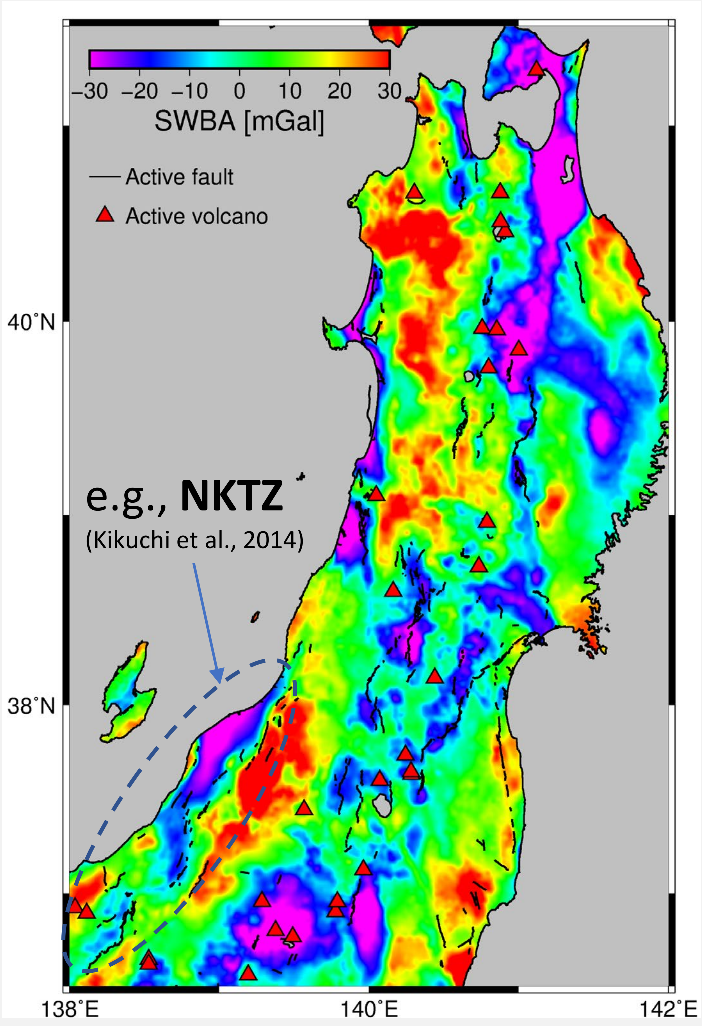
Short-wavelength Bouguer anomaly and active faults in the northeastern Japan arc from the viewpoint of differential geometry

G4.3 EGU21-14053

Mitsuhiro HIRANO, Hiroyuki NAGAHAMA and Jun MUTO (Department of Earth Sciences, Tohoku University)

Objective: We investigate short-wavelength (< 160 km) Bouguer anomalies (SWBA) due to faulting.



Gravity change due to fault dislocation

Volumetric strain $\boldsymbol{\varepsilon_v}$ under continuum dislocation field α_{ij} causes,

Gravity potential change

$$\boldsymbol{\delta\varphi} = \int G\rho\boldsymbol{\varepsilon_v}(\alpha_{ij})\frac{1}{r}dV \,. \tag{1}$$

(Yamasaki & Nagahama, 1999)

Accumulated fault dislocation can generate anomalies around -10 mGal.

Differential geometric correspondence

Fault dislocation is associated with the curvature of crustal bending (Nye,1953;Nagumo 1969ab).

