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Tectonophysical Model of Seismic Activation of a Fault

Bornyakov SA*

Tectonophysics laboratory, Institute of the Earth's Crust Siberian Branch of RAS, Russia

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***Corresponding author:** Bornyakov SA, Tectonophysics laboratory, Institute of the Earth's Crust Siberian Branch of RAS, 128, str. Lermontov, Irkutsk 664022, Russia and Deological faculty, Irkutsk State University. 3, str. Lenin, Irkutsk, 664001 Russia, Russia

Abstract

In our study of the deformation dynamics of a large fault, analogue modeling is based on an elastic-viscoplastic model of the lithosphere. The aim is to discover a mechanism that controls preparation and subsequent complete seismic activation of large faults considered as strong earthquake sources. Digital image correlation (DIC) is applied to process the optical images taken during the experiments, which show fault segmentation and phased activation. Between complete activation stages, a fault consists of segments, and its active segments undergo regressive and progressive phases of their evolution. During the regressive phase, segmentation develops, several large segments are formed, and, later on, numerous small segments occur and gradually degenerate into point-shaped defects. During the progressive phase, an opposite process takes place, and active segments become longer and rapidly join to form a completely activated fault with impulse offsets in its wings. Our experimental results contribute to establishing the tectono physical aspect of the 'stick-slip' model and suggest that strong earthquakes may be prepared in large seismically active fault zones of the lithosphere due to the segmentation mechanisms.

Keywords: Analogue modeling; Seismic fault; Activation; Stick-slip; Segmentation; B-Value, Entropy

Introduction

Faults that already exist in a seismic zone are periodically activated. In most cases, activation takes place in accordance with the 'stick-slip' model [1] that has been reproduced in numerous studies in laboratory conditions [2]. Experiments were mainly based on models loaded at a fixed velocity. Generally, a model consists of two blocks made of rocks or artificial materials that have mechanical properties similar to the rocks. In these experiments, the major task was instrumental recording of various physical phenomena preceding the occurrence of an impulse displacement that is analysed as a model analogue of an earthquake in nature. Considering the theory of similarity [3,4] the reported models (with specified boundary conditions) investigated preparation and occurrence of weak seismic events caused by seismogenic activation of small faults in the flexible upper lithosphere. However, during preparation of a strong earthquake, deformation takes place within large volumes of the lithosphere, which exhibit both elastic and a number of non-elastic rheological properties, and this must be taken into account in simulations of activation of large seismically active faults. To investigate the deformation dynamics of a large fault, we use analogue modeling based on an elastic-viscoplastic model of the lithosphere. The aim is to discover a mechanism that controls preparation and subsequent complete seismic activation of large faults considered as strong earthquake sources.

Methods

The boundary conditions for simulation of periodic activation of a large fault are determined by the criterion of similarity [3,4]:

$$\eta / \rho gLT = const$$

where is viscosity, P ; is density, kg/m^3; g is acceleration due to gravity, m/s^2; L is linear size, m; T is time, s. The model material is an aqueous paste of montmorillonite clay. Clay model (1) (0.65m long, 0.45m wide, and 0.1m thick) is put on glass board (2) covered with paraffinic oil (Figure 1). Sides (3) and (4) of the model are fixed. A 0.45m long vertical fault cuts the model at an angle of 40o to the direction of movement of active stamp (6). It simulates a large fault in the lithosphere, which length amounts to a few hundred meters in nature. Active stamp (6) moves at a constant speed of 10-5m/s. There are springs (8) between stamp (7) and stable side (9) of the model structure. When the model is compressed, stamp (7) can move towards stable side (9). A Basler" acA1920-40gm digital camera is used to record the process developing in the working area of the model (10). Optical images of the deformed model surface are taken every second (1fp/s) and processed by Digital Image Correlation (DIC) [5].

