Geothermal gradient can be used to estimate the maximum magnitude of earthquakes

We estimated the spatial variation of the maximum earthquake magnitude in the crust under Japan. The maximum width of faults in the crust, which gives the maximum magnitude of earthquakes, should be determined by the thickness of the brittle layer in the crust. The thickness itself, in turn, should be generally related to the geothermal structure in the upper crust. Therefore, it is expected that the geothermal gradient in the upper crust can be used to estimate the maximum magnitude of earthquakes.

Relationship between Maximum Earthquake Magnitude and Geothermal Gradient

In order to verify above inference, we examined a relationship between the maximum magnitude of earthquakes and the geothermal gradient in the crust. Two data sets of large earthquakes (M≥6.5) which occurred in the inland area of the Japanese Islands are used:

(1) earthquakes occurring in 1927-2005 (Japan Meteorological Agency Earthquake Catalogue) and


In this study, interplate earthquakes are excluded. An areal distribution of earthquakes used in this study is shown in Fig. 1.

For the geothermal gradient data, the database by Tanaka et al. (2004) was referred. The spatial distribution of the geothermal gradient is estimated by low (L≥100km) pass-filtering of the gradient data observed in deep (D≥1000m) boreholes (Fig. 2).

For the earthquakes of the two groups, we obtain curves which clearly confine the upper-limits of the magnitude distributions as a function of the geothermal gradient.

Fig. 3 shows the relationship between maximum earthquake magnitude and geothermal gradient. The circles and the diamond points in this figure show recent (after 1927) earthquakes and historical (after 1500) ones, respectively.

The relation between a geothermal gradient and the maximum magnitude can be explained as follows, and the comparison with an actual observation result was tried.

(I) The relation between fault length L and earthquake scale M is given as

\[ M = 1.67 \log L + 4.83 \]  (Matsuda, 1975).

(II) The fault length L is assumed to be twice the fault width W.

(III) If the brittle fracture happens in the crust whose temperature is 400°C or less, the thickness of the fracture area of the region is given as

\[ W = \frac{2 \sqrt{x^2 + 400}}{1000 \text{ km}} \]  (geothermal gradient 10°C/km, temperature 400°C)

Then, the relation between geothermal gradient T g and maximum magnitude M max is assumed to be

\[ M_{\text{max}} = -1.67 \log T_g + 9.93 \]  (1)

The lower curve in Fig. 3 is this maximum magnitude curve. On the other hand, when two adjacent faults rupture consecutively, \( M_{\text{max}} \) is given as

\[ M_{\text{max}} = -1.67 \log T_g + 10.43 \]  (2)

This maximum magnitude curve is the upper one depicted in Fig. 3.

In this inference, we examined a relationship between the maximum magnitude of earthquakes and the geothermal gradient in the crust. Two data sets of large earthquakes (M≥6.5) which occurred in the inland area of the Japanese Islands after 1500.

Geothermal gradient can be used to estimate the maximum magnitude of earthquakes

- Maximum magnitudes of earthquakes and the geothermal structure in Japanese inland area
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- Maximum magnitude maps over the Japanese Islands
- When assuming that the activity of the inland earthquake in the Japanese Islands is constant, future activity of a time scale can be expected from a past seismic activity of the same time scale. The maximum earthquake magnitude can be estimated from the relationship between the maximum magnitude and the geothermal gradient. The geothermal gradient data observed in deep (D≥1000m) boreholes (Fig. 2).

References:
- Utsu, T. (1985), Catalog of large earthquakes in the region of Japan from 1885 through 1980 (correction and supplement), Bulletin of the Earthquake Research Institute, University of Tokyo, No.60, 639-562. (in Japanese with English abstract)