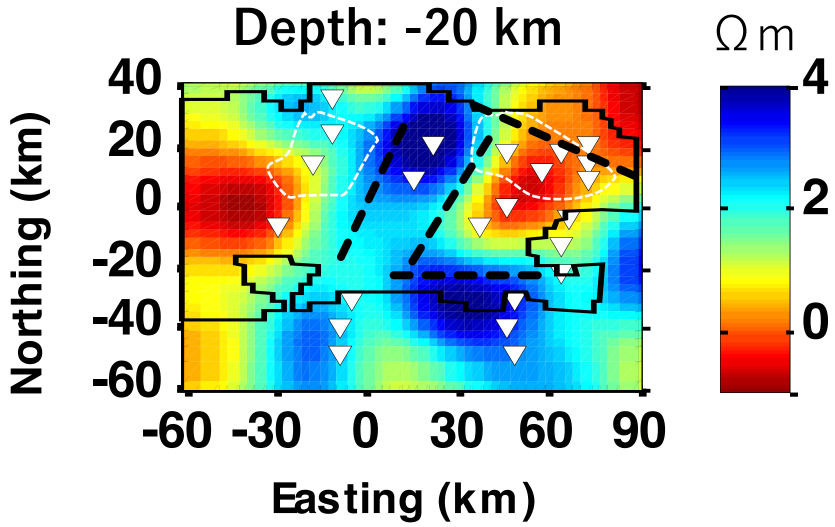
Kaya et al. (2013, Geophys. J. Int)

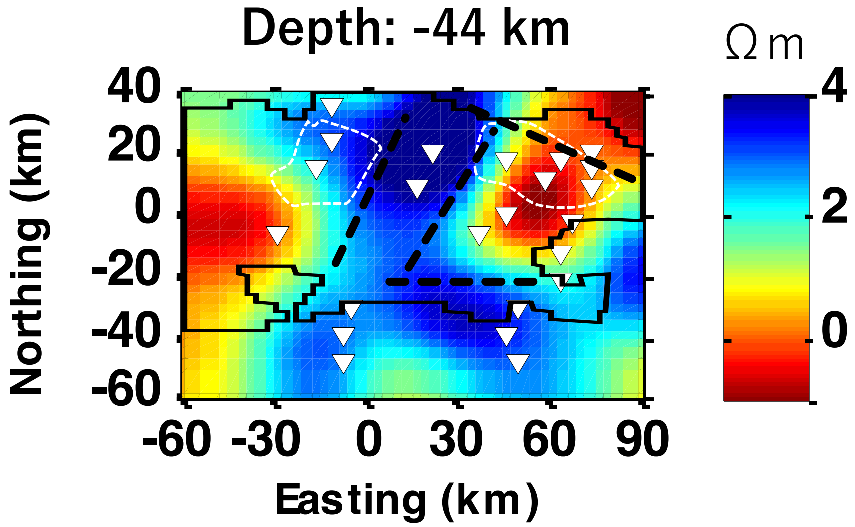
3d inversion result

“seismic gap” as a resistor



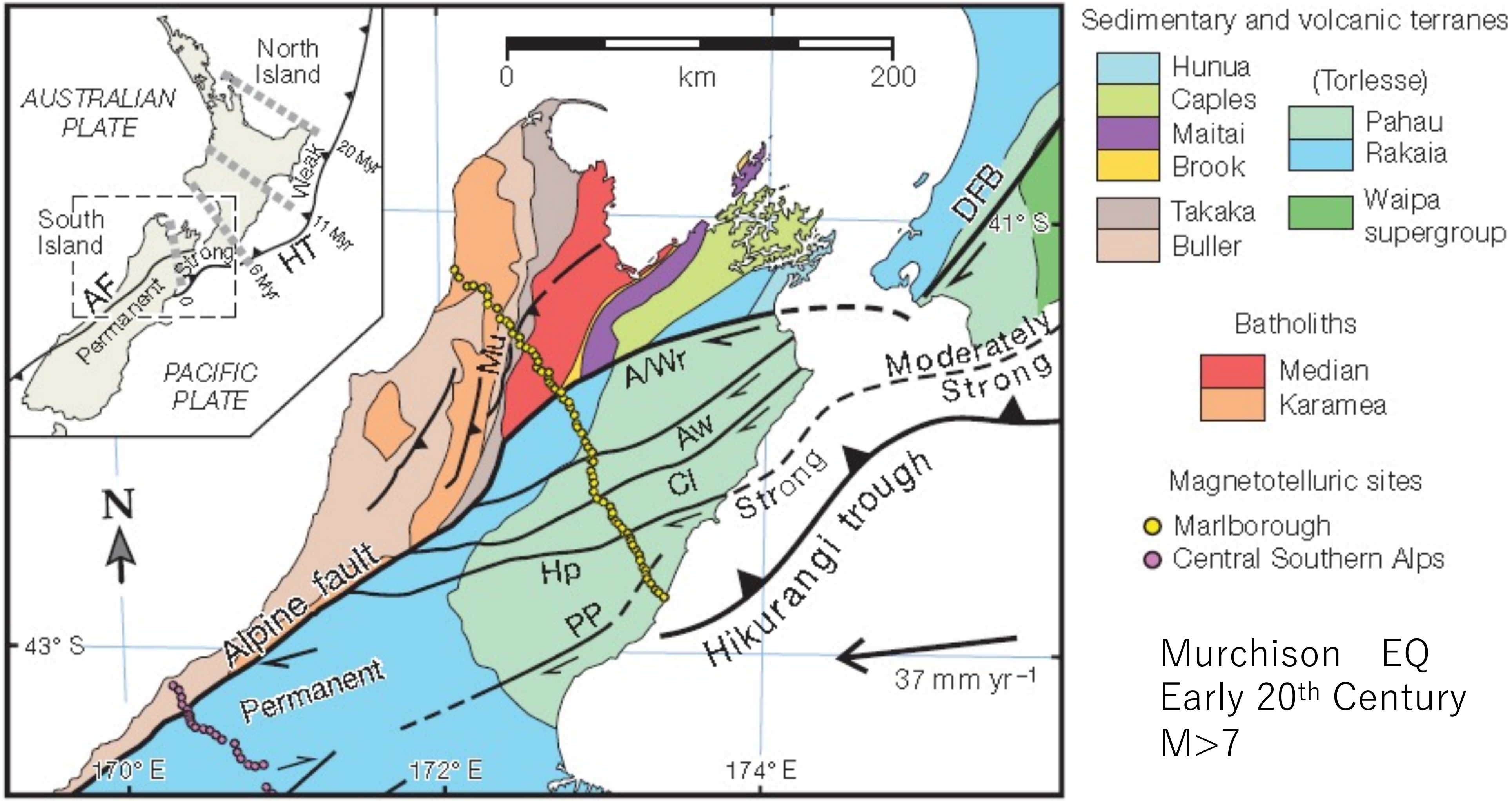






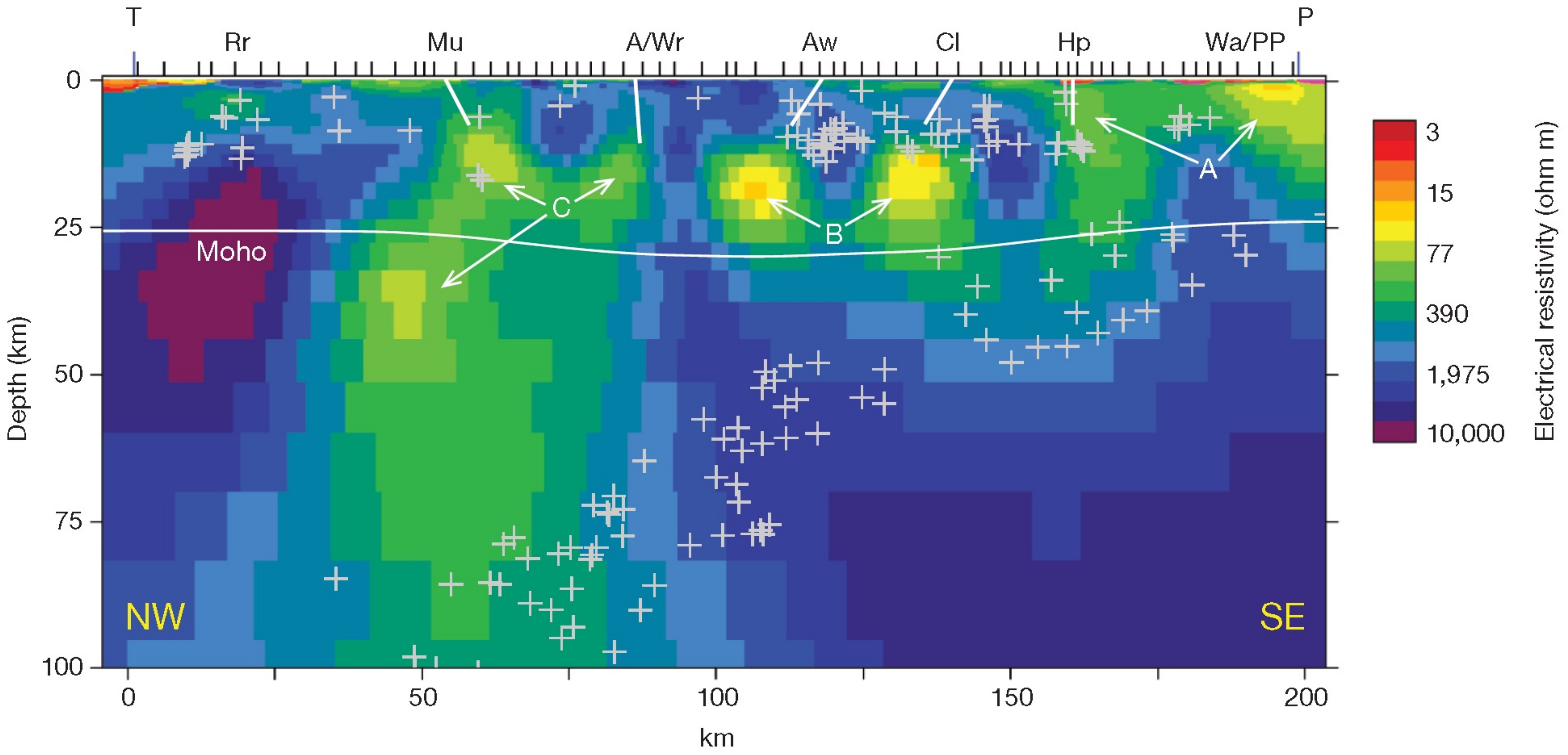
Kaya (2012, PhD Theis)

South Island, New Zealand

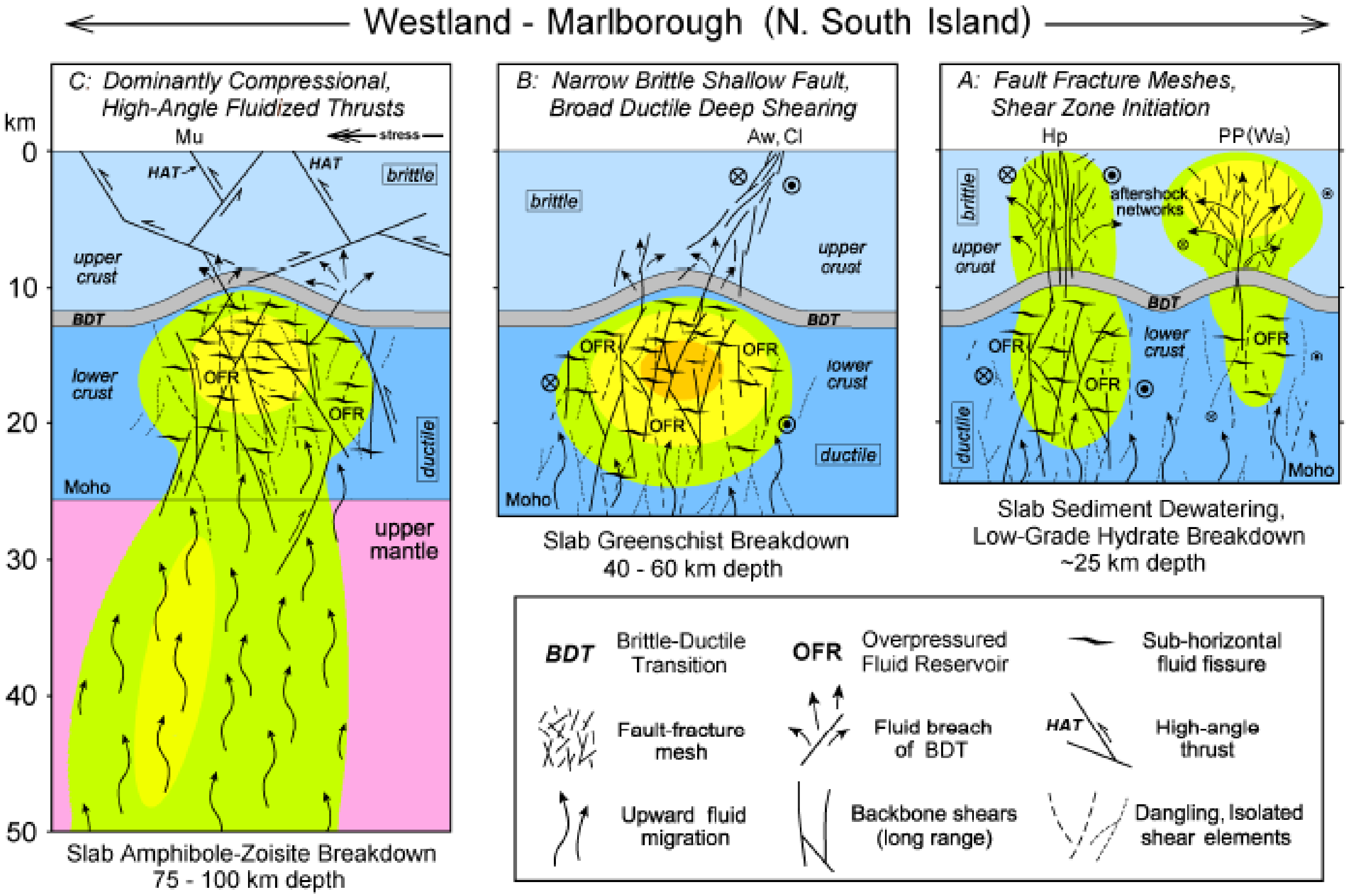


Murchison EQ
Early 20th Century
M>7

Wannamaker et al. (2009, Nature)

