Sources of Microseismic *P* Waves

By L. P. Vinnik[1])

Summary – Origin of *P* waves detected earlier in microseisms of very quiet locations in the USSR is discussed in detail. It appears that the most pronounced sources of *P* waves are tropical cyclones over the Pacific. The amplitude of the force in the source for a medium power typhoon is found to be of the order of 10^{16} dynes. The effective source area is estimated as 10^4–10^5 km^2 approximately. The shape of the amplitude spectrum of *P* wave corrected for the absorption in the mantle does not contradict with the standing wave theory of microseisms generation. Results of observations at various epicentral distances give strong evidences of the predominant attenuation of the fundamental Rayleigh mode as compared with higher Rayleigh modes and *P* waves in the frequency band of 0.3–0.15 cps.

It was shown a few years ago that microseisms at very quiet locations in USSR consist at least partly of *P* waves [1, 2][2]). It was suggested also that these waves are mostly ocean generated. In this paper results of detailed study of *P* wave sources are presented. Records of microseisms were obtained at two seismograph arrays which operated in South and East Kazakhstan for a few months in 1961 and 1962.

Figure 1 shows our wave-number spectral estimates. Direction of propagation of each detected wave is shown by an arrow. The length of the arrow is related to the horizontal velocity of wave propagation. Horizontal velocity of *P* wave depends on the distance from the source. Therefore location of the source of each detected *P* wave can be found. An interesting case is exposed in the spectrum VII. In this case horizontal velocity of *P* wave is close to infinity. The source of such wave is located just at the opposite point of the Globe. Figure 2 shows origin areas of *P* waves. Almost all of origin areas are in the Pacific. In the Atlantic sources of *P* wave were never detected.

In some cases meteorological situation related to the *P* wave origin is quite simple. Figure 3 shows one of such situations. Origin area of *P* wave is marked by the dotted line. In the large part of the Pacific around this region one can see only one pronounced event. It is tropical cyclone Violett. Azimuths of typhoon and of *P* wave source are very close. Some difference between the distances to the receiver may be due to an error of measurement. It should be noted that the distance between the source and the receiver is very large; approximately 9000 km. In general origin areas of *P* wave

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[2]) Numbers in brackets refer to References, page 289.

