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Detection of Plastic Strain Using GNSS Data of Pre- and Post-seismic Deformation of the 2011 Tohoku-oki Earthquake

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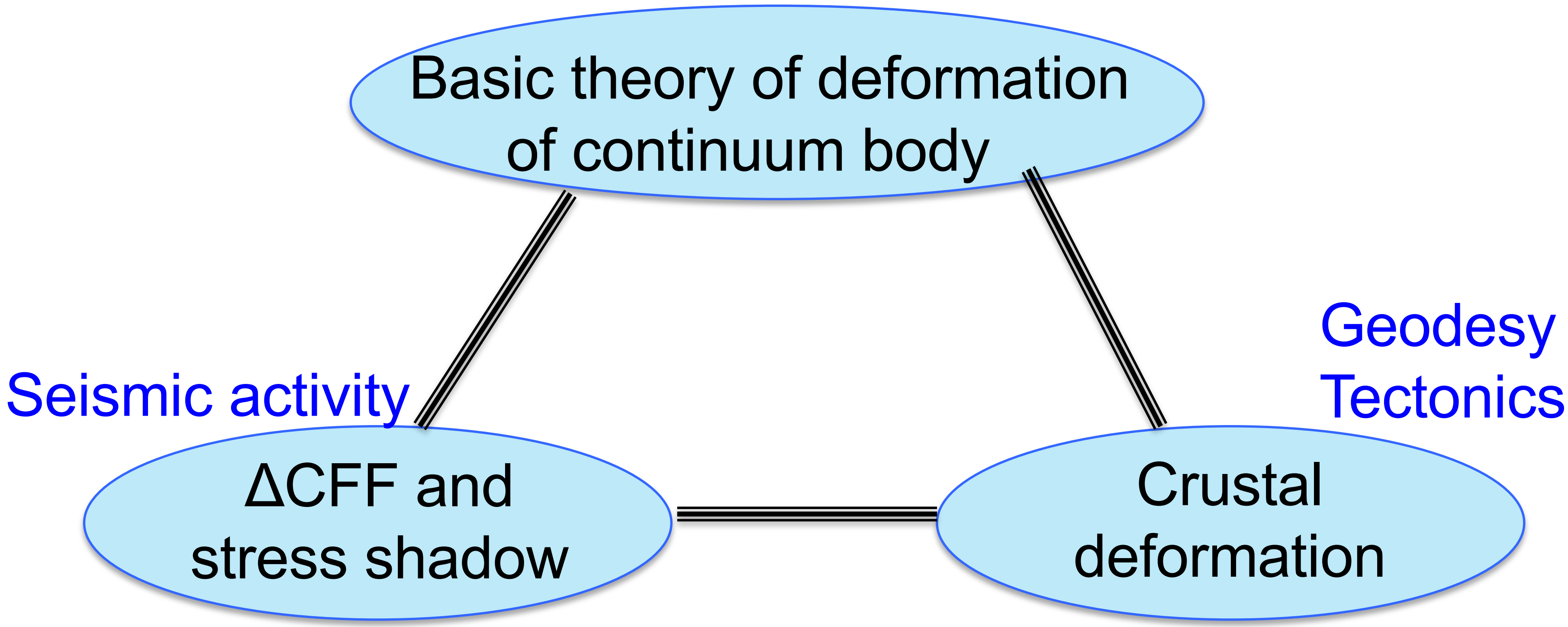
We succeeded in separating plastic deformation as well as viscous deformation from GNSS data in a strain concentration zone in Japan for pre- and post-seismic periods of the Tohoku earthquake.

This study has already been published from Earth Planets and Space:
Fukahata et al. 2020. *Earth Planets Space*, 72:28, https://doi.org/10.1186/s40623-020-1144-1

Framework of this study



Toda et al. (2011)
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Meneses-Gutierrez & Sagiya (2016)
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The concept of stress shadow on the basis of ΔCFF is useful not only to seismic activity but also to crustal deformation.

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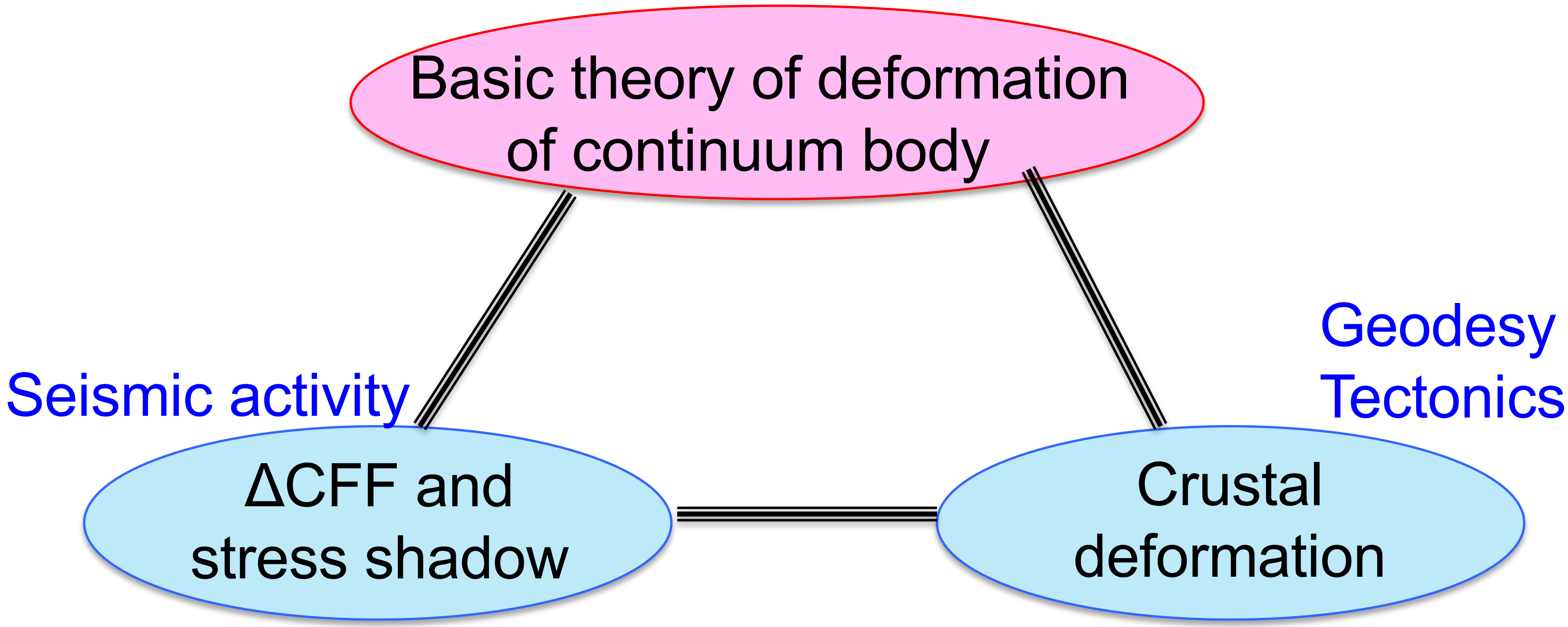

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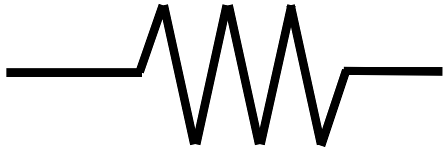
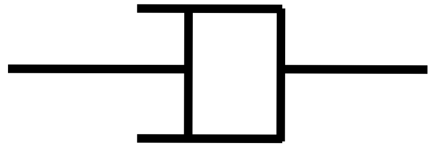
Basic theory of deformation of continuum body

