Interplate Strain Concentration and Large Inland Earthquakes in the Japan Islands

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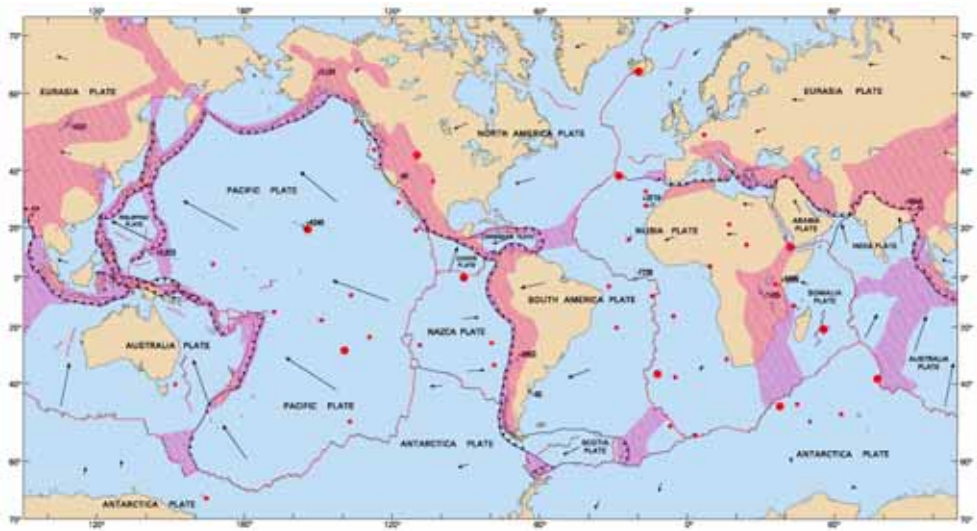
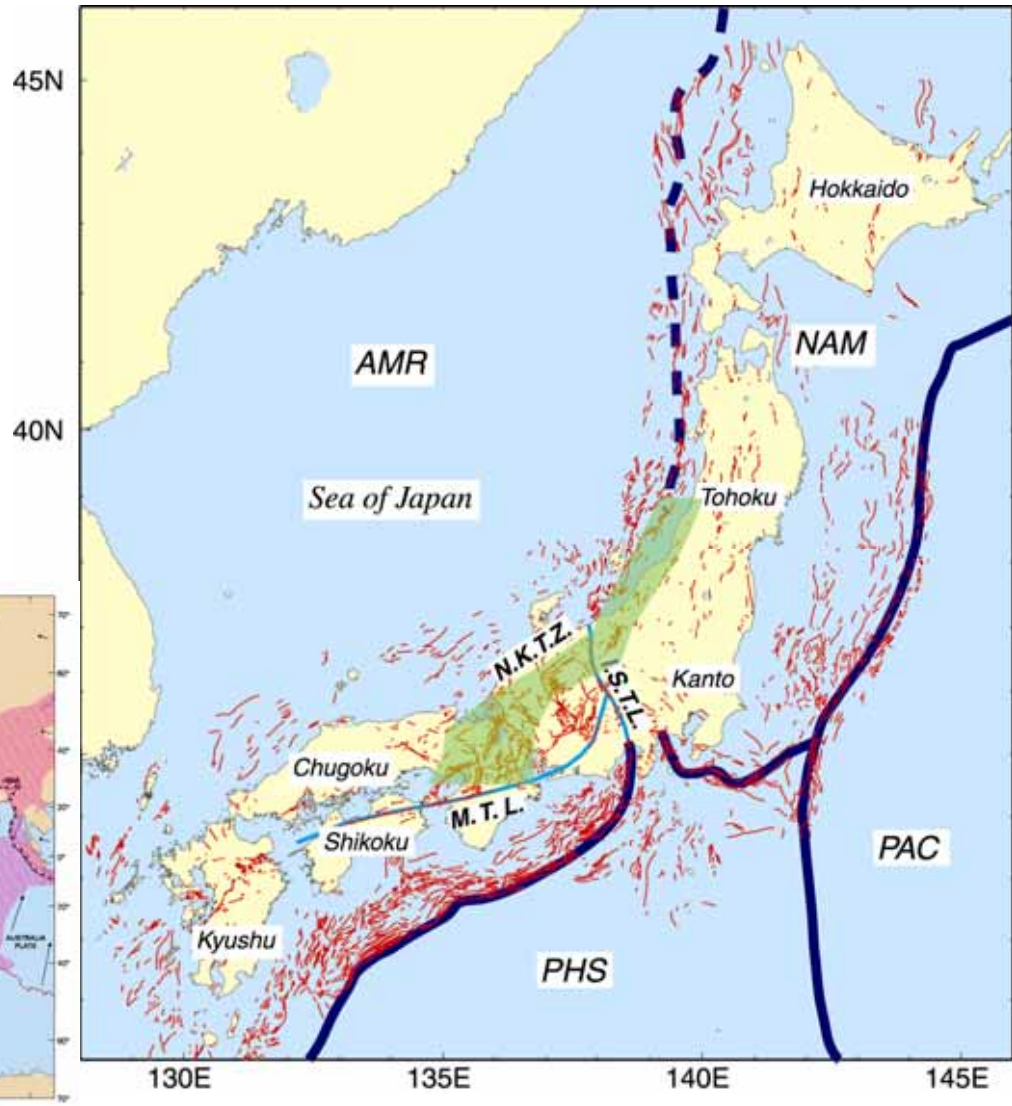
Tectonic Background of Japan

- Convergent boundary of 4 tectonic plates
  - PHS: 30-60mm/yr
  - PAC: 80-90mm/yr
- Opening of Sea of Japan: 15-20Ma
- Whole Japan Islands are located within a deformation zone



(Simkin et al., 2006)



