PSP07

Scaled Energy for Natural and Induced Seismicity

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SUMMARY

The relations between seismic moment M0 and seismic energy Es for various scale events were considered.
Averaging over the entire scale range gives relations close to the self-similar assumption. A more detailed examination reveals several hierarchical levels, in which changing the event parameters with the scale occurs by different laws, often strongly deviating from the self-similar scaling.
The first class of events is presented by small events with Mw <1 ÷ 2, located at shallow depths of about 1-2km. In this interval, the value of scaled energy Es/M0 regularly increases with the scale, which is related mainly to the dependence of rock shear modulus on scale. The second interval should include small earthquakes located at seismogenic depths. If hypocenters are confined to small cracks located aside from the central part of major faults, their parameters correspond to the self-similar laws and Es is proportional to M0. Earthquakes with moment magnitude Mw ~ 3.5-4 make the transition band, which is the boundary between the two ranges in which the scaling relations differ significantly.

Introduction

One of important questions in seismology is whether large and small earthquakes are governed by the same mechanics. The question of whether radiation efficiency of earthquakes scales with magnitude or it is constant and doesn't depend on event size as for self-similar events is widely debated and is still essentially unresolved.

Method and results

We have collected and analyzed a wide range of experimental data, about 2,000 events in the entire range of scales, which concern the seismotectonics and geomechanics. The relations between seismic moment M_0 and seismic energy E_s both for microevents and for megaearthquakes were considered. We also investigated the laws of changing the geometric characteristics of faults and fractures and their mechanical properties with the scale.

Averaging over the entire scale range gives relations close to the self-similar assumption. A more detailed examination reveals several hierarchical levels, in which changing the event parameters with the scale occurs by different laws, often strongly deviating from the self-similar scaling (Fig.1).

The first class of events (the seismicity induced by mining or by filling reservoirs) is presented by small events with Mw <1 ÷ 2, located at shallow depths of about 1-2km. In this interval, fracture stiffnesses decrease inversely proportionally to their length, which corresponds to the self-similar laws. However, the value of scaled energy E_s/M_0 regularly increases with the scale, which is related mainly to the dependence of rock shear modulus on scale. The second class of events should include small earthquakes located at seismogenic depths. Here the parameters of events with Mw ~ 0 ÷ 3 are largely determined by the location of earthquake sources. If hypocenters are confined to small cracks located aside from the central part of major faults, their parameters correspond to the self-similar laws and Es is proportional to M_0. If sequences of repeated earthquakes occur directly on the segments of major fault zones, the stiffnesses of which differ significantly from those of small fractures, one can find significant deviations from the self-similarity.

The fault lengths of about 500-1000 m, which correspond to earthquakes with moment magnitude Mw ~ 3.5-4 make the transition band, which is the boundary between the two ranges in which the scaling relations differ significantly.

In order to analyze the trend of the scaled energy we performed average of relations $e = E_s / M_0$ in every magnitudes range with step equal to 1. The results are shown in Fig. 2 as a histogram. As one can see both for mine seismicity and for middle earthquakes the value of scaled energy gradually increase several times. The red lines show the results estimations made on the basis of the model developed in this study.

Conclusions

In the case of induced seismicity, the stiffness of fractures decreases inversely with the length. This corresponds to the similarity laws. However, regular deviations from the similarity associated mainly with the dependence of the effective shear modulus of the scale. The stiffness of the mature faults varies with the scale noticeably slower than in self-similar case. It leads to a rapid increase in several times the average value of the scaled energy in the range of magnitudes Mw 3 ÷ 5. For larger earthquakes, this effect is almost negligible.

Acknowledgements

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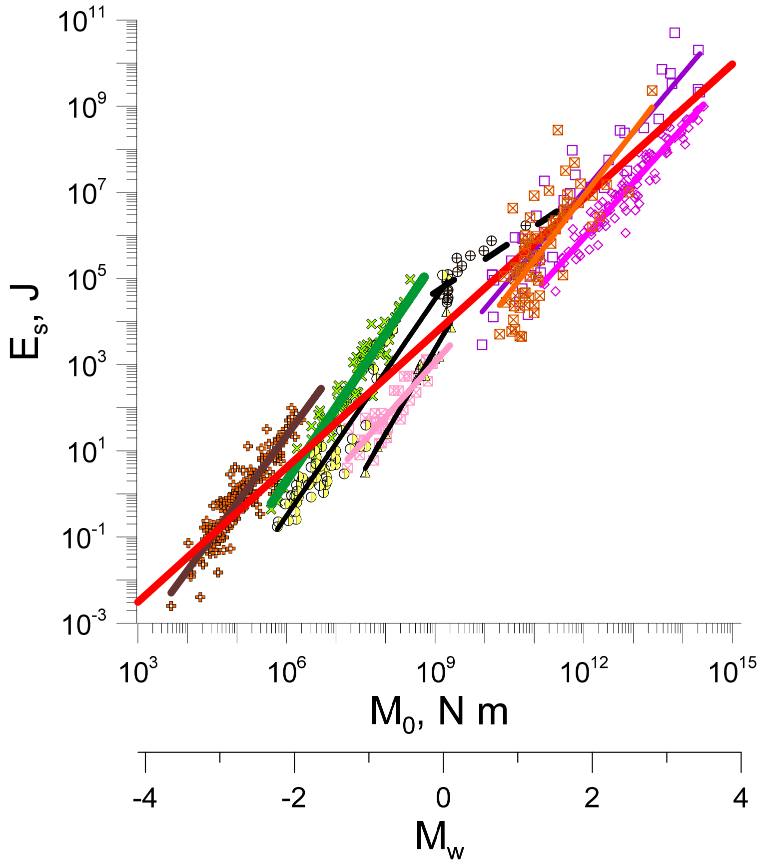

Figure 1 *Radiated energy versus seismic moment for several datasets. Red line corresponds to the self-similar scaling E~*M_0*.*

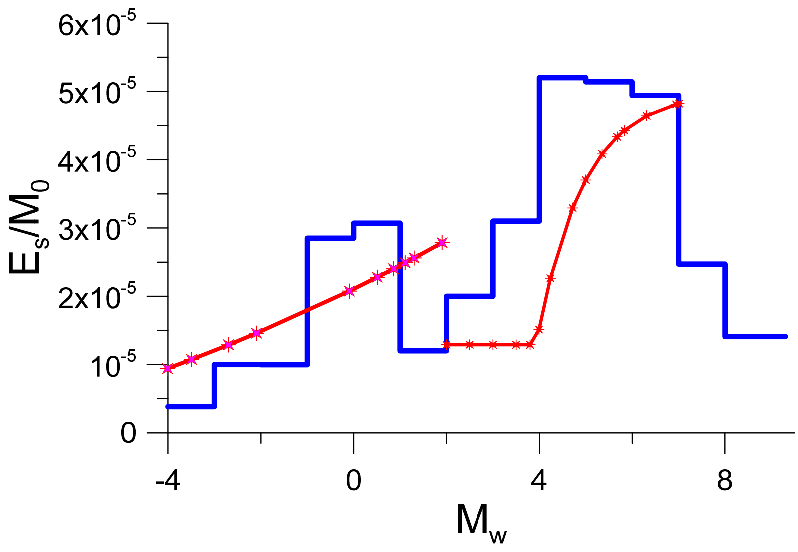

Figure 2 *The value of scaled energy versus moment magnitude of seismic events. Blue line is the average value in every* M_w *range with step equal to 1. The red lines are the results of analytical calculations.*