Results

Figure 2 shows an example of the deformation dynamics of the fault per second from one complete activation to another, which corresponds to a seismic cycle in nature. Complete activations mean activation of the fault along its entire length within the working area referred to for calculations see (10) in Figure 1. After the first activation (Figure 2-A, A'), displacements along the fault occur fragmentarily on several relatively large segments (Figure 2-B, B'). In the next six-time intervals, these large segments are fragmented into a series of smaller segments. The number of segments increases, while their average and total lengths are decreased, and the inclination angle of the recurrence curve is increased. This angle is calculated by the maximum likelihood method [6] from the lengths of the segments see Figure 2-C/- H/, & Figure 3. Before the next complete activation, the segmentation process stabilizes. Later on, it reverses, and the discussed parameters show opposite changes see Figure 2 – I, I/, J, J/. Based on the structural schemes see Figure 2–A/-J/ the number and average lengths the segments are determined, b-value and information entropy (Si) are calculated see Figure 3.

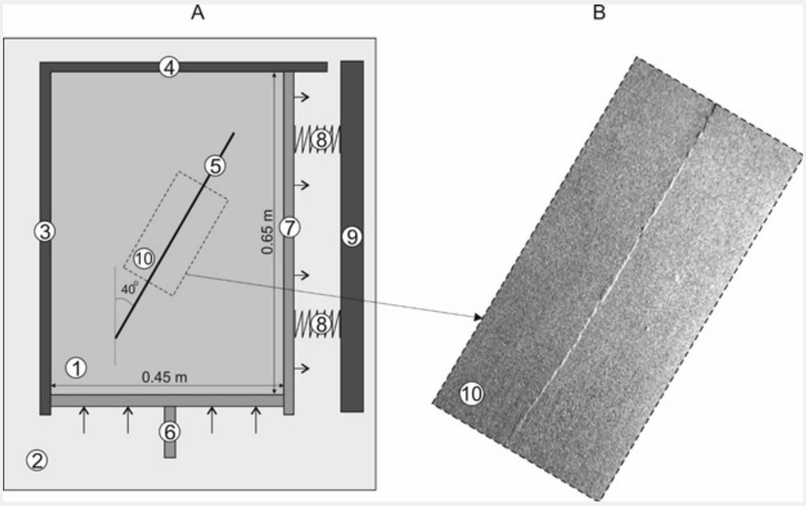

Figure 1A: Model schematics.
Figure 1B: Image of the model with the fault. See details in the text.

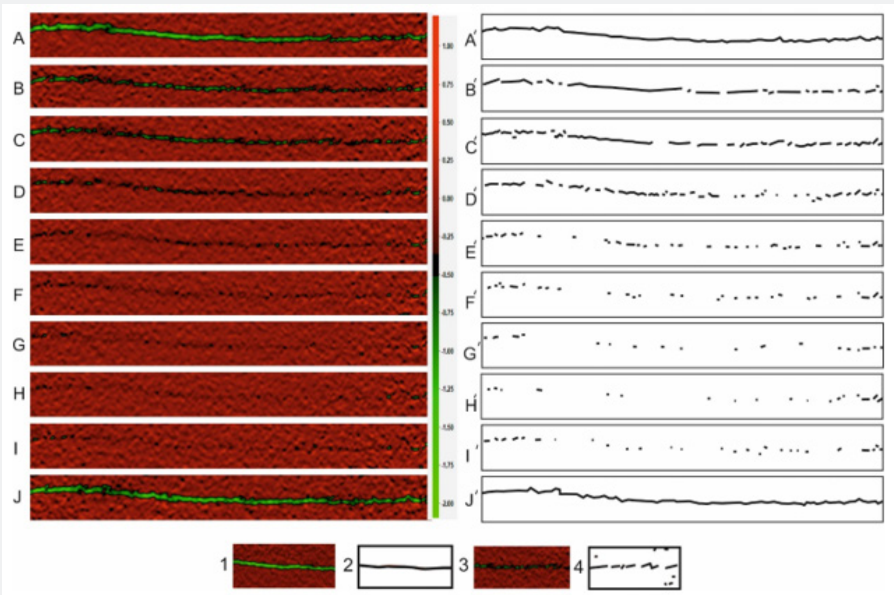

Figure 2: Evolution of the active fault segments in the model between two complete activations. 1 - active fault in the model (DIC-processed images); 2 - active fault in the scheme; 3 - set of active segments detected in the DIC-processed images; 4- set of active segments in the scheme**.**