- Elasticity: $\Delta\varepsilon = \Delta\sigma / k$



due to the change of stress
(particularly to the coupling at the plate-interface)

- Viscosity: $\dot{\varepsilon} = A\sigma^n$



depending on absolute stress

- Plasticity: $\Delta\varepsilon > 0$ *when* $\sigma \geq y_s$

(y_s: yield stress)

including both brittle and aseismic deformation

in-elastic deformation ⇨ ***permanent deformation***

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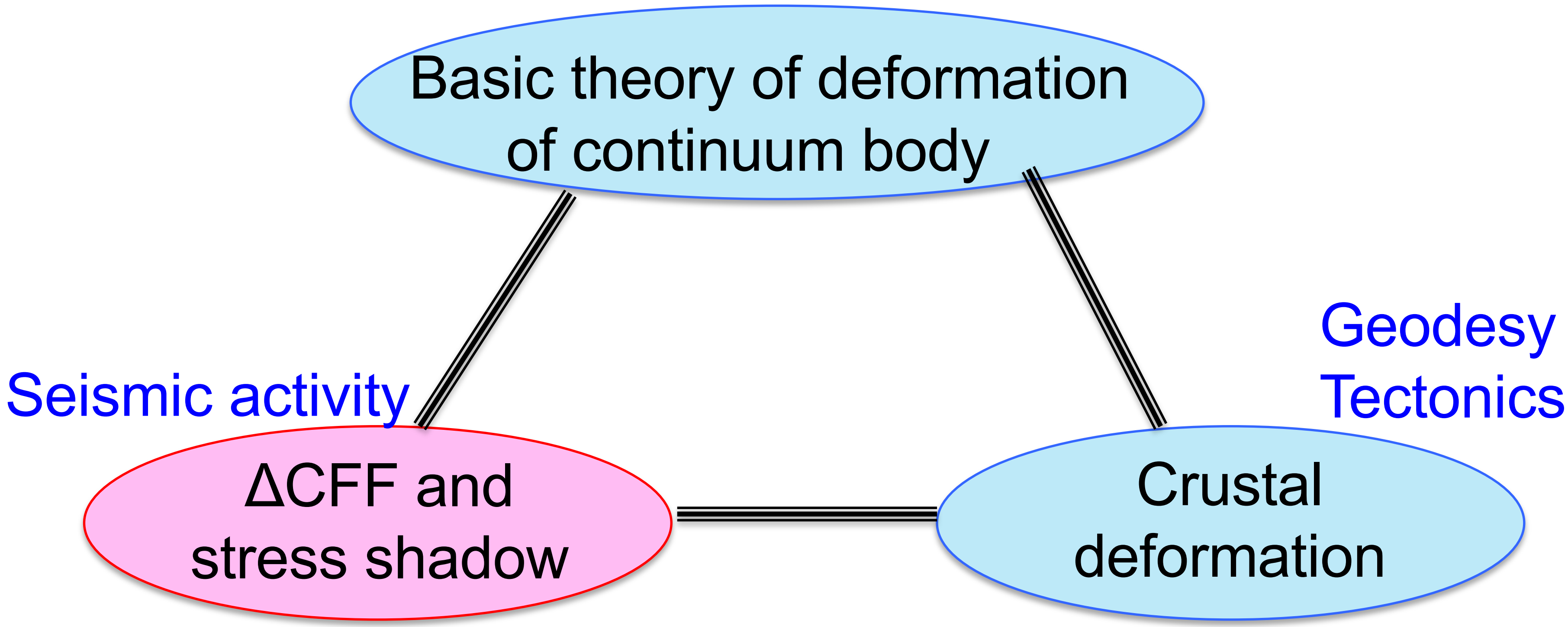

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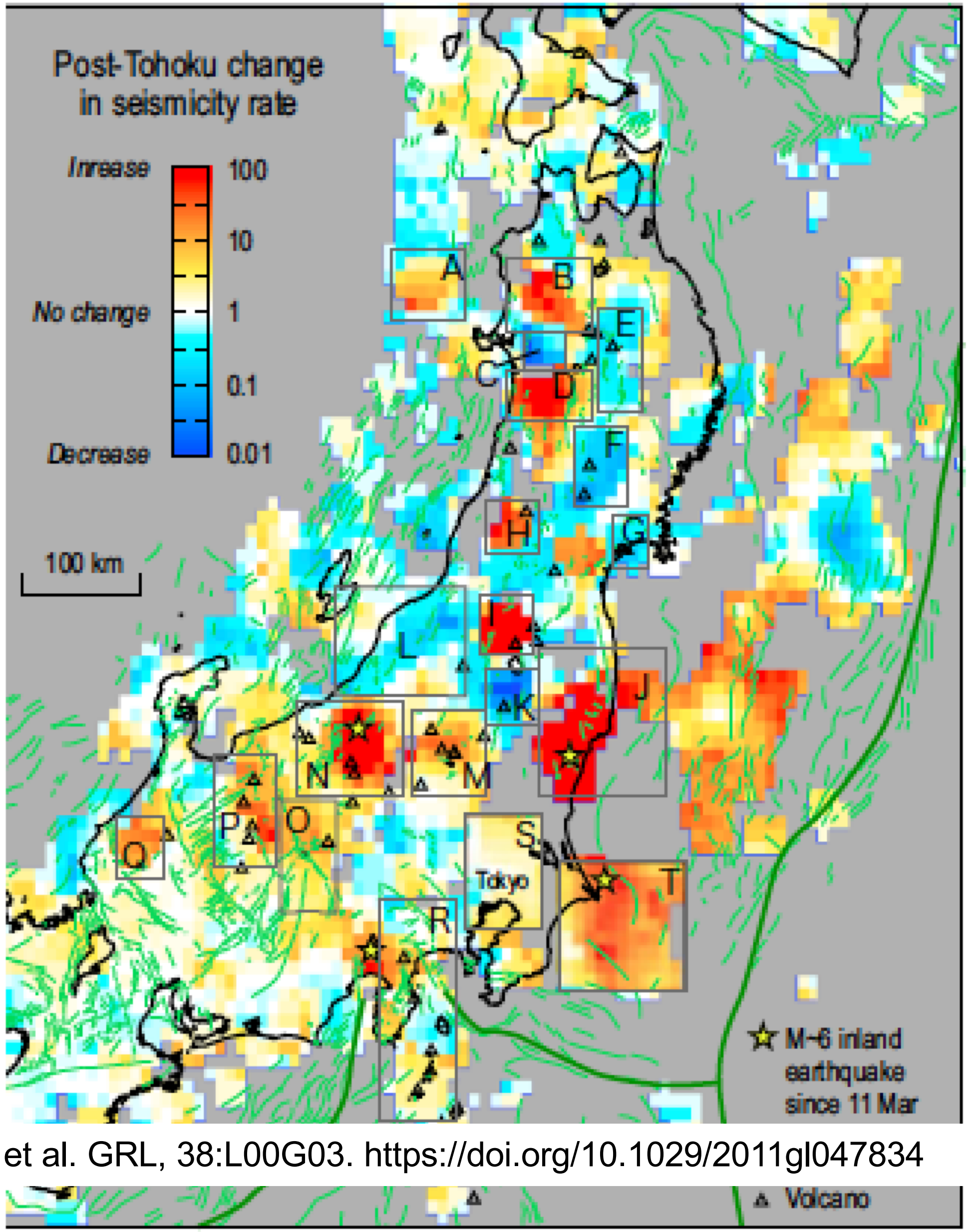
ΔCFF and stress shadow（after the Tohoku-oki earthquake）



Toda et al. GRL, 38:L00G03. https://doi.org/10.1029/2011gl047834

Tohoku-oki earthq.