GEONET: ~1,200 CGPS sites

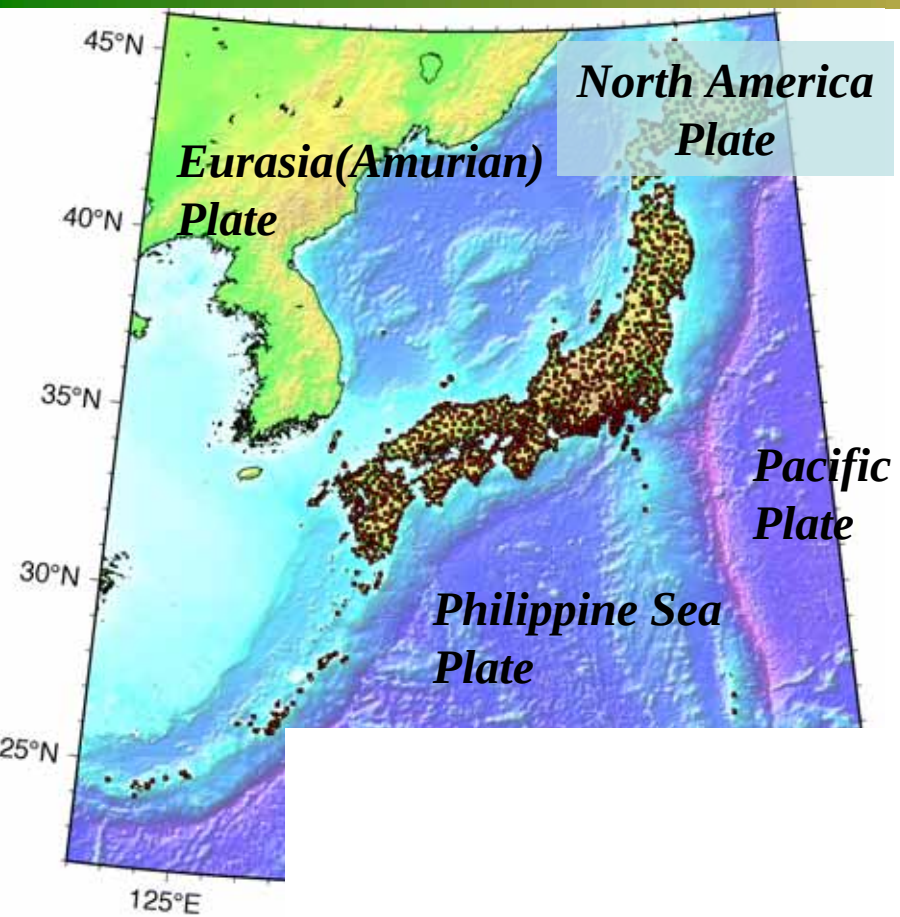


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Photo by GSI

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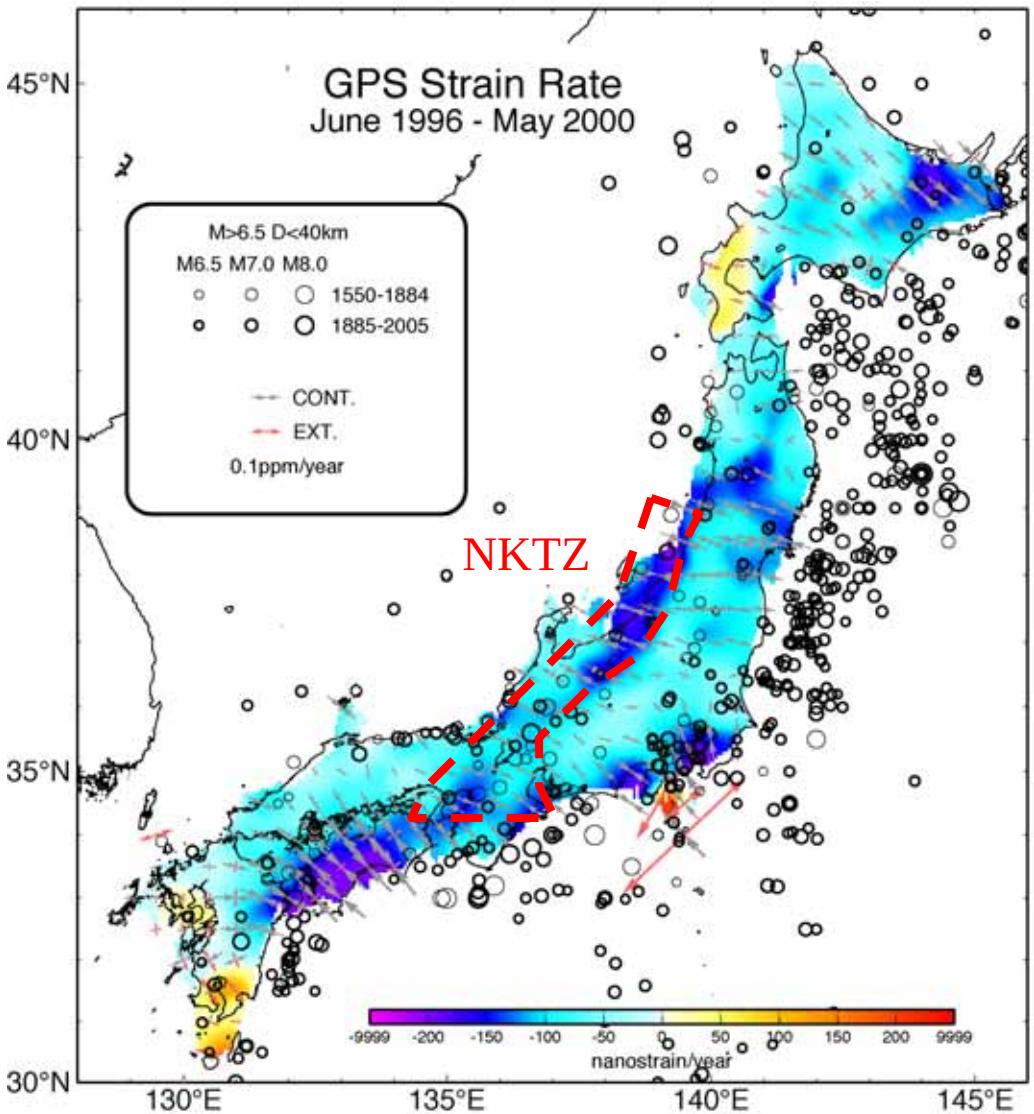
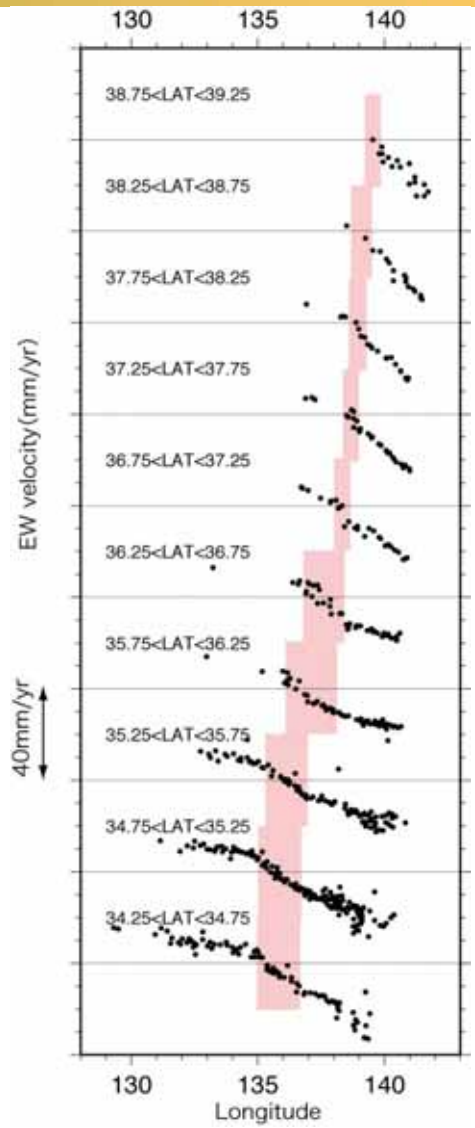
Strain Rate Map



(Sagiya, 2004)

EW Vel.



(Sagiya, 2007)

2007 Chuetsu-oki Earthquake

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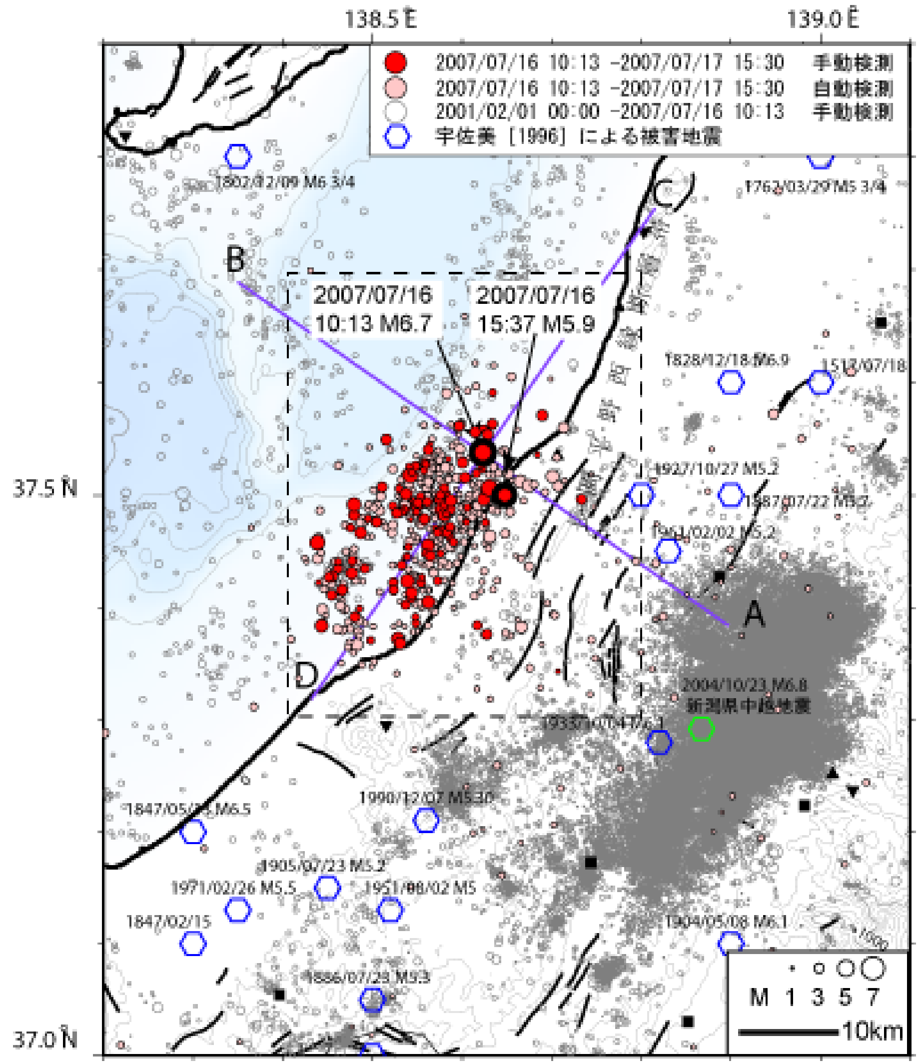
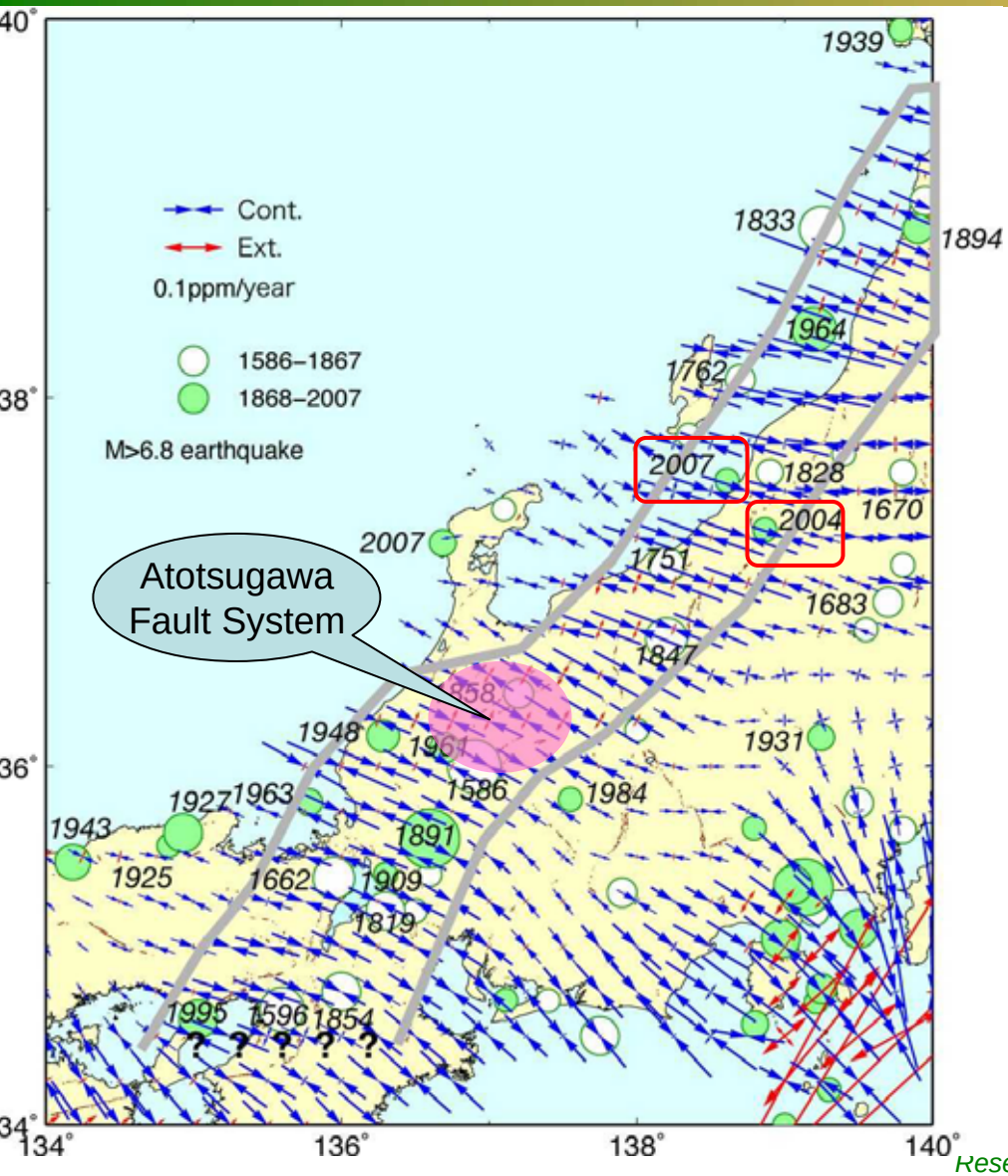


(NIED, 2007)