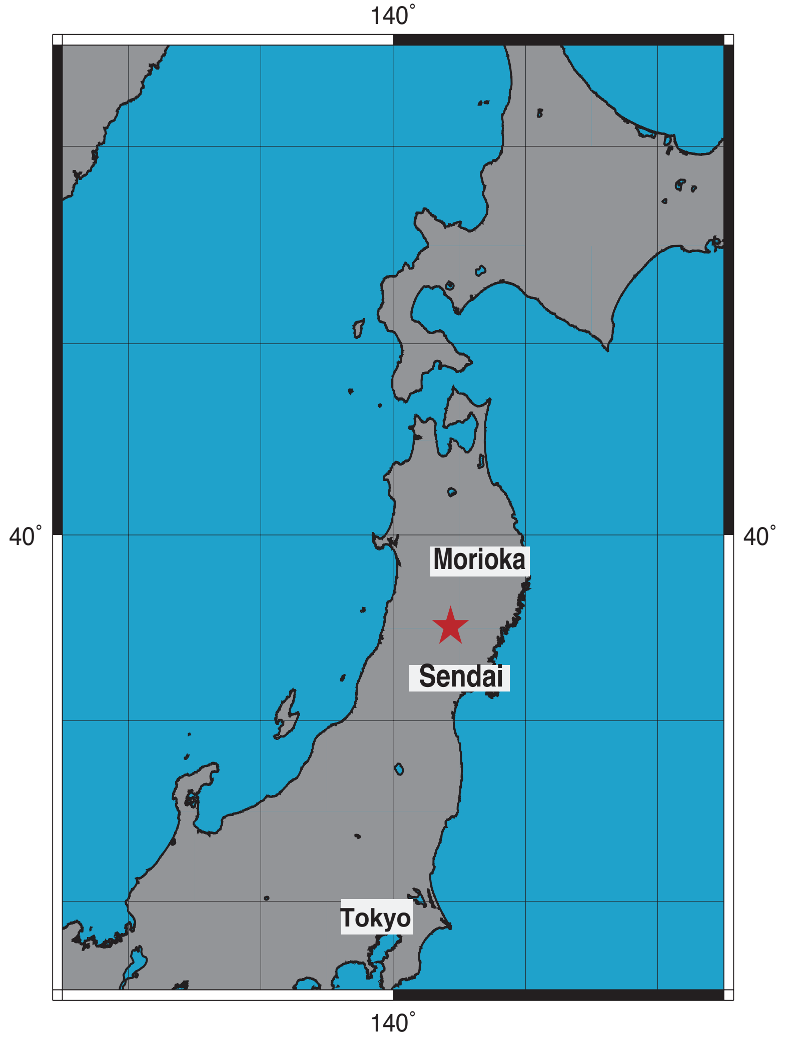


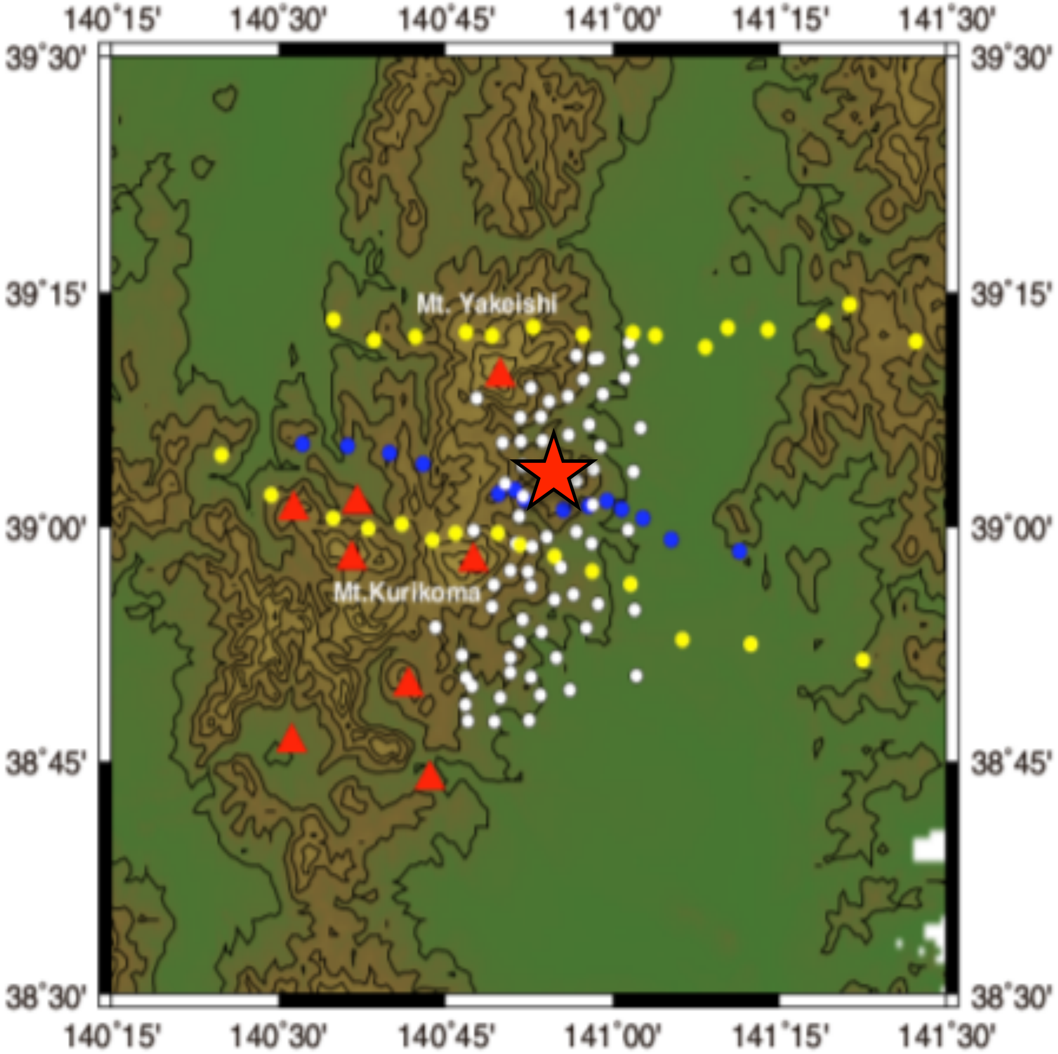
Wannamaker et al. (2009, Nature)



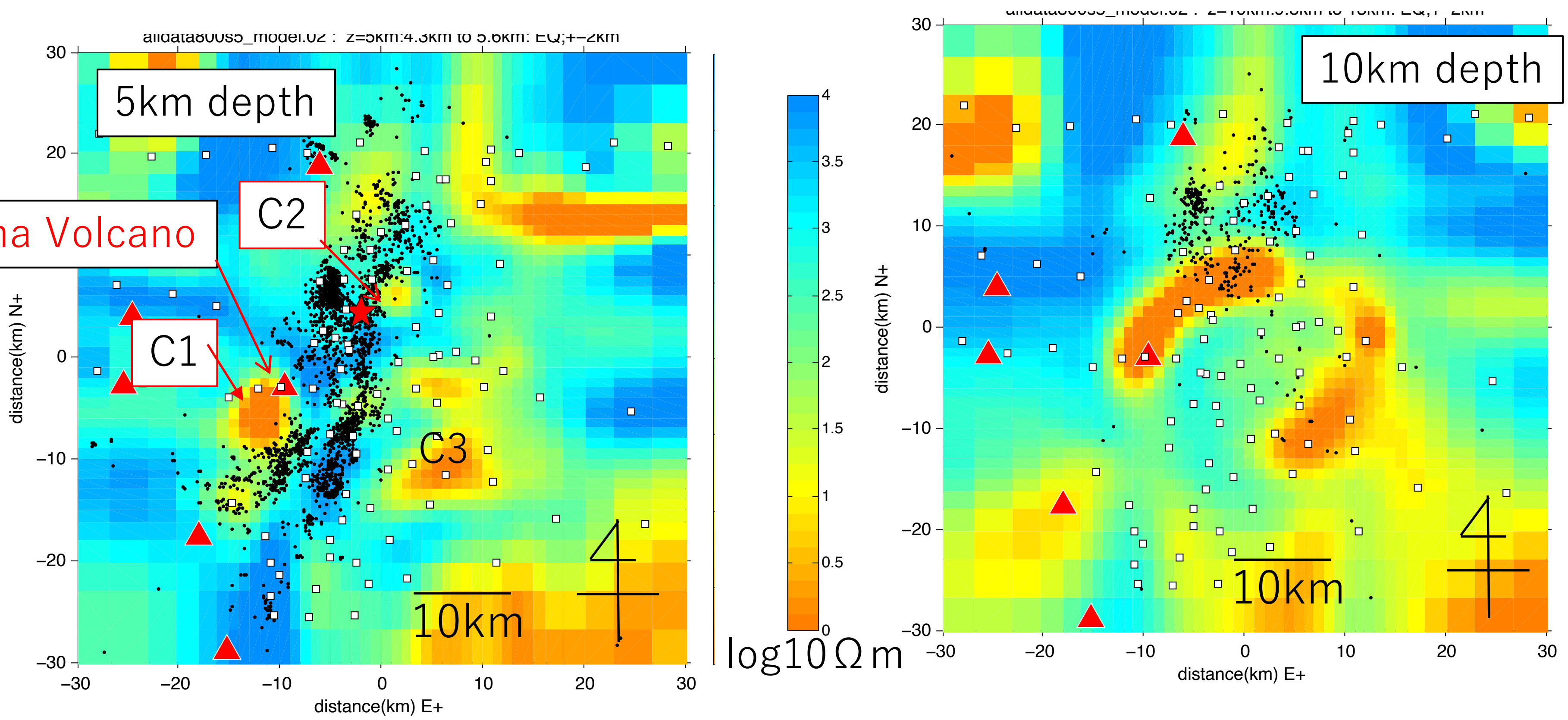
Wannamaker et al. (2009, Nature)

Volcano-Earthquake Link





- 2008 Iwate-Miyagi Nairiku Earthquake (M7.2)



RMS=1.53

Aftershocks @ Resistive area

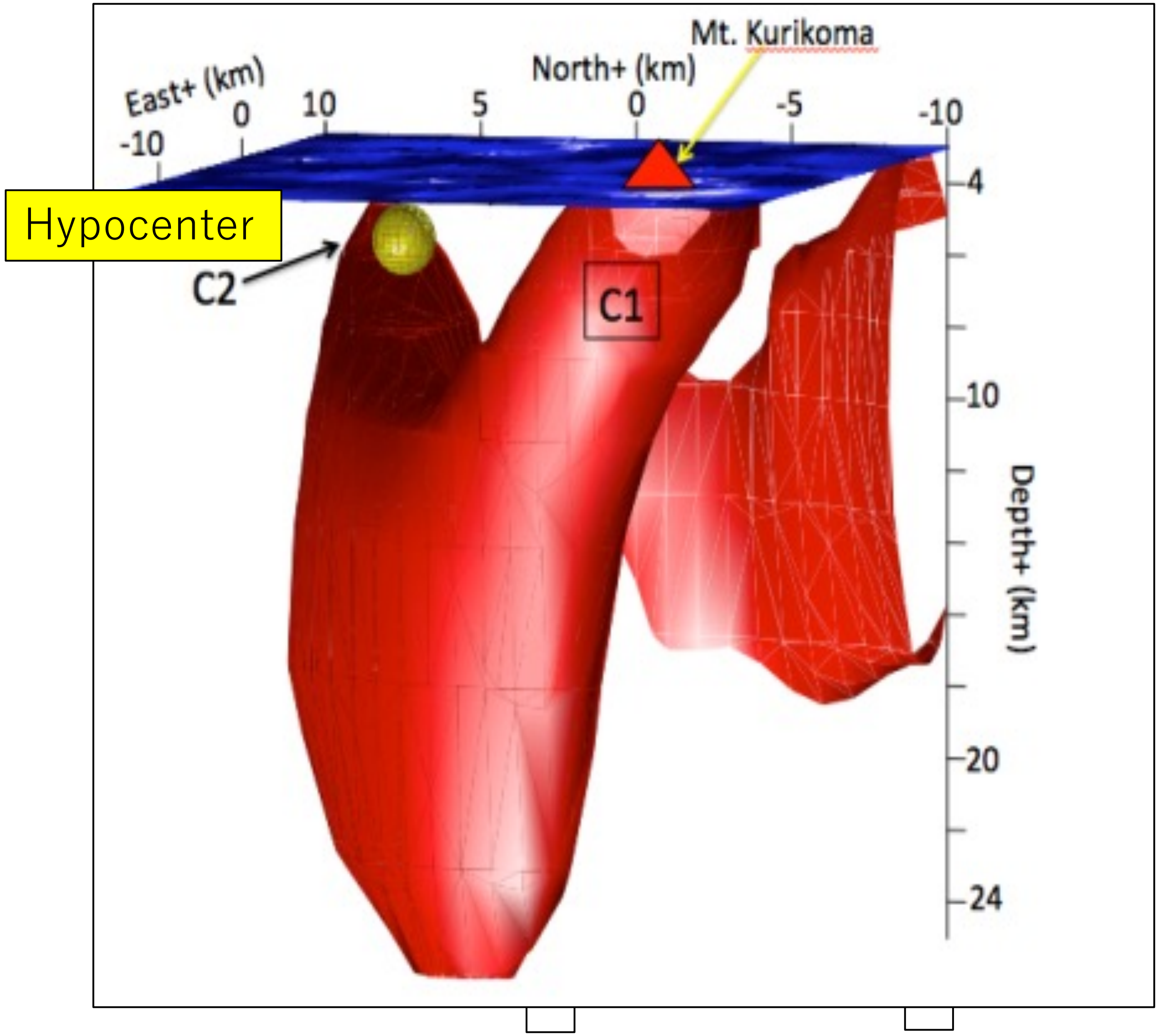
@5km：C1 @ Kurikoma volcano

C2@ low seismicity zone

@10km: C1 & C2 connected（volcano-hypocenter link)