↓

Reduction of EW compression

↓

Less seismicity

well understood with ΔCFF

$$\Delta \mathrm{CFF} = \Delta\tau_s + \mu\Delta\sigma_n$$

Change of seismicity after Tohoku-oki（Toda et al. 2011）

Stress shadow in SW Japan (Hori & Oike, 1996, 1999)

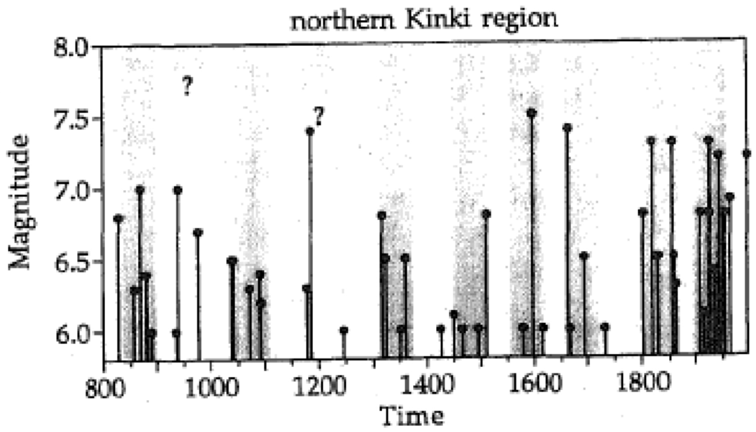


Fig. 4. Magnitude-time plot in the northern Kinki region. The shaded belts indicate the periods from 50 years before to 10 years after the Nankai trough events in 887, 1096, 1360, 1498, 1605, 1707, 1854 and 1944. The shaded part with "?" mark indicates the periods before and after the possible Nankai trough events in the 10–11th and 12–13th centuries (Sangawa, 1992).

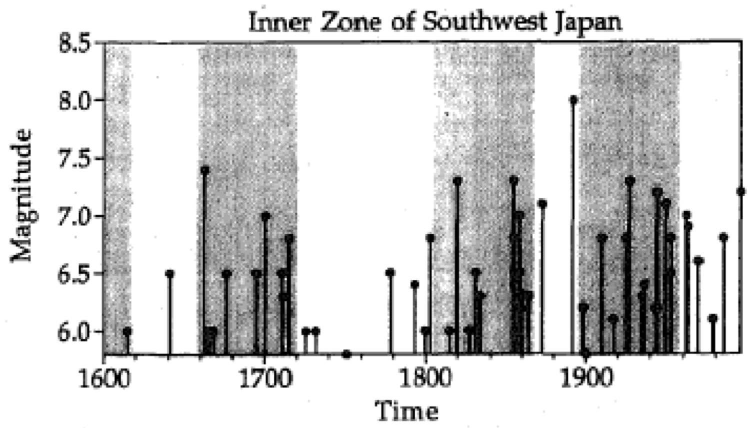
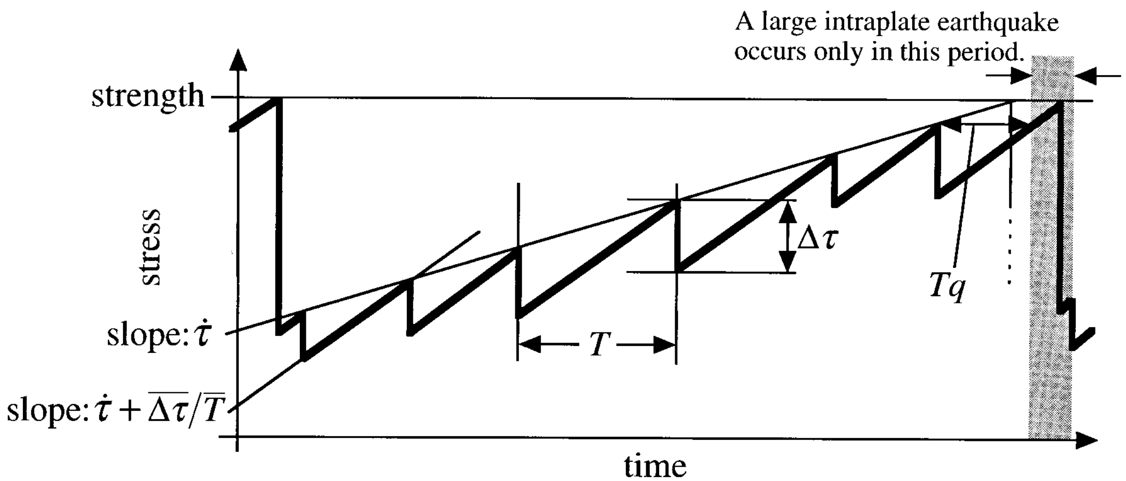


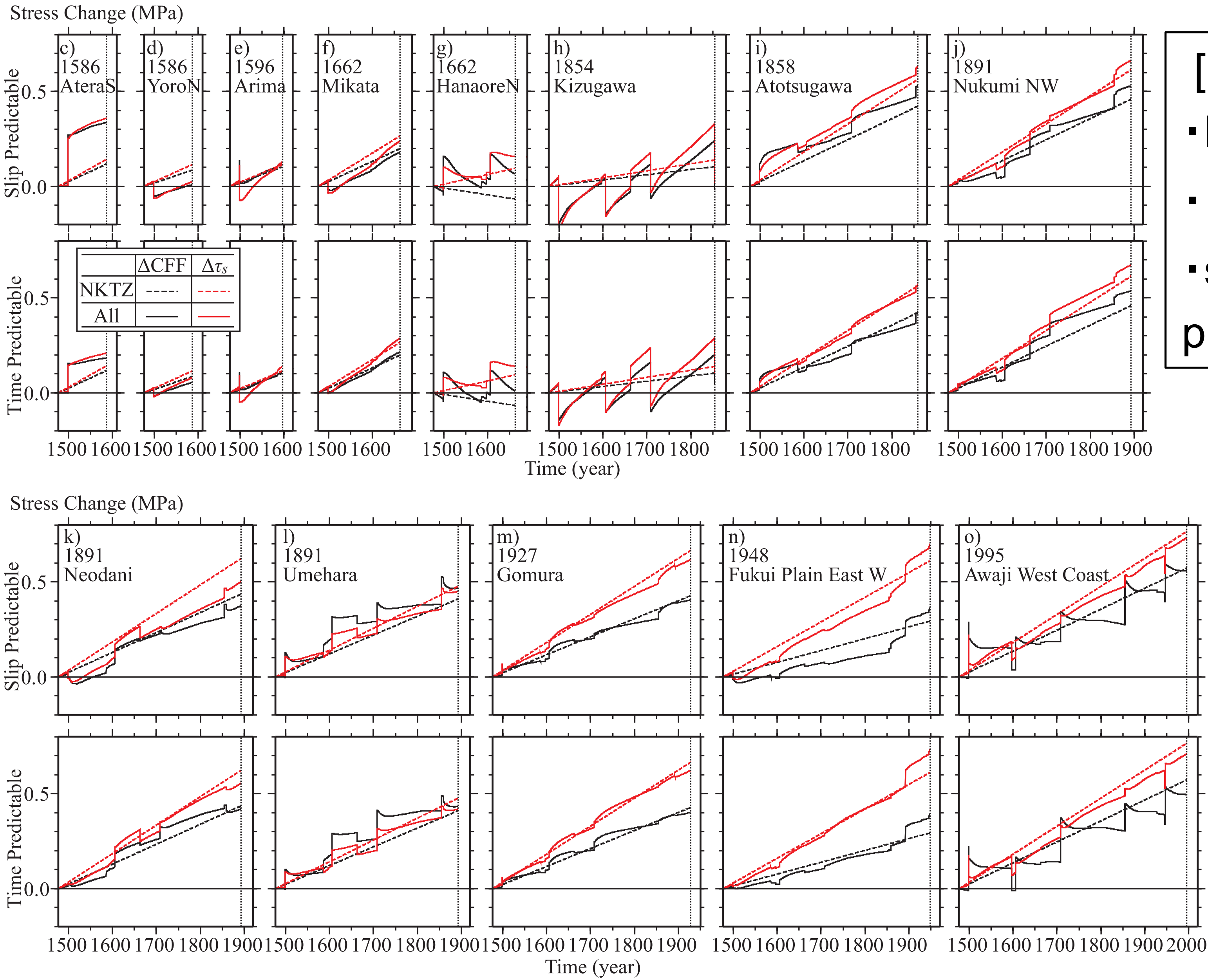
Fig. 5. Magnitude-time plot in the Inner Zone of Southwest Japan. The shaded zones indicate the periods from 50 years before to 10 years after the Nankai trough events in 1605, 1707, 1854 and 1944.

