Corresponding Member of the Academy of Sciences of the USSR Yu. V. RIZNICHENKO

1965

SovietRxiv

Abstract

Full Text

GEOPHYSICS

Corresponding Member of the Academy of Sciences of the USSR Yu. V. RIZNICHENKO

THE CONNECTION BETWEEN THE FLOW OF ROCK MASSES AND SEISMICITY

1. The present study is aimed at establishing a closer quantitative connection between heterogeneous results from the study of present-day seismotectonic movements, carried out, on the one hand, by methods of seismology, which study only earthquakes proper, and, on the other, by a number of other methods that make it possible to determine directly the displacements of rock masses. These include: geophysical tilt and extensometric measurements, partly methods for studying temporal changes associated with displacements of masses and changes in the force of gravity, geodetic methods of repeated height and horizontal measurements, and geological and geomorphological methods for estimating the magnitude and rate of relative displacements of rock masses.

2. The motion of rock masses occurring under the action of tectonic forces in large space-time regions (tectonic flow) will be considered macroscopically as the continuous flow of an incompressible Newtonian fluid, for which one may write

$$\tau_0 = \eta_0(\partial v_0/\partial y), \tag{1}$$

where τ_0 is the shear stress, $\partial v_0/\partial y$ is the rate of shear deformation or the gradient of the flow velocity, and η_0 is the viscosity. The y-axis has the direction of the maximum change in the flow velocity v_0.

3. The microstructure of this process is composed of continuous—quasiplastic—and discontinuous—seismic—deformations of individual volumes of rock masses. As the simplest scheme of an elementary discontinuous process, we shall adopt the well-known Reid-Benioff model of a seismic focus ([1]): under increasing shear stress τ, the shear deformation $\varepsilon = \tau/\mu$ (μ is the shear modulus) of an initially cubic "seismic element" of volume $V_i = l_i^3$ increases to the limiting value $\varepsilon_{\max} = \tau_{\max}/\mu$, when this element ruptures by shearing into two equal parts, which then straighten and grow together in a new, displaced position; the process may then be repeated. It is assumed conditionally that, at rupture, all the previously accumulated elastic energy is released,

$$E_i = {}^1/_2\tau_{\max}\varepsilon_{\max}V_i. \tag{2}$$

It is transformed into the energy of seismic waves and can be determined by known seismological methods.

4. The multiplicity of seismic elements providing the discontinuous part of the flow is taken into account. The numbers N of these elements are distributed according to the energies of the corresponding earthquakes in accordance with the earthquake recurrence law known from observations, $N = N(E)$. In the simplest case this law is expressed by the equalities

$$N = A \cdot 10^{-\gamma(K-K_0)} \quad \text{for } K \leq K_{\text{max}},$$

$$N = 0 \quad \text{for } K > K_{\text{max}}. \tag{3}$$

Here N is the frequency of recurrence of earthquakes with seismic energy $E = 10^K$, referred to a unit volume; K is the energy class of the earthquake; A is the seismic activity, equal to the recurrence of earthquakes of the fixed energy class K_0; γ is determined from

observations, the slope of the earthquake recurrence graph plotted in the coordinate system $K(= \lg E), \lg N$. The transition from the density quantities N and A adopted here to quantities corresponding to decimal energy classes was considered in (2).

5. As a zero approximation, let us assume that the entire macroscopic flow (1) is determined structurally only by its seismic, rupture part—that the entire tectonic motion is seismic flow. In this connection we shall assume that the displacement of a macrovolume, consisting in the accumulation of some large cube, is composed of analogous displacements of its constituent microvolumes—seismic elements—which occur in the same direction. Thus, here the assumption of collinearity of displacements in the small, in structural details, is conventionally adopted—that is, of the laminarity of the flow under consideration. Taking into account (1), (2), and the recurrence law $N = N(E)$, under these conditions we obtain

$$\frac{\partial v_0}{\partial y} = \frac{2^{4/3}}{\tau_{\text{max}}^{4/3} \varepsilon_{\text{max}}^{4/3}} \int_{-\infty}^{K_{\text{max}}} N E^{4/3} \, dK. \tag{4}$$

This formula gives the general relation between the velocity gradient of the flow (1) of a macrovolume of rock masses and the elastic-strength properties $(\tau_{\text{max}}, \varepsilon_{\text{max}})$ of microvolumes of rocks, as well as with the long-term average characteristics of the seismic regime: the recurrence law $N = N(E)$ and the energy $E_{\text{max}} = 10^{K_{\text{max}}}$ of the maximum possible earthquakes in the given region.