Gravity field (space-time)

$$R^{\mu\nu} - \frac{1}{2}g^{\mu\nu}R = \kappa T^{\mu\nu}$$

(Einstein's equations)

Continuous dislocation field (material space)

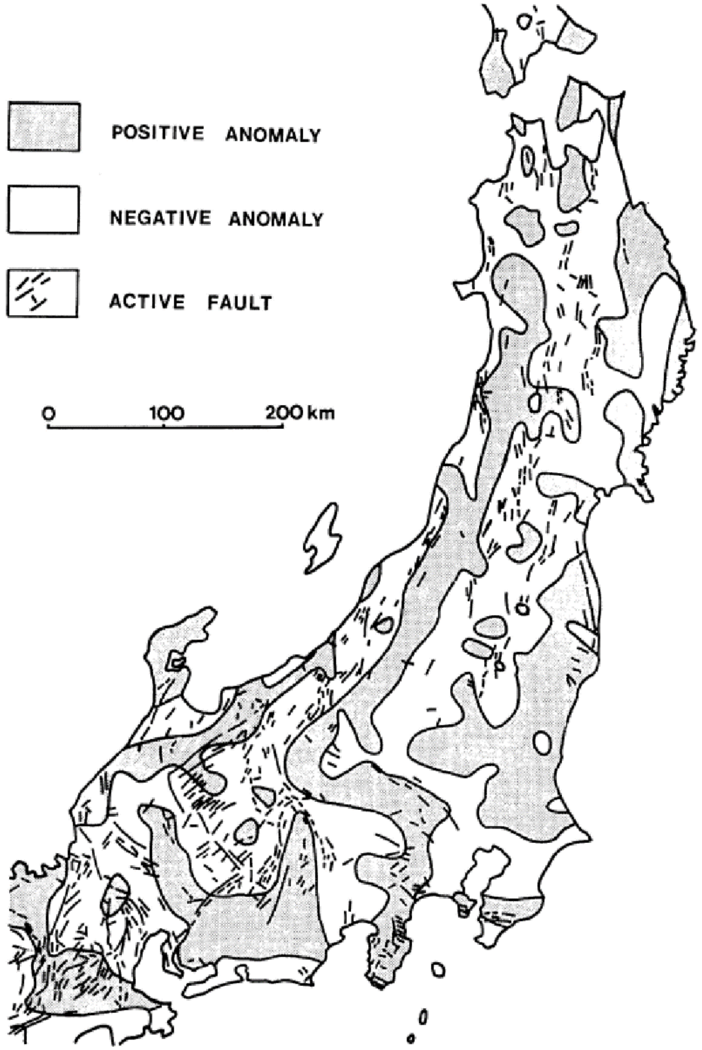
$$\alpha_{ij} = \epsilon_i{}^{lk}\left(\frac{1}{\sqrt{-g}}S_{lkj} + \frac{1}{g}R_{lkj}{}^{n}\nu_n\right)$$

(e.g., Kondo, 1955; Yamasaki & Nagahama, 1996)