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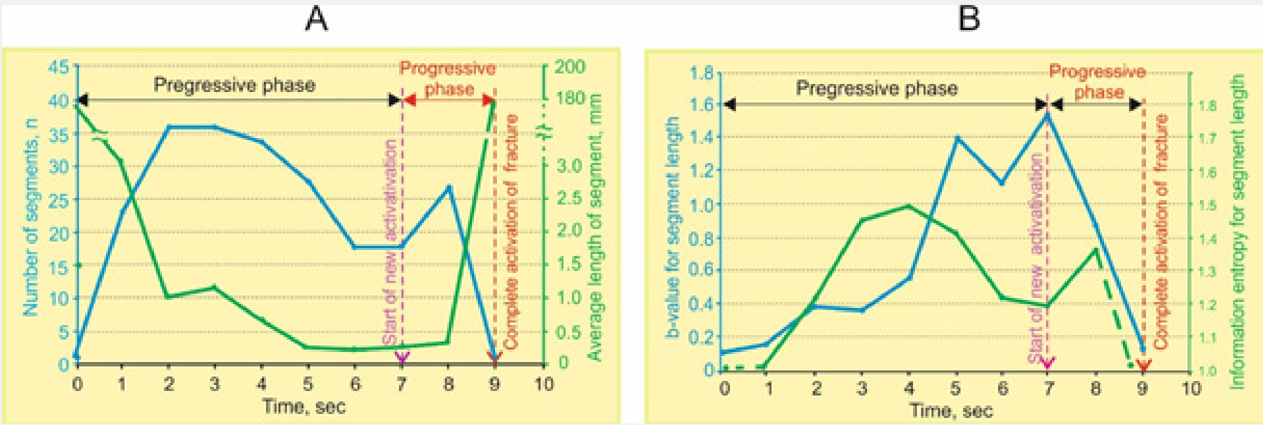

Figure 3: Variations in the number total and average lengths of segments (A), the b-value and information entropy (B).

Discussion

The experiments show that despite the fact that the loading velocity is constant, the evolution of displacements along the existing fault in the elastic-viscoplastic model is non-uniform and proceeds according to the stick-slip mechanism [1]. At the moments of impulse activation, displacements occur along the entire fault or its larger part (Figure 4-A, A', J, J'), while its activity is concentrated on separate segments (Figure 4–B-I, B'-I'). Considering the 'stick-slip' process developing in the model in terms of repeated self-organized criticality [7], it can be expected that immediately before complete activation of the fault, as the critical level of stress on the fault plane is achieved, the system of active segments should reach the state of self-organization [8], and the latter should be preceded by the state of chaos. Experimental data on acoustic emission of loaded rock samples and analysis of seismicity in strong earthquake sources show that parameter β reflects the stress level and is inversely dependent on stress [9,10]. An indicator of the degree of chaos in the systems is thermodynamic entropy or its statistical analogue, Shannon information entropy (Si).

Details of the evolution of the active fault segments between its impulse activations are reflected in changes of the number of segments, their average length, b-value and information entropy (see Figure 3). In these changes, two main trends can be distinguished, which make it possible to divide the deformation process into regressive and progressive phases - time intervals 0s-7s and 7s-9s, respectively. The progressive phase of deformation is much shorter than the regressive one - it lasts for a few seconds. Furthermore, the shorter is the progressive phase, the more intense and complete is activation of fault. Conversely, with an increase in its duration, activation of the fault is less intense, and the fault is activated but not along its entire length. In the first phase, the segmented structure of the fault gradually degenerates due to the directional fragmentation of large segments into smaller ones (some of them become passive), which is reflected in a decrease in their number and average lengths (Figure 3). At this phase, increasing values β and Si show that segmentation takes place at the background of stress relaxation and increasing chaos in the distribution of segments differing in length By the end of the regressive phase, only short segments of the fault are active and tend to get uniformly distributed along the fault strike.

