The scaling of source parameters of mining earthquakes.

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Scaling relationships among various source parameters are important clues to understand source processes of earthquakes. In particular the relationship between the corner frequency, fc, and the seismic moment, Mo , has been investigated by many researchers. Aki (1967) investigated the spectrum of seismic waves and reported a relationship of Mo~fc-3. For small earthquakes, the breakdown of this relationship has been reported. Recently, no breakdowns of the relationship for microearthquakes were reported from high quality observation at deep boreholes on the San Andreas fault in southern California(Abercrombie,1995) and on the Nojima fault in Japan (Hiramatsu et al., 2002) and in a deep gold mine in South Africa (Ogasawara et al., 2001). Here, we perform accurate analyses of fc and Mo of microearthquakes from near source observation in a deep gold mine and report the scaling relationship between fc and Mo. And we estimate various source parameters and also conclude its scallings.

We analyze waveform data recorded by nine tri-axial borehole accelerometers in Precambrian quartzite (typical Young's modulus of 70Gpa) within 200 m along a haulage tunnel 2650m deep in the Mponeng mine in South Africa from February to December in 1996. More than 25 thousand seismic events were recorded with a sampling frequency of 15 kHz and a dynamic range of 120 dB. The recording system has a flat response up to 2 KHz. Among those events, we select 126 events (10^8~Mo~10^12 Nm) with high S/N and precise source mechanism.

We locate hypocenters assuming the infinite medium with the P-wave velocity 6.1 km/s and the S-wave velocity 3.6 km/s. We also assume the omega square model by Brune (1970) as the source spectrum. First, we estimate the attenuation effects of Q from the observed spectrum of band-pass filtered seismograms (10~1000Hz) by separating the source and the site terms by the inversion method. Second, we perform the moment tensor inversion with Q values obtained above using band-pass filtered velocity waveforms(50-300Hz). The Green function is calculated by the discrete wave number integral method into account the effect of anelasticity (Takeo, 1985). Finally, we estimate the corner frequency and the static stress drop from the displacement spectra of band-pass filtered displacement waveforms (10-1000Hz) of P- and SV-, SH- waves applying the Brune's model, Q values, the radiation coefficients and then the average values are adopted as the corner frequency and the static stress drop of each event. And by a method of Ide and Beroza(2001), we estimate the apparent stresses.

The choice of Q value is an important key for the study of source parameters because the low-pass filter effect of Q affects the values of source parameters. A rough assumption of a constant Q and an average radiation coefficient causes an error of ~40% for fc and an error of ~200% for Mo, resulting an error of ~250% of Ds. These large errors could be critical for studies of detail spatial and temporal variations in source parameters.

The earthquakes analyzed in this study show the constant stress drop of 0.1~10MPa in the ranges of 40~fc~500Hz and 10^8~Mo~10^11 Nm. This supports that Mo scales as fc-3. This result is consistent with the previous works by Ogasawara et al. (2001). We can find no difference of the scaling relationship between induced earthquakes in a deep gold mine and natural earthquakes observed at deep holes on the fault zones by Abercrombie (1995) and Hiramatsu et al. (2002). And The apparent stresses are 0.1~apparent stress~10MPa for events of 10^8 ~Mo~10^11 Nm. It is likely that the apparent stresses is constant and independent of earthquake size in these range. The apparent stress are the same that obtained by other reserchear for other moment ranges, implying that there is no difference between mining earthquakes and natural earthquakes.