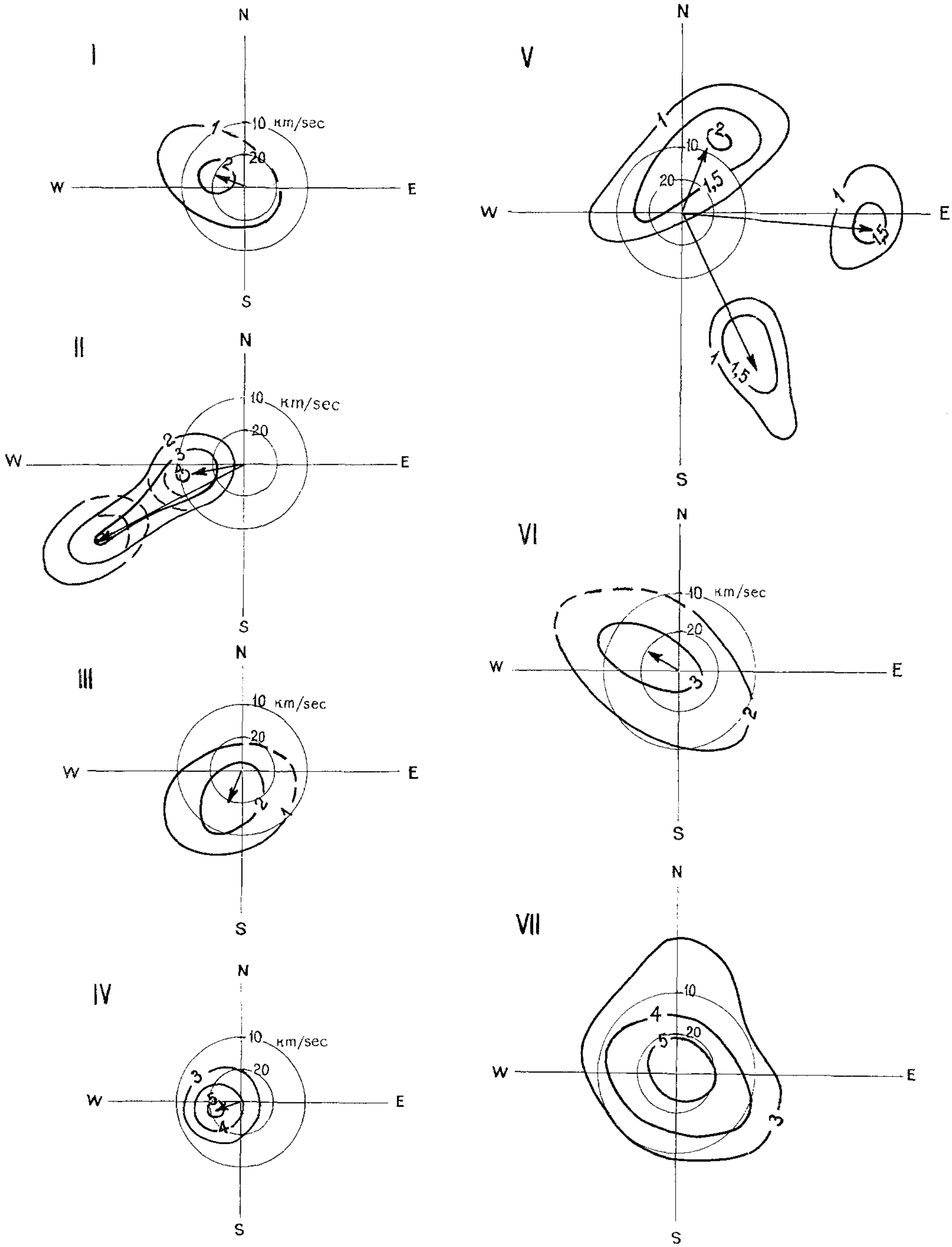

Figure 1
Wavenumber spectral estimates of microseisms: I–V dominant frequency 0.2 cps; VI, VII dominant frequency 1.0 cps