Inland earthquakes in SW Japan happen much more frequently 50 years before and 10 years after the Nankai Earthquakes.
This phenomena can also be under-stood with ΔCFF (stress shadow).



Hori and Oike 1996. J Phys Earth 44:349–356
Hori and Oike 1999. Tectonophysics 308:83–98

more detailed study by Shikakura, Fukahata & Hirahara (2014, JGR)



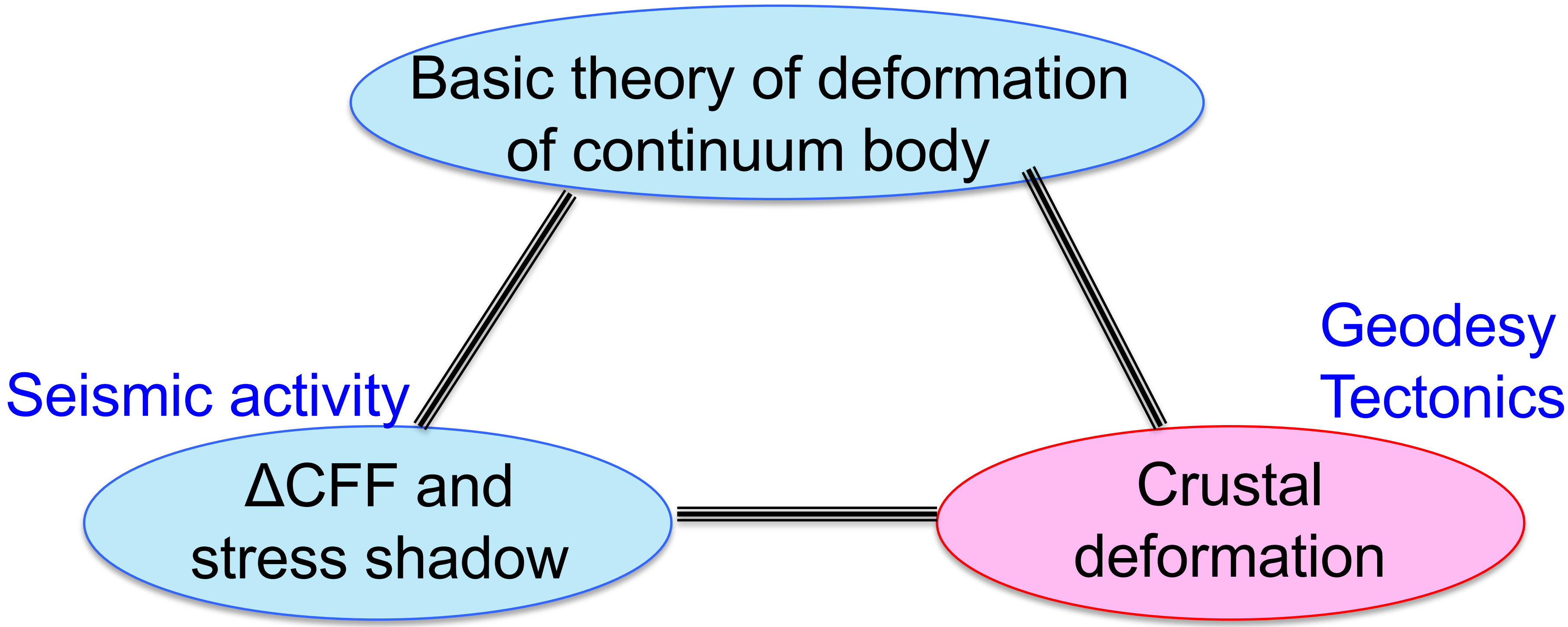
[Source of stress]

- Nankai earthq.
- Inland earthq.
- secular EW compression (3 kPa/yr)