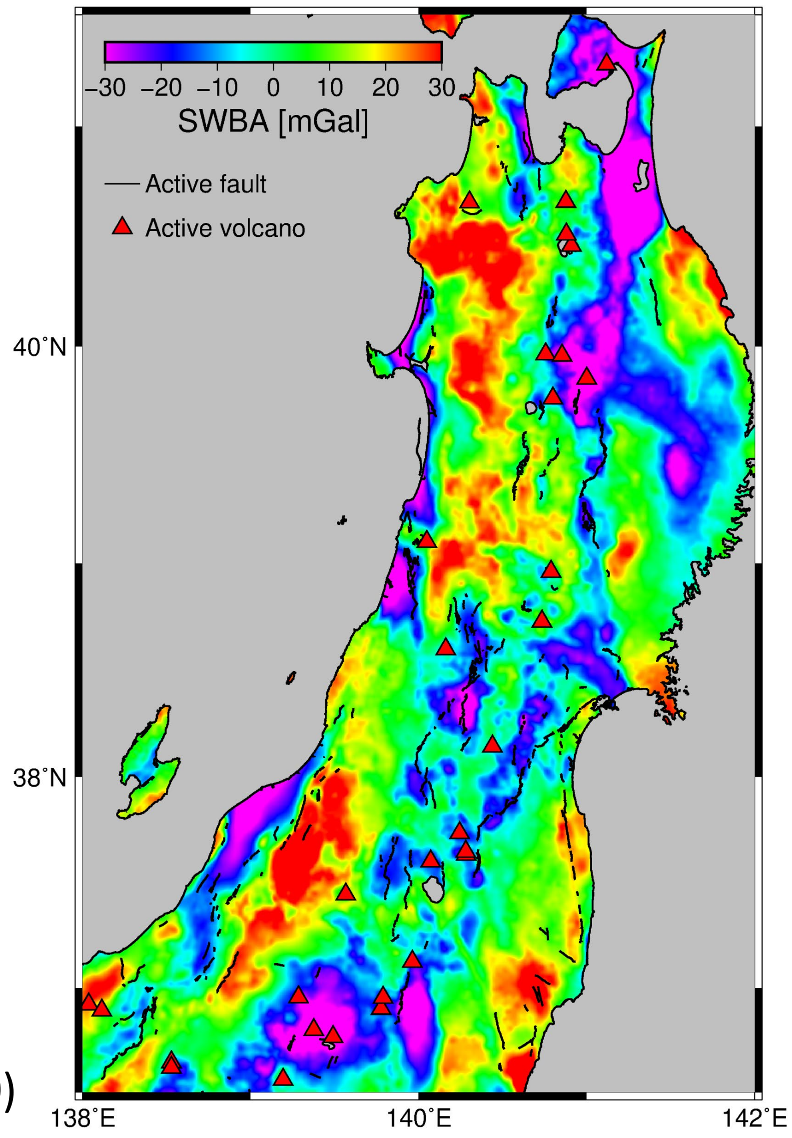
Conclusion: The SWBA is the result of projection of correspondence between curvature $\boldsymbol{R^{\mu\nu}}$, $\boldsymbol{R}$ and torsion $\boldsymbol{S_{lkj}}$ in space-time and material space.

Support Information

Short-wavelength (< 160 km) Bouguer anomaly



(Hagiwara, 1980)