Red star：The epicenter
Black circles: Aftershocks
(Okada et al.(2009))

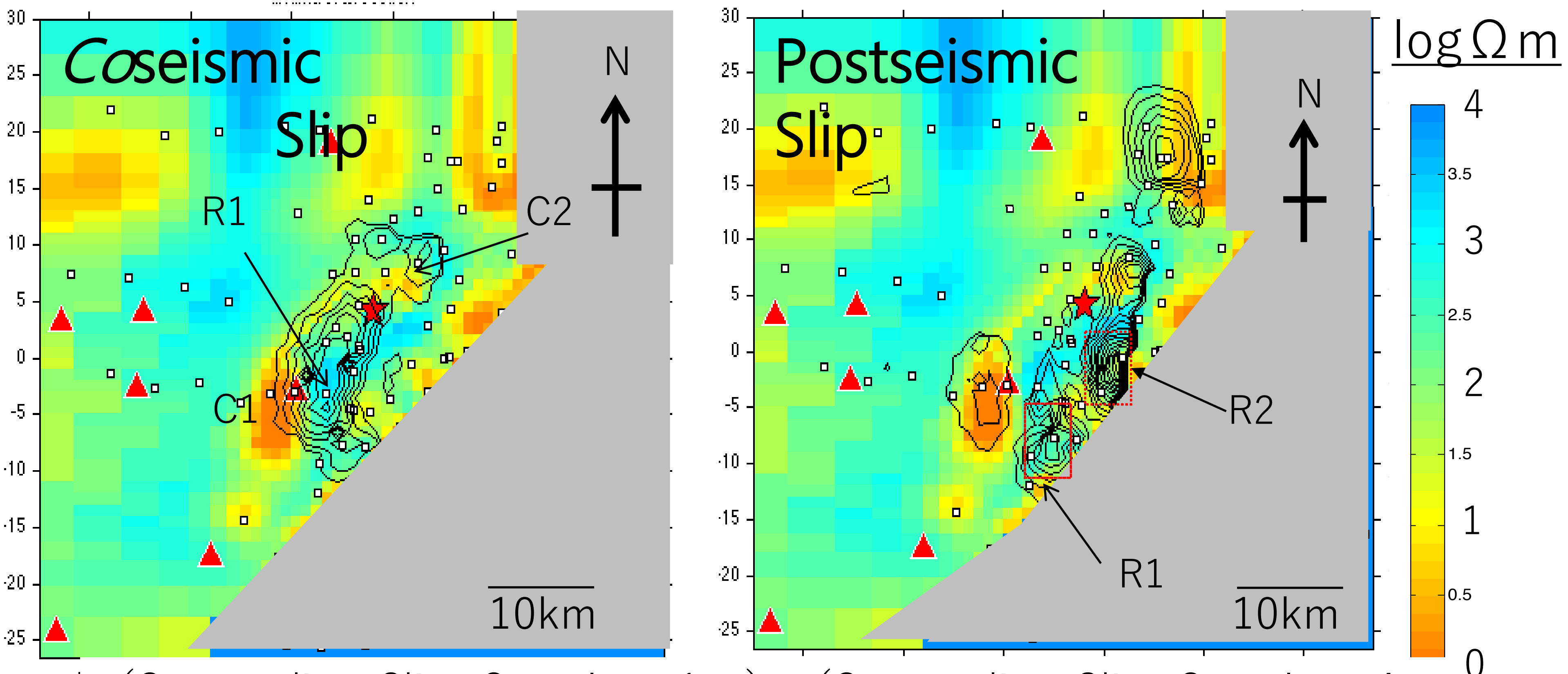
Fluid branching



Equi-resistivity surface (10Ωm)

Fluid branching:
(1) One to the volcano
(2) The other to the hypocenter

Co-, post-seismic slips and resistivity distribution *on the fault planes*



(Contour line: Slip, Cont. Int.: 1 m) (Contour line: Slip, Cont. Int.: 4 cm)

Co-seismic slip corresponds to R1 (asperity)

Post-seismic slip corresponds either to R or C

Postseismic slips are caused by static stress change or pore pressure change (Iinuma et al., 2009)

Seismology targets

- Intraplate earthquakes
  - Active faults, shear zones, fluid reservoir, deformation
  - NE-Japan
  - North Anatolian Fault(NAF)
  - NZ
  - Volcano-Earthquake link
- Plate interface at subduction zones
  - NZ
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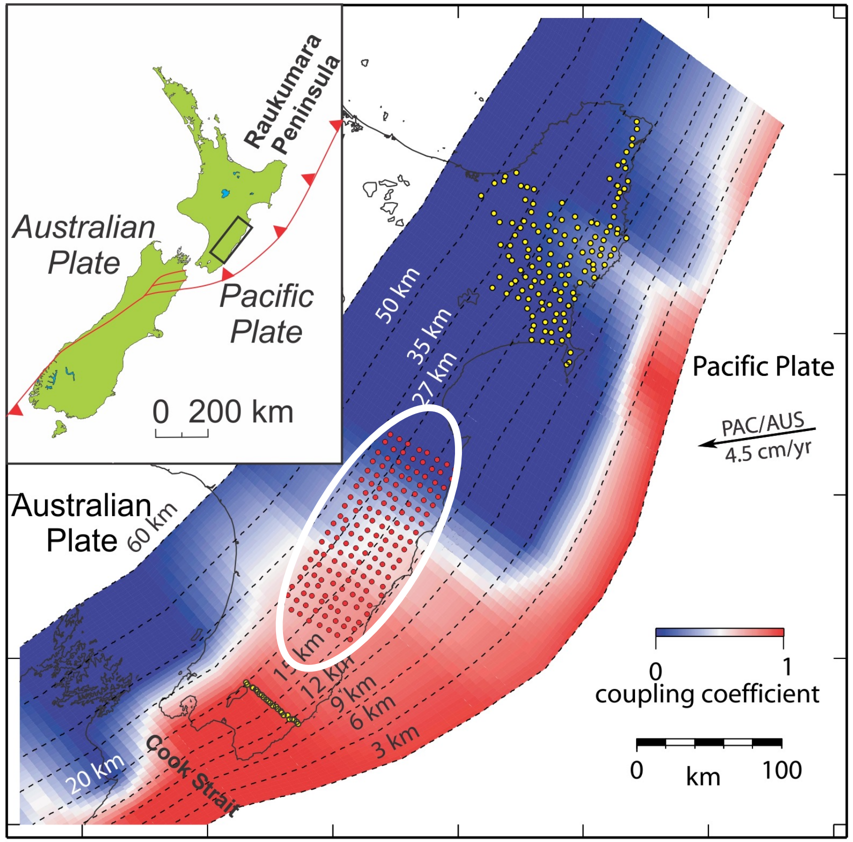
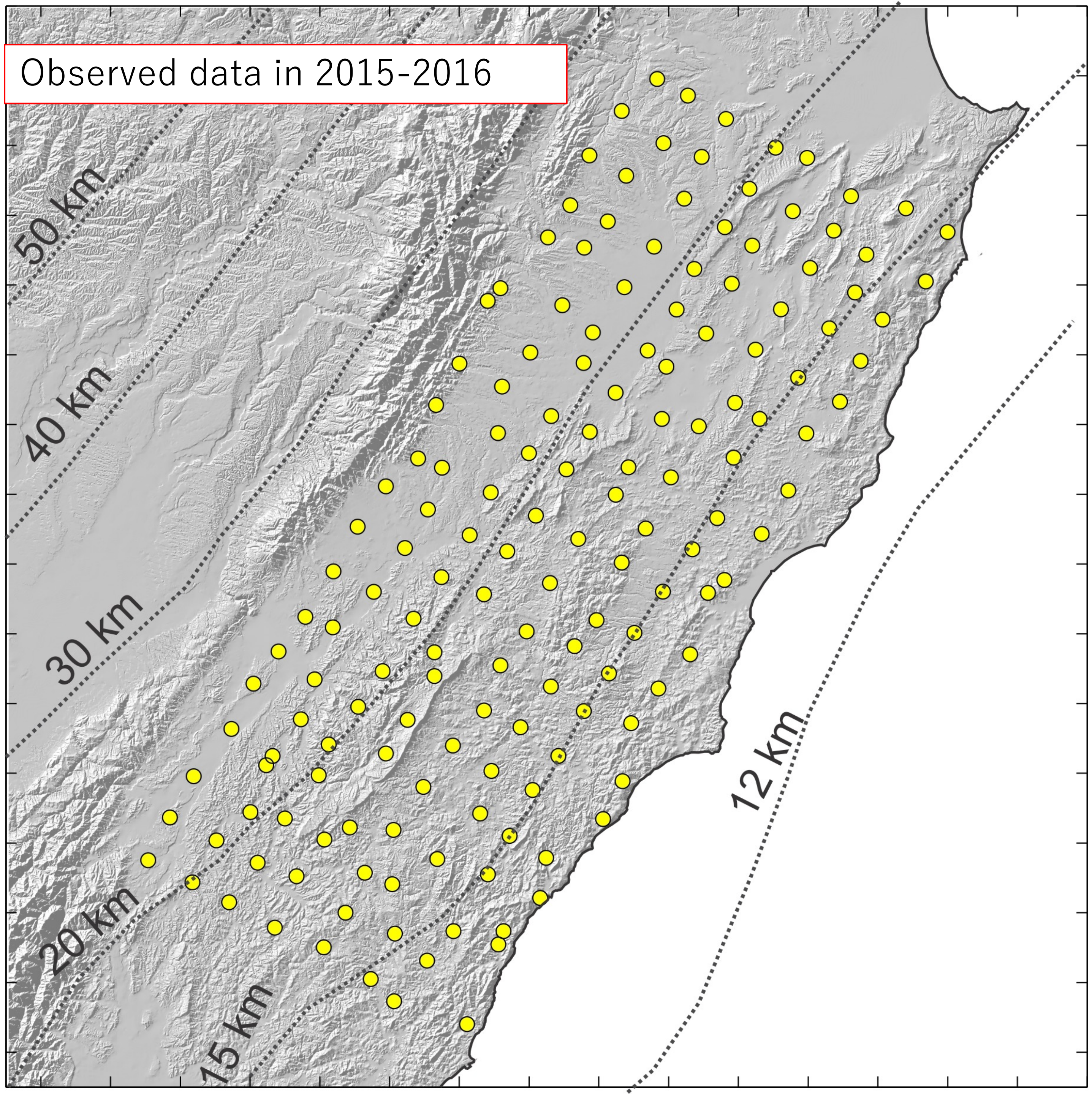
Hikurangi subduction, NZ

