Doklady of the Academy of Sciences of the USSR

1965

SovietRxiv

Abstract

Full Text

Doklady of the Academy of Sciences of the USSR
1965. Vol. 162, No. 5

GEOPHYSICS

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STRUCTURE OF 4-6-SECOND MICROSEISMS

(Presented by Academician V. V. Shuleikin on 24 XII 1964)

Microseisms with periods of 4-6 sec, which are a serious disturbance for seismological observations, have been intensively investigated over the last two decades. It is generally accepted that they consist of interfering surface waves of the Rayleigh and Love types, excited by the motion of large water masses. This concept has become established as a result of numerous studies carried out by various methods, of which the most reliable is the method of tripartite stations, which makes it possible to measure the velocity of wave propagation between stations by means of phase correlation. However, the reliability of the results of this method is limited because of the difficulty of deciphering the actual, very complex wave pattern; in practice, when interpreting observations from tripartite stations, a number of assumptions are used, either explicitly or implicitly, that cannot be verified within the framework of this method.

In the study whose results are presented below, a new methodology for this problem was applied, based on the principle of directional reception carried out by a group of stations. The field material used in the work was obtained in October 1961 in Eastern Kazakhstan, in the area of Ust-Kamenogorsk. Here, for one month, a temporary group of seismic stations operated (Fig. 1). All stations stood on bedrock of the granite or crystalline-schist type and were equipped with identical apparatus: USF seismographs with a natural period of 1.5 sec, F 117/3 photoelectric amplifiers, and GK-VII galvanometers, recording on RS-2 recorders at a sweep speed of 240 mm per minute. The magnification at 5 sec was about 20,000. The results reported in this note were obtained mainly by processing records from vertical seismographs. During the observation period there was a monotonic increase in the level of the microseisms: their root-mean-square magnitude increased on the last seismogram by a factor of 4 in comparison with the first. For processing, 5 seismograms were selected in such a way that they would be as representative as possible. According to various bulletins, no earthquakes occurred during this time.

Fig. 1. Layout of the stations. Legend: *a*—vertical seismographs, *b*—three-component installations

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The processing method used is, in principle, reducible to summing the records of individual stations with time shifts that depend linearly on the coordinates of the station in the plane, and to calculating the root-mean-square value of this sum for different tunings of the group. The order of the calculations is constructed somewhat differently. If $x(t)$ denotes the output of the group, and $x_i(t)$ the record of the i-th station with or without a time shift, then the mean square of the output of the group can be represented as follows:

$$\overline{x^2}(t) = \sum_i \overline{x_i^2}(t) + \sum_{i,j,\ i\neq j} \overline{x_i(t)x_j(t)},$$

where the bar above denotes averaging. The first sum, made up of the mean squares of the records from the various stations, does not change as a function of the group setting. The second sum contains the coefficients of mutual correlation between all possible pairs of stations; these coefficients, and together with them the entire sum, change as a function of the group setting. They are all known if the mutual-correlation functions between the records of the various pairs of stations have been calculated. In practice, we first computed estimates of the required mutual-correlation functions

$$R_{ij}(\tau) = \lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} x_i(t)x_j(t-\tau)\,dt,$$

then normalized them according to the rule

$$\hat{R}_{ij}(\tau) = R_{ij}(\tau)/\sqrt{R_{ii}(0)R_{jj}(0)},$$

after which we computed sums of the form $\sum \hat{R}_{ij}$ and plotted them on correlation diagrams. In order to pass from a diagram constructed in this way to the mean squares of the group output, the quantities taken from the correlation diagram must be doubled and the number n—the number of seismographs in the group—must be added to them. The averaging time in the calculation of the correlation functions was 20 min. In carrying out the normalization of the mutual-correlation functions, we assume that the microseism level at each station is the same and that the existing differences are associated with some scatter in the gains of the recording apparatus. In interpreting the correlation diagram, certain concepts of the statistical theory of grouping and of controlled

