BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 38 (1960), pp. 207-218

12. An Attempt to Detect Azimuth Effect on Spectral Structures of Seismic Waves (The Alaskan Earthquake of April 7, 1958).

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(Read March 22, 1960.—Received March 31, 1960.)

Summary

The author worked out a spectral analysis of the seismic waves radiated by the Alaskan earthquake of April 7, 1958. It purposes to make a kind of tests whether or not the "point" or the "spherical" origin models of earthquakes explain the actual mechanism of wave radiation completely. Because, suppose these models represent the nature of earthquake origins very well, then the waves of the same spectral structure (*P*- and *S*-waves) are to be observed at all the azimuths.

Seismograms recorded with the Press-Ewing type seismographs at Tsukuba and other six stations were used conveniently. These stations except Resolute Bay are located at nearly equal epicentral distances (40–55°), so that the comparison of their data can be made fairly simply.

It was found out that no special azimuth effect was observed in the spectra of *P*-waves. On the other hand, as to *S*-waves, a notable difference in the spectrum type was detected between three groups of stations. This difference is more likely to be attributed to the mechanism of wave radiation, rather than to the distortion of spectra caused by some conditions of wave propagation. Since the available data are very few at present, definite conclusions will be postponed until more examples are obtained.

1. Introduction

The mechanism of earthquake origins has been studied by many seismologists on the basis of simplified models of spherical (or point) origins.[1] In fact, we know numbers of examples reported by them, in which the model provides a reasonable explanation for the observational

1) *f.i.* J. H. HODGSON (Editor), *Publ. Dominion Obs.*, **20** (1958), 251–418.

results, such as azimuthal distribution of push-pull sense and amplitude of the initial disturbances. These models assume suitable types of stress distribution changing in time over an spherical surface which is imagined in the earth. The patterns of wave radiation from them, whether we take the force type I or II, are independent of the frequency of the origin forces. In other words, it is the amplitude (including polarity) of waves that are seriously influenced by the azimuth whereas the same wave-form (or the spectral structures) must be observed at different points around the origin.

The author's previous study has found out a notable characteristics of the fault origin model. The pattern of wave radiation from it is given by $C_0+C_2\cos 2\theta+\cdots$ for S-waves, where θ is the azimuth and $C_0, C_2, \cdots$ are the constants.[2] Since the ratios of C_0 to $C_2, C_4, \cdots$ are the functions of ω (frequency of origin excitation), the radiation pattern will take different types for different values of ω. That is to say, the wave-form changes from azimuth to azimuth. As to P-waves, such an effect is not expected to be remarkable, because its pattern is given by the single term of $B_2 \sin 2\theta$ approximately, provided the effect of very high frequencies is negligible. Because of the difficulty in numerical calculation, the author could not show the above-stated effect in detail. In the F. Press's[3] paper reporting a model study, however, we clearly notice the variation of wave-form (S-waves) with azimuth, which might be the proof for the azimuth effect of the fault origin model.

Taking these circumstances into consideration, we may say that it is worth attempting to detect the effect of azimuth on the actual seismograms. Whether we obtain positive results or not, it must give us valuable information about the physical state of earthquake origins.

2. Analysis of seismograms

The present paper deals with a set of seismograms of the Alaskan earthquake of April 7, 1958 recorded with the Press-Ewing seismographs. According to the report from the U.S. Coast and Geodetic Survey, the epicentre was located at $66°\frac{1}{2}$N, 157°W, and the magnitude was estimated at about $7-7\frac{1}{2}$ by several stations.[4] The depth of the origin has not

2) K. KASAHARA, *Bull. Earthq. Res. Inst.*, **36** (1958), 21-53.

3) F. PRESS, *Publ. Dominion Obs.*, **20** (1958), 271-277.

4) *Seismological report from the Central International Bureau of Seismology, I.U.G.G.* (Strasbourg).

been known accurately, but the station at Saint Louis reported h=0.00 R. As to the macroseismic features, this earthquake has not been known very well except the preliminary report written by T. N. Davis, who observed a great volume of mud appearing on the surface at the epicentre[5]. The focal mechanism has not been reported yet by any authority, but according to the author's rough estimation, it is to be sorted into the strike-slip group (see section 4).