Niigata-Kobe Tectonic Zone

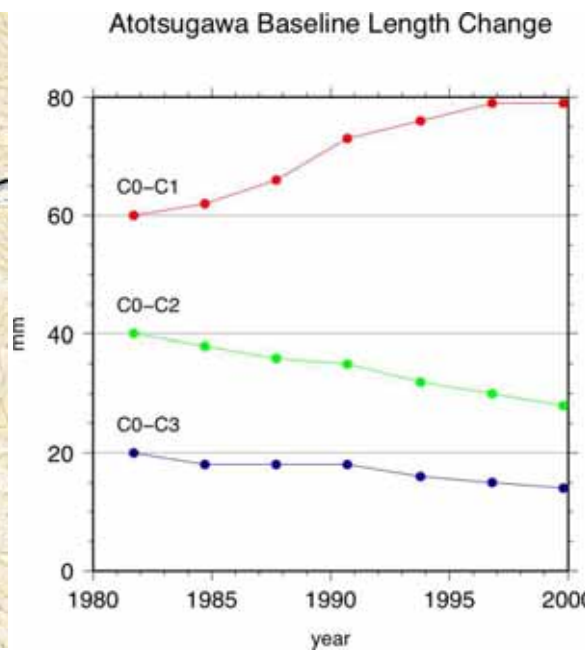


(Sagiya, 2007)

- Good correspondence with historical earthquakes
- Recent large earthquakes
  - 2004 Chuetsu (M6.8)
  - 2007 Chuetsu-oki (M6.8)
  - Filled a seismic gap

The Atotsugawa Fault System

- ENE-WSW trending right-lateral strike slip faults
  - Atotsugawa Fault(AGF)
  - Mozumi-Sukenobu Fault(MSF)
  - Ushikubi Fault(UKF)
- Report of a possible fault creeping at the central part (Tada, 1998)



(Ohzono et al., 2006)

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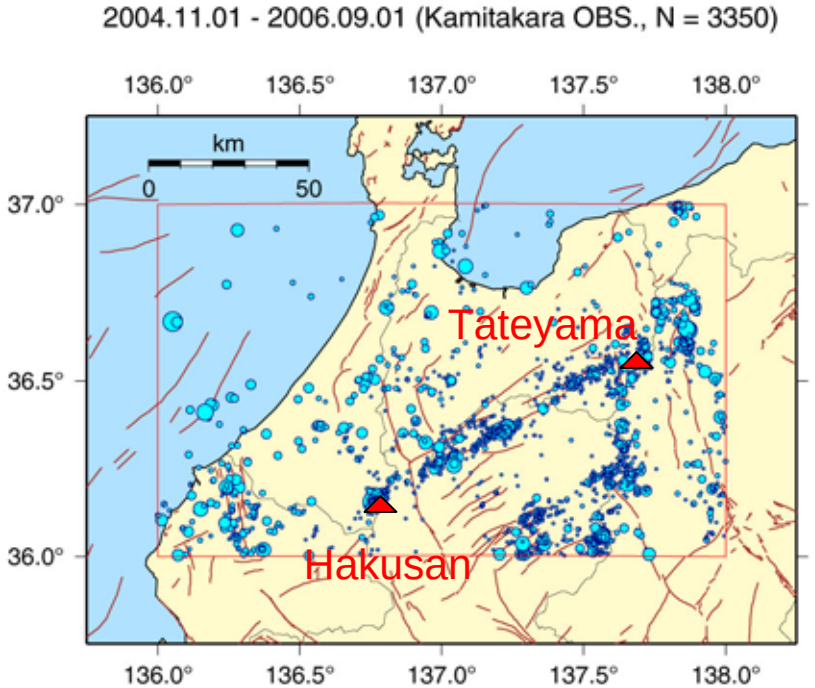
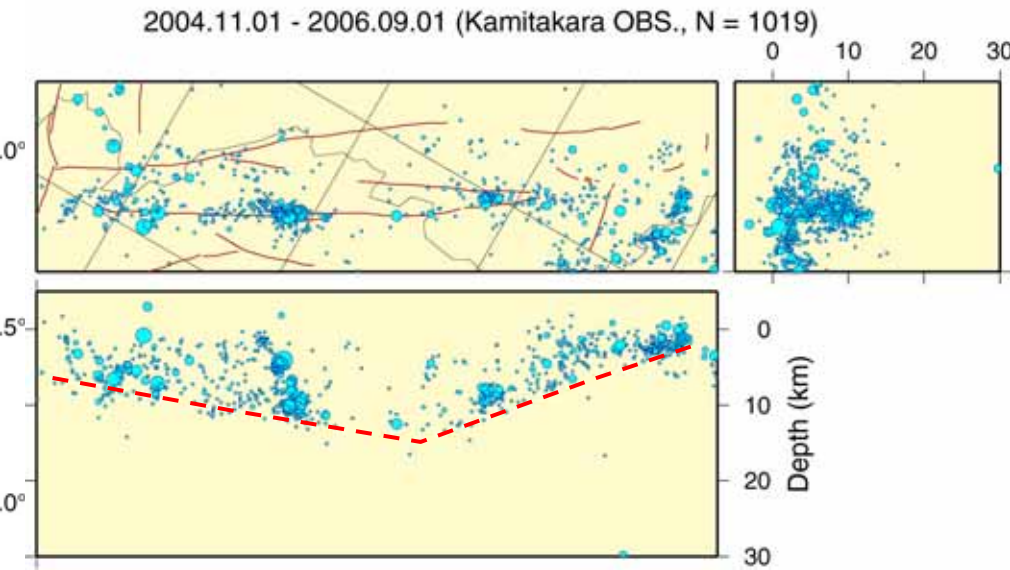
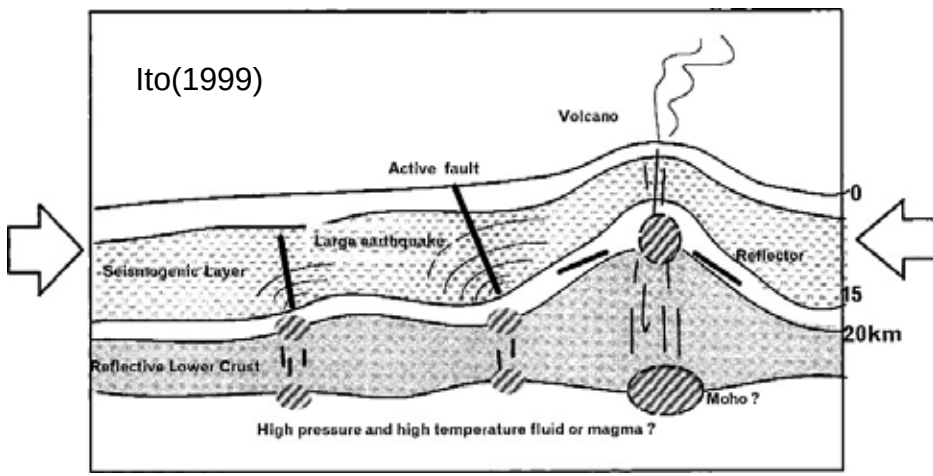
Seismicity along the Atotsugawa Fault





- Linear distribution
  - Aftershocks of the 1858 Hietsu earthquake (M7.1) ?
- Downward convex distribution
  - High T associated with Volcanoes (Tateyama, Hakusan)