Shikakura et al. 2014. JGR 119:502–518. https://doi.org/10.1002/2013J B010156

Inland earthquakes happen, when ΔCFF renews the maximum

Framework of this study



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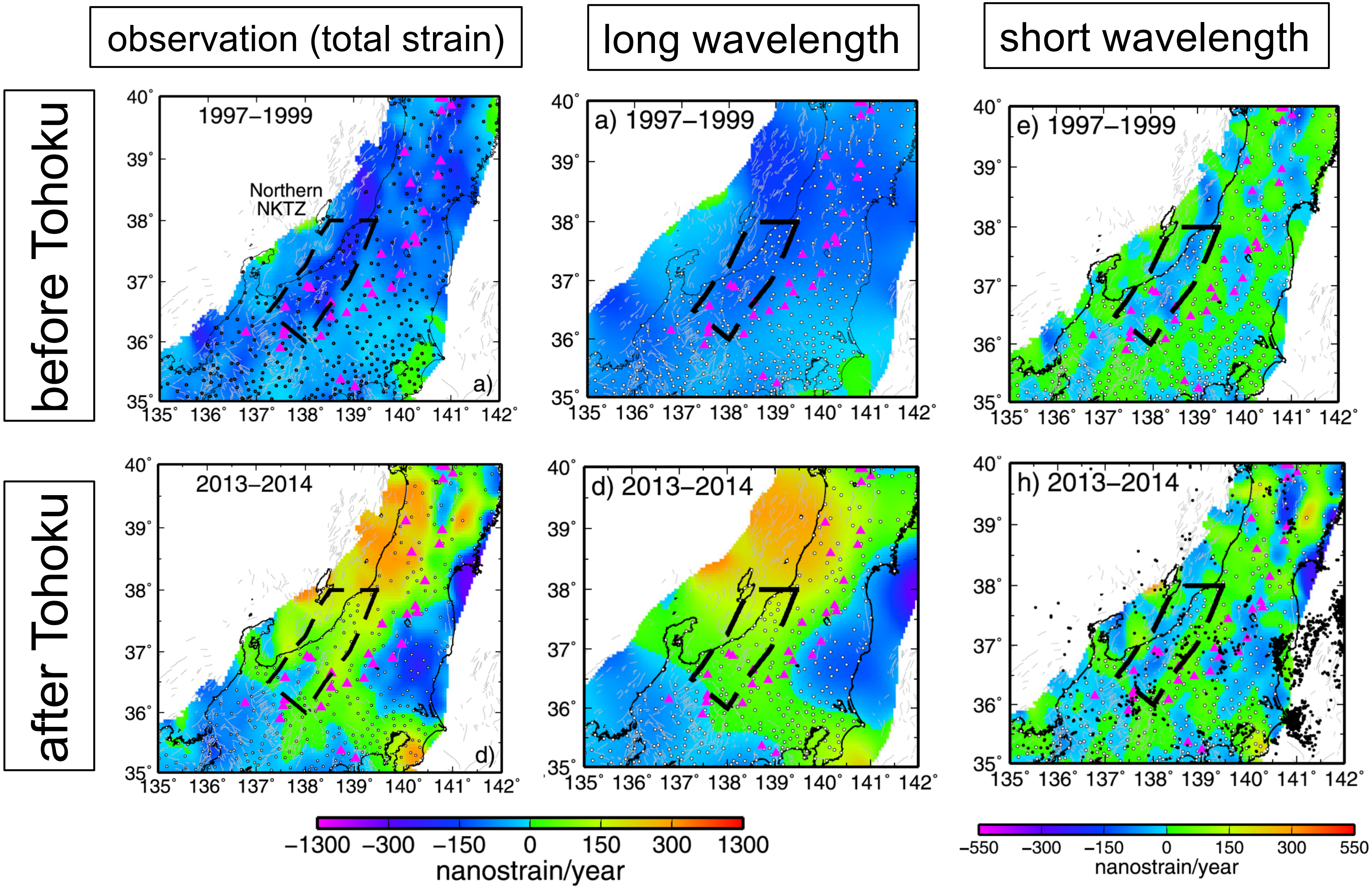
The concept of stress shadow on the basis of ΔCFF is useful not only to seismic activity but also to crustal deformation.

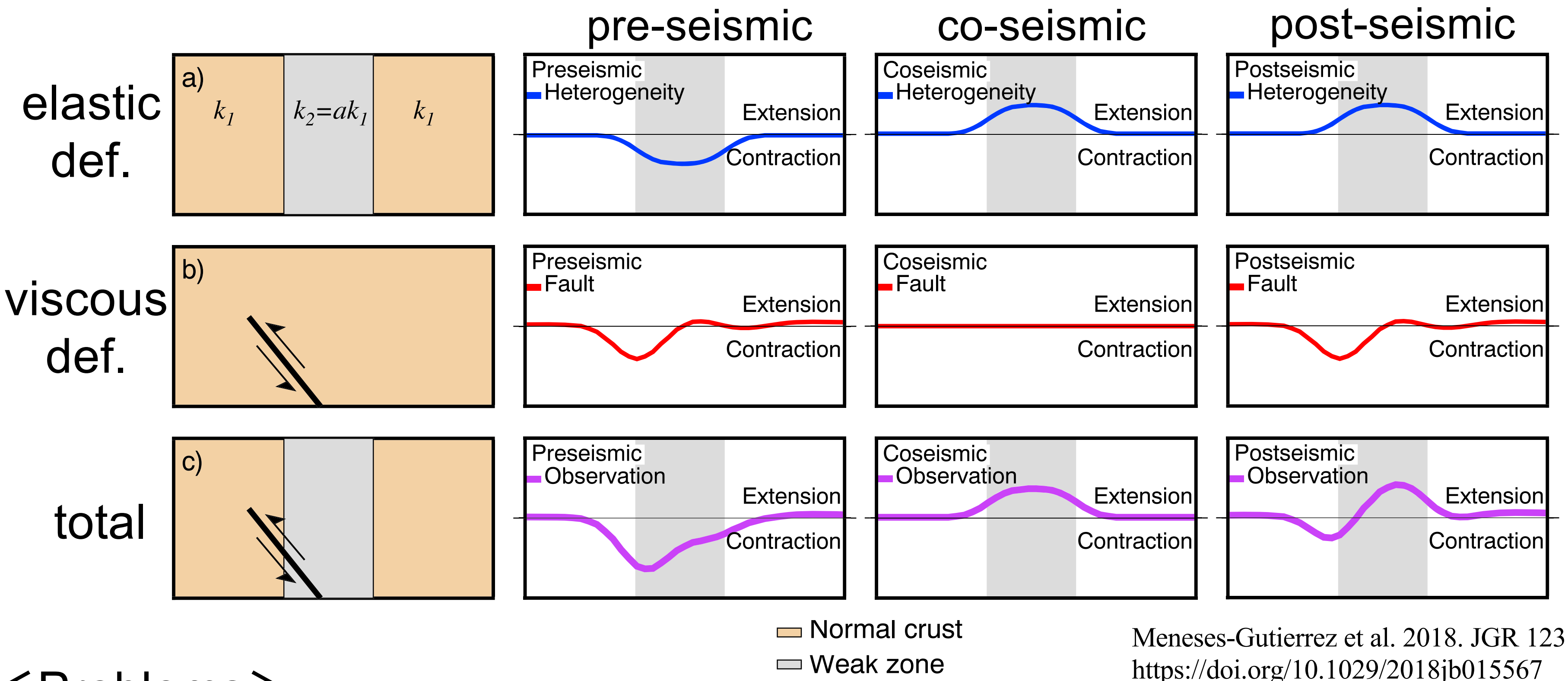
Meneses-Gutierrez & Sagiya (2016, EPSL)

Analyzing GNSS data of pre- and post- Tohoku-oki earthq., they succeeded in separating elastic (long w.l.) and inelastic (short w.l.) deformation.



Meneses-Gutierrez & Sagiya 2016. EPSL 450:366–371. https://doi.org/10.1016/j.epsl.2016.06.055

Meneses-Gutierrez et al. (2018): more detailed analysis using the below model



Meneses-Gutierrez et al. 2018. JGR 123:6072–6085.
https://doi.org/10.1029/2018jb015567

＜Problems＞

・Contrast of elastic constant (the value of a): 0.8 ~ 0.9 times (coseismic)
0.3 ~ 0.4 times (interseismic)

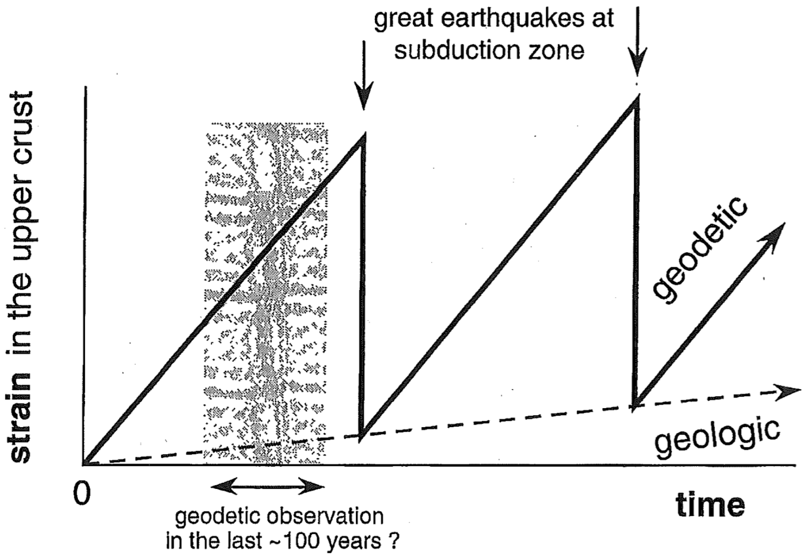
・Slip rate of the buried fault is significantly slower in the post-seismic.