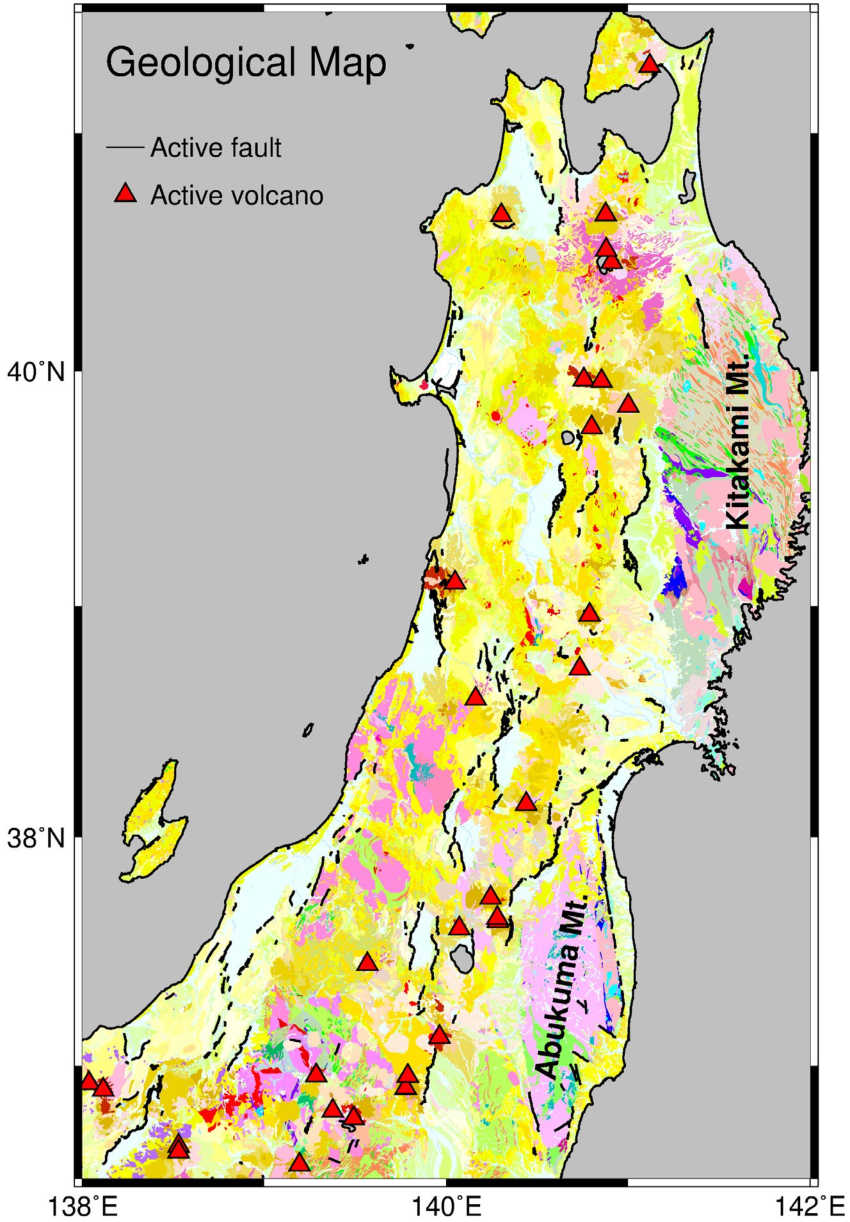


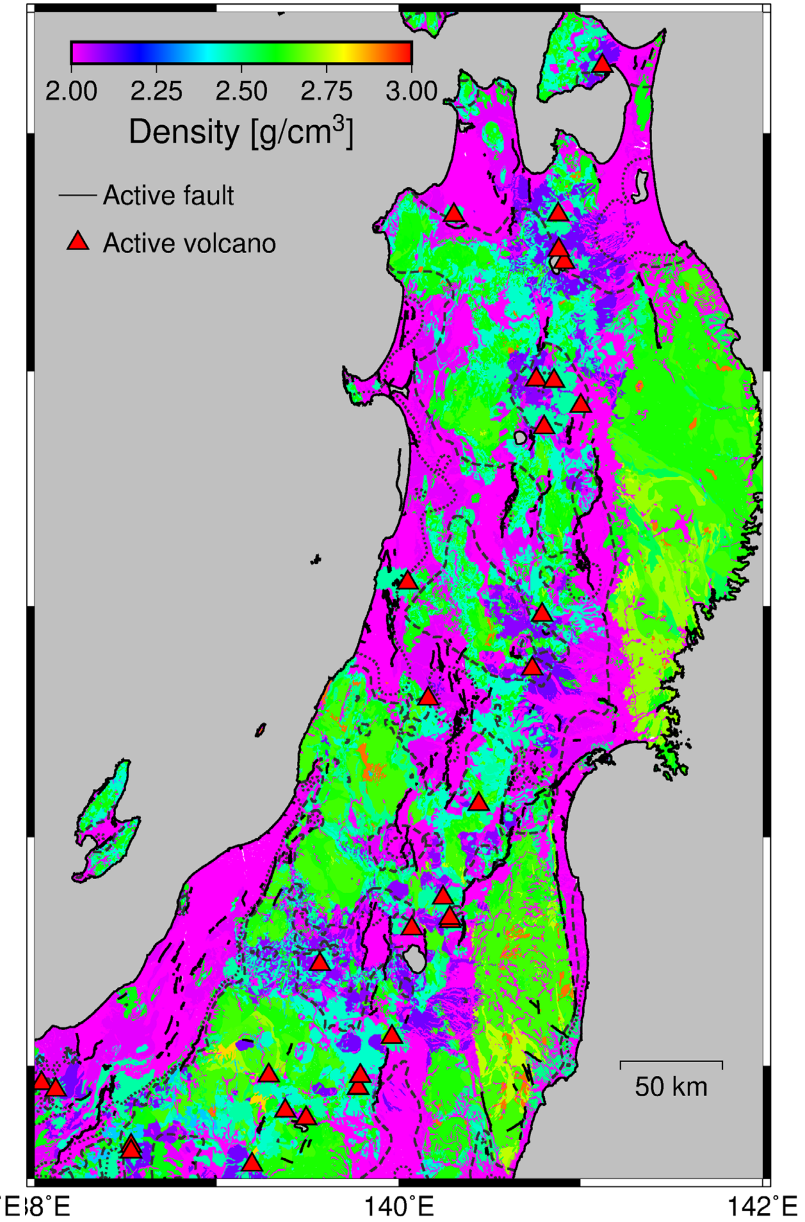
Short-wavelength (<160 km) Bouguer reflects only crustal structures because the crust cannot sustain topography at wavelengths greater than 160 km (Hagiwara, 1979, 1980).

