Some Problems on Poisson's Ratio in the Earth's Crust

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Abstract

Instead of the time-distance graph, the P-S diagram is effectively employed to estimate the value of Poisson's ratio in the earth's crust. This diagram is advantageous, especially to detect its local anomaly or distribution. The obtained results are as follows:

1) Applying this method to eighteen earthquakes occurring in south-western Japan, the domain with anomalously large Poisson's ratio was found in the Kyushu district. This hints to the possibility of an existence of a local magmatic reservoir.

2) The azimuthal distribution of the crustal Poisson's ratio in case of earthquake occurrence was investigated and it was found to be considerably different in the push- and pull-zone of initial seismic motion. This may be related to the state of stress accumulation causing the earthquake occurrence.

1. Introduction

In general, Poisson's ratio in the earth's crust is considered to be nearly constant. Its value is slightly less than 0.25 in the relatively shallow depths of the crust and is about 0.25 in the lower layers (GUTENBERG, 1955). Recently it was ascertained that the earth's crust in Japan has a distinctly local character (NISHIMURA and KISHIMOTO, 1956). In the present article, this character is clarified in more detail from the investigation of Poisson's ratio. And in the latter part, the distribution of the crustal Poisson's ratio in case of earthquake occurrence is discussed.

2. P-S diagram method

Theoretically, Poisson's ratio is related to the velocity ratio of the P-wave to the S-wave according to the following equation.

$$\frac{Vp}{Vs} = \sqrt{1 + \frac{1}{1 - 2\sigma}},$$

where Vp and Vs are the velocities of longitudinal and transverse wave respectively, and σ is Poisson's ratio.

In order to estimate the value of Vp/Vs, especially its local anomaly the P-S diagram method is effectively employed. In this diagram the arrival time of P-wave (Tp) is taken as abscissa and that of S-wave (Ts) as ordinate. The observed value at one station corresponds to one point. The value of Vp/Vs is given by the following formula

$$\frac{Vp}{Vs} = \frac{Ts - T_0}{Tp - T_0},$$

where T_0 is the origin time at the hypocenter, being common for the P- and S-waves. Compared to the usual time-distance curve analysis, this method has some merits mentioned below.

1) In order to construct the time-distance graph, the position of the hypocenter and the origin time at the hypocenter must be known and to estimate the value of velocity, some assumption about the subterranean structure is inevitably required, whereas in the P-S diagram analysis, only the origin time at the hypocenter is necessary and the value of Vp/Vs can be directly obtained without any assumption.

2) Furthermore, in order to detect only the local anomaly or distribution of Vp/Vs, the

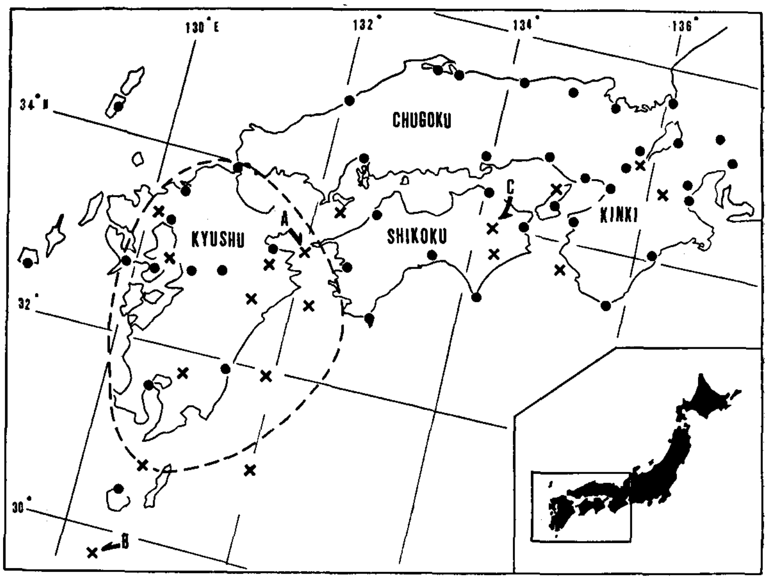

Fig. 1. The location of observation stations and epicenters. ● represents the observation station and × represents the epicenter. The dashed line shows the horizontal contour of the region with anomalously large Poisson's ratio. Three earthquakes A), B), and C) are mentioned in the section 3.

origin time is not always necessary, and they are immediately obtained from the distribution of points in this diagram. However, it is remembered that the value obtained by the P-S diagram is the mean value which is estimated along the seismic wave path from the hypocenter to the station.