・The recurrence interval of the Tohoku-oki earthq. is only about 300 – 500 years (because of faster strain rates in the pre-seismic period).

suggest the strain rate was faster in the pre-seismic

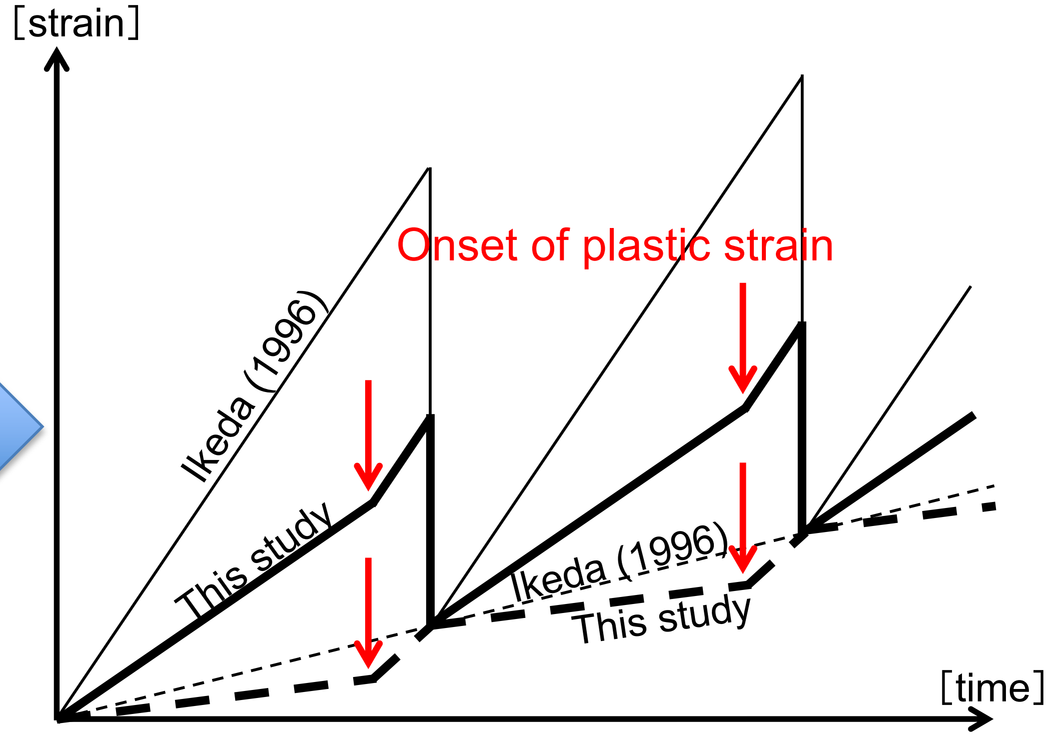
Assertion of this study

The concept of stress shadow on the basis of ΔCFF would be applicable not only to seismic activity but also to crustal deformation.



Ikeda (1996; Active Fault Res.)

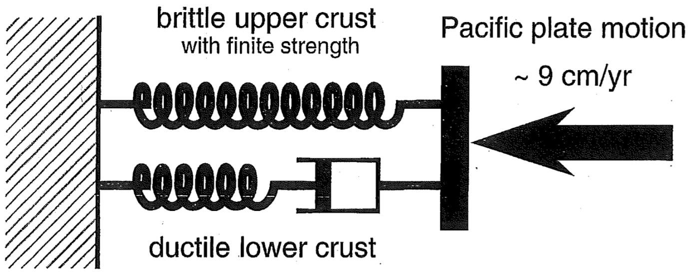
Ikeda 1996. Active Fault Res 15:93–99

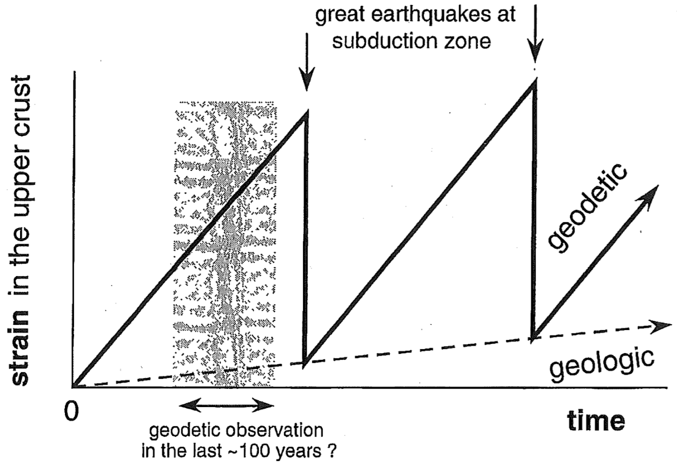


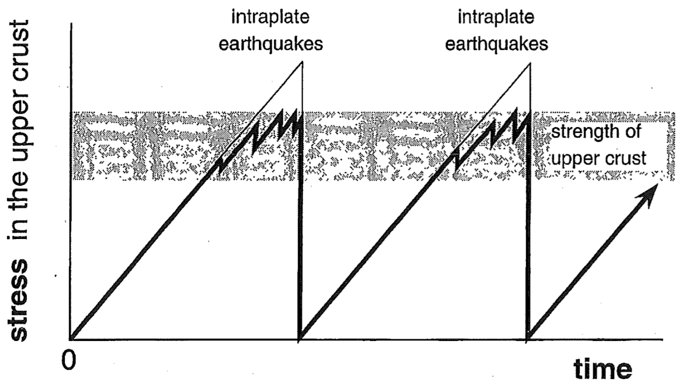
broken : inelastic strain (viscous + plastic)
solid : total strain (inelastic + elastic)
thin: Ikeda (1996); **bold: this study**

Because of plastic deformation, the EW shortening rate would be faster before the Tohoku-oki earthquake.

Ikeda (1996)