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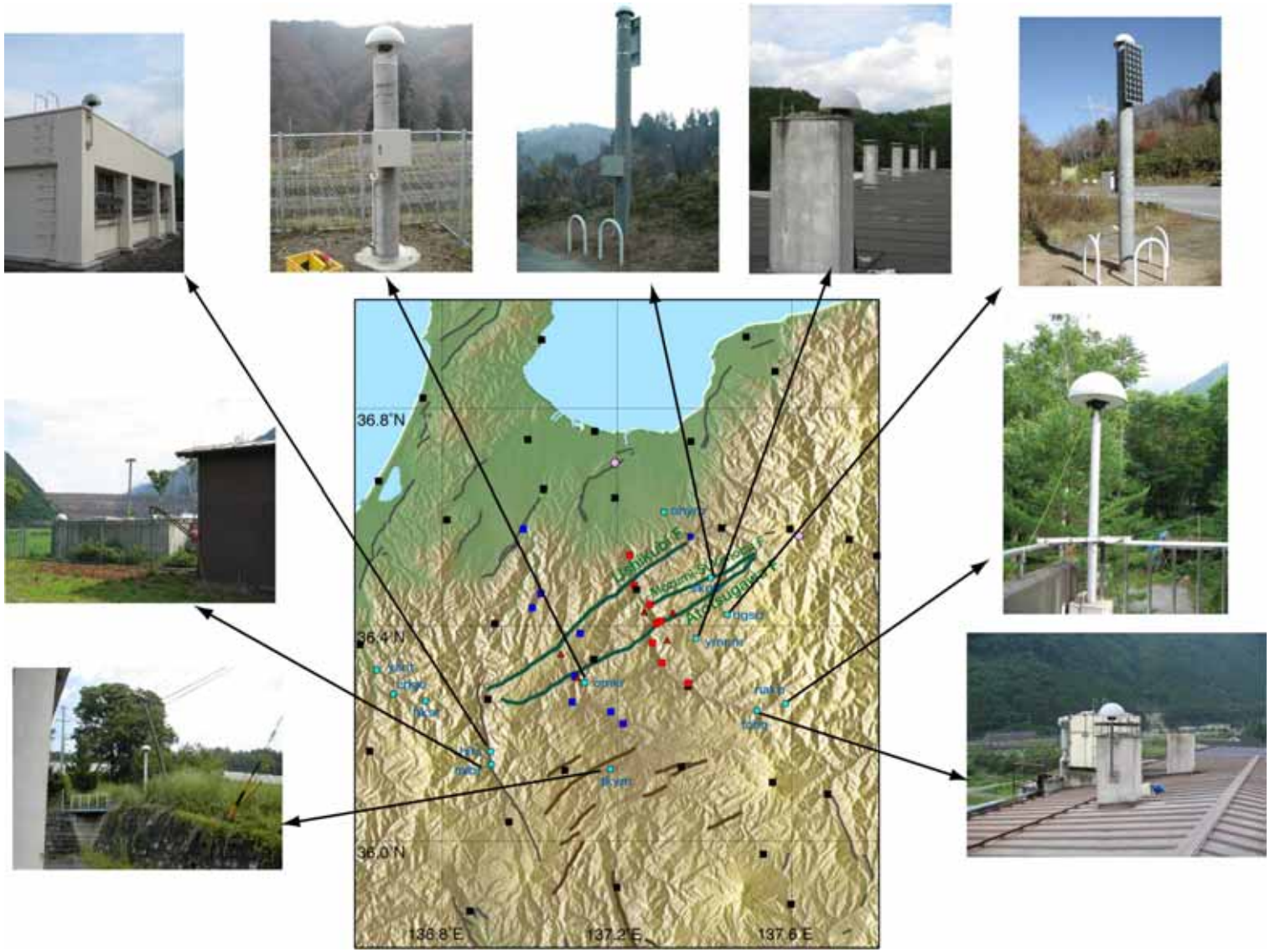
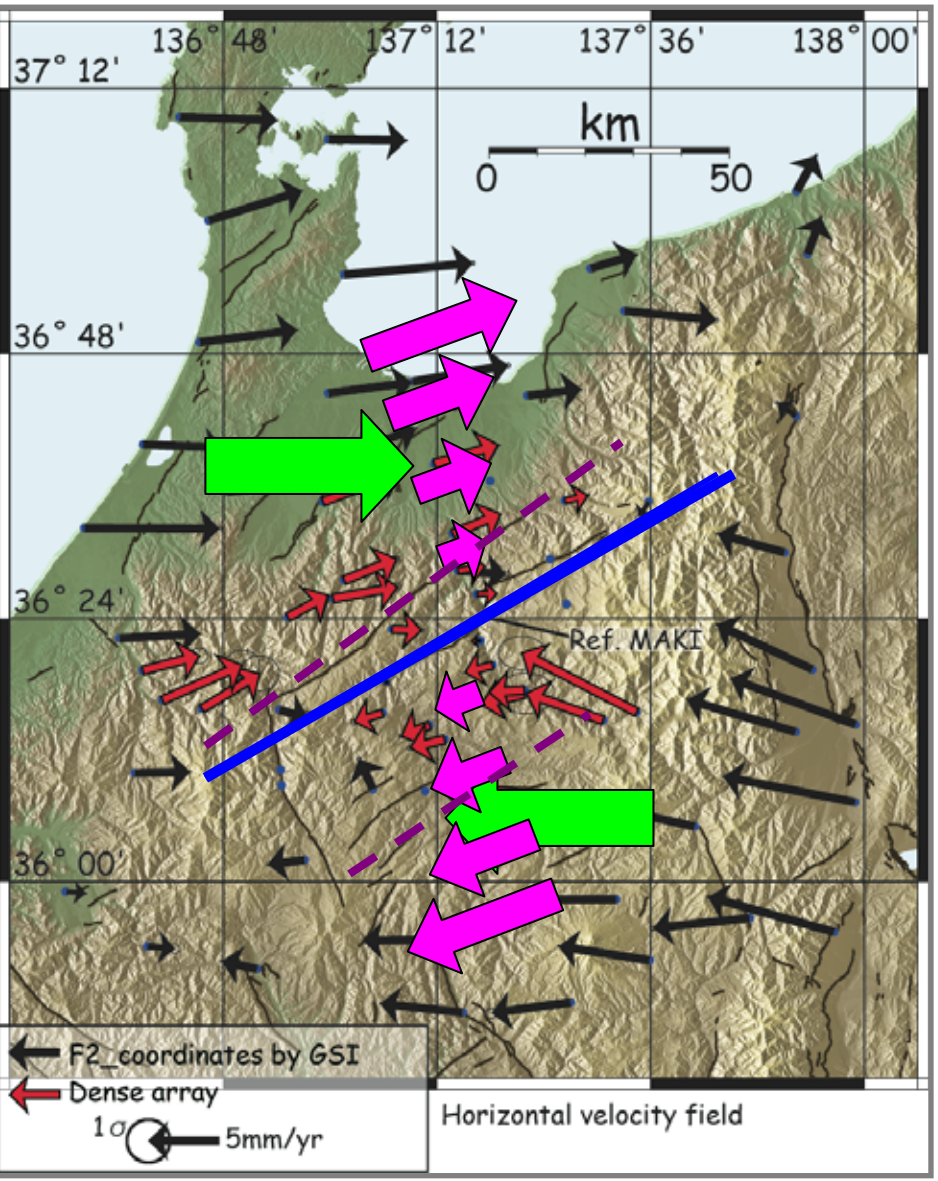
Dense GPS Network



Detailed Deformation Pattern



- Dense continuous GPS observation since 1998
  - Additional sites in 2001-2005
- mm/yr level accuracy of displacement rate
- Detailed deformation pattern has been revealed
- E-W contraction is accommodated around the Atotsugawa Fault System
- Gradual change across the fault

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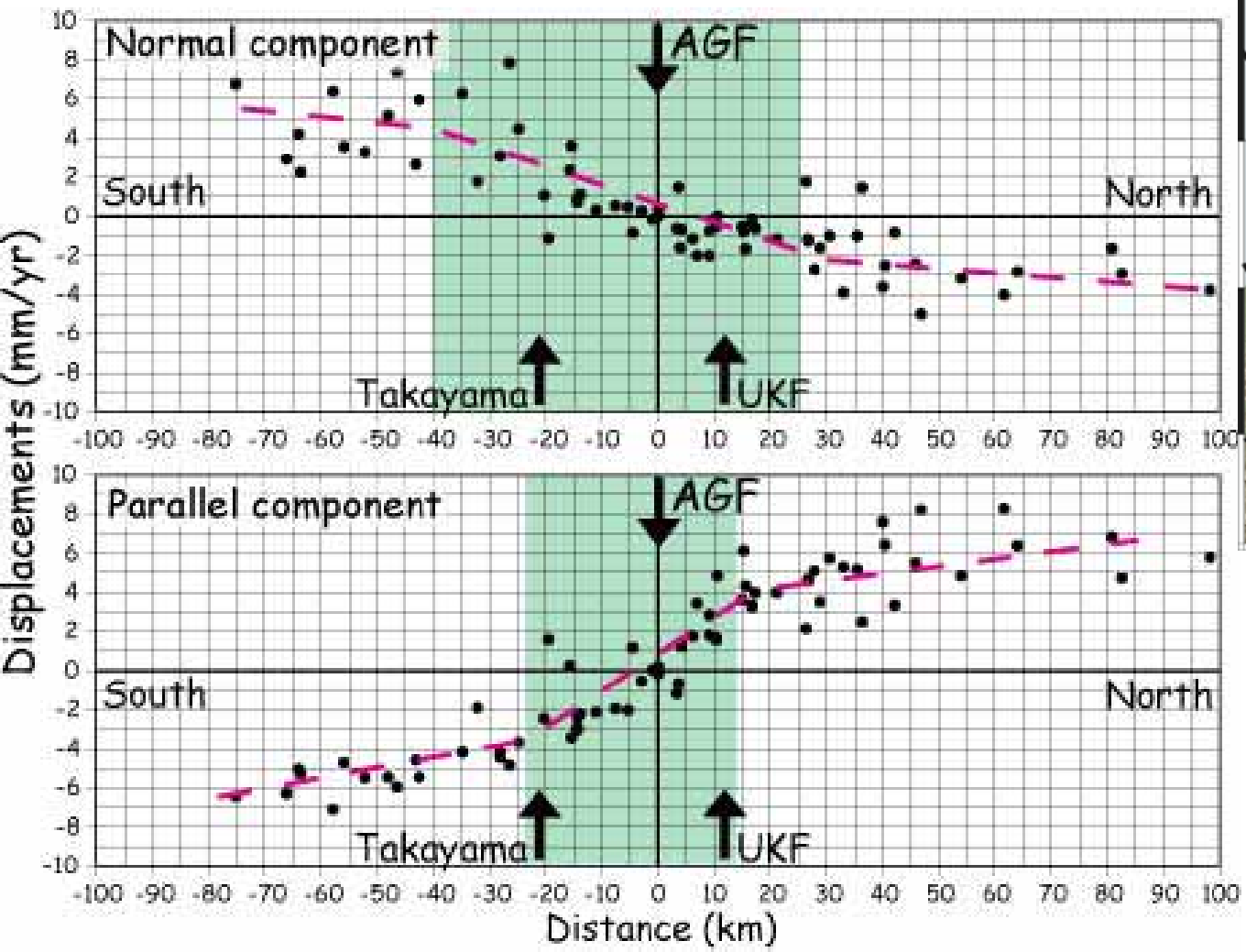
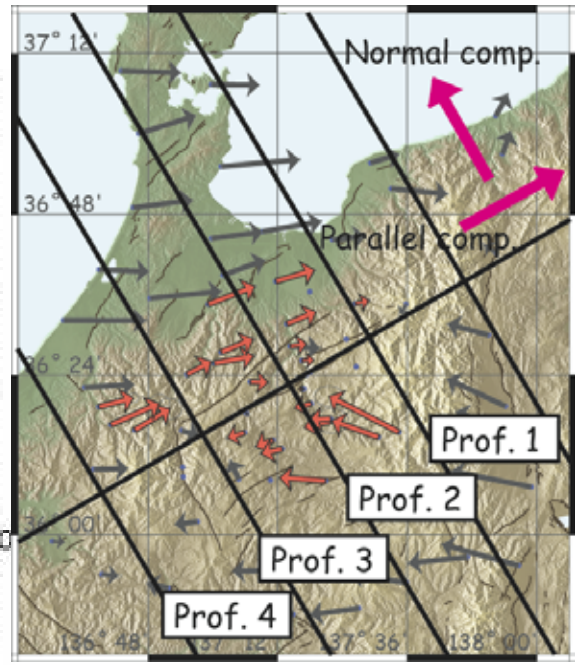
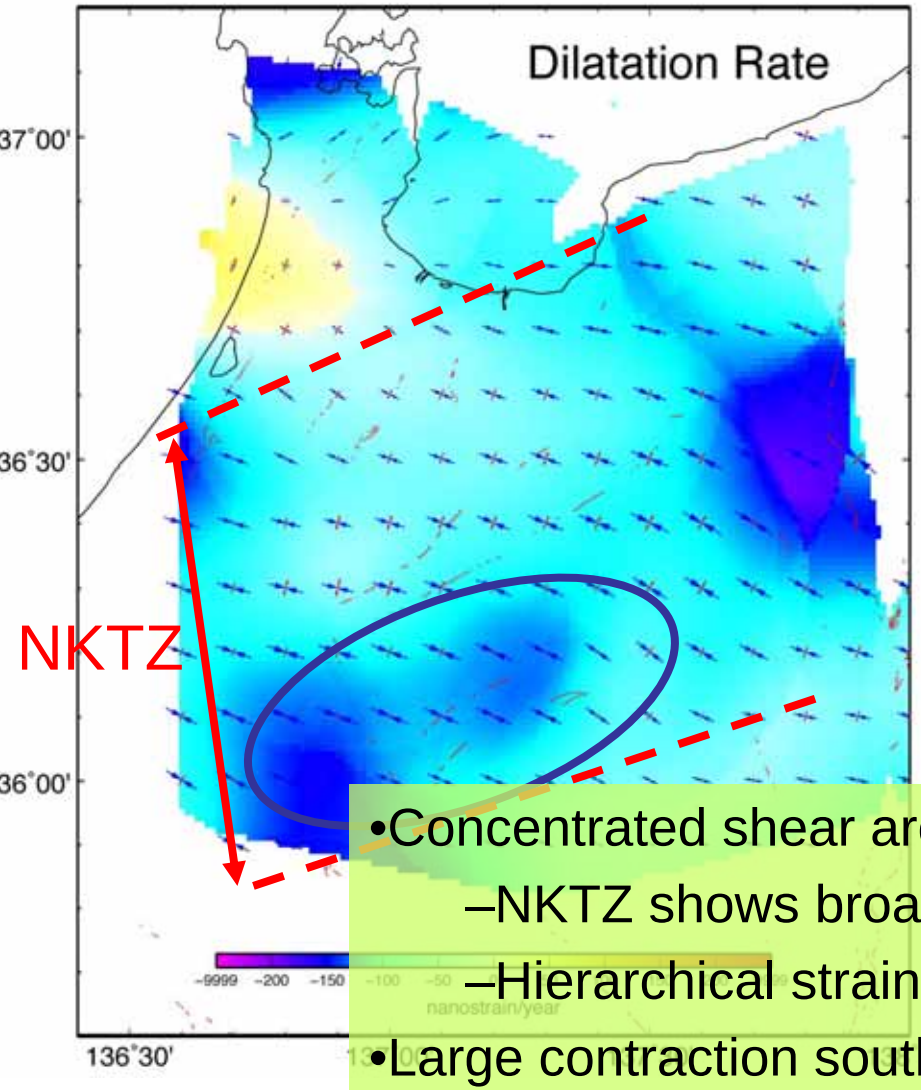
Velocity Profile