3. Local character of Poisson's ratio

In this section, the crustal Poisson's ratio in south-western Japan is investigated, especially with regard to its local character. For this purpose, eighteen earthquakes are selected, twelve having rather deep foci (40—130 km depth) and the remaining six having shallow foci (10—30 km depth). The location of epicenters and observation stations are shown in Fig. 1. In the following, three examples are mentioned. For details, reference is made to the paper by KAMITSUKI (1959).

Earthquake A) 1953 Jan. $23^d\ 11^h\ 47^m\ 59^s$
($\lambda = 33.3°$N $\varphi = 132.2°$E, H = 40 km)

The points are separated into two groups. The upper group points are those of the stations in and near the Kyushu district and the

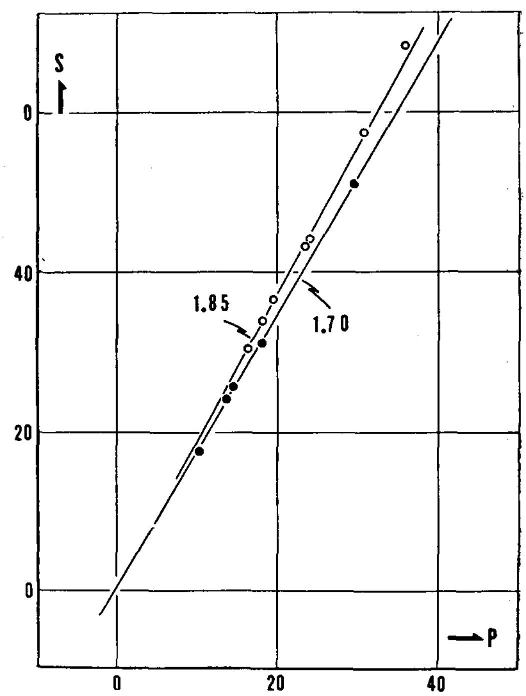

Fig. 2. The P-S diagram of the earthquake on Jan. 23, 1953. Vp/Vs (1.85) corresponds to σ (0.29), and 1.70 corresponds to 0.24.

lower group points are those of the stations in the Shikoku and Chugoku districts. (Fig. 2)

Earthquake B) 1955 Mar. 28^d 18^h 12^m 20^s
($\lambda = 29.4°$ N $\varphi = 130.1°$ E, $H = 60$ km)

A straight line through the points of stations in the Shikoku and Chugoku districts is drawn. The remaining points which are those of the stations in the Kyushu district deviate upwards from this straight line. (Fig. 3)

Earthquake C) 1957 Nov. 14^d 22^h 29^m 09^s
($\lambda = 34.0°$ N $\varphi = 134.2°$ E, $H = 40$ km)

All points are those of the stations in the Shikoku, Chugoku, and Kinki districts and they are completely arrayed on a straight line within the limit of accuracy. (Fig. 4)

In all cases, the points of stations in and near the Kyushu district deviate upwards, and their deviations amount to about 1.5 ~ 3.0 sec in the arrival times of S-waves. The shallow earthquakes, the foci of which are situated in the

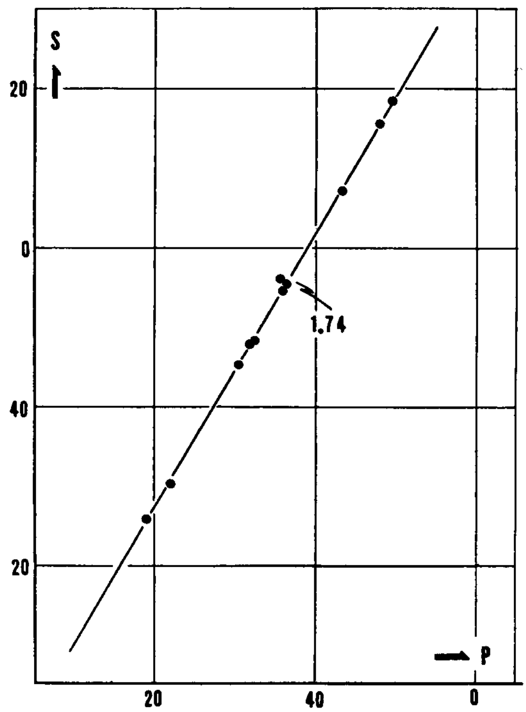

Fig. 4. The P-S diagram of the earthquake on Nov. 14, 1957. Vp/Vs (1.74) corresponds to σ (0.25).