Negative anomalies around active faults can be related to "active deformation" including crack and volumetric strain (Hagiwara, 1979, 1980,1991; Yamasaki & Nagahama, 1999).

The new SWBA was calculated from Gravity database of Japan, DVD edition (Komazawa et al., 2013) by FFT filtering.

Geological and Rock density maps





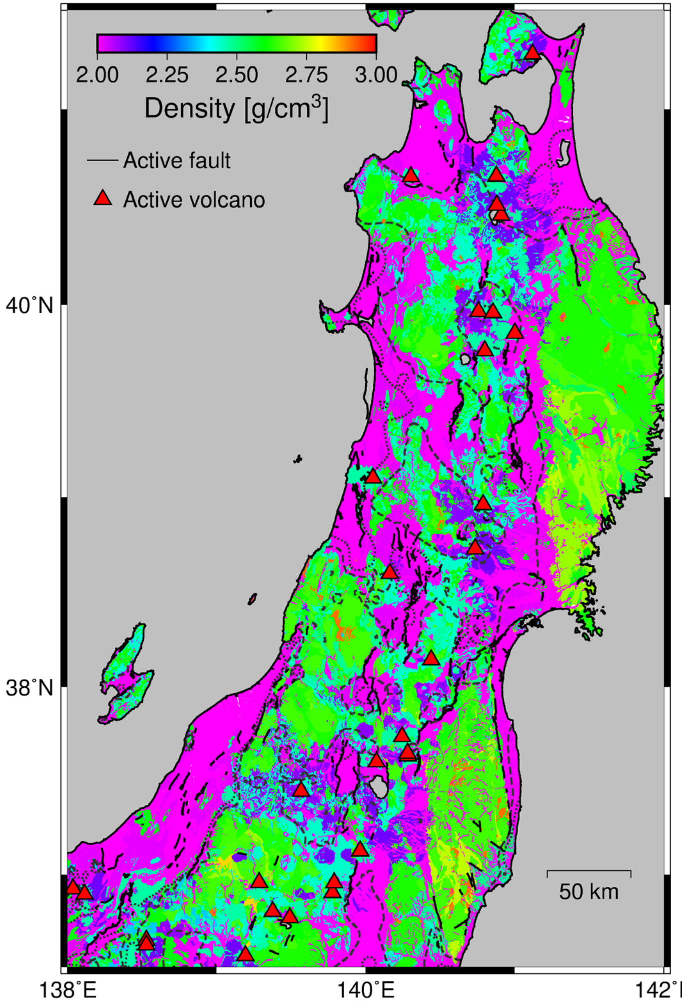
The northeastern Japan arc has a variety of geological distribution (Seamless Digital Geological Map of Japan (Basic), https://gbank.gsj.jp/geonavi/geonavi.php?lang=en&mode=pub).