The Press-Ewing seismograph is very useful for the present purpose, because it keeps large magnification over a wide range of low frequency. This type of seismograph has been distributed over the world during the IGY. The records at seven stations among them were used for the analysis, they are Tsukuba, Honolulu, Pasadena, Waynesburg, Palisades, Resolute Bay and Uppsala. All of these stations, except Resolute Bay, are located at the distance of about 40—55° from the epicentre. Use of the seismo-

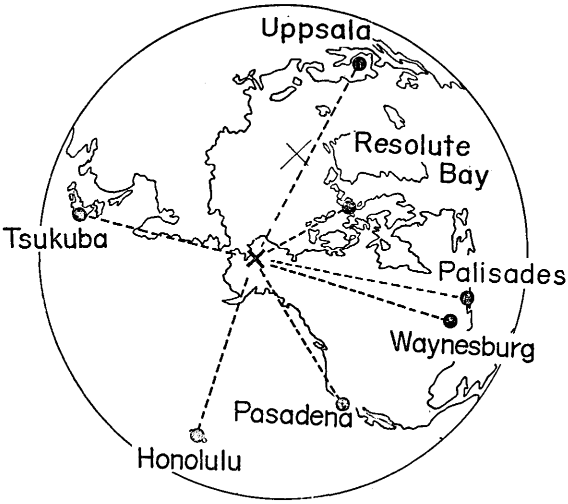

Fig. 1. Epicentre of the earthquake (×) and the seismograph stations (●).

Table 1. Stations and seismographs used for the analysis.

Station	Abbreviation	Distance	Azimuth	Seismograph	Component of Record		Remark
					P	*S*	
Tsukuba	Ts.	46°	N 97°W	"Press-Ewing" 15^s– 75^s	NS, EW, UD	EW	
Honolulu	Ho.	44	N175°W	15 – 75	—	EW	
Pasadena	Ps.	38	N125°E	30 – 90	UD	UD	
Waynesburg	Wy.	52	N 85°E	15 – 75	UD	UD	
Palisades	Pl.	52	N 80°E	30 –100	UD	UD	
Resolute Bay	Re.	21	N 43°E	15 – 75	NS	—	
Uppsala	Up.	55	N 5°E	15 – 75	UD	NS, EW, UD	

5) T. N. Davis, *Trans. Amer. Geophys. Union*, **39** (1958), 941–942.

grams recorded with the instruments of the same type at nearly equal epicentral distance made the following comparison of data fairly simple.

It would be reasonable to investigate the spectrum of P-waves

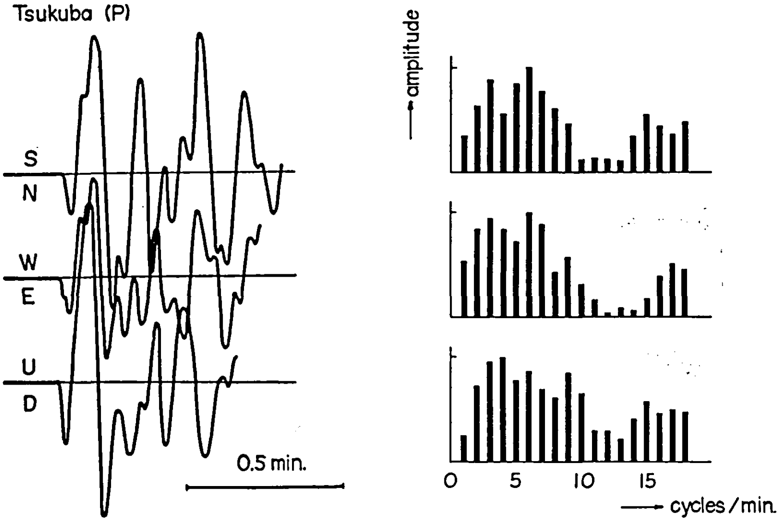

Fig. 2. Spectra of the three-component records at Tsukuba (P-phase).

