DATA REPOSITORY ITEM 2002052

Estimation of crustal deformation rates from earthquake statistics

METHOD

Crustal deformation rates can be related to earthquake rates through seismic moment rates. We use the approach presented by Anderson (1979) and Hyndman and Weichert (1983), which assumes that the seismicity follows a Gutenberg-Richter recurrence relation up to a maximum magnitude. This method requires to estimate both the maximum magnitude and the form of the recurrence curve close to the maximum magnitude. We assume that the maximum magnitude limit is an abrupt truncation in the earthquake density function (i.e. no characteristic earthquakes). The estimation of crustal deformation rates form earthquake catalogue statistics follows four main steps.

1) Frequency-magnitude (Gutenberg-Richter) distribution

We use a catalogue composed of ~1500 earthquakes, M_L = 3 and above, from 1907 to 2000. We use the statistical approach developed by Weichert (1980) for completeness of the catalogue varying with magnitude. The frequency-magnitude relation is:

$$\log(N) = a - b\,M_L$$

where N is the cumulative number of events per yr for a given magnitude M_L, and a and b are the distribution parameters solved for. a and b are mostly constrained by the small magnitudes. Their uncertainties follow a Poison distribution.

2) Magnitude to moment

Magnitude rates are converted to moment rates using an empirical relation (Hanks and Kanamori, 1979). Magnitudes in our catalogue are local magnitude M_L, for which the conversion to moment M_0 is given by:

$$\log(M_0) = 9.05 + 1.5\,M_L$$

3) Total moment rate

The total moment rate M_0' is estimated by integrating the magnitude-frequency distribution up to the assumed maximum magnitude M_X:

$$M_0' = b\ 10^{(1.5-b)\ MX + a + 9.05} / (1.5 - b)$$

4) Moment rate to deformation rate

The seismic slip rate s' on a fault is proportional to the rate of seismic moment release M_0' per unit time and per unit fault area:

$$s' = M_0' / (\mu\ A)$$

where μ is the shear modulus. Assuming that the seismicity is accommodate along a characteristic fault type, the overall deformation rate d' is:

$$d' = C\ M_0' / (2\ \mu\ A')$$

where A' is the cross section area in a plane parallel to the main fault direction and C depends on the type and orientation of faulting with respect to the regional motion; for a strike-slip fault C = 0.5, and for a thrust fault C = 0.75-1 (c.f., Anderson, 1979; Molnar, 1979).

APPLICATION TO THE MACKENZIE AND RICHARDSON MOUNTAINS

We use C = 1 (thrust fault) and C = 0.5 (strike-slip fault) in the Mackenzie and Richardson Mountains, respectively, based on the dominant earthquake focal mechanisms and the structural style in each belt. The cross section area is calculated assuming a seismic thickness of 10-15 km, based on local studies of earthquake depth distribution (Wetmiller et al., 1988; Cassidy and Bent, 1993). This maximum seismogenic depth is supported by our thermal model, which indicates a temperature of 350 °C at ~15 km depth.

We choose the maximum magnitude for the Mackenzie and Richardson Mountains region using the maximum fault area in each region and and empirical relation between magnitude M and fault area A (Wells and Coppersmith, 1994):

$$\log(A) = -4.07 + 1.0\ M$$

In the Mackenzie Mountains, the main structure is the Plateau fault, a westward dipping thrust with a trace ~270 km long (Gabrielse, 1991). The largest earthquakes in this region correspond to thrust mechanisms along ~30° dipping faults (Wetmiller et al., 1988). Given a seismic thickness of 12 km, the rupture area for an earthquake along a 250 km long, 30° dipping thrust is 6000 km^2, implying a maximum magnitude M_X ~7.8. In the Richardson Mountains, the largest events are associated with 50-70° dipping strike-slip faults. No direct estimate of the maximum fault length is available for this region, thus we choose a length of 200 km based on the N-S extent of the seismicity. With a 12 km seismic thickness, this leads to a maximum rupture area of ~2800 km^2 and a maximum magnitude M_X ~7.5.

We estimate the range of possible deformation rates using the following range of parameters: C = 1, M_X = 7.5-8.0, thickness = 10-15 km for the Mackenzie Mountains; and C = 0.5, M_X = 7.2-7.8, thickness = 10-15 km for the Richardson Mountains. The statistical uncertainties on the deformation rate estimates are 0.3-0.7 mm/yr. We obtain 2.0-5.6 mm/yr of shortening for the southern Mackenzie region, 3.1-7.2 mm/yr of shortening for the northwestern Mackenzie, and 2.2-7.7 mm/yr of strike-slip for the central Richardson region. If we use the largest historical earthquake in each region to constrain M_X, the deformation rates are significantly lower: 1.3 mm/yr (M_X = 6.9), 0.8 mm/yr (M_X = 6.6), and 1.0 mm/yr (M_X = 6.6), respectively.

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