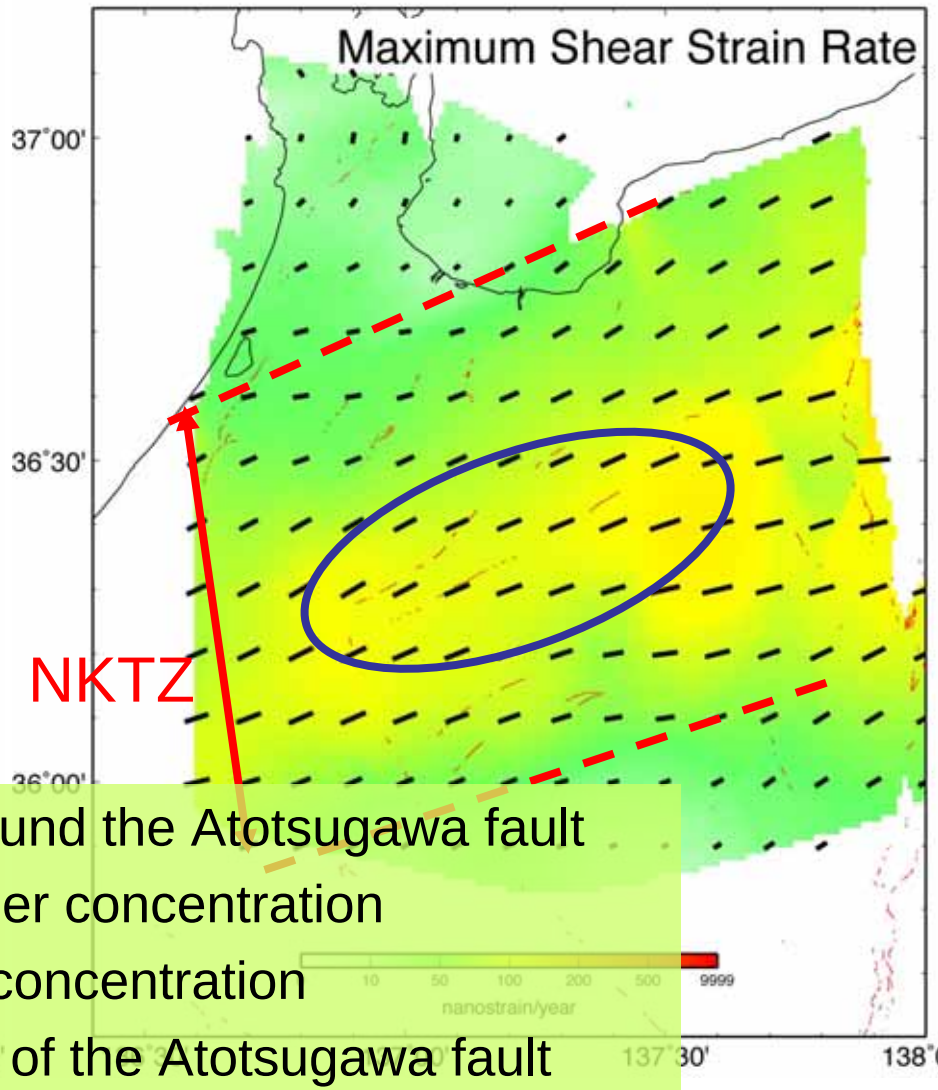




Different deformation zone width between normal and parallel components

Strain rate distribution



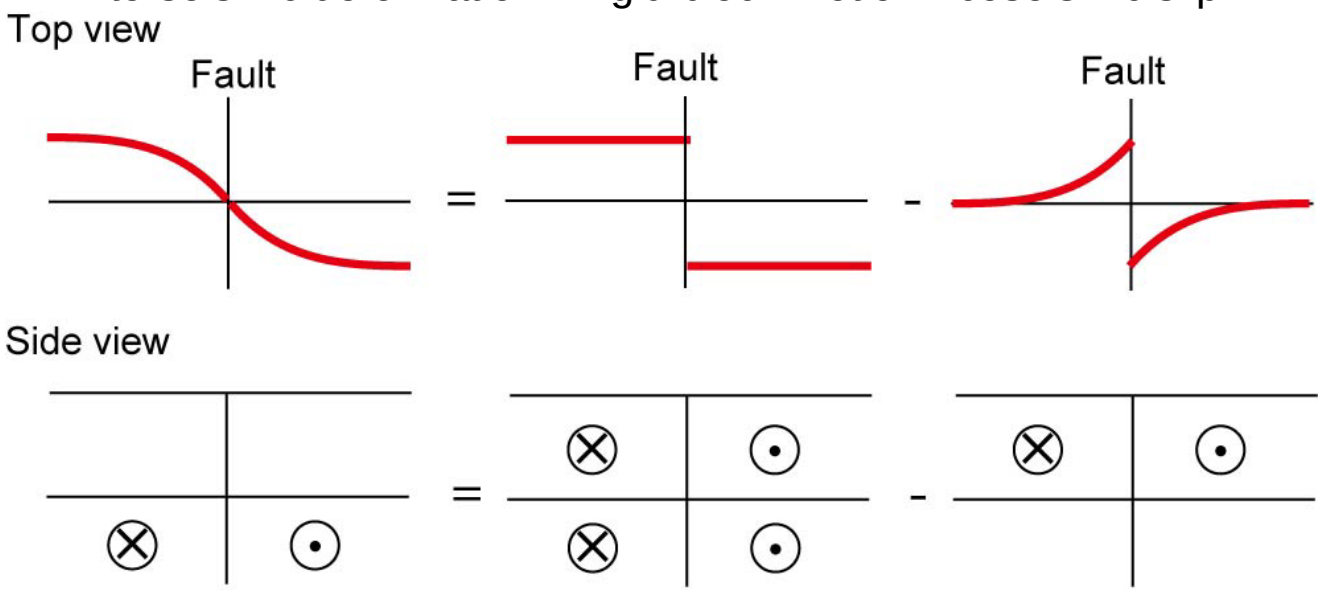


- Concentrated shear around the Atotsugawa fault
  - –NKTZ shows broader concentration
  - –Hierarchical strain concentration
- Large contraction south of the Atotsugawa fault
  - –Strain-partitioning **?**

Block-Fault Model

Hashimoto & Jackson (1993); Matsu'ura et al. (1986)