At the beginning of the progressive phase, stress increases; the number of active segments initially increases to a certain critical density; chaos in their distribution increases and then reduces due to their rapid propagation and merger to form larger segments. Later on, at the moment of complete activation, the segments join together to form one fault. During the progressive phase, the fault evolution corresponds, generally, to the model of avalanche-unstable fracturing [11]. The only difference is that in our case, the role of newly formed fractures is played by propagating and selectively joining active fault segments.

Summary

Physical simulation of 'stick-slip' along a large fault contributes to studying the mechanism of preparation and occurrence of periodic complete activations of faults in the elastic-viscoplastic lithosphere. Our experiments show that this mechanism is the process of segmentation, when an existing fault is fragmented into sets of alternating active and passive segments. This process is regularly phased, and the regressive and progressive phases of deformation cause two scenarios (regressive and progressive) of the evolution of active fault segments. During the first phase, at the background of stress relaxation on the fault plane, displacements occur along several relatively large segments that are subsequently fragmented into sets of smaller segments. Most of these smaller segments become passive by the end of this phase. During the second phase, stress decrease is replaced with stress increase, and the process of segmentation is reversed – small segments merge into larger ones and, as a result, the fault is completely activated. Variations in activity of the fault segments are closely related to stress variations in the vicinity of the fault, wherein the systems of plastic microshears are observed. Our experiments show that in some time intervals, the deformation dynamics is considerably different for active fault segments and plastic microshears in the fault wings. This gives

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grounds for an important methodological conclusion concerning statistical prediction models and assessments – earthquake records from the areas of large seismically hazardous faults should be analysed separately and in a more detail. It is needed to distinguish a narrow central subzone (including the main fault plane) and two wide subzones framing the central subzone, i.e. the main source of seismicity and potential sources of foreshocks and aftershocks, respectively. Our experimental results suggest that strong earthquakes may be prepared in large fault zones due to the segmentation mechanism and contribute to the development of ideas about the geodynamics of large faults in seismic zones of the lithosphere.

References

1. Brace WF, Byerlee JD (1966) Stick-slip as a mechanism for earthquake. Science 153(3739): 990-992.
2. Rosenau M, Corbi C, Dominguez S (2017) Analogue earthquakes and seismic cycles: experimental modelling across timescales. Solid Earth 8: 597-635.
3. Hubbert MK (1937) Theory of scale models as applied to the study of geologic structures. Bulletin of the Geological Society of America 48(10): 1459-1519.
4. Gzovsky MV (1975) Fundamentals of Tectonophysics. Nauka Moscow Russia, Russia.
5. Sutton MA, Orteu J, Schreier H (2009) Image Correlation for shape, motion and deformation measurements. Springer New York NY, USA.
6. Akki K (1965) Maximum likelihood estimate of bin the formula $logN = a - bm$ and its confidence limits. Bull. Earthquake Res Inst Tokyo Univ 43: 237-238.
7. Bak P, Tang C (1989) Earthquakes as a self-organized critical phenomenon. Journ Geoph Res 94 (B11): 15635-15637.
8. Ma J, Guo Y, Sherman SI (2014) Accelerated synergism along a fault: A possible indicator for an impending major earthquake. Geodynamics & Tectonophysics 5(2): 87–99.
9. Amitrano D (2003) Brittle-ductile transition and associated seismicity: Experimental and numerical studies and relationship with the b value. J Geophys Res 108(B1): 2044.
10. Goebel THW, Kwiatek G, Becker TW, Brodsky EE, Dresen G (2017) What allows seismic events to grow big? Insights from b-value and fault roughness analysis in laboratory stick-slip experiments. Geology 45(9): 815-818.
11. Myachkin VI, Kostrov BV, Sobolev GA, Shamina OG (1975) Fundamentals of the physics of earthquake focus and fore runners. In: MA Sadovsky (edn.), Physics of Earthquake Focus, Nauka Moscow Russia, pp. 6-29.

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