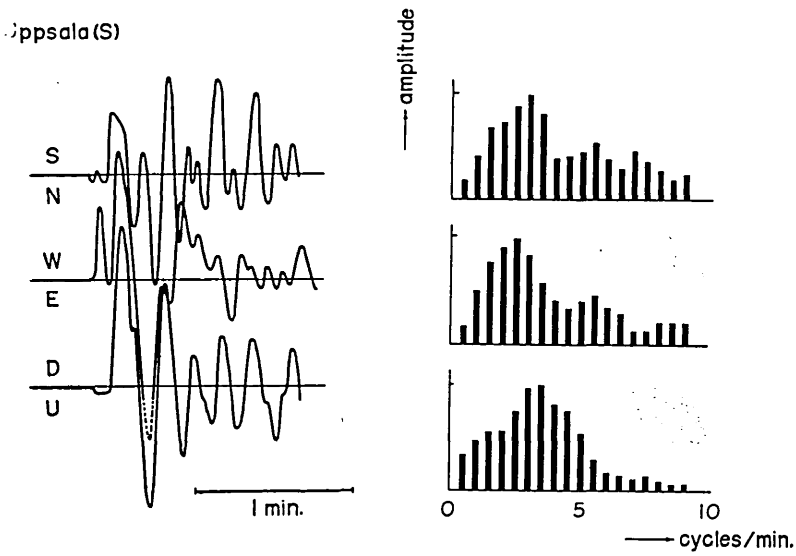

Fig. 3. Spectra of the three-component records at Uppsala (S-phase). A part of the EW-component record was off scale, which was assumed as shown with broken line (see also Fig. 5).

putting most stress on the records of vertical component, whereas to study *S*-waves taking one of the two horizontal components which is most responsible to *SH*-waves. However, this standard of selection could not be applied to all the stations, where the other component was used

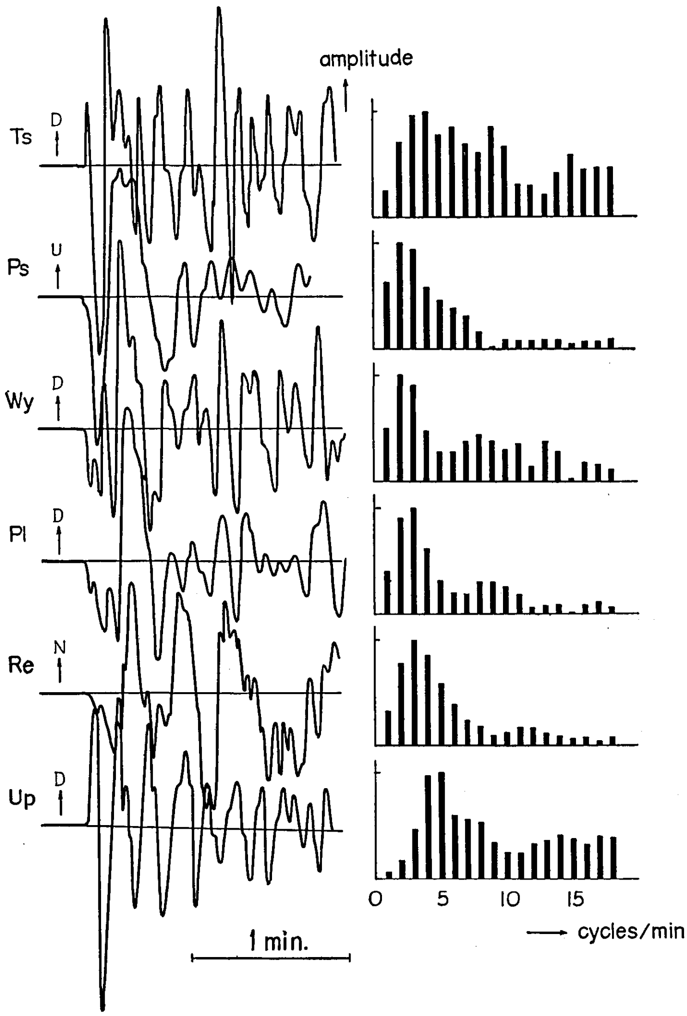

Fig. 4. Spectra of *P*-phase (before correction).

temporarily (see Table 1). This sort of replacing is believed to cause no serious troubles in conclusions as can be seen in the following examples.