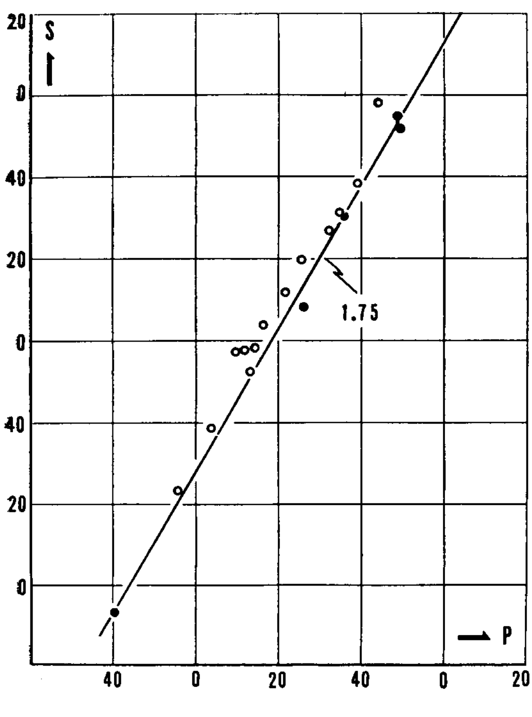

Fig. 3. The P-S diagram of the earthquake on Mar. 28, 1955. Vp/Vs (1.75) corresponds to σ (0.26).

upper layers of the crust do not show such an effect as seen in the above-mentioned cases. From these, it is concluded that the crustal Poisson's ratio in the Kyushu district (0.28 ~ 0.30) is anomalously larger than that in the neighbouring districts (0.22 ~ 0.25) and that the anomalous domain is situated at the depths from about 20 km to 40 km. The horizontal contour of this domain is roughly shown in Fig. 1 with the dashed line.

Several years ago, one of the writers (NISHIMURA, 1950) reported that from the long period tiltmetric observation at Makimine ($\lambda = 32°38'$ N, $\varphi = 131°24'$E), the earth tidal amplitude of the M_2-component shows a large fluctuation beyond the observation error, and that this is attributed to the variation of properties of subterranean material associated with the seismic activity in the surrounding area. Furthermore, the Kyushu district is one of the most volcanically active regions in Japan. By more extensive study from these various standpoints, it will be expected

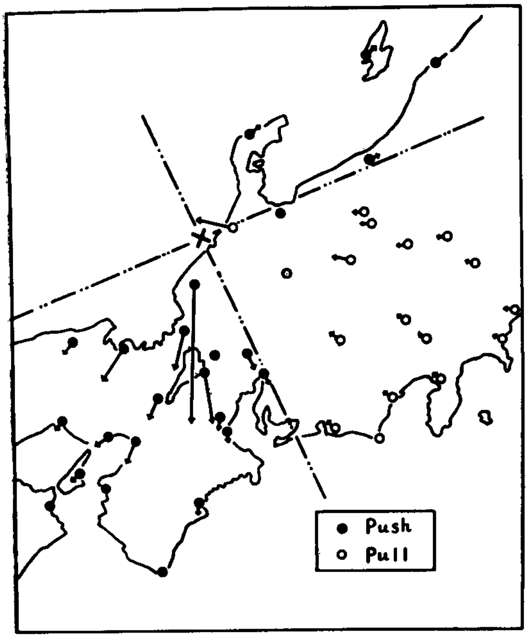

Fig. 5. The push-pull distribution of initial seismic motion of the Daishoji-Oki earthquake.

to clarify the existence of the domain with anomalously large Poisson's ratio in more detail.

4. Azimuthal distribution of Poisson's ratio in case of earthquake occurrence

It is generally accepted that earthquakes are caused by stress accumulation in some limited region of the earth's interior and subsequent release of such energy according to the occurrence of the fracture-like event. The detailed process is, however, far from being completely understood.