Interseismic deformation = rigid block motion - coseismic slip

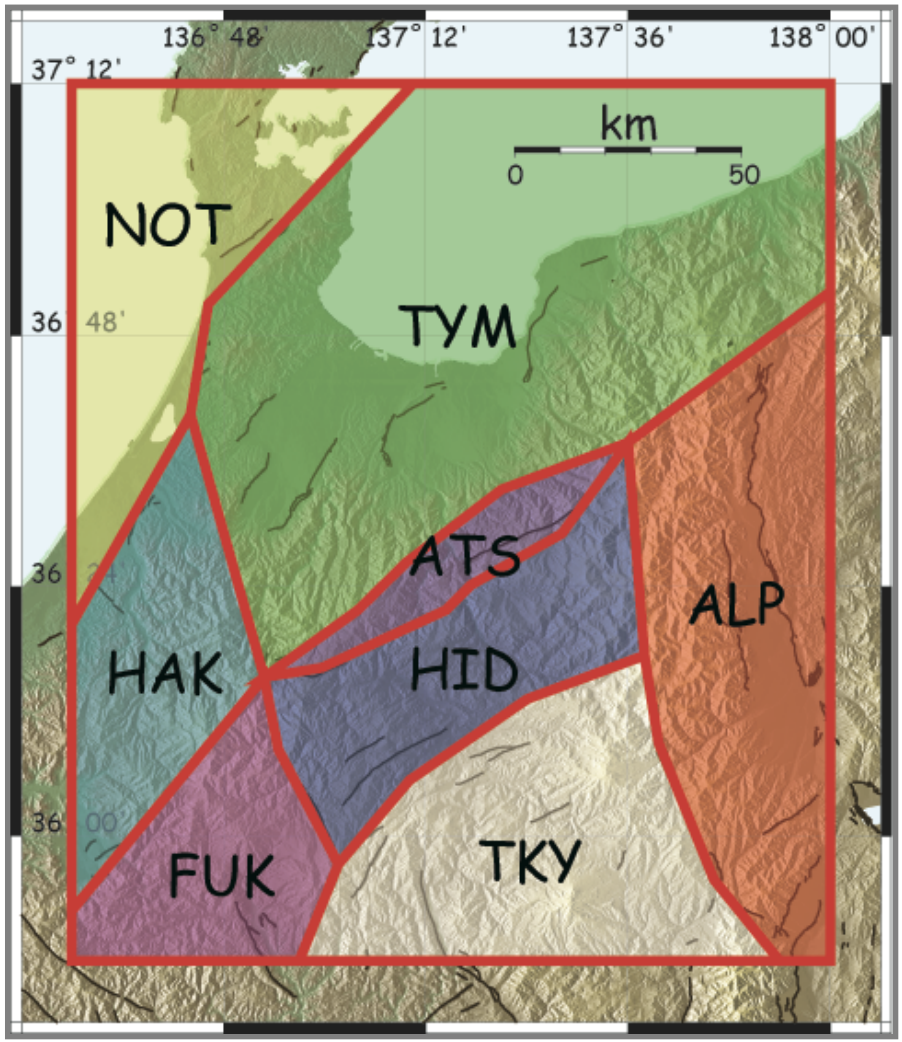


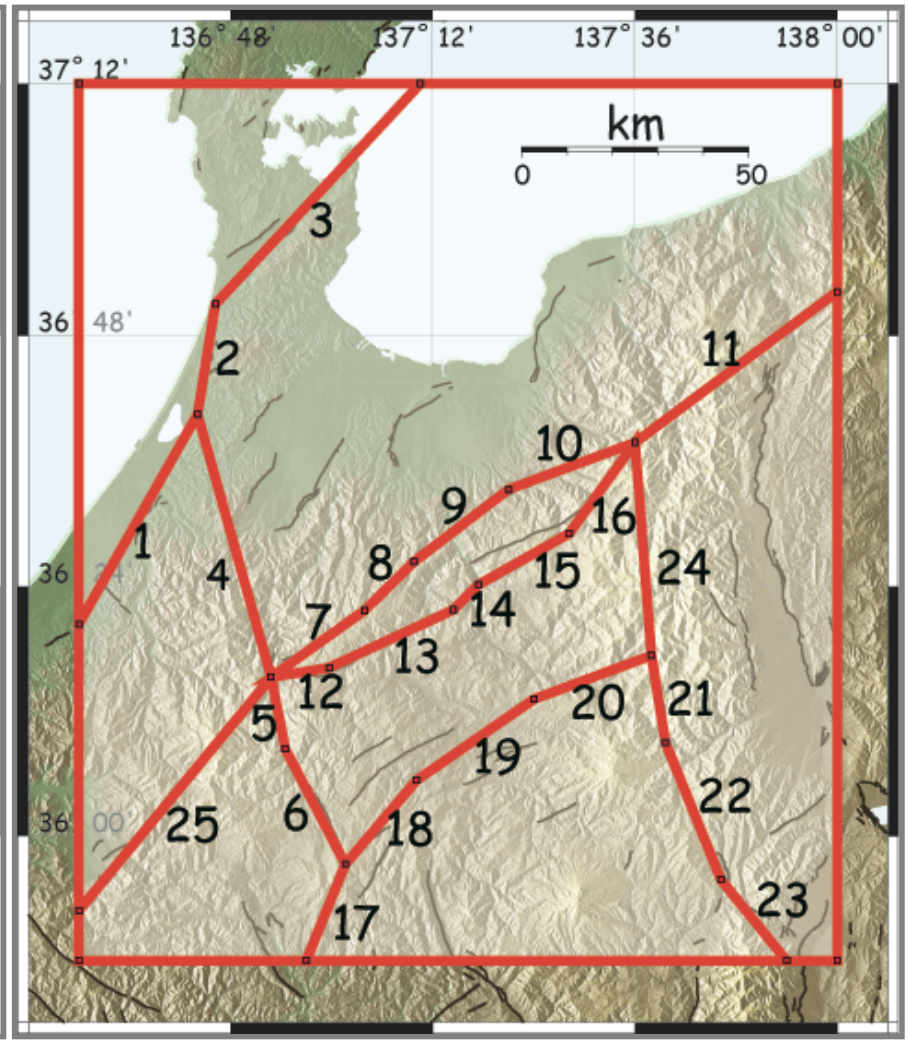
A priori Information
- Seismicity
- Fault trace
- Fault parameter
- GPS result

Block and fault geometry (8 blocks and 25 faults)

Results
- Block motion
- Slip deficit
- Block contraction
- fault creep

Block and Fault Geometry





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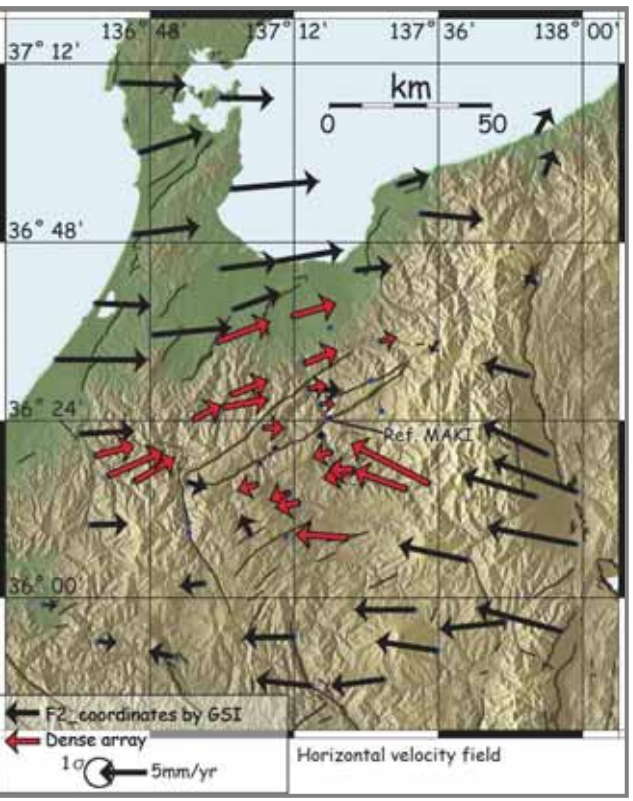
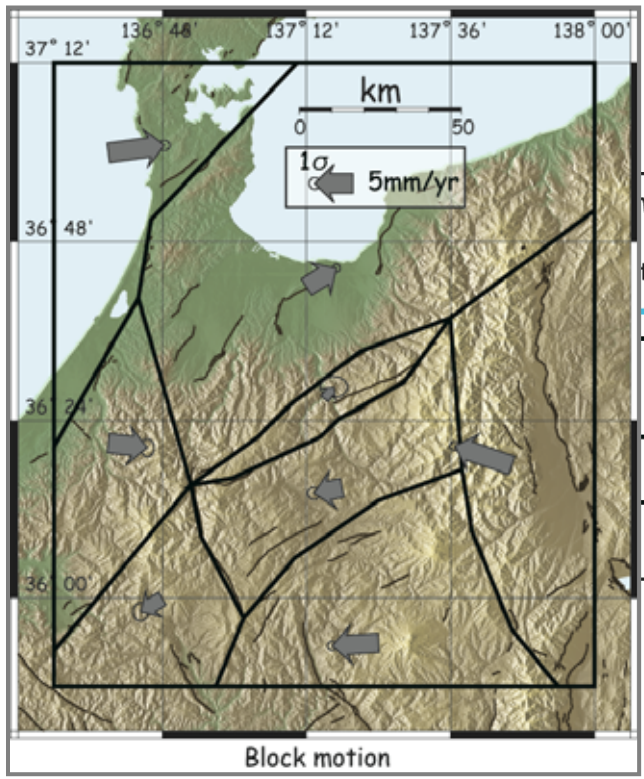
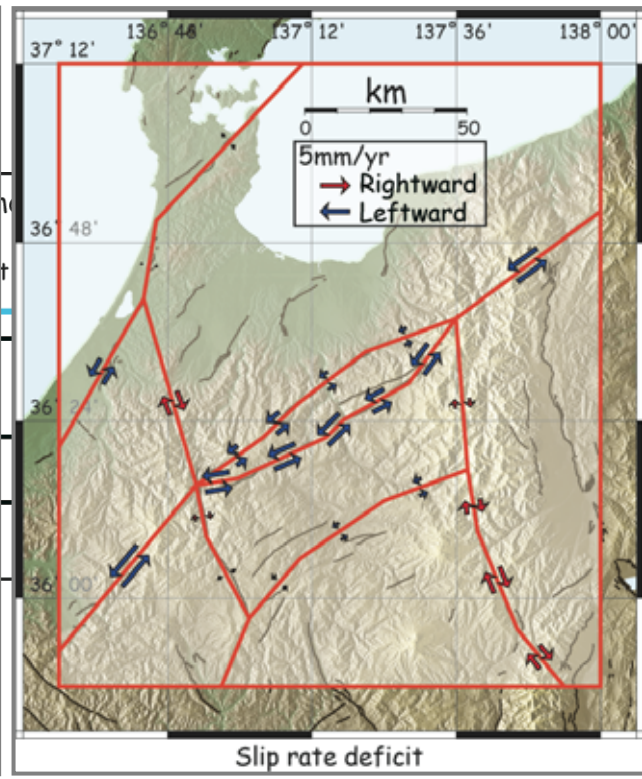
Inversion Results

- Deformation zone between the Ushikubi and the Takayama-Oppara faults
- Large slip deficit along the Atotsugawa fault