Fig. 2 illustrates the spectra of the three-components of *P*-phase recorded at Tsukuba (before the correction for the frequency response of the instruments), in which we observe no remarkable discrepancy between them. For the same purpose Fig. 3 is drawn taking the three component records of *S*-phase at Uppsala. The two horizontal components have the spectral structures quite similar with one another. The vertical

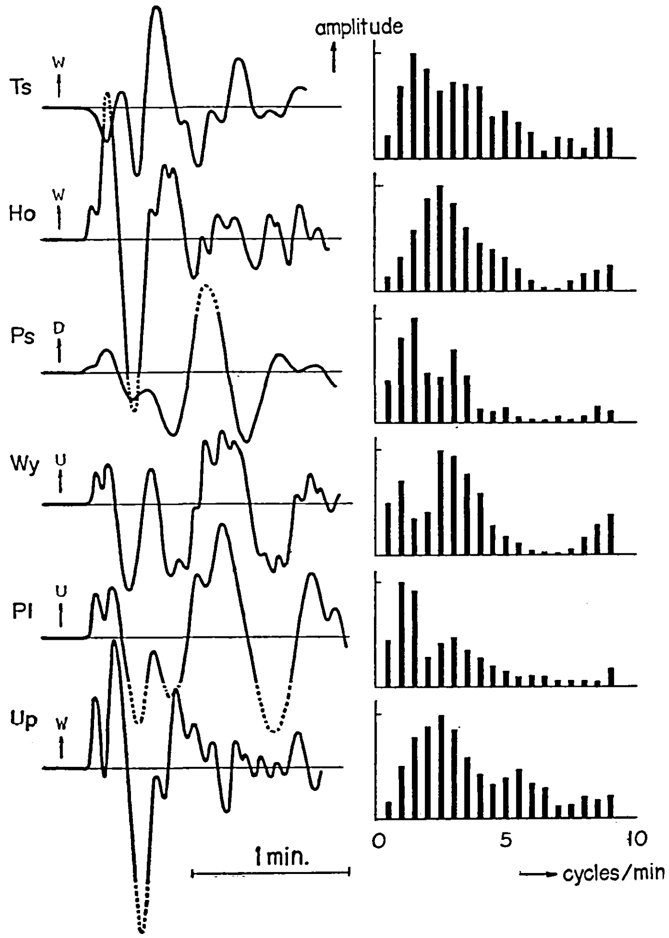

Fig. 5. Spectra of *S*-phase (before correction). Broken lines: assumed parts.

component is likely to show somewhat different feature. But the difference is not so large that replacement of the data of horizontal component with the vertical one might be allowed in such cases when the former is unavailable.

The method of analysis, used here, is quite same with that explained in the previous paper[6]. The fundamental period is 1 min. for *P*-phase whereas 2 min. for *S*. Figs. 4 and 5 are the spectra drawn in this way, where no correction is made for the frequency response of the instruments.

3. Spectra influenced by various sorts of factors

Before drawing a conclusion from the results in Figs. 4 and 5, we have to know how much the spectrum is influenced by various sorts of factors and make the necessary correction for them. The spectrum of a seismic record $R(\omega)$ consists of several basic components in the following way,

$$R(\omega)=P(\omega)\cdot O(\omega)\cdot Y_1(\omega)\cdot Y_2(\omega)\ , \tag{1}$$

where, $P(\omega)$, $O(\omega)$, $Y_1(\omega)$ and $Y_2(\omega)$ represent the spectral characteristics of the origin force, wave radiation from the origin (impulsive excitation), conditions of seismic wave path, and the seismograph, respectively. It is beyond the scope of the present paper to study $P(\omega)$ and $O(\omega)$ separately, so that we shall investigate the last two factors only.