As described previously, the P-S diagram method is very advantageous to detect any local distribution of Poisson's ratio. In the present section, this merit is profitably used to investigate the azimuthal distribution of Poisson's ratio in case of earthquake occurrence.

For this purpose, three shallow earthquakes, the foci of which are situated in the earth's crust are examined, one being accompanied by aftershocks, and the other two belonging to the earthquake swarm occurring in the Shikoku district. The report by KAMITSUKI (1959) may be consulted for details.

1) The Daishoji-Oki earthquake
1952 Mar. 07^d 16^h 32^m ($\lambda = 36° 45' N$
$\varphi = 136° 20' E$, $H = 20$ km, $M = 7$)

The push-pull distribution of initial motion is seen in Fig. 5 which shows the so-called quadrant-type pattern. The P-S diagram is shown in Fig. 6.

In this figure, the points are arrayed on the two branched lines. The points on the upper line are those of the stations in the pull-zone, while those on the lower line are of the stations in the push-zone. The gradients of these two lines are 1.70 and 1.90 respectively and the former is a little larger and the latter is much larger than the normal value of 1.67 (YOSHIYAMA, 1957). Reflecting upon the construction of the P-S diagram, the gradients of these two lines represent the apparent values of Vp/Vs. If the origin time point is determined,

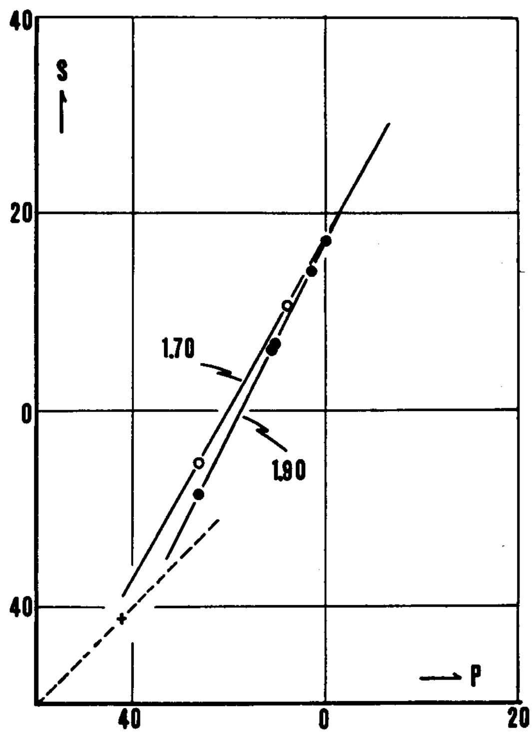

Fig. 6. The P-S diagram of the Daishoji-Oki earthquake. (Solid circle: push, open circle: pull).

the true value of Vp/Vs can be obtained. Assuming the origin time at the hypocenter being common for the P- and S-waves, the corresponding point slides on the 45°-gradient line through the origin of this diagram. From the time-distance curve analysis, the origin time is presumed to be plotted on the segment between two branched lines. Accordingly, the value of Vp/Vs increases from about 1.60 to 1.68 in the push-zone while it decreases from 1.80 to 1.68 in the pull-zone.

2) The Tokushima earthquakes

1955 Apr. $10^d\ 11^h\ 09^m\ 12^s$ ($\lambda = 34.1°$ N $\varphi = 134.2°$ E, $H = 10$ km, $M = 4.6$)

1955 May $18^d\ 13^h\ 39^m\ 24^s$ ($\lambda = 33.8°$ N $\varphi = 134.3°$ E, $H = 0 \sim 20$ km, $M = 4.9$)

In the Tokushima prefecture, Shikoku district, small earthquakes have frequently occurred. Their magnitude are reported as from about 4 to 6. Two examples are shown in Figs.