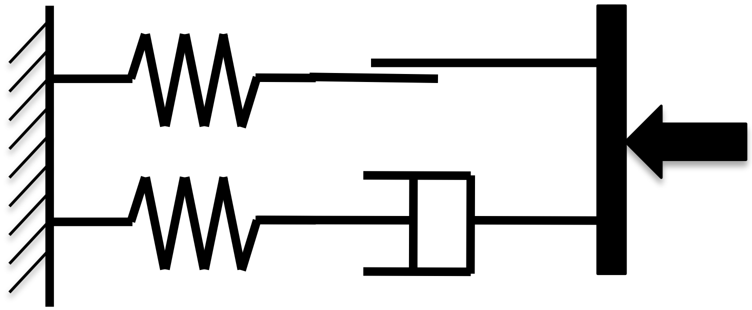


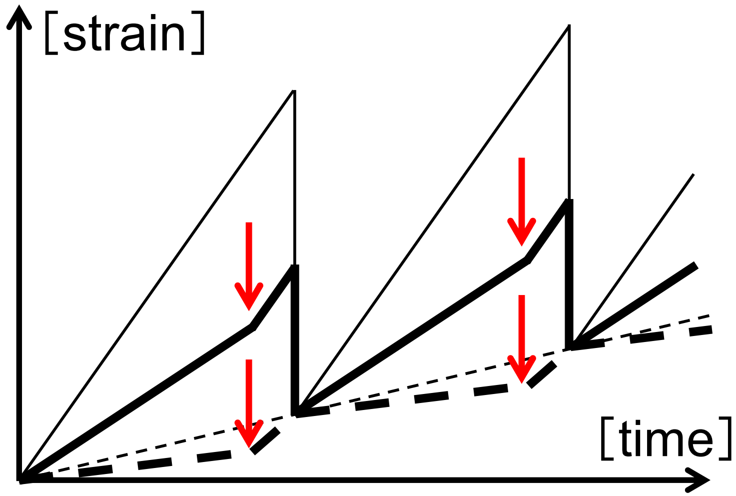


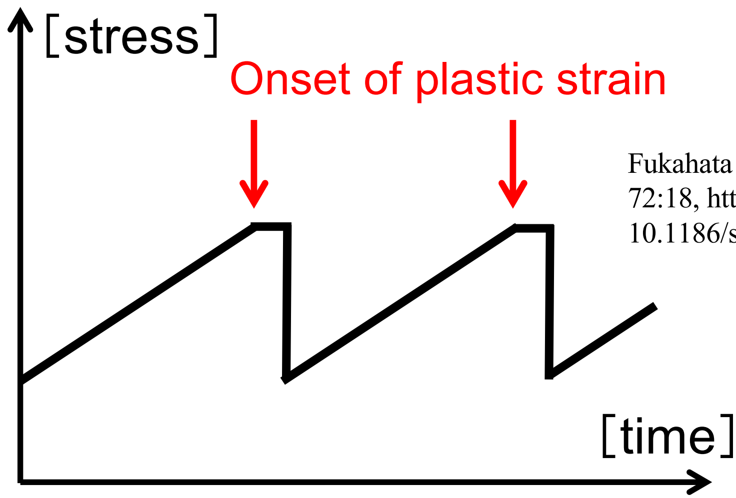


Ikeda 1996. Active Fault Res 15:93–99

This study







Fukahata et al. 2020. EPS 72:18, https://doi.org/10.1186/s40623-020-1144-1

Towards a quantitative estimate of plastic strain rate

Total strain rate: $d = V_E + V_V + V_P$

d: observation, V_{E}: elastic, V_V: viscous, V_P: plastic

Separation into short (S) and long (L) wavelength components:

$$d = d_L + d_S; \quad V_i = V_{iL} + V_{iS} \qquad (i = E, V, P)$$

Because $V_{ES} \cong 0$, we obtain for before (b) and after (a) the Tohoku-oki,

$$d_S^b = V_{VS}^b + V_{PS}^b$$

$$d_S^a = V_{VS}^a \qquad \text{(We assumed } V_P^a \cong 0\text{)}$$

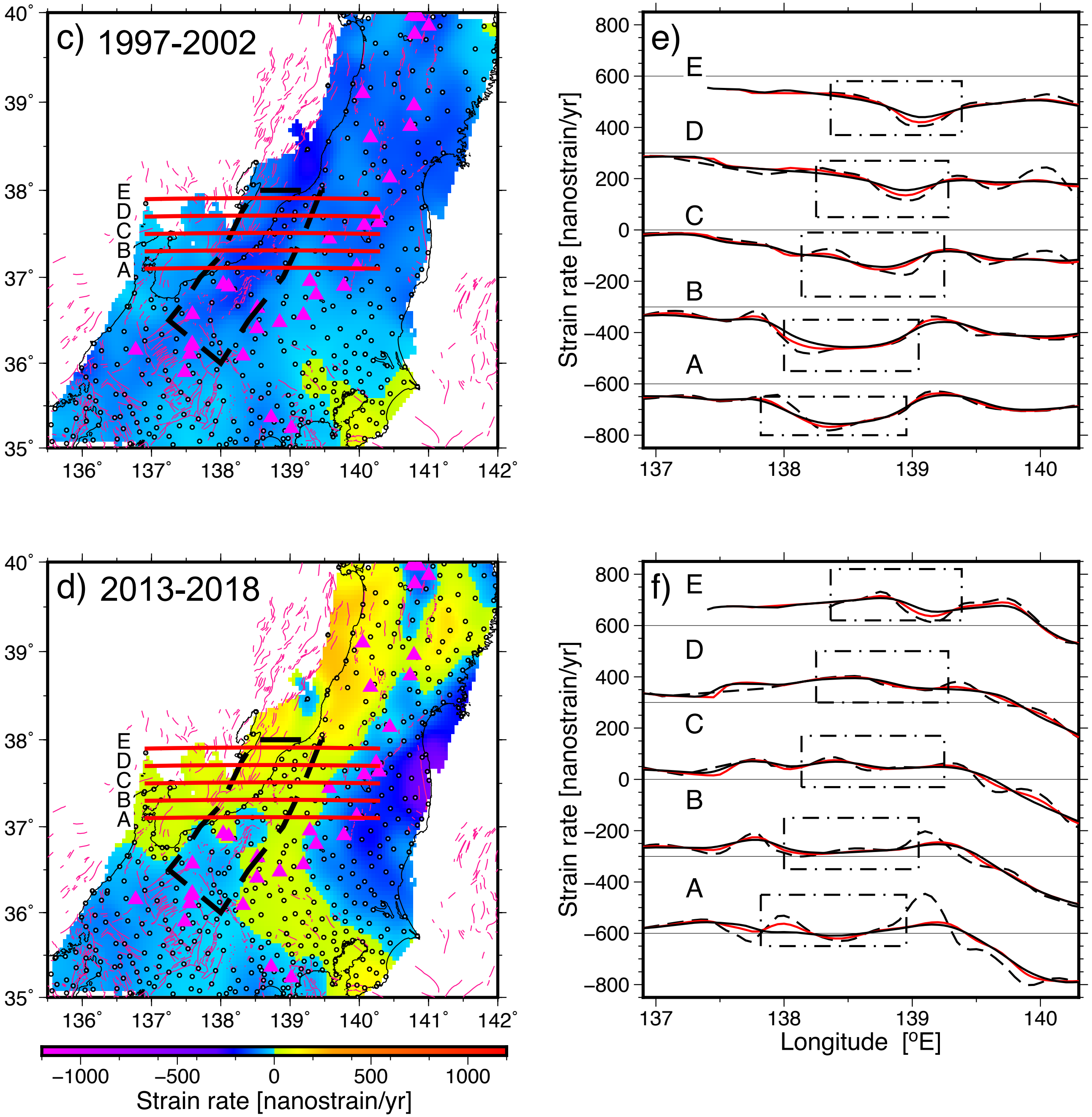
Because $V_{VS}^b \approx V_{VS}^a$, $\Rightarrow$ $\boxed{V_{PS}^b \cong d_S^b - d_S^a}$

Fukahata et al. 2020. EPS 72:18, https://doi.org/10.1186/s40623-020-1144-1

Comparison of contraction rates before and after Tohoku earthquake

Before Tohoku

After Tohoku



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Contraction rate is faster before the Tohoku-oki earthquake.