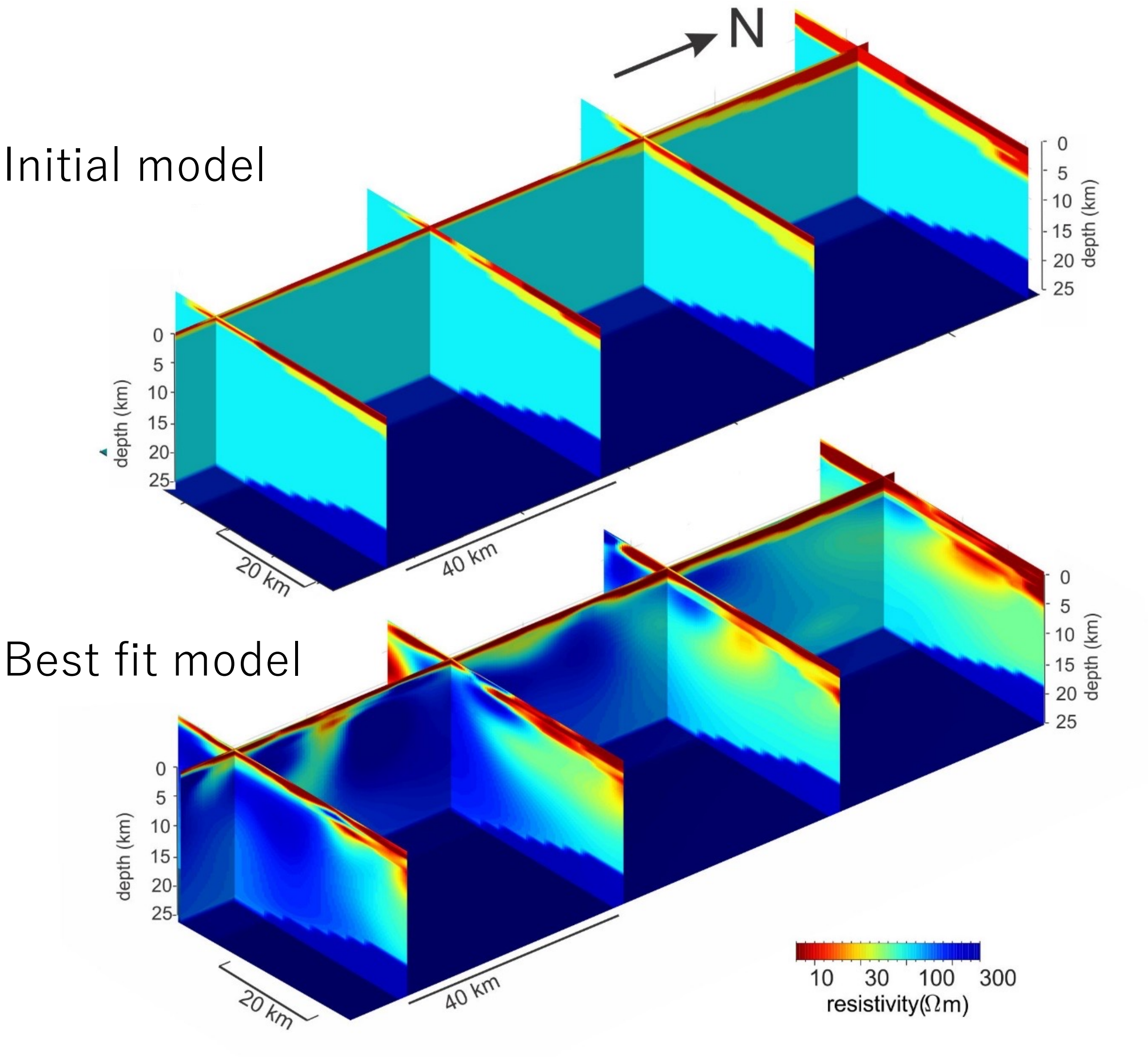


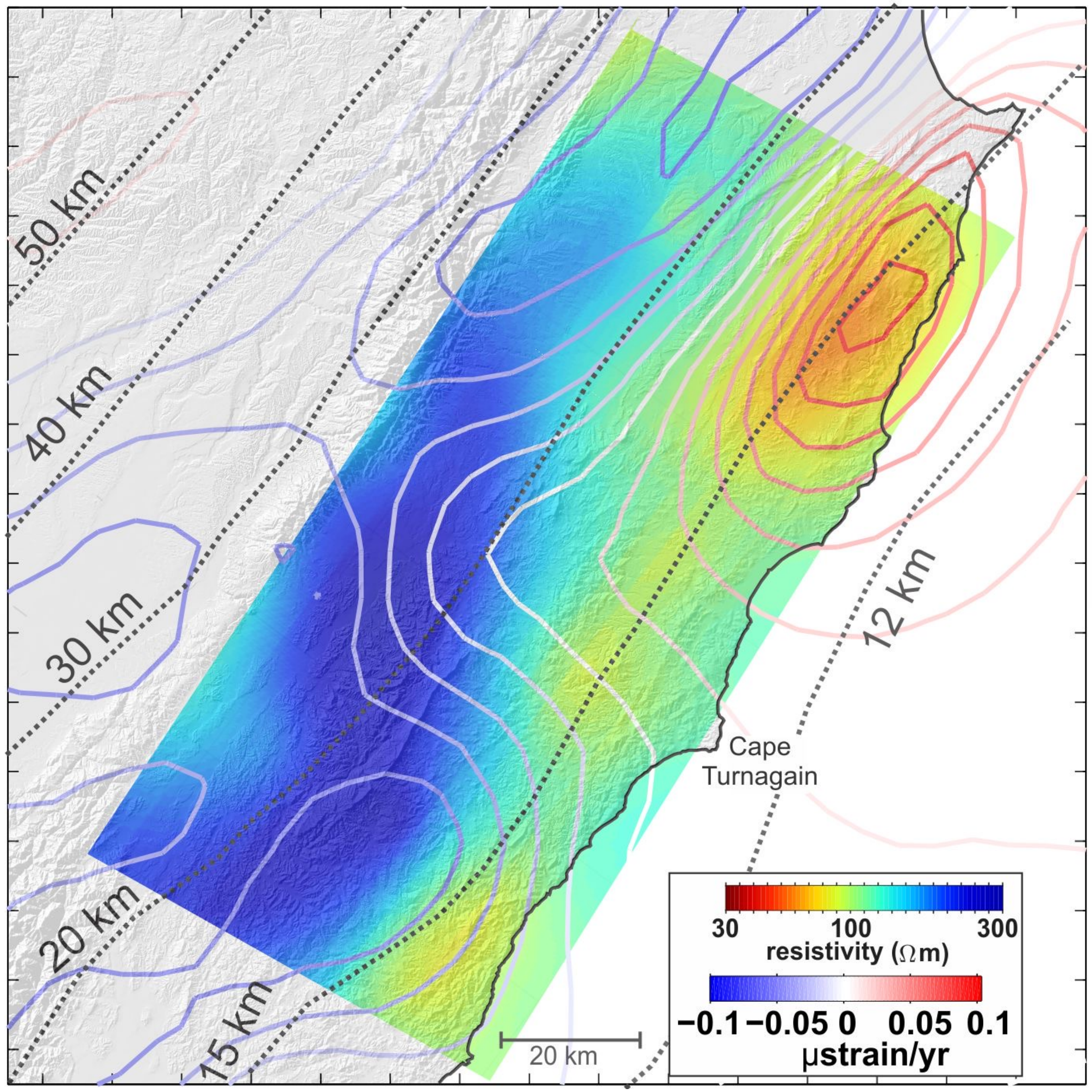
MT measurements in 2016-2017 at Transition zone from weekly- to strongly- coupled.

Heise et al (2019, EPSL)



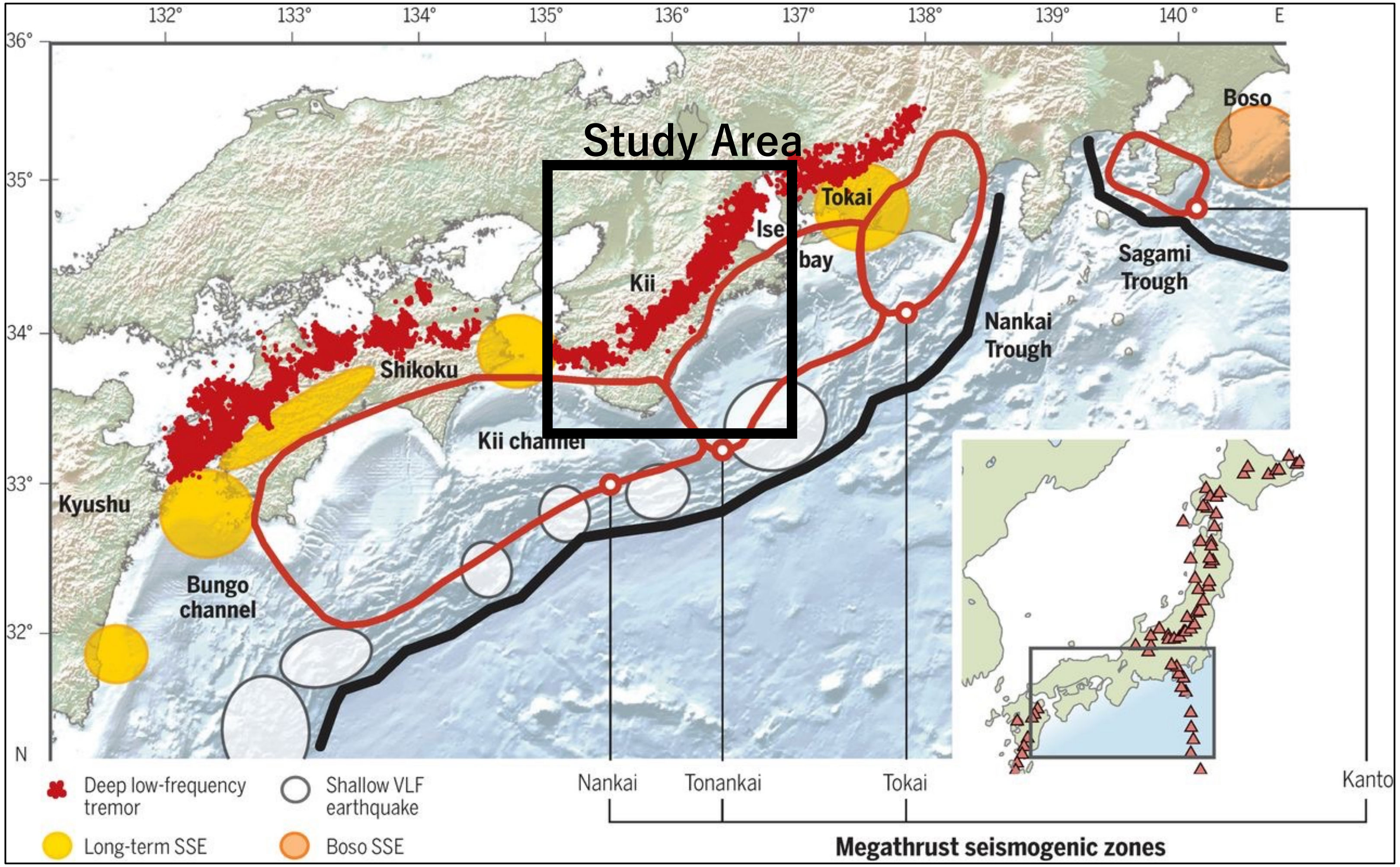
Comparison between areal strain rate and resistivity at the plate interface