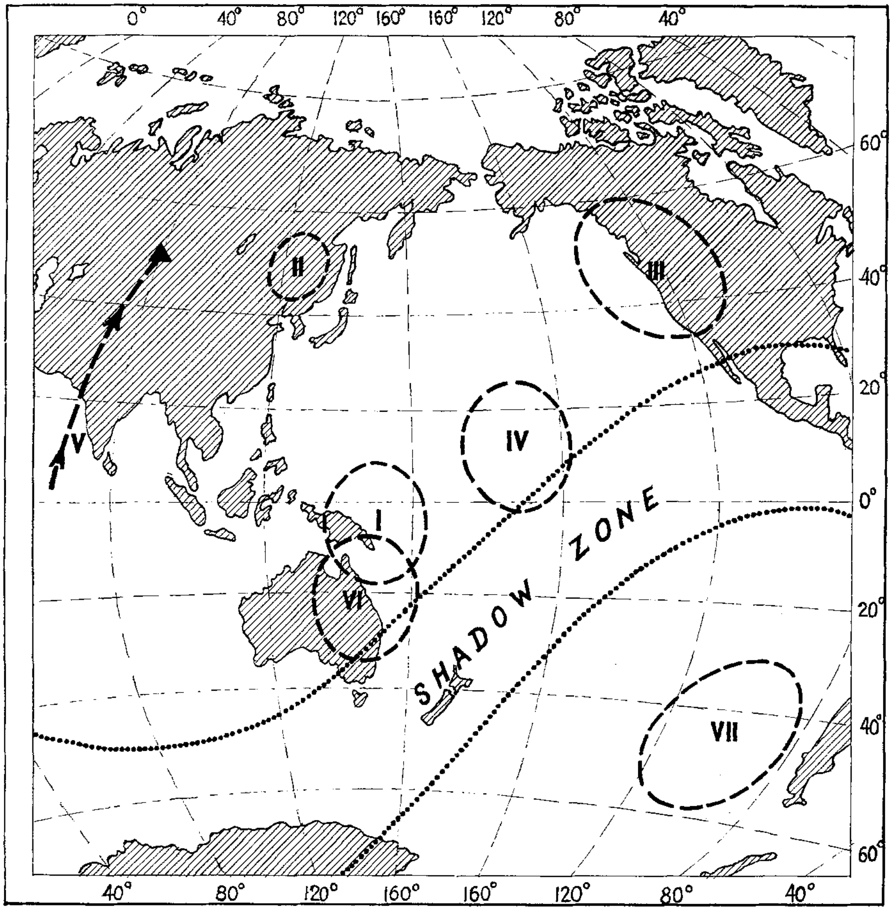

Figure 2
Origin areas of *P* wave

in most cases are related to the definite stormy areas of the ocean. Their most pronounced sources are tropical cyclones over the Pacific.

In the past much attention was given to the study of surface waves in microseisms. Unhappily it is very difficult to extract meaningful information about dynamic properties of the source from short-period surface wave. The amplitude and the frequency spectrum of short-period surface wave depend on the properties of the Earth's crust between the source and the receiver much more than on the source properties. At the same time short-period *P* wave from a distant source propagates mainly in the mantle and propagation effect can be easily calculated.

The force that is responsible for the origin of microseisms may be approximated by the vertical force applied to the free surface of the liquid layer on the solid halfspace.

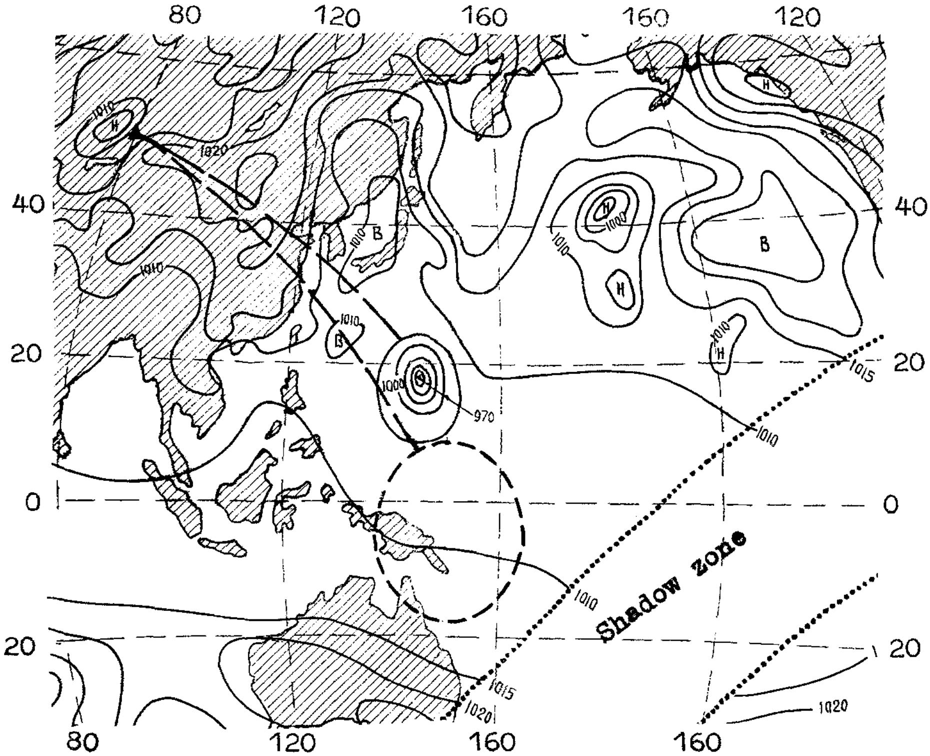

Figure 3
Meteorological situation of 5th October 1961

Solution of this problem obtained by Scholte and modified by Longuet-Higgins [3] does not predict the observation of *P* wave. The reason is that the emergence of the *P* wave on the surface of the Earth is caused by the curvature of the surface and by the refraction in the mantle. Both these phenomena are not taken into account in the discussion of the problem by Scholte and by Longuet-Higgins. I treat this problem with some simplifications. My approach is based on the expression for the mean intensity of the *P* wave, generated by the disk of small radius vibrating normally to the free surface of the solid halfspace [4]. In order to obtain F_0 – force in the source, V – velocity of oscillation at the receiver is used. The relationship between F_0 and V is given by the expression:

$$F_0^2 = \frac{2\,R\,\varrho\,v_P^3\,\bar{V}^2(tg^2 e - \sin^2 e)^{1/2}\,\sin\Delta\,\exp(2\,\pi\,f\int Q^{-1}\,dt)}{[\phi(e)]^2\,f^2\,\mu^4|d^2T/d\Delta^2|}. \qquad (1)$$