Comparison of contraction rates before and after Tohoku earthquake

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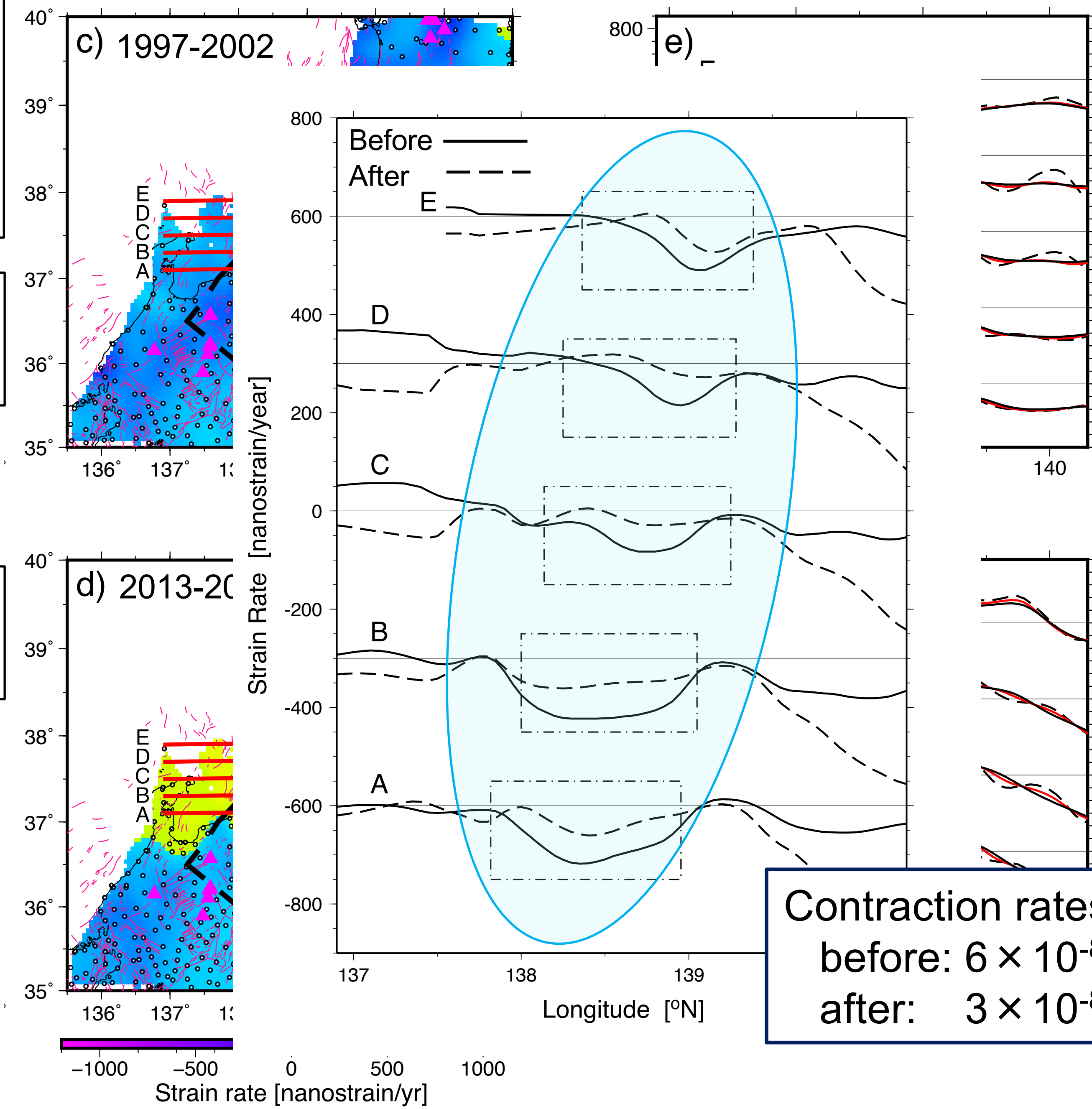
After Tohoku



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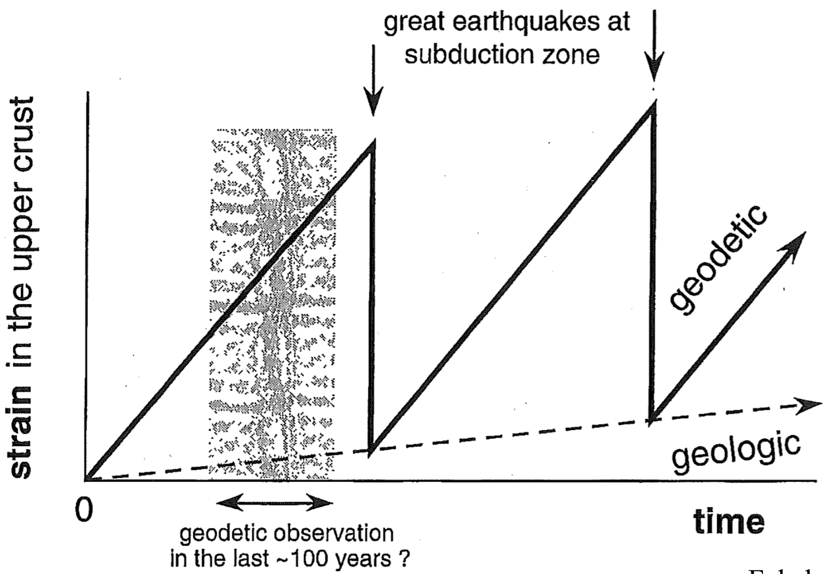
Contraction rates:
before: 6×10^{-8} yr
after: 3×10^{-8} yr

Contraction rate is faster before the Tohoku-oki earthquake.

Summary

・The concept of stress shadow based on ΔCFF would be applicable not only to seismic activity but also to crustal deformation.

・EW shortening rate was significantly faster before the Tohoku-oki, probably because plastic strain proceeded at that time.



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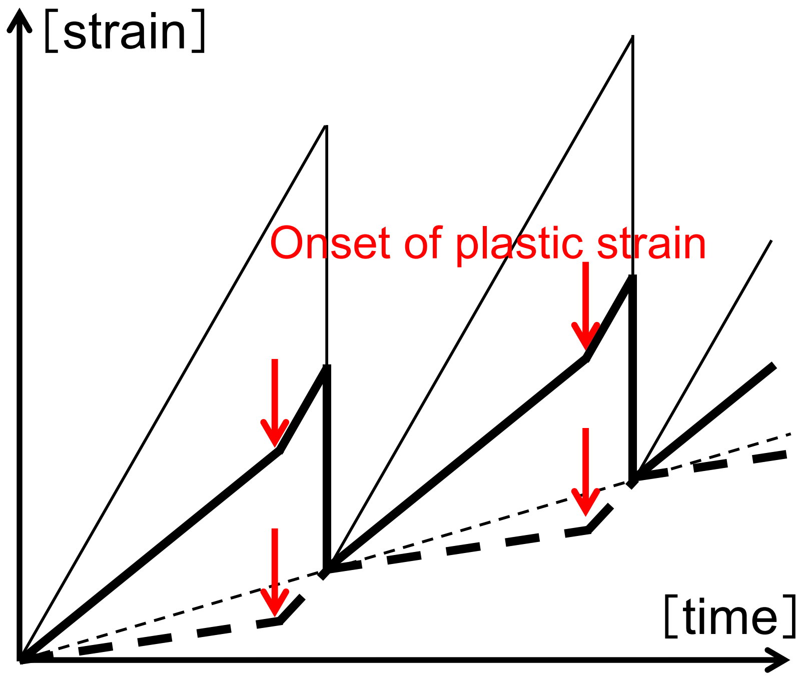

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