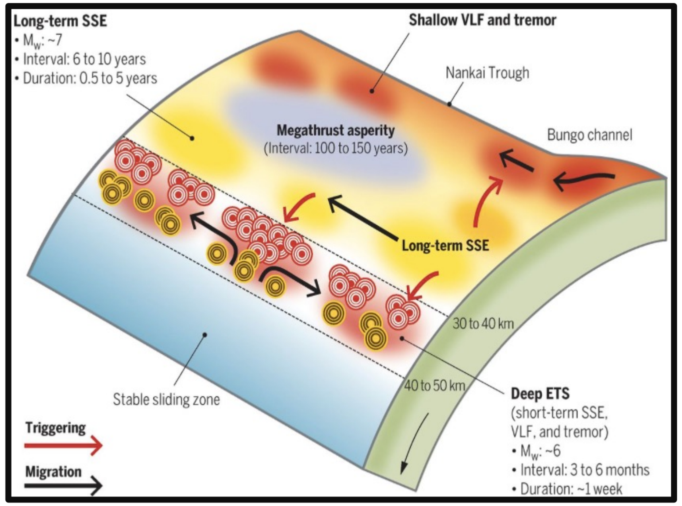




Heise et al (2019, EPSL)
Subducting Plate fixed: 5 km below the plate interface

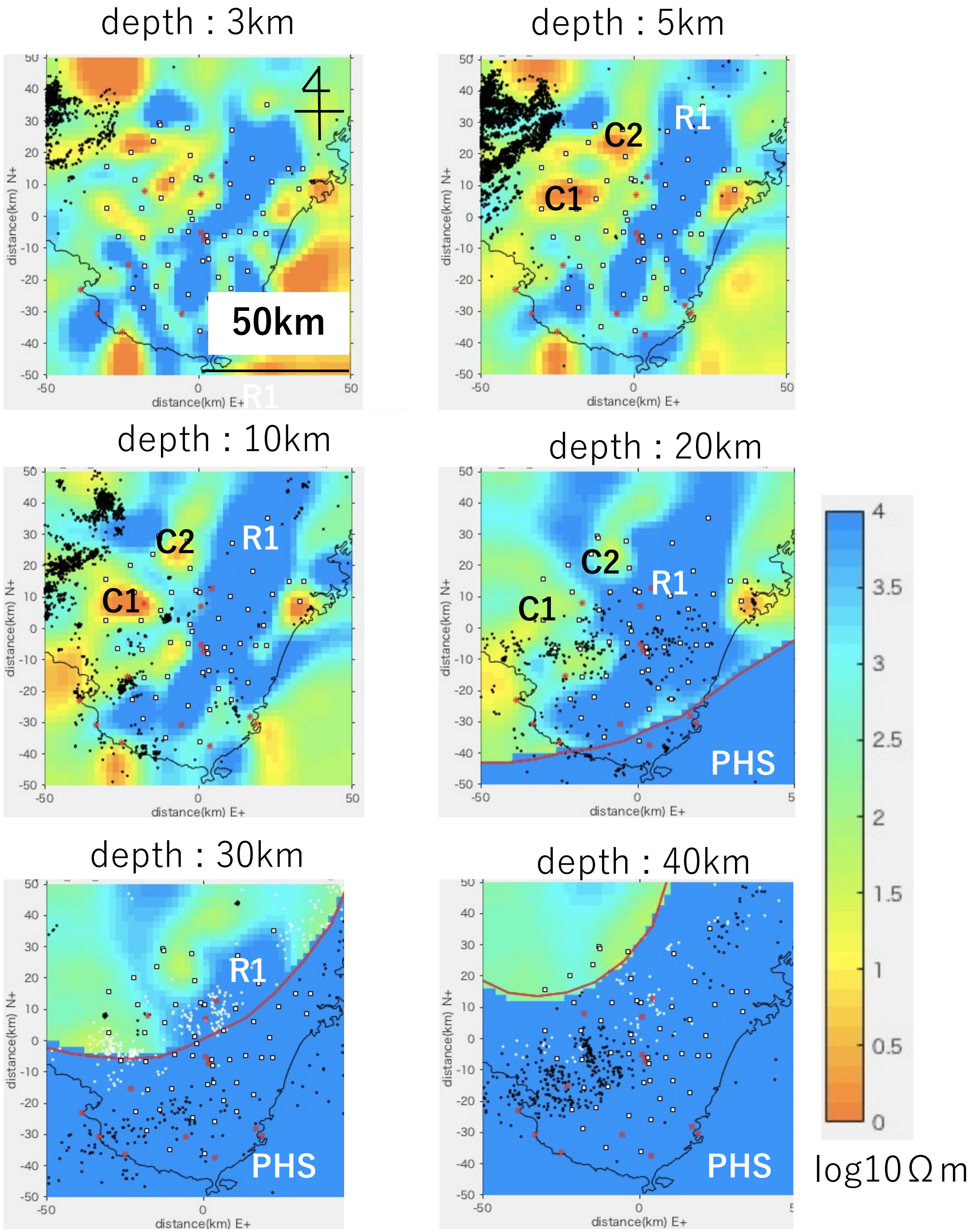
Philippine Sea Subduction, SW Japan



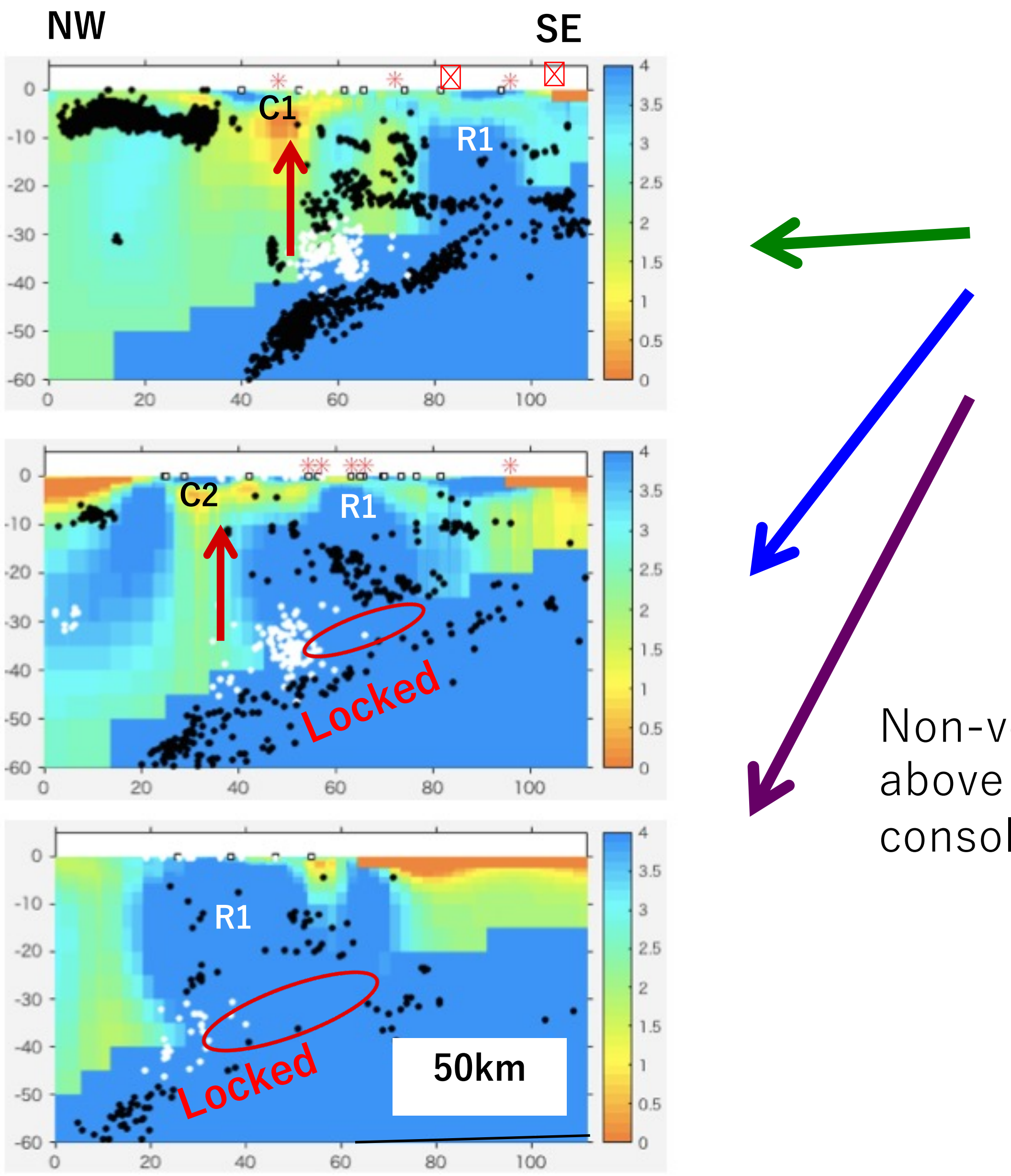


(Obara and Kato et al., 2016)

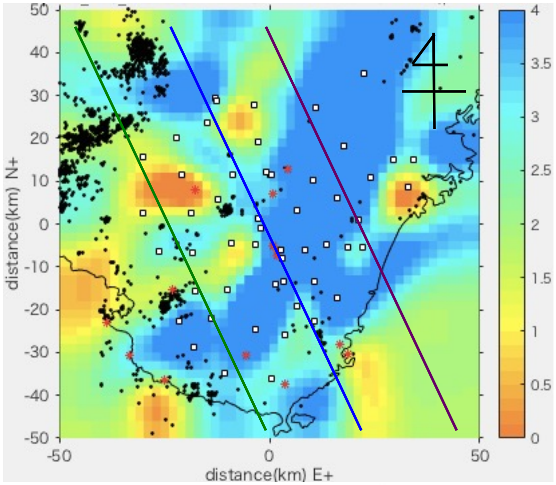
Philippine Sea Subduction, SW Japan



Philippine Sea Subduction, SW Japan



10km depth

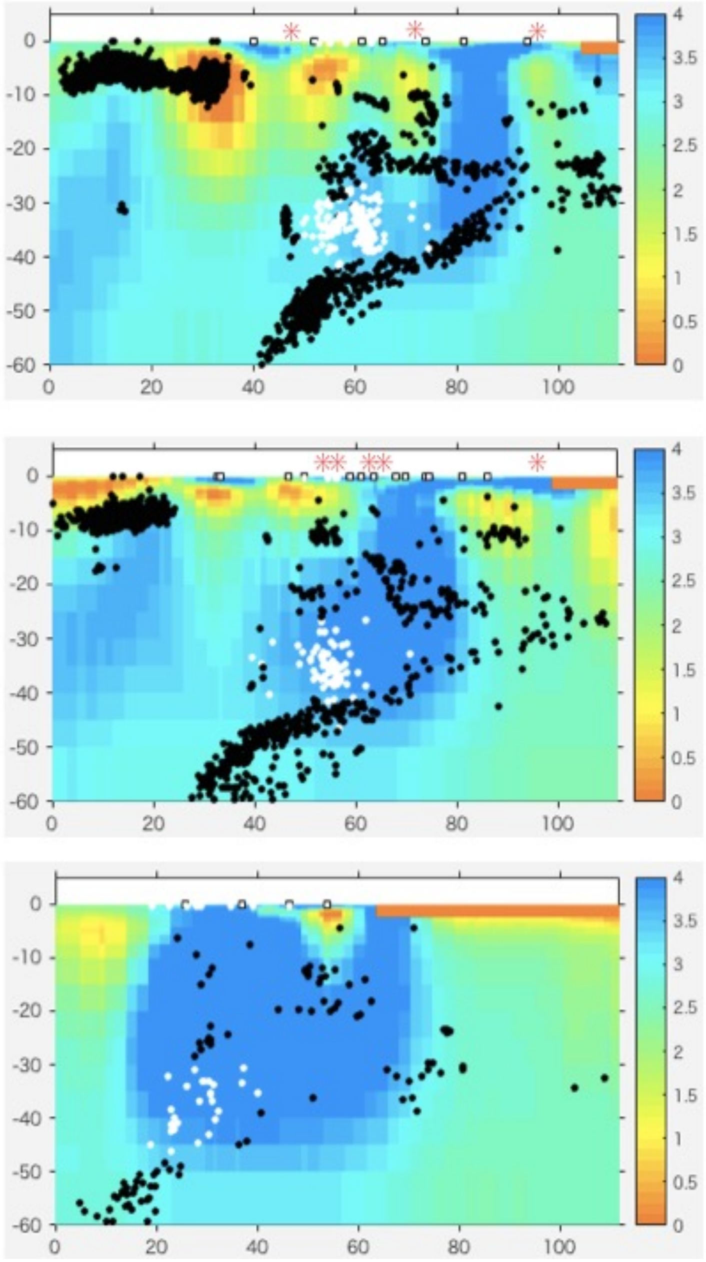


Three NNW-SSE profiles

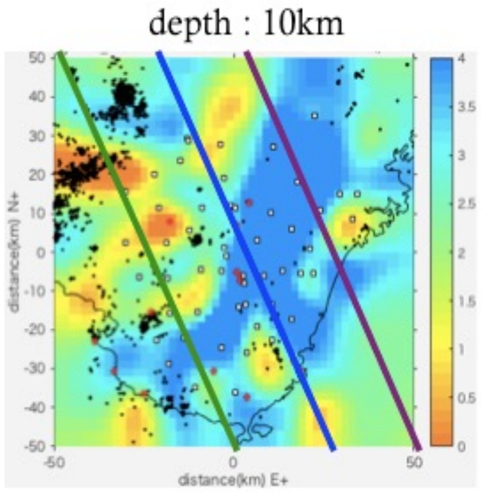
Non-volcanic tremor (white dots) are located above the place, adjacent to the large silicic consolidated magma body.

Kinoshita (2018, M.Thesis)

Philippine Sea Subduction, SW Japan



If the plate is not constrained



Kinoshita (2018, M.Thesis)

Volcanology targets

Imaging Magma pathways

Imaging Geothermal system
- Clay cap
- Silica Cap
- Super Critical Fluids below the BDT

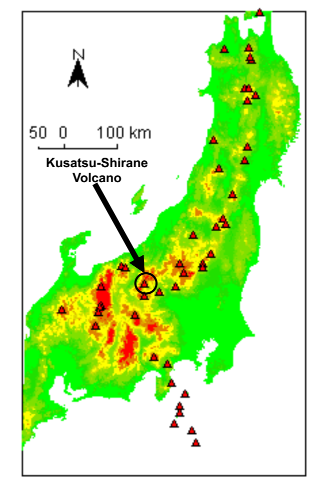
Temporal resistivity changes
- Magnetotelluric monitoring
- Controlled source monitoring (EM-ACROSS)

Kusatsu-Shirane Volcano, Japan

Objective

Understanding the phreatic eruption architecture
in particular for the 2014 unrest
[edifice inflation / seismicity / increased lake temperature/ increased magmatic gases]

by 3D resistivity distribution to 2~3km depth
using 91 MT/AMT sites

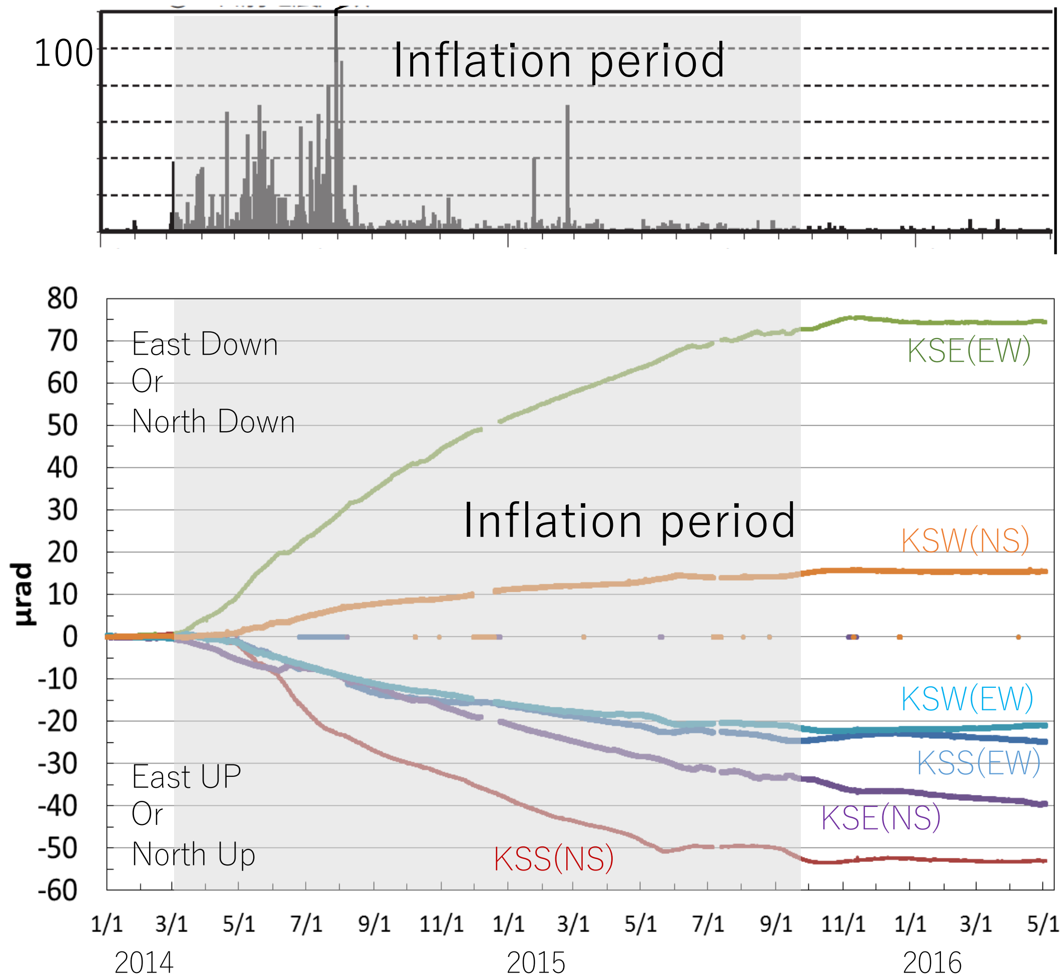


Key Words:

Phreatic eruption, Clay Cap, Brine, Supercritical Fluid

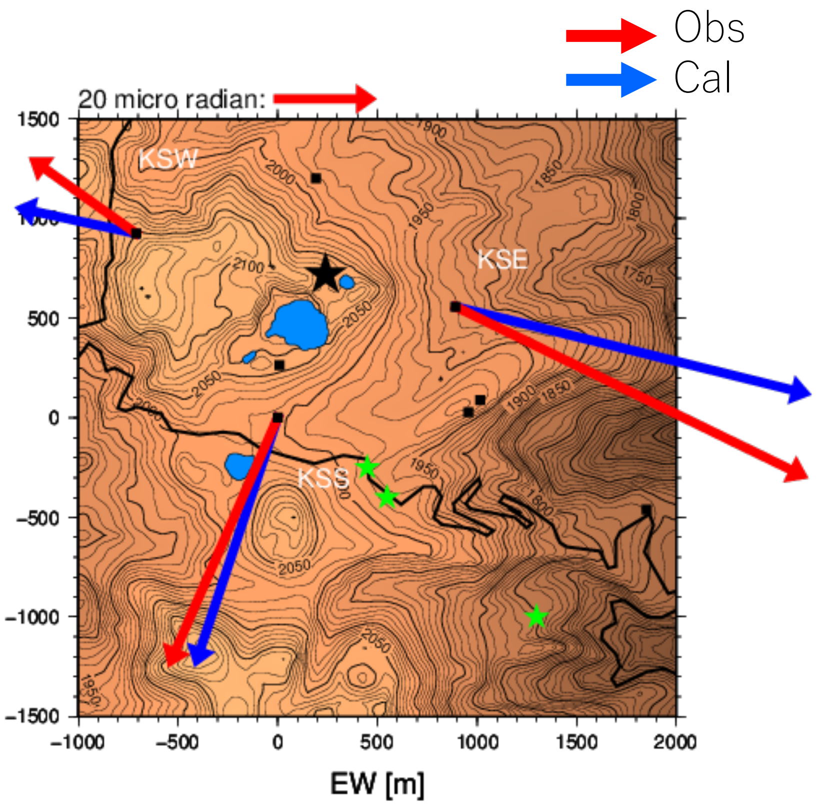
Final Paper Number: GP006-06
Session Date and Time: Tuesday, 15 December 2020; 04:00 - 05:00 PST

2014 Volcanic Unrest

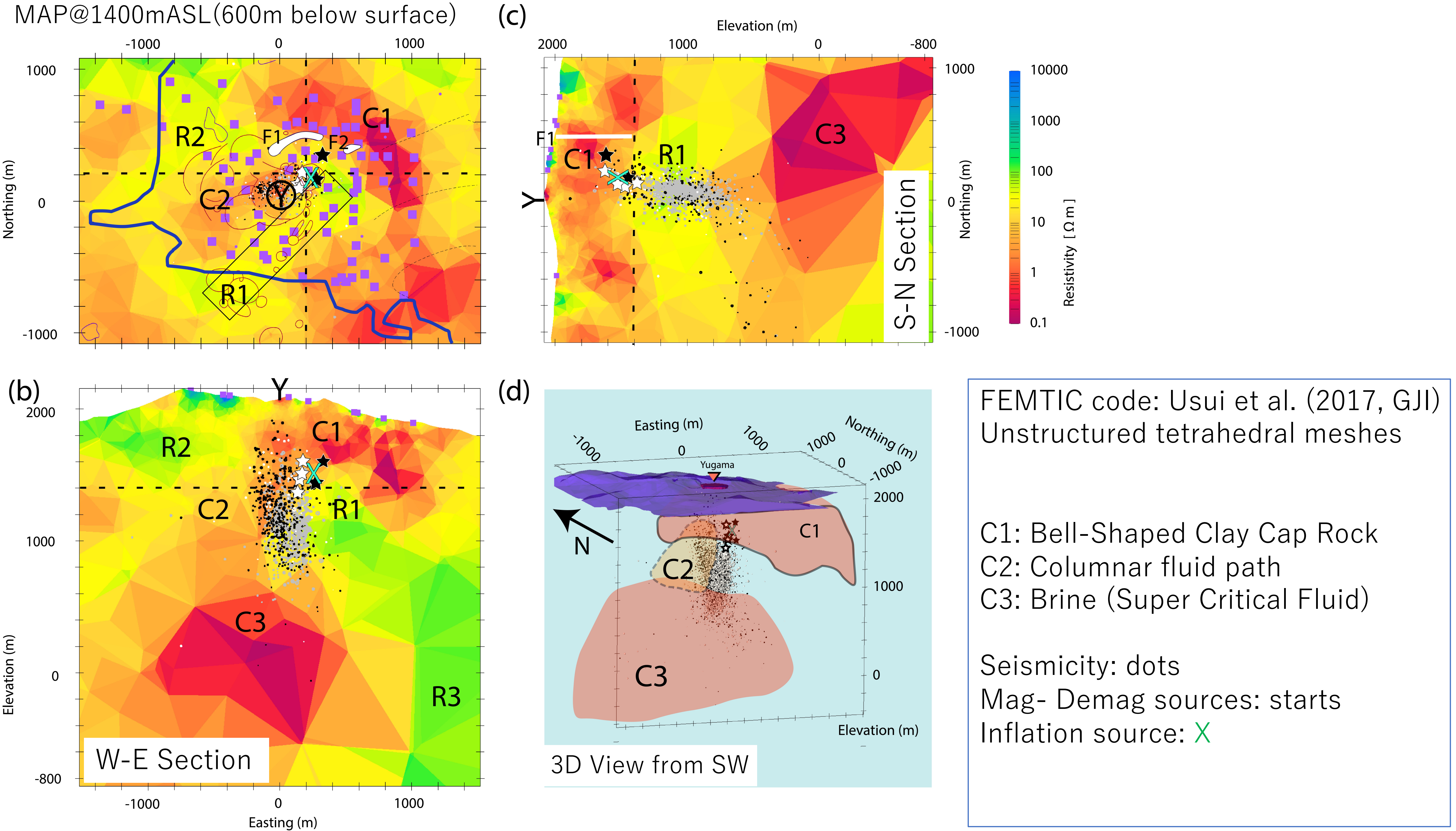


Terada et al.(2016)

Point source analysis
for 2014 Jan to 2016 May



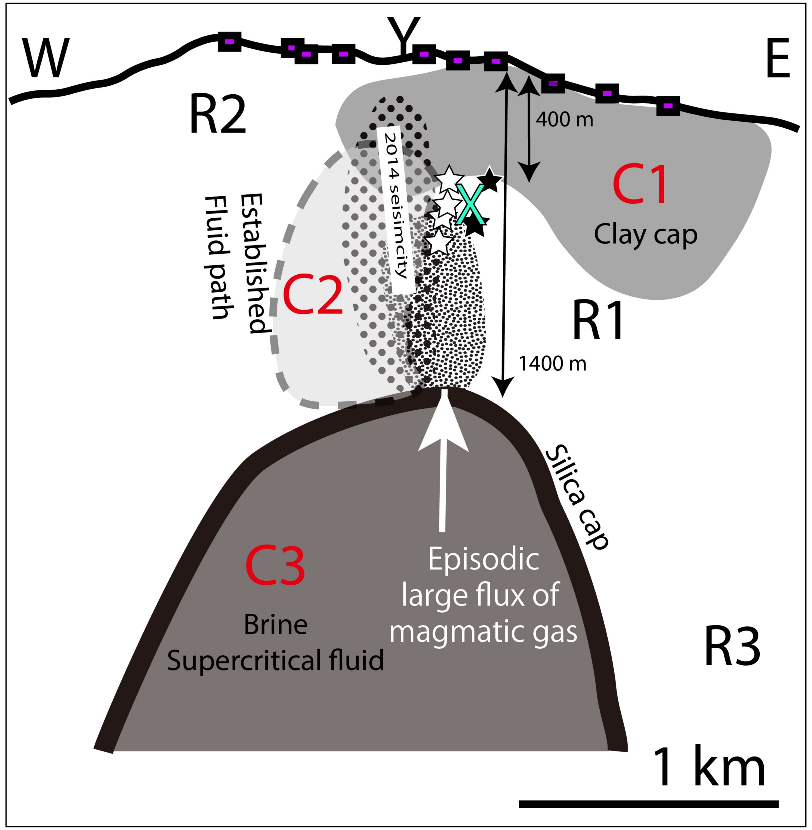
- Source Depth at 1500m(ASL): 500m below surface
- Total volume 1.2×10^5 m^3

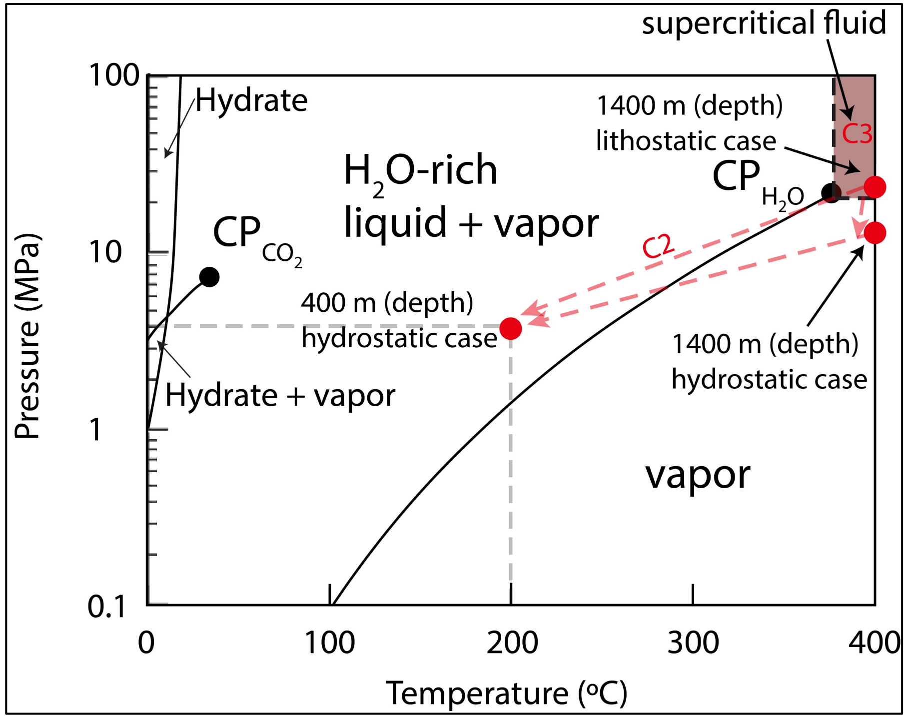

MAP@1400mASL(600m below surface)
(b)
(c)
(d)
Elevation (m)
Northing (m)
Easting (m)
R1
R2
R3
C1
C2
C3
F1
F2
Y
W-E Section
S-N Section
Resistivity [Ω m]
Yugama
N
3D View from SW
FEMTIC code: Usui et al. (2017, GJI)
Unstructured tetrahedral meshes
C1: Bell-Shaped Clay Cap Rock
C2: Columnar fluid path
C3: Brine (Super Critical Fluid)
Seismicity: dots
Mag- Demag sources: starts
Inflation source: X

Phreatic eruption architecture

C1: Clay cap (<200 degC): Capping Inflation Source X and *Mag-*☆ *Demag-*★ Sources
C2: Vertical fluid path
C3: Brine (>400 degC) : Super-Critical Fluid Capped by Silica

Episodic magmatic gas flux through the brine (C3) broke the silica cap and induced seismicity, migration of vapor and inflated the edifice under the clay cap (C1)