Let us first discuss $Y_1(\omega)$ dissolving it into two components: (a) the effect of wave propagation through the idealized earth having spherically symmetric structures, and (b) the effect of local underground structures near the station. One of the factors which contributes to (a) is the viscosity in the medium. The magnitude of its influence has been estimated by several seismologists[7]. These results must be taken into consideration if we discuss the absolute values of amplitudes or spectra of waves. However, since our interest lies in comparing the data from the stations located at nearly equal distance from the origin, relative distortion of spectra due to viscosity is negligibly small.

When one phase of waves is overlapped by others, distortion in the spectrum would be observed. This possibility can be easily tested by examining the travel-time curves drawn by authorities. It is clear, then, that *P*- or *S*-waves arrive at those points listed in Table 1 separately from other phases, such as *pP*, *PP*, and so on. The only exceptional case is noticed for Pasadena ($\Delta=38°$), at which *S* and *PcS* arrive successively (*S* and *PcP* will arrive at Resolute Bay nearly at the same time, but the latter will have no much influence upon the records of horizontal components). However, this effect might be neglected when the energy of *PcS* is not so large as that of *S*.

6) K. KASAHARA, *Bull. Earthq. Res. Inst.*, **35** (1957), 473–532.
7) *f.i.* A. KUBOTERA, *Zisin* (*Journ. Seis. Soc. Japan*), [ii], **5** (1952), 77.

Magnitude estimation of the factor (b) is more difficult than that of (a). Incidence of the original waves to the earth's surface of complicated structures will cause multiple reflection and conversion of waves there. If these waves have sufficiently large energy they will cause the distortion of spectrum. After simple consideration[8], we know that this effect can not be disregarded particularly when the waves attack the surface successively with the time delay that falls in the range of period in which the predominant components of spectrum appear. Since our interest lies in the range of period from several seconds up to several tens seconds, the effect due to structures of very small scale, that sometimes plays an important role in the vibration characteristics of the ground, might be neglected. The lack of our knowledge about fairly large scale structures of the crust makes it quite difficult to discuss the present effect quantitatively. The only possible way is to arrange the results of analysis in the order of azimuth of each station and examine whether or not this undesirable effect disturbs the systematic characteristics of the phenomenon. From this point of view, comparison of the data at Honolulu with that at Uppsala gives us an interesting suggestion. As to the crustal structures, Honolulu must show remarkable contrast with other stations lying one the continental structures. Nevertheless, its record has spectral structures quite similar to that of Uppsala, located at the opposite position with respect to the origin (see Fig. 5 or Fig. 7). Similarity of the spectra of Waynesburg's data to those of Palisades is also notable. These two stations are a few hundred kilometres apart from one another, but the records of similar features have been obtained there.

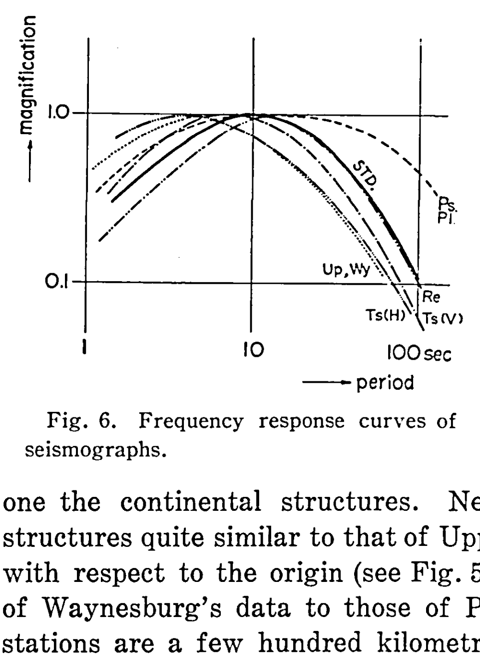

Fig. 6. Frequency response curves of seismographs.

These facts might be the evidence for the influences of the local structures being not remarkable on the spectrum of long period components, though there still remains some uncertainty in this supposition.