GPS Observation

Block motion

Fault Slip deficit

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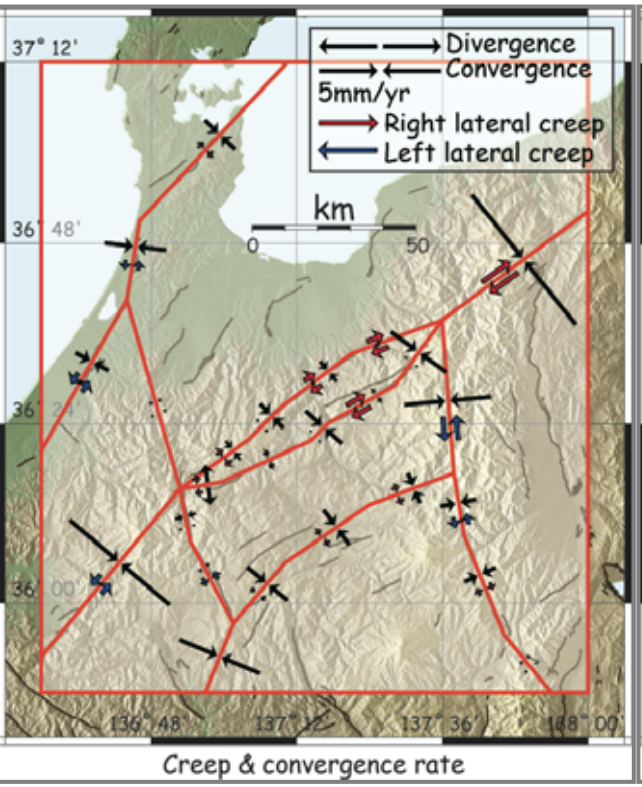
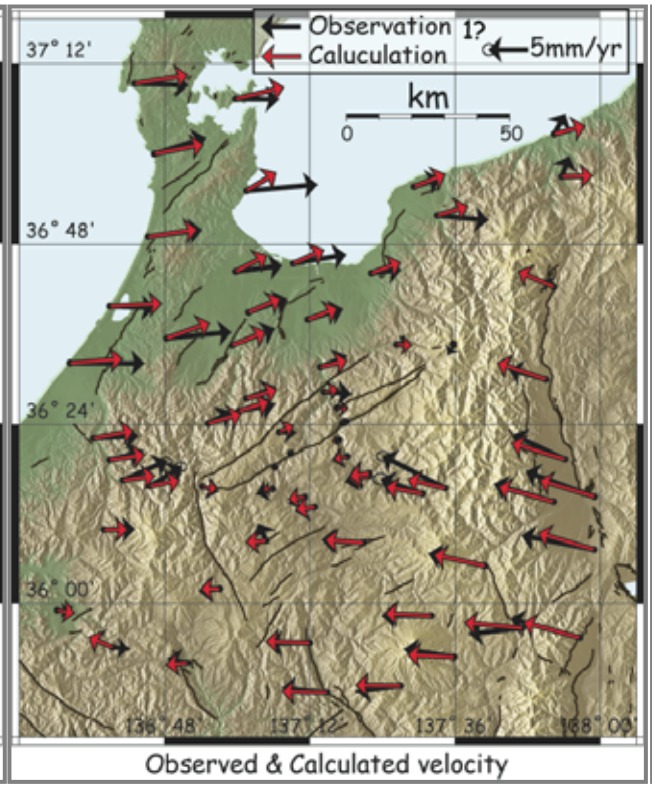
Inverstion results

Significant fault creep does not exist.
Large contraction along the Takayama-Oppara fault



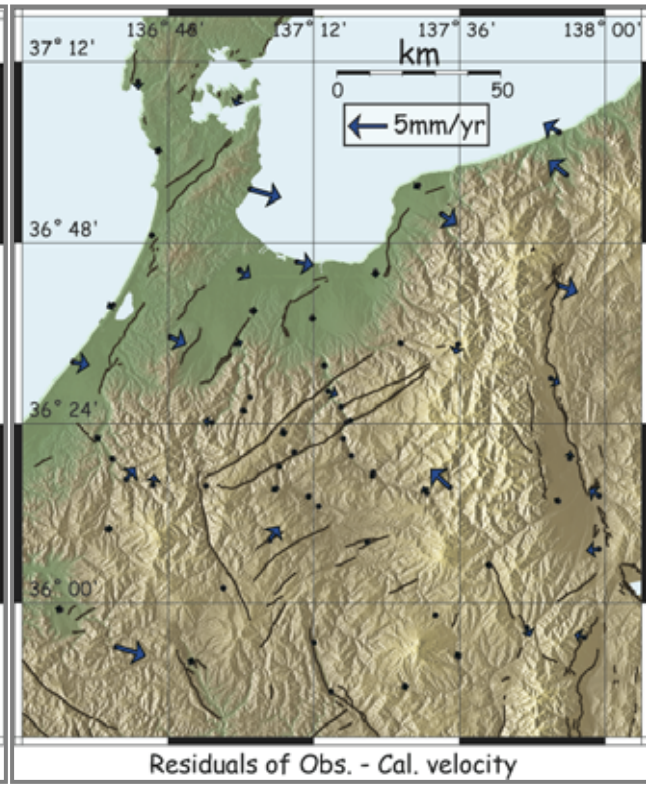
Creep & convergence rate

Creep and Contraction



Observed & Calculated velocity

Obs vs. Cal.



Residuals of Obs. - Cal. velocity

Residual

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Comparison with Geologic Data

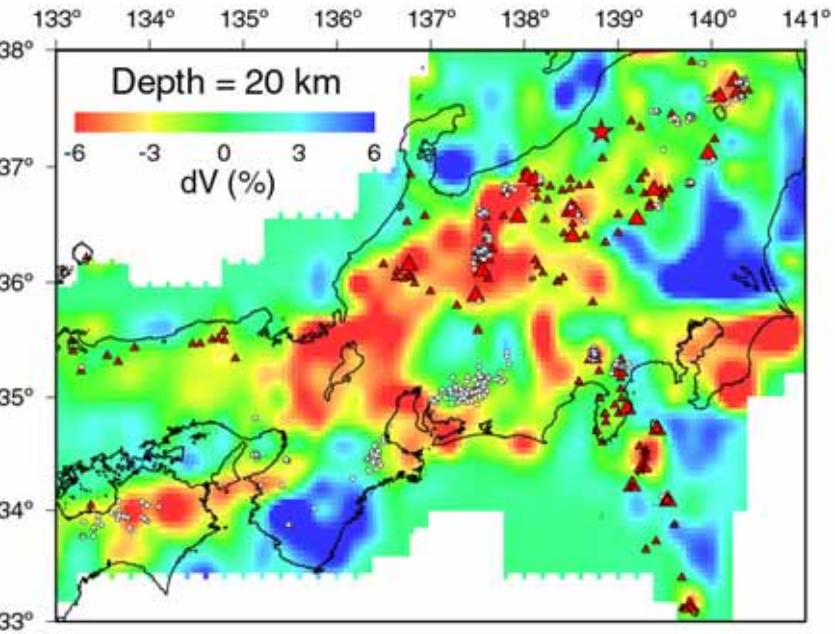
fault	No.	型	δ	D_{max} (km)	Geol. SSlip (mm/y)	Geol. DSlip (mm/y)	GPS SSlip (mm/y)	GPS DSlip (mm/y)	GPS Creep (mm/y)	GPS Cont. (mm/y)
Atotsugawa	12 13 14-16	RL	90	10 12.5 15	2.0-3.0	1.1	4.6	1.7	0.6	0.7
Ushikubi	7,8 9,10	RL	90	15 20	0.6-0.9	0.1-0.2	1.9	1.7	0.8	0.7
Takayama-Oppara	18-20	RL	90	10	1	-	1.2	0.2	0.5	1.6

- GPS and geological data are generally consistent
- How is the contraction across the Takayama-Oppara fault accommodated?

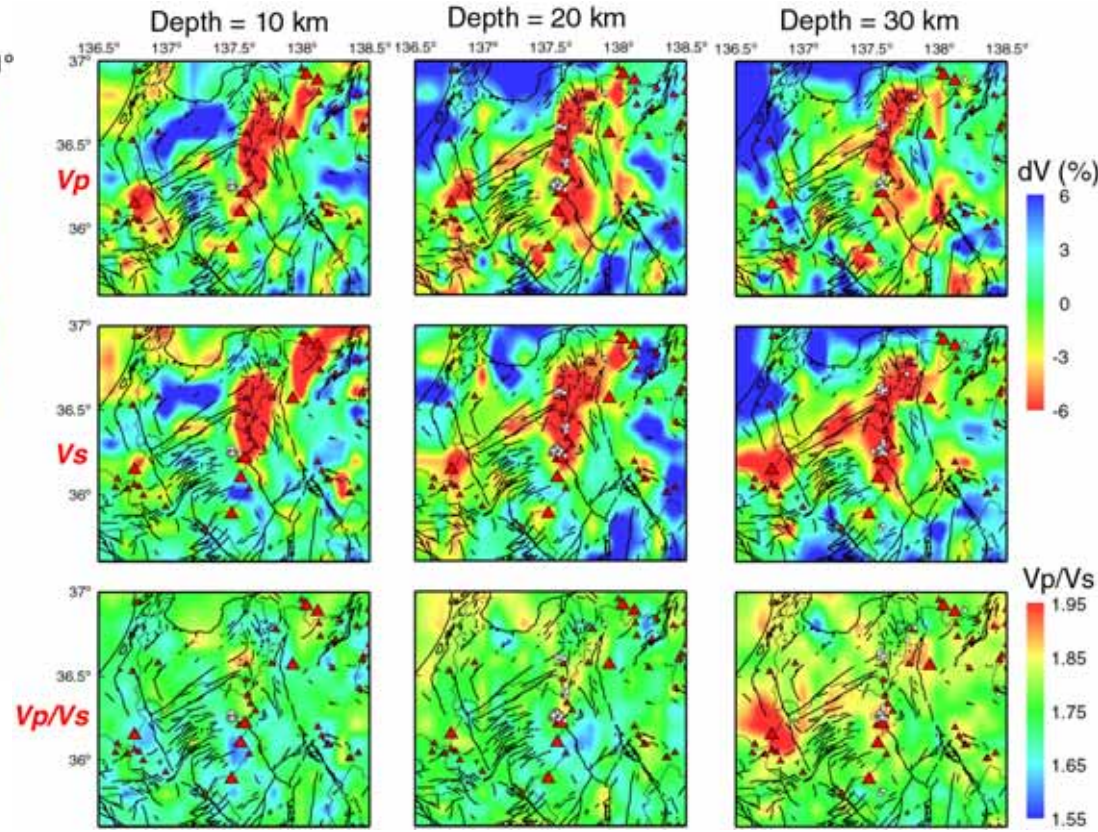
Strain Concentration

- Strain concentration zone
  - ~0.1ppm/yr in the 50-200km wide zone
  - Distributed shear and contraction
- Atotsugawa fault
  - Large shear (0.3ppm/yr) within 20km from the fault
  - Partitioning between shear and contraction?
- Hierarchical strain concentration

Seismic Tomography



Nakajima and Hasegawa (2007)



Nakajima et al. (2007)

- Low velocity along NKTZ
- Difference between NE and Central Japan
- Concentrated LVZ along the Atotsugawa fault
- Consistent with the deformation pattern