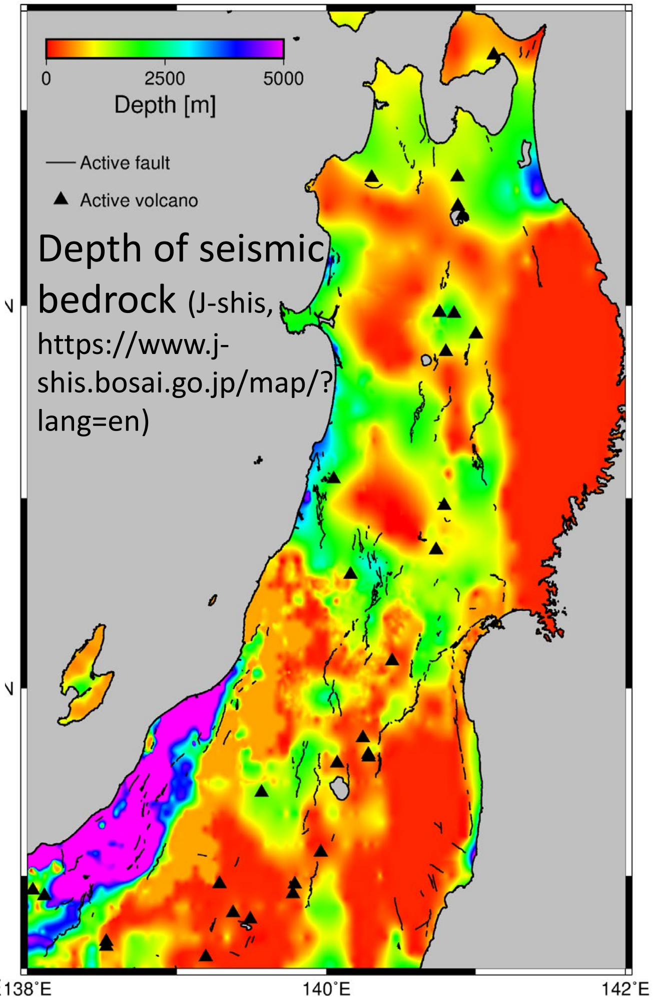
Based on rock density for each geological unit (Iwaya and Kano, 2005), we repaint the geological map to the rock density map.

Estimation of gravity anomaly due to sedimentation

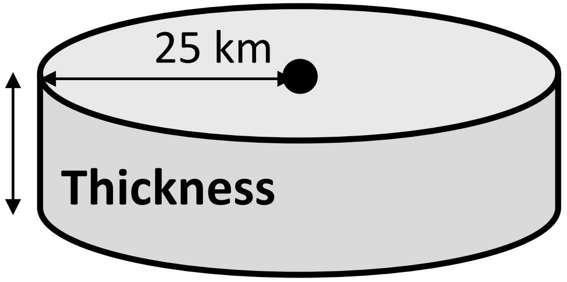
Anomaly at the center of a cylindrical model→the maximum contribution of the sedimentary layer

Upward connection filter (8 km)→more than 70 % long wavelengths (> 160 km) are removed.