The influence of the frequency characteristics of a seismograph is more easily corrected than the above effects. Fig. 6 shows the response

8) K. KASAHARA, *loc cit.* 6).

curves for all the stations in the same coordinates. We shall temporarily take the curve of thick line (STD.) as the standard and reduce the results from all the stations to it. Since our purpose is in the comparison of the data, such temporary way of correction may be permitted. Fig. 7 illustrates the curves of spectra after this correction.

4. Discussion

Taking the above discussion into account, we may regard the curves in Fig. 7 as representing the fundamental characteristics of wave radiation without much distortion. First we compare the curves for P-phase with each other. All of them have a quite similar appearance to each other although a slight discrepancy is noticed for the curve of Tsukuba. They have a single peak at the frequency of about 3 cycles/min. and the slope monotonously approaching zero at lower frequency. In the high frequency range no remarkable peaks can be seen. The present result is very interesting and is to be explained reasonably by the ordinary models of spherical origins.

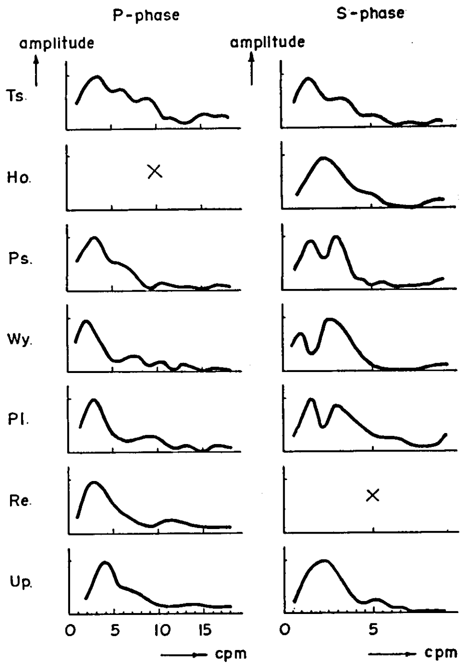

Fig. 7. Spectra of P- and S-phases (after correction).

The curves for S-phase present, on the other hand, another notable tendency. We can see no such similarity there as was noticed for P-phase. Roughly speaking, we may say that the curves are classified into two or three groups. The first group, which includes Honolulu and Uppsala, is of a single-peak type having its maximum at the frequency 2 or 3 cycles/min. The data at Pasadena, Waynesburg, and Palisades are likely to present the second type. This type has double peaks, the first peak at about 1.5 cycles/min. and the second one at 3 cycles/min or so. One may say that this difference should be attributed not to the mechanism of wave radiation but to the application of the vertical component record in place of the horizontal one. Since the horizontal component data were unavailable at these stations, the author can not strongly deny this objection. However, he would dare say that this is not the apparent effect but the real one, because the difference is still remarkable even if we compare these spectra with that for the vertical component record at Uppsala (see Figs. 3 and 5).

The data at Tsukuba is similar neither to the first group nor to the second one. In this sense, it must be classified as a third one, which is likely to be the intermediate type of the first two.

Before we make more definite discussion, we have to know the focal mechanism of the Alaskan earthquake in relation to the distribution of the stations. Unfortunately, this sort of study has not been reported by any seismologists yet. Therefore, let us take here a fault-plane technique in order to obtain a solution for temporary use. The seismological report from Strasbourg is used together with the materials given by some other observatories. Fig. 8 illustrates the result, in which the sense of the first P-phase (contraction or dilatation) at many stations is plotted with suitable symbols. By applying the fault-plane technique, the author draw a pair of nodal lines, from which the conditions of the nodal planes are estimated as shown in the same figure. It is interesting to examine whether or not this solution is consistent with the observational data of S-phase with respect to its polarity. The arrow marks in the same figure indicates the polarity of S-phase determined from the records of the Press-Ewing seismographs. On the other hand, the broken lines are the nodal lines of S-phase, which are given uniquely if we assume the mechanism of wave radiation to be the force type II[9]. It is very clear that these lines harmonize well with the observational data. It seems difficult to explain these data by