In this expression:

ϱ – density of the crust;

v_P – velocity of propagation of *P* wave in the crust;

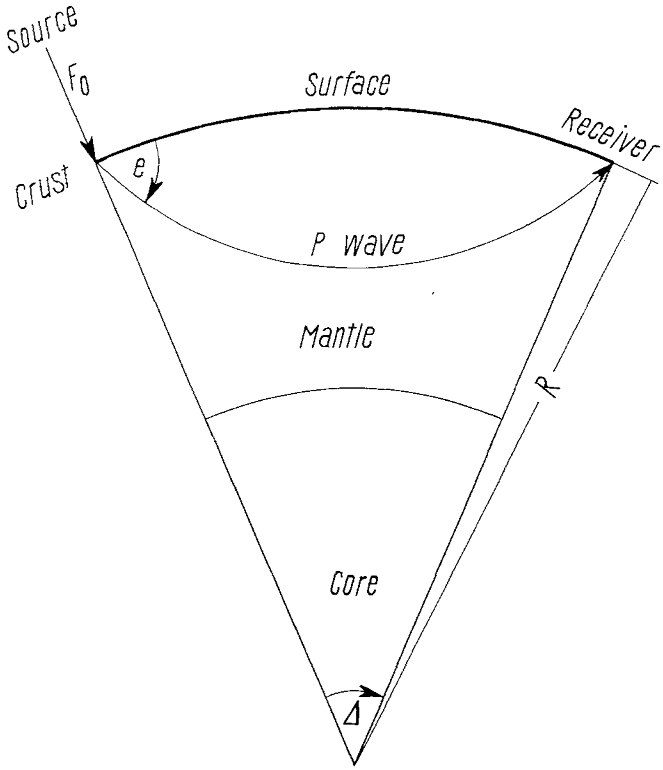

Figure 4
The geometry of the model

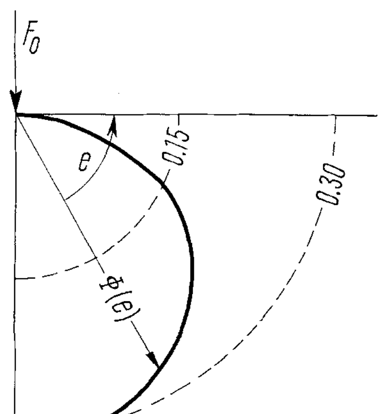

Figure 5
Radiation pattern of the source

v_s – velocity of propagation of S wave in the crust;
f – frequency of oscillation in cps;
μ – v_p/v_s;
$\exp(2\pi f \int Q^{-1}\, dt)$ – absorption factor;
T – travel time;
$\bar{V}^2$ – mean square of the velocity of oscillation at the receiver;
e, Δ, R, $\phi(e)$ – are explained by the Figures 4 and 5.

It is evident that actual field may be approximated by a large number of elementary radiators oscillating independently. For this reason if one put into expression (1) value of $\bar{V}^2$ taken from a seismogram, F_0 will present resultant force. According to my calculation amplitude of the resultant force with the period of 5 sec for a medium power typhoon like Violett is of the order of 10^{16} dynes.

Another important property of the radiator is its frequency spectrum. In order to obtain it, spectrum of P wave at the receiver should be corrected for the frequency dependent absorption in the mantle. Figure 6 shows the spectrum of the source obtained from my data. Experimentally determined spectrum is compared with that predicted from the standing wave theory. There is good agreement between the theoretical and experimental curves.