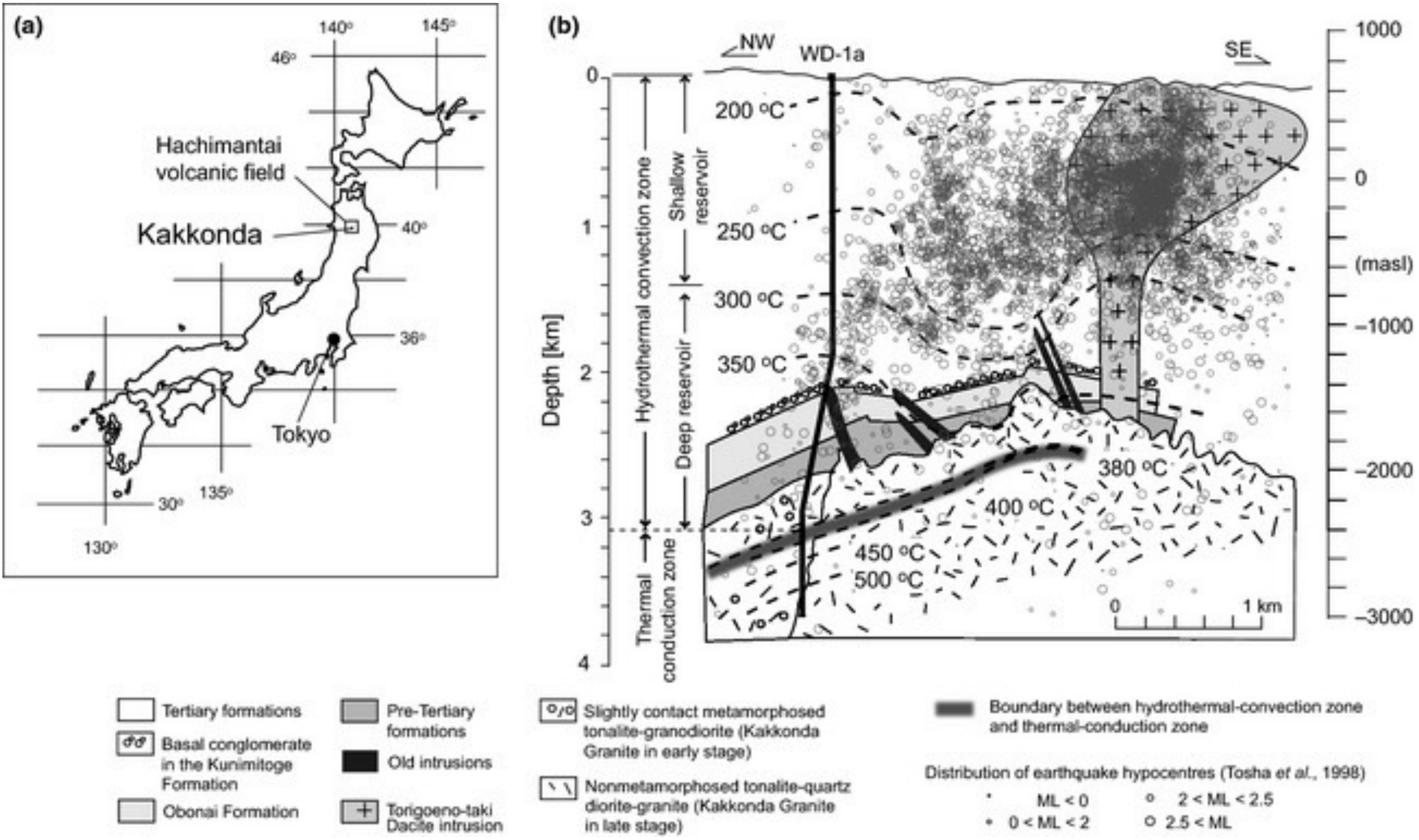


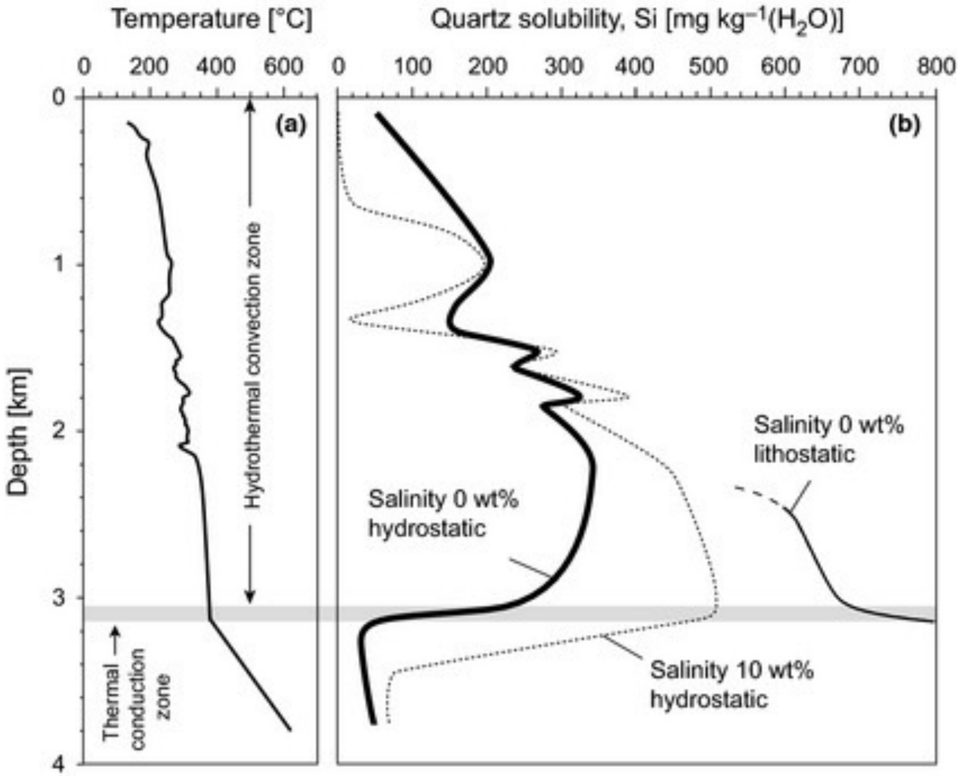


Modified from Hutnak et al. (2009, JGR)

Tseng, Ogawa, Nurhasan et al. (2020, EPS)
doi.org/10.1186/s40623-020-01283-2,

Silica Seal at Brittle-Ductile Transition (~400 degC)



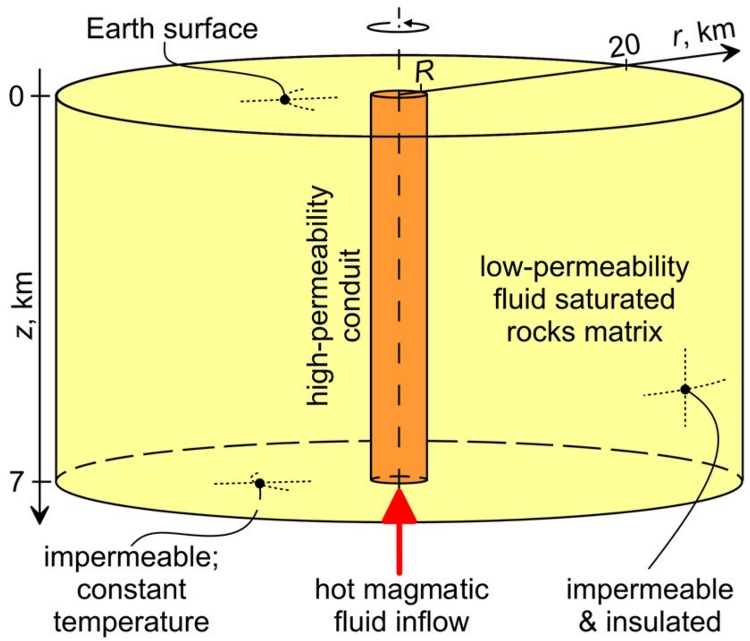


Sealing by low-solubility of silica

Saishu et al. (2015, Tera Nova)

Formation of Brine Lenses

Afanasyev et al. (2018, EPSL)



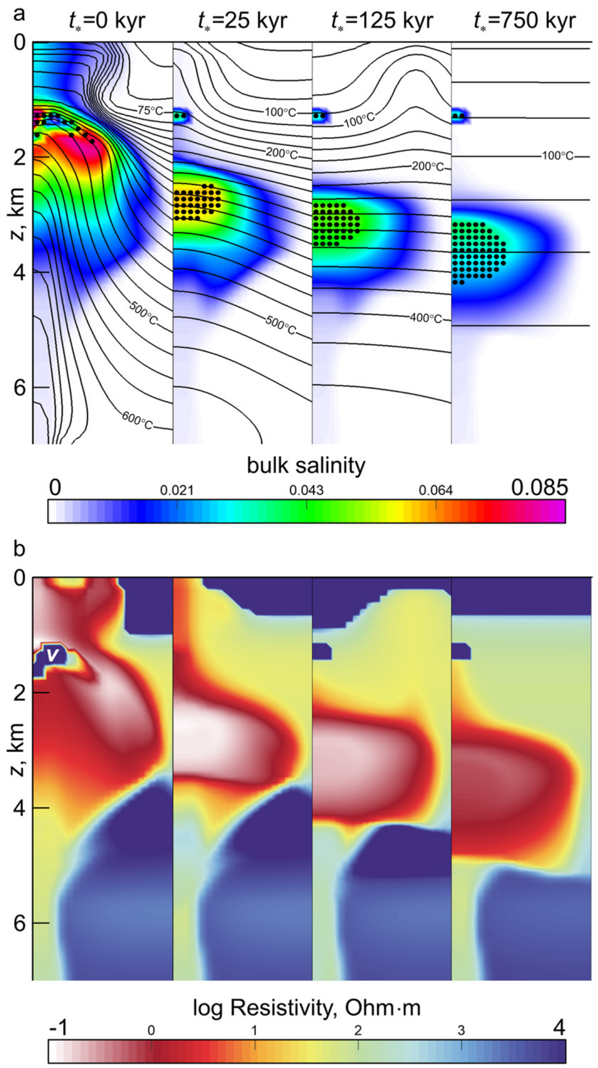


Fig. 8. Temporal evolution of (a) bulk salinity and (b) electrical resistivity following abrupt cessation of degassing for the reference scenario in Fig. 5. Time (t_*) is given as kyr since cessation of degassing. Symbol v as in Fig. 6. Isotherms contours are every 25 °C. Electrical resistivity is calculated as described in Supplementary material, for direct comparison to Fig. 1. Note equivalent colour scale in the range $1–10^4$ Ω·m in Fig. 1 and Fig. 8b.

With a conduit, brine lenses can be formed at 2-4km depth.

Brine can stay for 250 kyr.

Porphyry model

Blundy et al (2015)

Stage 1:
Slow process to create brines for 10k-100k years.

Stage 2:
Gas from the mafic magma interact with the brine

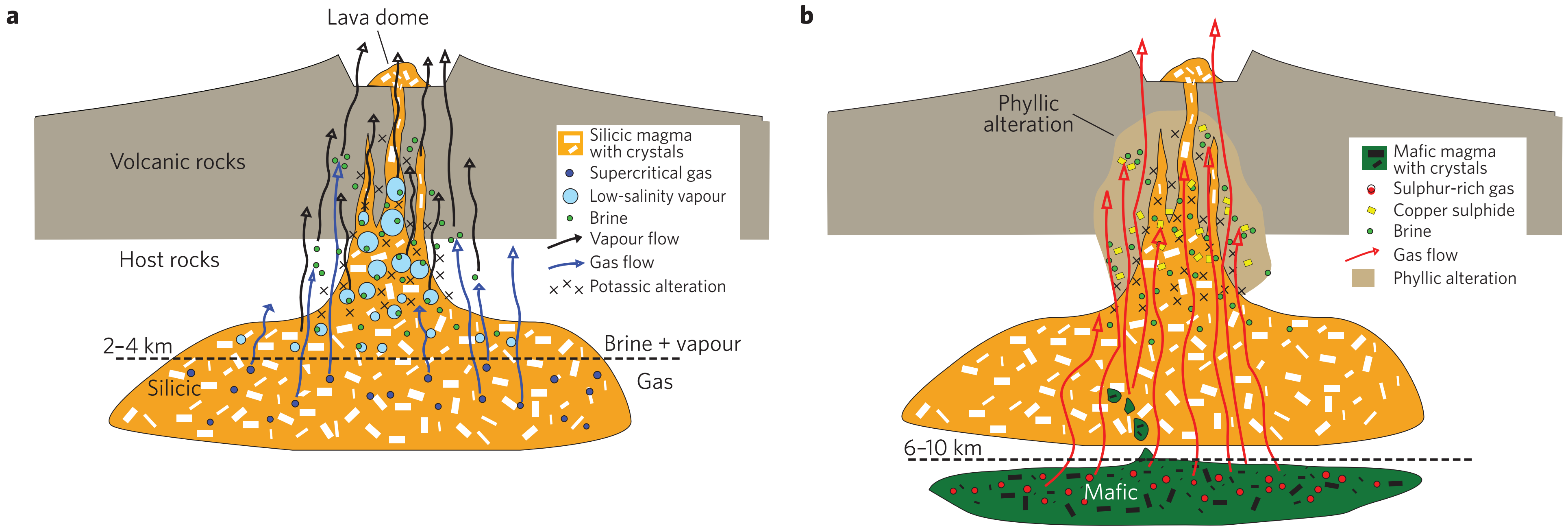


Figure 4 | Gas–brine reaction model for PCD formation. a, Stage 1. Slow accumulation, crystallization and degassing of dacite magma beneath small dome volcano. Below 2–4 km depth exsolved gas is supercritical, condensing at shallower levels to brine, which becomes trapped and accumulates (driving potassic alteration of host rocks), and low-salinity vapour, which escapes upwards. **b**, Stage 2. Periodic destabilization of a deeper magmatic system releases mafic magmas and sulphurous gases that react with trapped brines, forming sulphide minerals at temperatures of $\lesssim$850 °C. Mingling between mafic and silicic magmas may occur, but is not required. Hydrogen chloride produced by sulphide precipitation drives phyllic alteration in overlying rocks by feldspar hydrolysis below ~600 °C. Unreacted sulphurous gases drive alteration in the shallow lithocap.