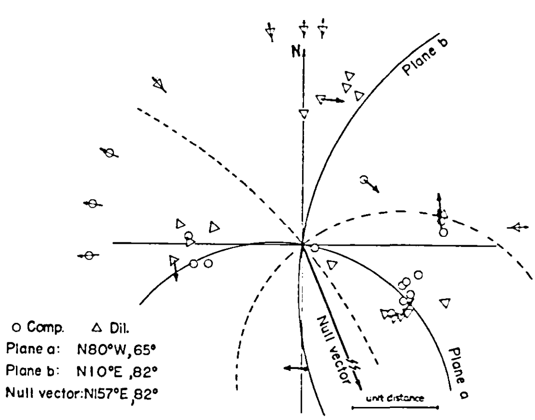

Fig. 8. Approximate solution for the focal mechanism.

9) *loc cit.* 1).

taking the model of the force type I. It is not the author's purpose to insist that the present solution is very decisive ; however, he considers it to represent the mechanism of the earthquake, approximately.

It is an interesting problem to make comparison of Fig. 7 with Fig. 8 for the purpose of finding out some relationship between the focal mechanism and the distribution of spectral types. From this point of view, it might be a notable fact that Honolulu and Uppsala are very close to the line of the plane b. These two stations belong to the first type of spectrum (*S*-phase) having a single peak, and the energy of *S*-waves observed there is likely to be larger than that of the other stations (this point is not very clear since magnification of all the seismographs is not known accurately). On the contrary, the other stations belonging to the second or the third types are far away from the above-stated line. Unfortunately, the present examples are too few to get a definite conclusion from them, so that the author would like here only to point out a bit of information relating to the problem.

5. Conclusions and acknowledgement

The author has pointed out a possibility of determining the "shape" of an earthquake origin by the examination of the azimuth effect on the spectral structures of *S*-waves. The case of the Alaskan earthquake is tested as a trial using the records of the Press-Ewing seismographs distributed over the world. A notable tendency has been found out in relation to the azimuth of the stations, though there still remains some uncertainty in concluding this to be a real azimuth effect. The author wishes to make this point very clear by accumulating this sort of data in future.

The author wishes to express many thanks to the Lamont Geological Observatory, the Seismological Laboratory at Pasadena, and all other stations which kindly gave him facility for using the seismograms recorded by them. He is also thankful to Prof. N. Nasu, Prof. T. Hagiwara and Dr. Y. Satô, who gave him encouragement and valuable advice in the course of this work.

12. 大地震発震スペクトルの方位特性に関する一つの試み (アラスカ地震の場合)

地震研究所　笠　原　慶　一

1958 年 4 月 7 日に起きたアラスカ地震の記録についてスペクトル解析を行なつた. その目的は, 震源から伝わる *P* 波および *S* 波のそれぞれが, あらゆる方向に同一のスペクトル構造をもつて射出されているか否かを検討しようとするものである. ふつう震源機構を説明するのには“点源”または“球状源”の模型を適用するのが常識になつているが, これらに共通する性質として *P* 波·*S* 波のスペクトル構造は各方位に同一の型を示すはずである. 一方, 断層模型などのようにスペクトル構造が規則的な方位特性を示すものも考えられる. 従つて, 観測事実が方位特性を肯定するか否定するかを明らかにすることは, 震源の形を知る上に重要な手がかりを与えてくれる.

解析にあたつては,筑波をはじめとする計 7 カ所の記録を資料として用いた. これらの観測所はすべて Press-Ewing 型長周期地震計を備えており, しかも Resolute Bay を除いてはほぼ同一の震央距離 (40～55°) にある. このことは解析結果を相互に比較する上に大へん有利である.

P 波のスペクトル構造に関しては格別の方位特性は認められない. これに反し *S* 波のそれは, いろいろな因子の影響を考慮してもすべての観測点で同一型式とは考え難いように見える. 数少ない資料であるから具体的にどういう方位特性であるか断定できないし, まして, どういう震源模型が最適であるか決めることは難しい. しかし, 今後この種の資料が集積されるにしたがつて, 震源の性状に関する一つの決め手が得られるものと期待される.