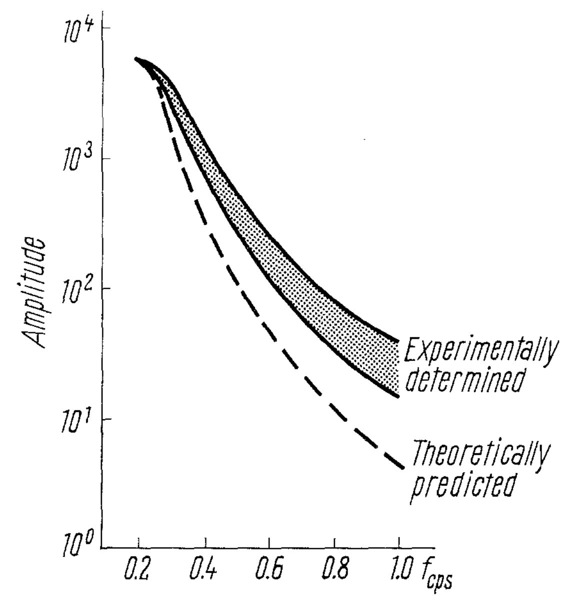

Figure 6
A comparison between theoretically predicted and experimentally determined spectra of P wave in the source.
Theoretical prediction: f – frequency of oscillation; $h^2(f)$ – power spectrum of the sea surface; u – area of sea wave interaction at the wavenumber plane: 1. $F_0 \propto h^2(f) f^2 u^{-1/2}$ (LONGUET-HIGGINS), 2. $h^2(f) \propto f^{-5}$ (KITAJGORODSKY), 3. $u \propto f^3$ (Author's suggestion), finally $F_0 \propto f^{-4.5}$

Since standing wave theory provides good explanation for the *P* wave spectra it may be further used as a proper theoretical basis. In particular from the value of the force one can evaluate effective area of the source. It appears from my data that the effective radius of the source area for a medium power typhoon is close to 100 km.

Since in our disposal there are sources in very wide range of epicentral distances it is possible to look at the variation of wave composition of 5 sec microseisms as a function of distance (Fig. 7). At the short distances (less than 20°) fundamental Ray-

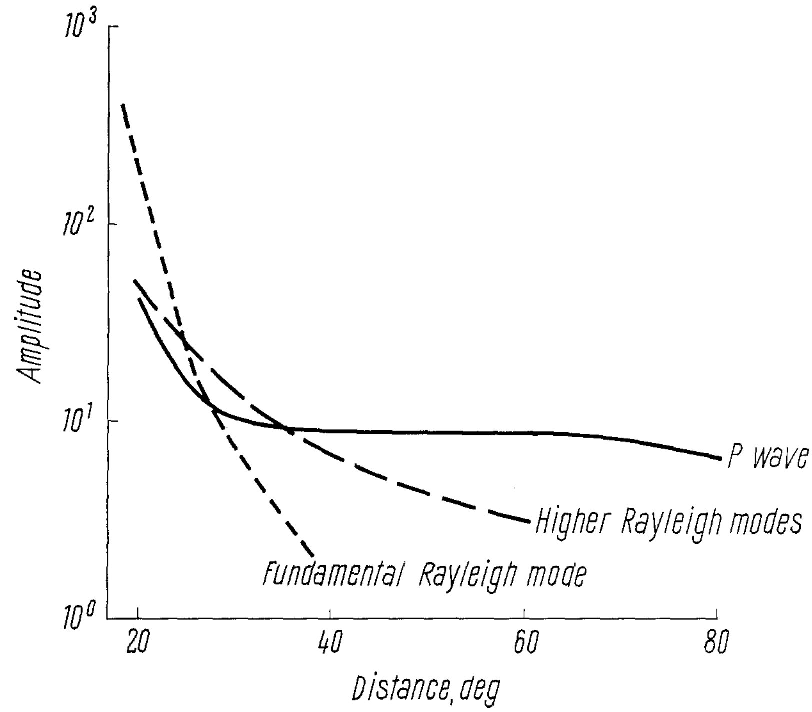

Figure 7
Composition of the vertical component of 0.2 cps microseisms

leigh mode is strongly dominant. At the distances more than 50° *P* wave is the only wave that can be detected. The figure explains why so many efforts to detect distant cyclones from records of microseisms were so unsuccessful. Earlier works were based on the assumption that useful information can be extracted from records of surface waves at near-shore seismograph stations. There is little doubt now that the information about distant cyclones can be found in *P* waves only and these waves can be detected only in central parts of large continents.

References

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