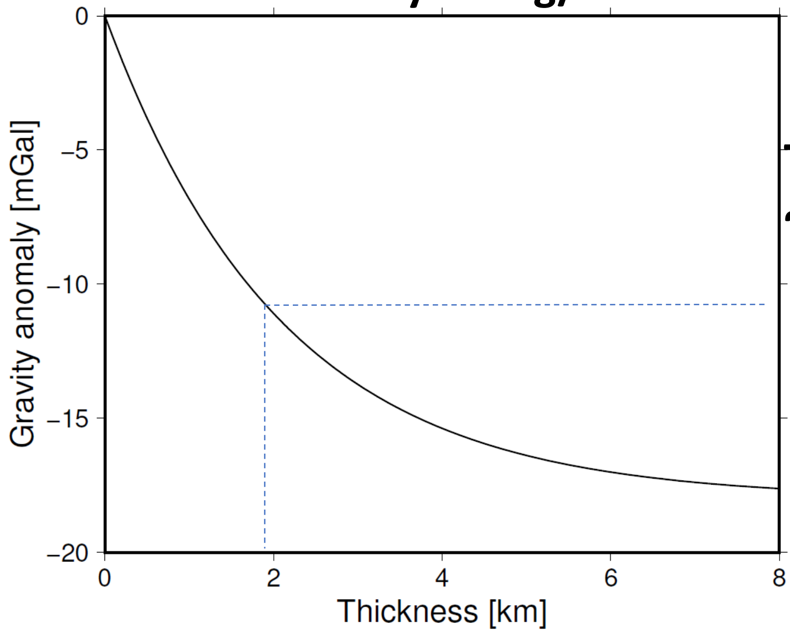


Surface density 2.0 g/cm^3



Density exponentially closing a constant
(Cordell,1973; Hagiwara,1983)

Lower density 2.67 g/cm^3



Thickness ~2 km：
Min. -10 mGal

Min. -20 mGal

Estimation of gravity anomaly due to faulting

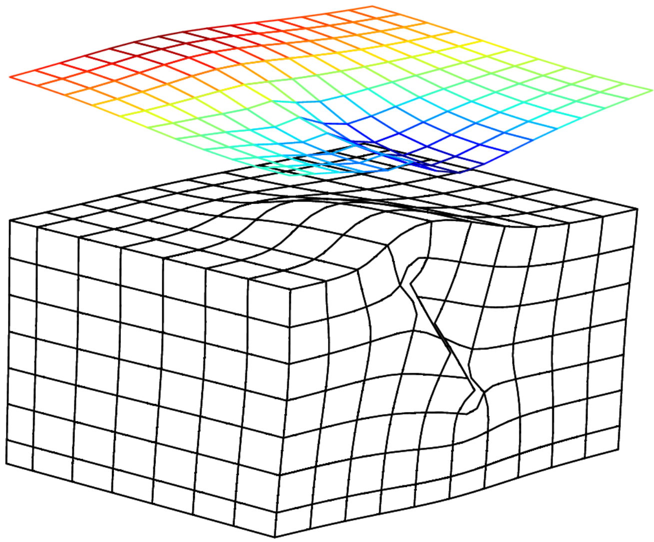
According to the equation of gravity change $\delta\varphi$ based on the continuum dislocation theory (Yamasaki & Nagahama, 1999),

$$\delta\varphi = \int G\rho\varepsilon_v(\alpha)\frac{1}{r}dV\,,$$

$$\varepsilon_v = \int C_{pqmn}\partial_q P_{ip}\epsilon_{inh}\alpha_{hm}\,dV.$$

G: Newtonian constant
ρ: density
C_{pqmn}: elastic modulus
P_{ip} : propagator function
ϵ_{inh}: Levi-Civita symbol