Volcanology targets

Imaging Magma pathways

Imaging Geothermal system

- Clay cap
- Silica Cap
- Super Critical Fluids below the BDT

Temporal resistivity changes

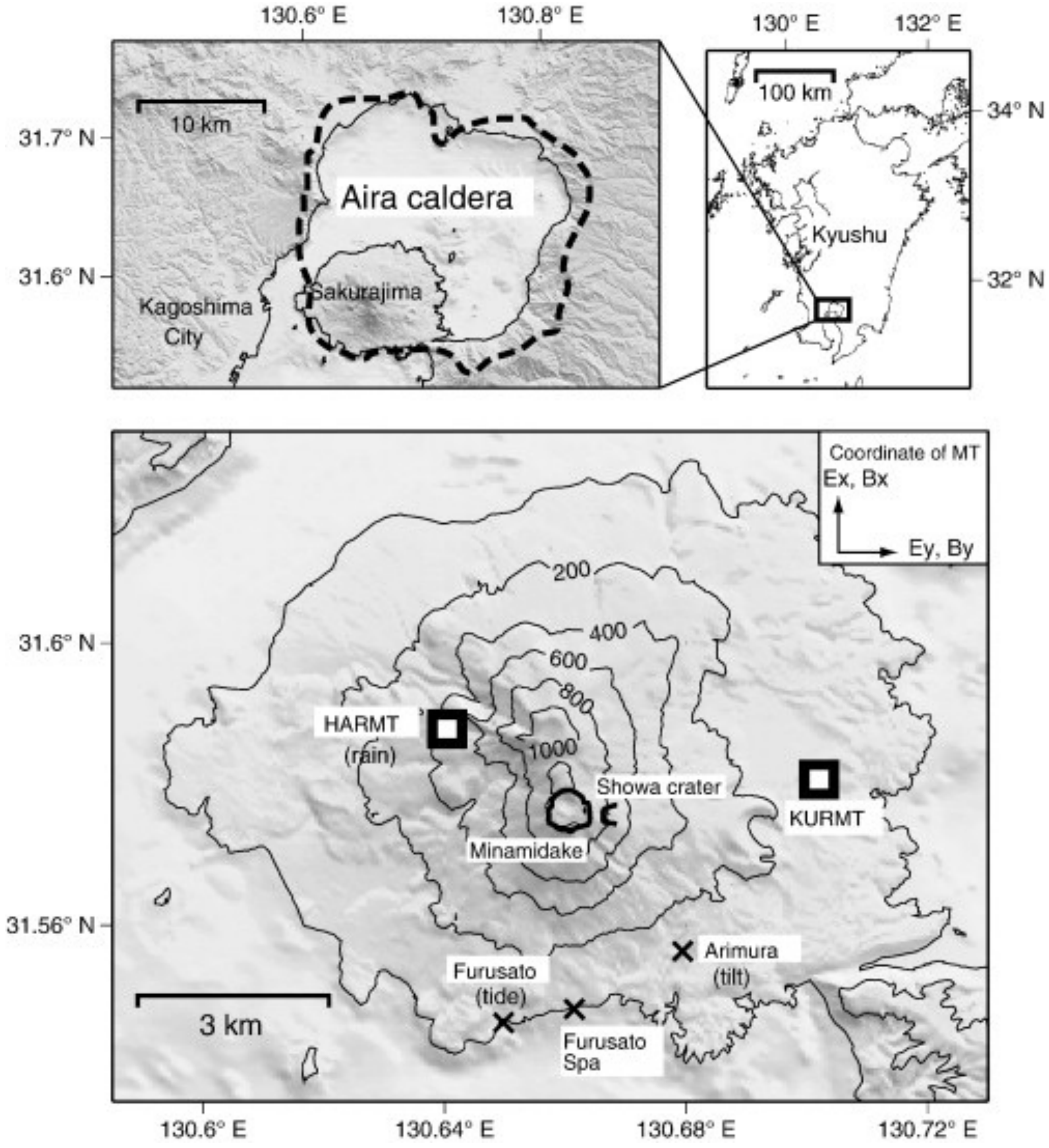
- Magnetotelluric monitoring
- Controlled source monitoring (EM-ACROSS)

Temporal resistivity changes

- MT monitoring
  - **Aizawa et al. (2011, JVGR) Sakurajima volcano**
  - Peacock et al. (2013, Geophysics) , Thiel (2017, Surv Geophys) EGS
  - **Hill et al.(2020, GRL) Tongariro eruption, NZ**

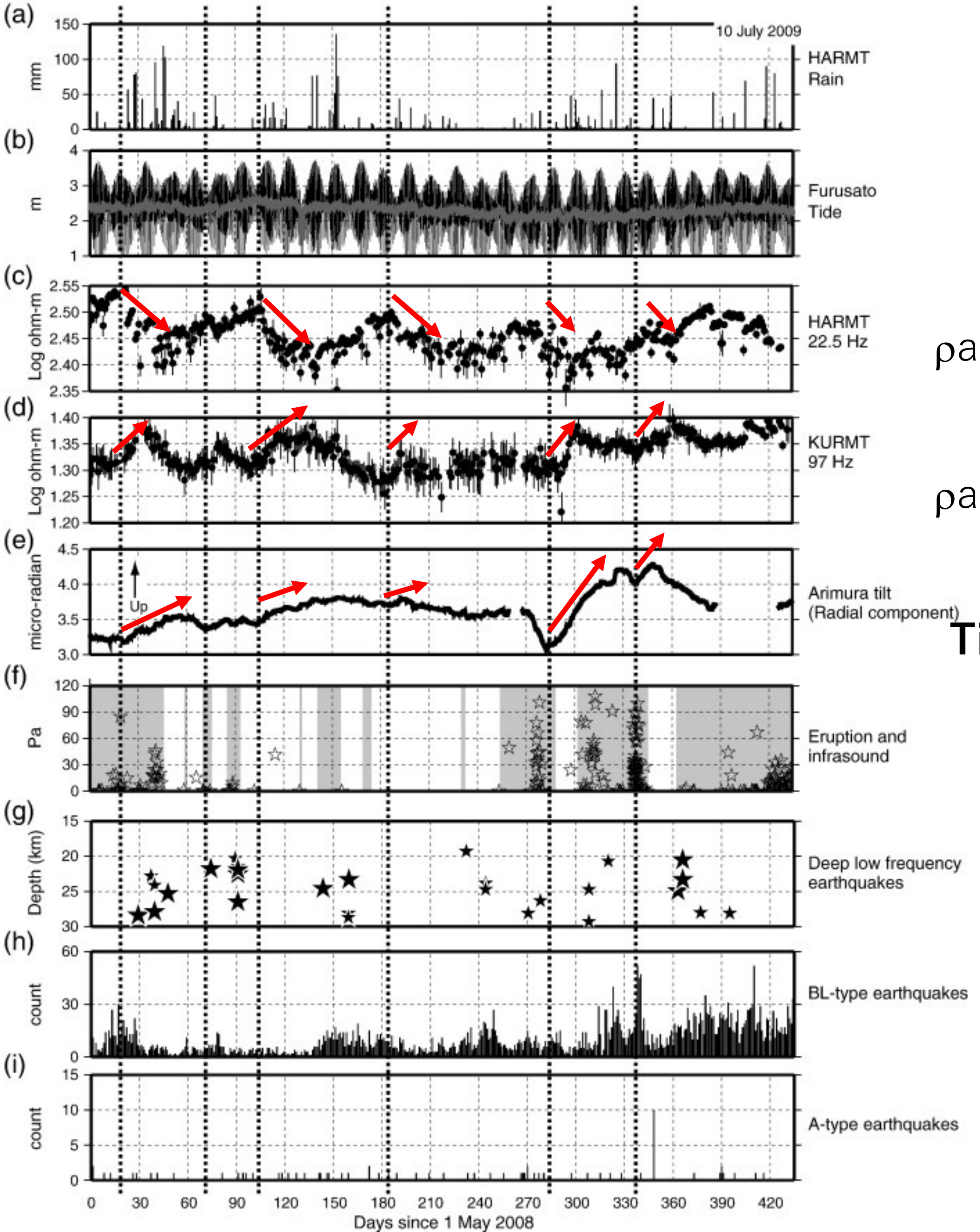
- Controlled source monitoring
  - Tseng et al. (2020, PhD thesis) EM-ACROSS

Sakurajima Volcano, Japan: resistivity monitoring by MT



Aizawa et al. (2011, JVGR)

Resistivity change in response to *tilt*: Ground water migration?



ρ(Volcanic fluid) < ρ(ground water)

ρa (22.5Hz) @HARMT near (2km) the vent

ρ(Volcanic fluid) > ρ(**saline** ground water)

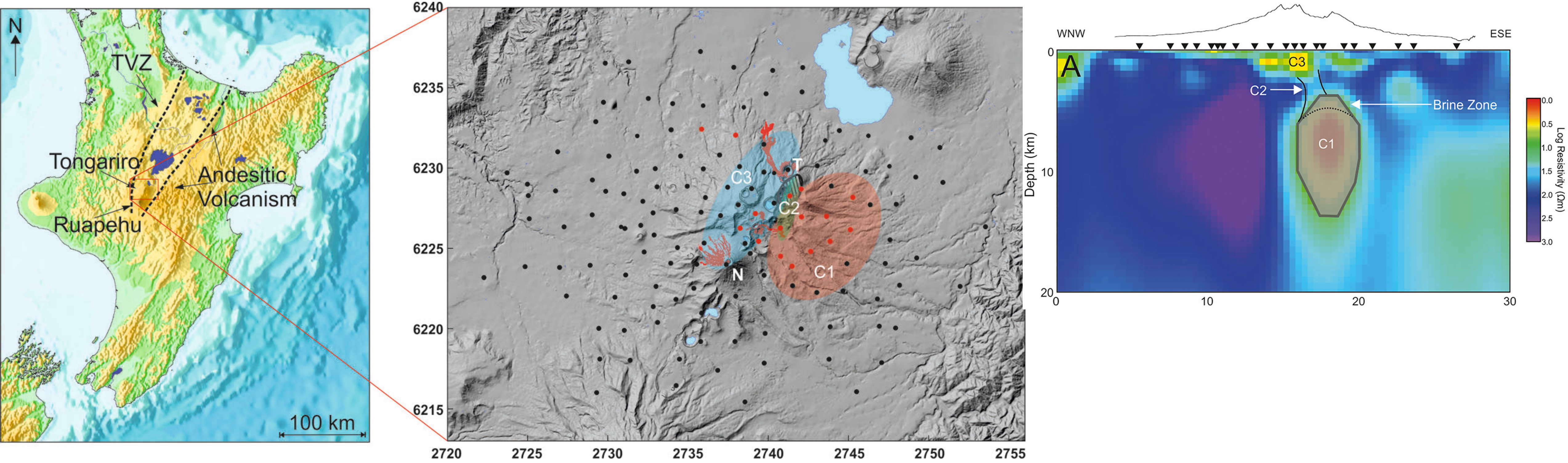
ρa (97Hz) @KURMT far (4km) from the vent near the shore

Tilt record: "start of the magma intrusion"

Limited number of sites (2)
Limited impedance components
Limited frequencies

Aizawa et al. (2011, JVGR)

2012 eruption of Mount Tongariro, NZ (Hill et al., 2020, *GRL*)

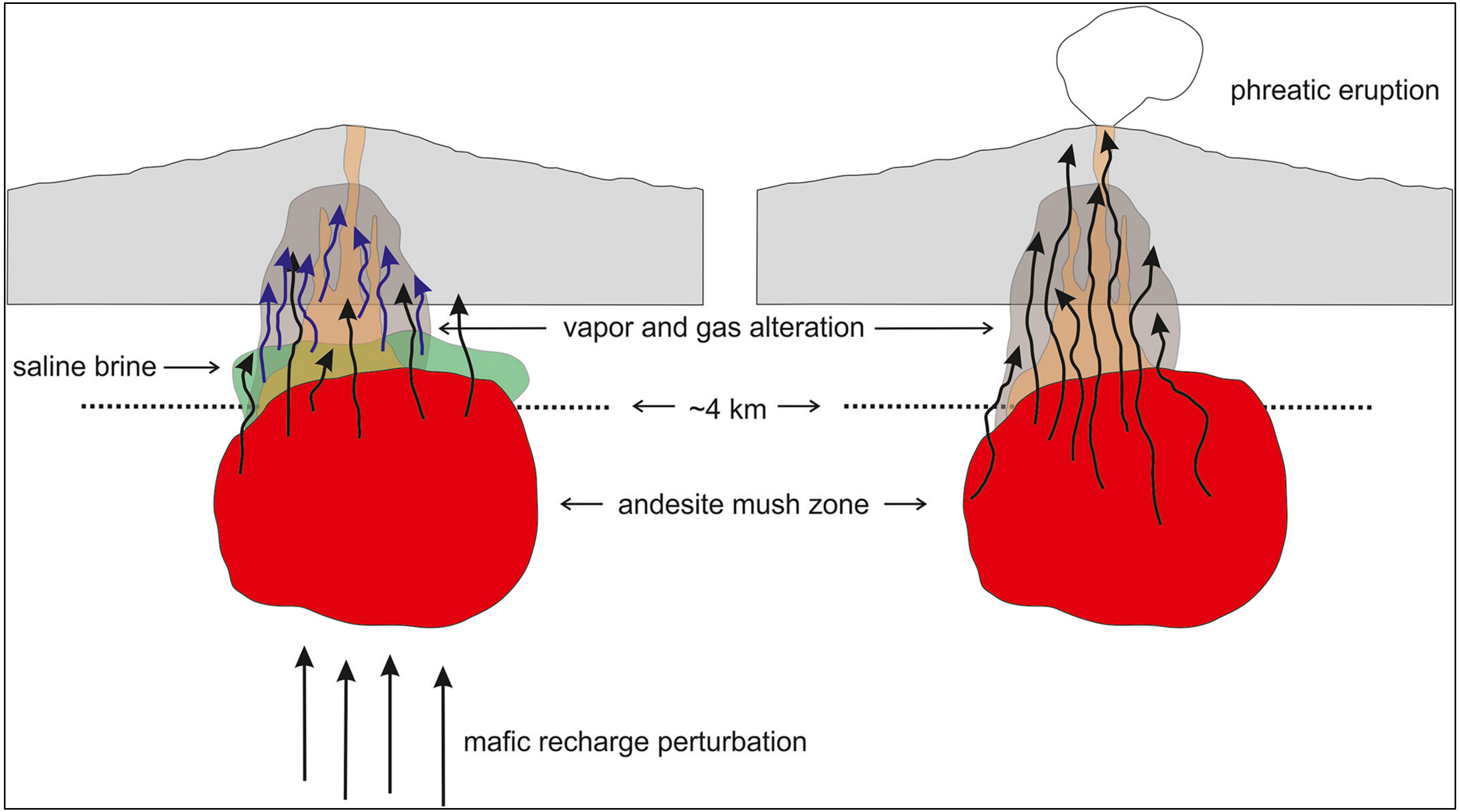


MT survey (• 2008 – 2010) Before the phreatic eruption from T(Te Maari) crater

Te Maari eruption in Nov 2012

Repeat MT survey (• June 2013) After the phreatic eruption from T(Te Maari) crater

Conductive brine was lost after the phreatic eruption



Summary

- Review on our magnetotelluric studies
- Seismology targets
  - Intraplate earthquakes
  - Plate interface at subduction zones
- Volcanology targets
  - Imaging Geothermal system
  - Temporal resistivity changes

    … Challenging topic

    MT

      removal of galvanic distortion (which can also vary with time)

      temporal alignment error (magnetic sensor)

      quest for high quality data

    Controlled source EM

Thank you very much for your attention!

Yugama Crater, Kusatsu-Shirane Volcano, Jap