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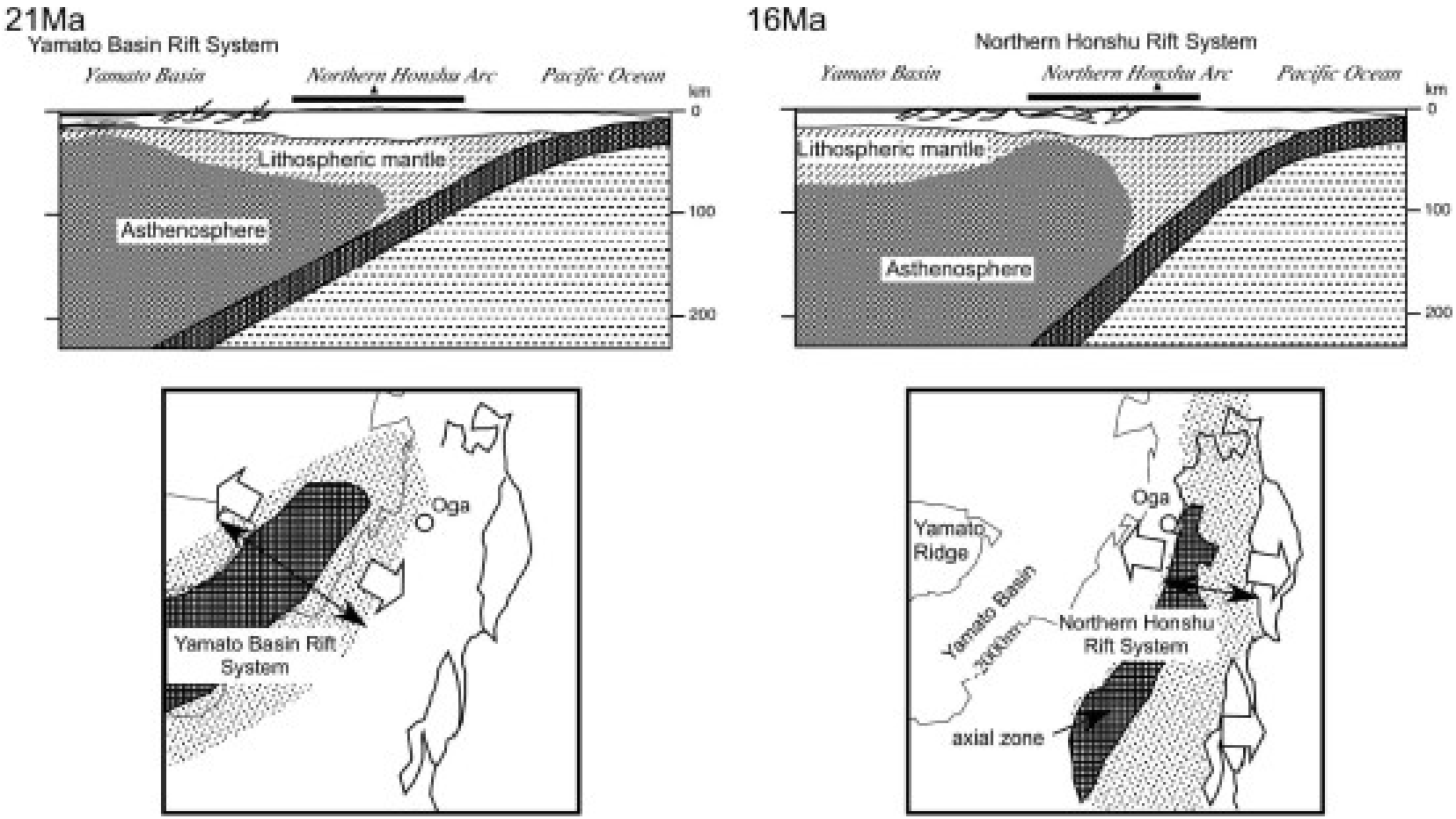
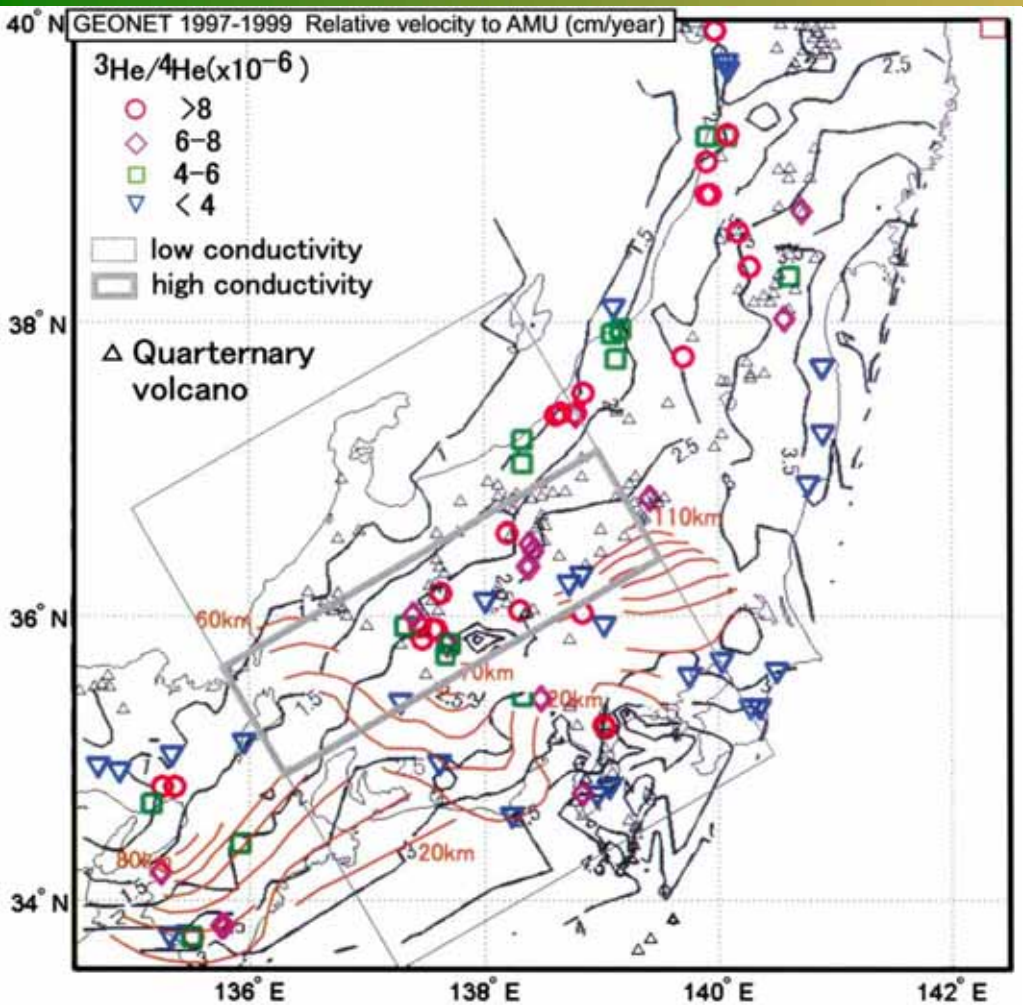
Strain concentration mechanism



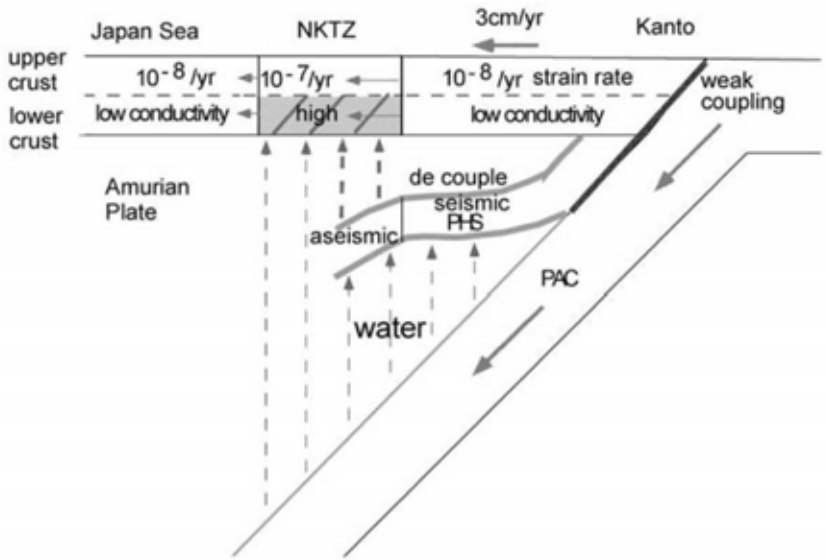
(Sato, 1994)

- NE Japan
- Tectonic inversion using faults created by Japan Sea opening
- Weak zone along the Japan Sea coast

Strain concentration mechanism

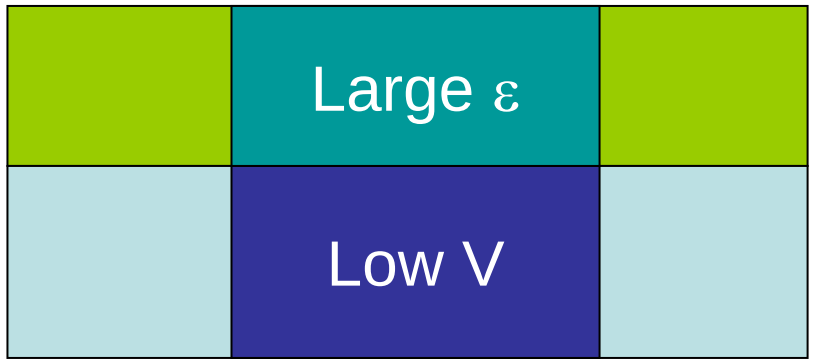


Iio et al. (2002)



- Central Japan
- Lower crustal fluid with mantle origin?
  - Large $^{3}He/^{4}He$
  - High conductivity
  - LVZ in lower crust

Strain concentration vs. low velocity



2 opposite scenarios

1) Low velocity: low rigidity

2) Easy to deform

3) Stress concentration in the upper crust

4) Large strain rate in the upper crust

1) Rupture in the upper crust

2) Increased shear stress in the lower crust

3) Strength decrease due to deformation and shear heating

4) Low velocity

Conclusion

- Nationwide GPS observation revealed the existence of strain concentration zone in the Japanese inland.
- The strain concentration zone is closely related to historical as well as recent seismicity.
- Dense GPS observation around the Atotsugawa fault elucidates detailed deformation within the strain concentration zone.
- Strain distribution in the concentration zone has a hierarchical structure, and shear and contraction deformations are accommodated differently each other.
- Low velocity structure corresponds to the strain concentration, but its physical interpretation is an unresolved problem.

Acknowledgments

- Collaborators
  - Graduate School of Environmental Studies, Nagoya University
    - M. Oishi, K. Ozawa, M. Fukuda, Y. Asahi
  - Graduate School of Science, Tohoku University
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  - DPRI, Kyoto University
    - M. Hashimoto, Y. Hoso, Y. Wada, K. Onoue, F. Ohya
  - Graduate School of Science, Kyoto University
    - K. Hirahara
  - Faculty of Science, University of Toyama
    - A. Takeuchi, R. Douke
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- GPS observation has been conducted as a part of the Earthquake Prediction Research Program of Japan