Gravity field due to faulting



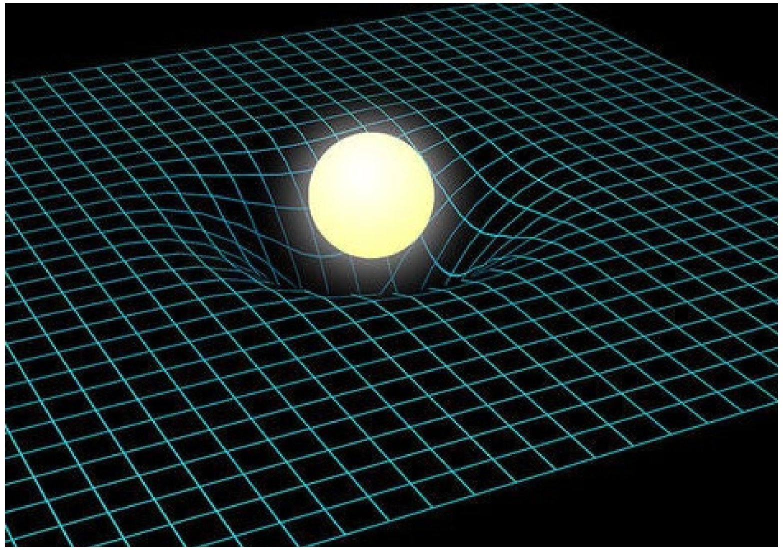
Fault dislocation model

Volumetric strain ε_v, in proportion to dislocation density α in the crust, generates gravity change $\delta\varphi$.

5 m dis-slips on the plane of a reverse fault along with a 45° dip-angle generate about -3.0×10^{-2} mGal at a maximum around the fault (Okubo, 1992).

Suppose that reverse faults with a 45 angle of dip uplifted as much as 1000~2000 m over the past three million years (e.g., sato et al., 2002), **accumulated fault dislocations can theoretically generate negative gravity anomalies of about -8.4~16.8 mGal at a maximum**.

The relatively theory and the continuum dislocation theory



(after https://gwpo.nao.ac.jp/gallery/000027.html)

In the relatively theory, gravity field is geometrized by Riemannian geometry.

$$R^{\mu\nu} - \frac{1}{2} g^{\mu\nu} R = \kappa T^{\mu\nu}$$

(Einstein, 1916)

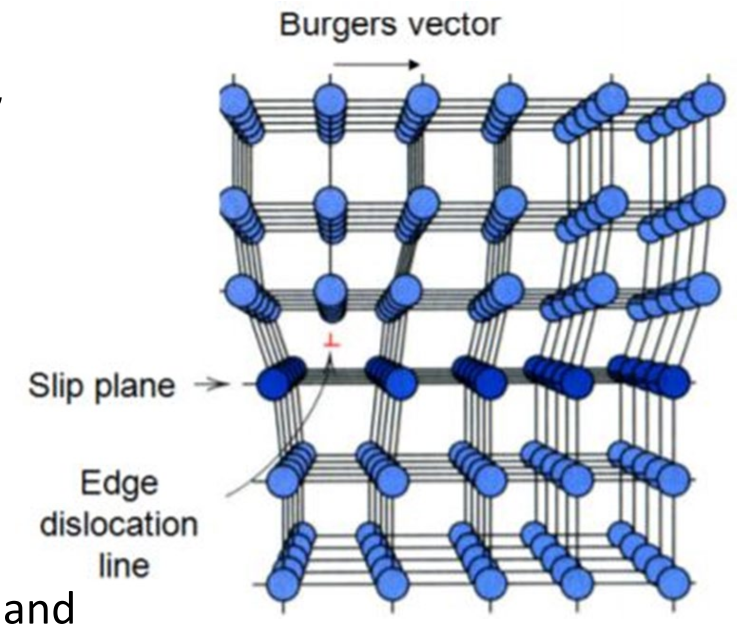
$g^{\mu\nu}$ defines the distortion of the space-time, being related to gravity potential.
$R^{\mu\nu}$ and R consited by $g^{\mu\nu}$ represent curvature in the space-time.
$T^{\mu\nu}$ is energy-momentum tensor.

In the continuum dislocation theory, dislocation density α_{ij} is express as curvature $R^{\mu\nu}$ and torsion tensor S_{lkj} in material space (Riemannian-Cartan space).

$$\alpha_{ij} = \epsilon_i{}^{lk} \left(\frac{1}{\sqrt{-g}} S_{lkj} + \frac{1}{g} R_{lkj}{}^{n} \nu_n \right)$$

(e.g., Kondo, 1955; Yamasaki & Nagahama, 1996)

ν_n is an arbitrary vector.



(after Kobasi&Takada,2016).

Based on the equations, Eq. (1) holds up under the correspondence between curvature and torsion in space-time and material space (Yamasaki and Nagahama, 1999).