6. To determine the remaining quantities in equation (1), we shall adopt the assumption of conservation of energy in the following form: let the flux of energy of tectonic forces, referred to unit time and volume, supplied to

the macrovolume under consideration from outside and dissipated during flow owing to the presence of effective viscosity, be equal to the flux of energy accumulated in potential elastic form by the seismic elements and subsequently passing into the energy of elastic seismic waves carried by them out of the given volume:

$$w_0 = \tau_0 \frac{\partial v_0}{\partial y} = \int_{-\infty}^{K_{\max}} NE\, dK. \tag{5}$$

From this we obtain the value of the stress τ_0 at which the flow (1) takes place,

$$\tau_0 = \frac{1}{\partial v_0/\partial y} \int_{-\infty}^{K_{\max}} NE\, dK. \tag{6}$$

Knowing $\partial v_0/\partial y$ from (4) and τ_0 from (6), one can determine the effective viscosity η_0 of the material of the rock masses participating in the flow,

$$\eta_0 = \tau_0 / \left(\partial v_0/\partial y\right). \tag{7}$$

7. In the particular case when the earthquake recurrence law has the form (3), the general relations (4), (6), and (7) lead to the following dependences:

$$\frac{\partial v_0}{\partial y} = \frac{2^{4/3}}{\tau_{\max}^{4/3}\varepsilon_{\max}^{1/3}} \frac{A \cdot 10^{\gamma K_0}}{(4/3-\gamma)\ln 10} \cdot 10^{K_{\max}(4/3-\gamma)}, \tag{8}$$

$$\tau_0 = \frac{\tau_{\max}^{4/3}\varepsilon_{\max}^{1/3}}{2^{4/3}} \frac{(4/3-\gamma)}{(1-\gamma)} \frac{1}{10^{K_{\max}/3}}, \tag{9}$$

$$\eta_0 = \left(\frac{\tau_{\max}^{4/3}\varepsilon_{\max}^{1/3}}{2^{4/3}}\right)^2 \frac{(4/3-\gamma)^2}{(1-\gamma)} \frac{\ln 10}{A \cdot 10^{\gamma K_0}} \frac{1}{10^{K_{\max}(5/3-\gamma)}}. \tag{10}$$

8. This solution is no more than a zeroth approximation; the description given for it is rather a demonstration of a possible general approach, the details of which must be improved. In subsequent approximations one should take into account, first of all, the rheological properties of the structural elements and the possibility of their nonbrittle destruction; the presence of turbulence in micromotions, which manifests itself the more strongly the smaller the energy of the earthquakes; and the difference between the total energy of the flow process and the seismic energy (the energy of seismic waves), which constitutes only part of the total energy.

Of the entire volume of information obtainable by seismic methods, only that part has been used here which pertains to the space-time distribution of earthquake foci and to their energy. Additional use of seismic data on the directions of forces and displacements in the foci, obtained by known methods for determining the so-called dynamic parameters of the focus, will make it possible to find not only the magnitudes of the stress and strain moduli, but also to assign them a spatial orientation.

9. Nevertheless, it appears that, even before the complete program is carried out, the use—at first of very imperfect quantitative relations, such as those given above, and then of increasingly refined ones—can serve as a substantial supplement to the qualitative comparisons of the heterogeneous aspects of the seismotectonic process that are commonly practiced today. These relations, being physical in nature, can help in carrying out statistical correlations of heterogeneous quantities obtained by different methods, for example seismic and geodetic or geological ones. A quantitative consideration of possible causal connections will help make these correlations more directed and clarify the physical meaning of the empirically obtained relations.

Schmidt Institute of Physics of the Earth
Academy of Sciences of the USSR

Received
8 XII 1964

CITED LITERATURE

[1] H. Benioff, *Science*, **143**, No. 3613, 1399 (1964).
[2] Yu. V. Riznichenko, *Izv. Acad. Sci. USSR, Geophys. Ser.*, No. 7, 969 (1964).

Note: Figure translations are in progress. See original paper for figures.