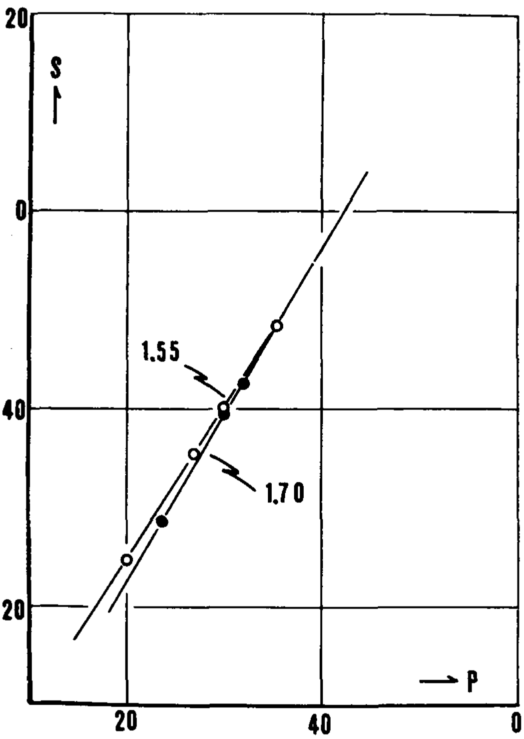

Fig. 7. The P-S diagram of the earthquake on Apr. $10^d\ 11^h\ 09^m\ 12^s$.

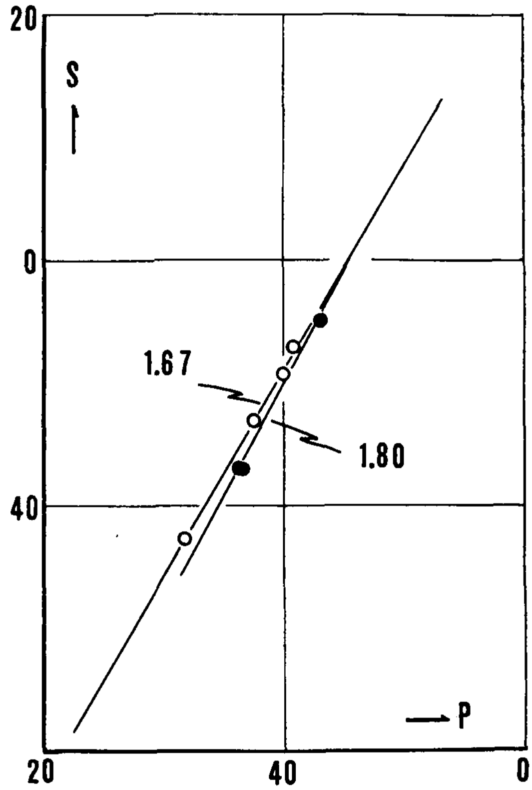

Fig. 8. The P-S diagram of the earthquake on May $18^d\ 13^h\ 39^m\ 24^s$.

7. and 8. An effect similar to the case of the Daishoji-Oki earthquake is found.

From the above-mentioned examples, it is found that the crustal Poisson's ratio in case of earthquake occurrence is considerably different in the push- and pull-zone of initial motion. As no local anomaly of Poisson's ratio is found in the region concerned in the present investigation, the above-mentioned effect must be attributed to the variation of the crustal Poisson's ratio which is related to the stress accumulation causing the earthquake.

5. Summary

In order to investigate the crustal Poisson's ratio, especially its local anomaly or distribution, the P-S diagram method is effectively employed. The advantage of this method is that the anomaly of Poisson's ratio can be directly detected without any assumption about the subterranean structure.

As a first treatment, the local character of the crustal Poisson's ratio was investigated. In the Kyushu district of south-western Japan a certain limited domain with anomalously large Poisson's ratio was found, and from the analysis of earthquakes having various focal depths it is estimated to be situated at the depths from about 20 km to 40 km.

Recently it is stated that low-velocity layers with large Poisson's ratio exist in the earth's crust and upper mantle. From the results of the present investigation, it is ascertained that there exists a layer with anomalously large Poisson's ratio in particular regions such as the Kyushu district. But the correlation between such anomaly of Poisson's ratio and the velocity variation with depth should be investigated more in the future.

Secondly, the azimuthal distribution of Poisson's ratio in case of earthquake occurrence was investigated and it was found that the crustal Poisson's ratio is considerably different in the push- and pull-zone of initial seismic motion. Especically this effect is distinctly observed in the domain close by the epicenter. This may be related to the state of stress accumulation causing the earthquake.

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EDITOR'S NOTE

Observational data, which since 1957 have been published in Tellus under the headings "Current data on the chemical composition of air and precipitation" and "CO_2 values in Scandinavia" will from this issue be printed as a separate report, appearing once a year. Orders for this report should be mailed to: The Chemical Laboratory, International Meteorological Institute, University of Stockholm, Lindhagensgatan 124, Stockholm K, Sweden.