Fig. 2. Energy characteristic of the directivity of the group

Figure 2: Fig. 2. Energy characteristic of the directivity of the group

directional reception are used (1). A process that evolves in time and on a plane (microseisms are such a process) is characterized by a spectral density depending on frequency and on two wave numbers corresponding to the two spatial coordinates. Since the process under study is extremely narrow-band, it can, without serious distortions, be considered monochromatic and one may restrict the analysis to the spectral density depending on two wave numbers and not depending on frequency. If such a process is interpreted as a superposition of several plane waves, then an increase of the spectral density at certain wave numbers means the presence of a wave with these wave numbers, from which it is simple to pass to the azimuth of the source and the velocity. Thus, if in the plane of wave numbers λ_x and λ_y a certain wave corresponds to the wave numbers λ'_x and λ'_y, then its velocity v can be determined from the formula

$$v = \omega / \sqrt{\lambda'^2_x + \lambda'^2_y},$$

where ω is the angular frequency. The radius vector of the point λ'_x, λ'_y, when the axes λ_x and λ_y are replaced by x and y, indicates the direction to the wave source. The group has a directional characteristic that makes it possible to pass components of the process with some wave numbers and to suppress others. Introducing time shifts when summing the records of individual stations makes it possible to move the directional characteristic over the plane of wave numbers.

Figure 2 shows the directional characteristic of our group. In addition to the main, central pass region, it has side pass regions with values of 0.3–0.5 (as compared with 1 in the central region). If there is some wave in the process under investigation, then an increase in the values of the correlation diagram will occur when the wave numbers of this wave fall both in the main and in the

side passbands of the directivity characteristic. In this case the determination of wave numbers may prove difficult, especially when several waves are present. The process of interpreting a correlation diagram can be formalized and automated to a high degree. In our present interpretation, which is predominantly qualitative in character, we simply tried various possibilities and regarded the maximum isolated on the correlation diagram as the principal one if it could not be obtained as a side

Fig. 2. Energy characteristic of the directivity of the group

maximum relative to some other maximum. In this way, in each case it proved possible to isolate from one to three waves, whose presence explains all the main features of the corresponding diagram. This procedure is conveniently illustrated by the example of diagram No. 4 (Fig. 3).

Fig. 3. Correlation diagram No. 4

Figure 3: Fig. 3. Correlation diagram No. 4

The diagram is constructed as follows: the rectangular coordinate axes coincide with the directions C— and B— (if the diagram serves to determine the direction of wave motion); these same axes serve as the axes of the corresponding wave numbers in operations with the directivity characteristic; on one of the axes, instead of wave numbers, the velocities themselves are plotted directly as the scale; the velocity range 3–4 km/sec, corresponding to surface waves, is indicated by a dashed line; the region of negative values is shaded; identical values are connected by isolines with a step of one unit. The diagram contains at least 5 maxima, which potentially could be the principal maxima of 5 different waves. However, comparison with the directivity characteristic, which is most simply carried out by superimposing the diagram on the directivity characteristic, makes it possible to isolate only one wave with a principal maximum near the origin. An analogous procedure is applied in the analysis of the remaining material. For a first estimate of the energy of the isolated wave, the largest value of its principal maximum is taken and divided by $n(n-1)/2$, where n is the number of stations in the group.

The principal result obtained in the interpretation of all the correlation diagrams is the constant presence of a component with a velo-

with a velocity of 10–20 km/sec and an energy amounting to 0.1–0.4 of the total energy of the process. Waves are also distinguished (though not in all cases) with a velocity close to 4 km/sec, which may be surface waves. However—

Fig. 3. Correlation diagram No. 4

—the high-velocity wave (or group of waves) either exceeds any other distinguished wave in energy or is comparable with it. In total, all the distinguished waves amount, in energy, to no more than 50% of the total energy of the process; the remainder falls to the irregular component, whose nature is not yet clear. The high-velocity waves, judging from the fact that they could not be distinguished on the records of horizontal seismographs, are apparently mainly longitudinal. We assume that these waves have the same origin as the other components of the microseismic background; we are convinced of this by the fact that, when the energy of the microseisms increased fourfold, the contribution of the high-velocity waves did not show any tendency to decrease.

The author expresses gratitude to V. I. Keilis-Borok for initiating the research problem, and to I. P. Pasechnik, N. M. Pryutskina, and K. A. Kossova for their assistance in the work.

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Received

18 XII 1964

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