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DETERMINATION OF SEISMIC ANISOTROPY OF METAMORPHIC ROCKS IN NATURAL CONDITIONS

By

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Abstract

Anisotropy of seismic wave velocities in schists is measured in natural conditions. The detected values of the anisotropy (P wave) are found to be 10~20%. The results are discussed in comparison with the supersonic method for the rock specimens.

Introduction

In the conventional seismic prospecting, the medium is assumed as isotropic. However, general media are not always isotropic. The most typical one is metamorphic rock.

By the way, the author has studied the application of seismic prospecting for metal mine. In metamorphic region of Japan, there are several important mines, which belong to Kieslagar type. From this point of view, seismic anisotropy of metamorphic rocks in natural conditions was studied. The author also believes that the study of anisotropy of metamorphic rocks is valuable for structural geology and petrography.

The experiment was carried out in the Sazare Mine, Ehime Prefecture, on March 1962. The Sazare Mine is one of the typical Kieslagar type mines, situated in

Fig. 1. Location of the Sazare Mine.
M: Sazare Mine
S : Sambagawa Zone

Sambagawa metamorphic zone (Fig. 1). The thickness of each unit stratum in this mine is not so large that it can be measured by the conventional seismic prospecting. And hence the author used high frequency seismic technique which has been developed by him for the prospecting in mines and civil engineering fields (Kitsunezaki, [1960a, 1960b, 1961, and 1963]). The principle of this method is simple. Detonation of a little amount of charge in rock (not in soil) generates high frequency seismic waves, from several hundreds cycles to several thousands. Therefore, the wave length is of the order of a few meters. It is short enough for the determination of the wave velocity in an unit stratum whose thickness is of the order of ten meters in this case.

The principle of the measurement is schematically illustrated in Fig. 2.

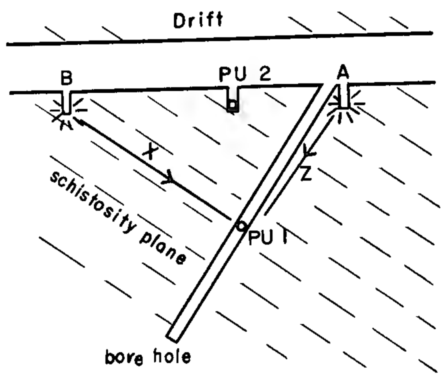


Fig. 2. Illustration of the method for determination of the velocity in anisotropic media.

In the drift, bore holes whose axial direction was perpendicular to the horizon of the strata (schistosity plane) were selected for the measurement. Two shot positions were prepared for each detector position located in the bore hole, i.e., one shot position (A) was located on the top of the hole and the other (B) on the same horizon as the detector position. Observing these two shots, the detector position was changed through the bore hole. By this method, the velocity in the directions perpendicular ($V_{\perp}$) and parallel ($V_{/\!/}$) to the strata was respectively determined. Principal observation was carried out with only one detector. However in this experiment, another detector was also used for two supplementary purposes, that is, the monitoring of shot strength and the observation of the waves propagating in a direction oblique to the strata.

The apparatus for the measurement is consisted of detectors, an amplifier and an electromagnetic recorder. The detectors and the amplifier (two channels) are specially designed by the author for this purpose. Hydrophones composed of barium

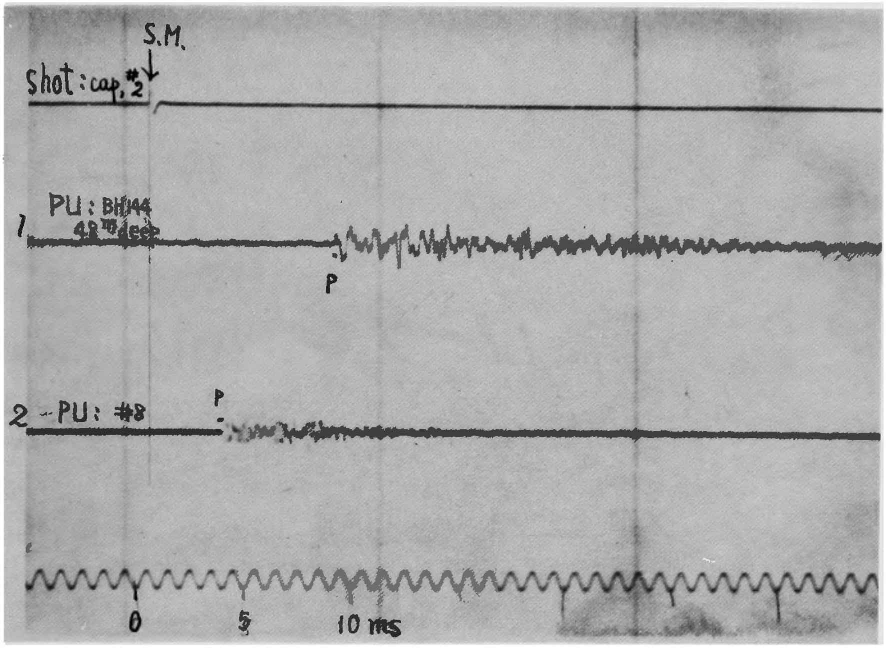


Fig. 3. An example of the record.

titanate cylinder and impedance transformer were used as the detectors. They are situated in holes containing water. The most important characteristics of recorder were high paper speed (used in 3～4 m/sec) and high resonance frequency (5,000 cps) of galvanometers.

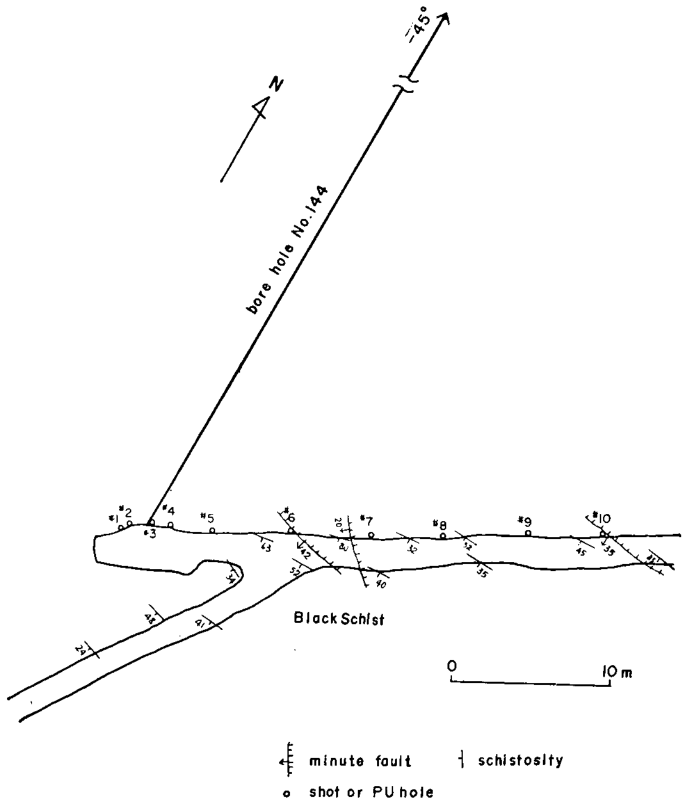
Examples of actual field conditions and the experimental datum (travel time curves) are demonstrated in Fig. 4. The results are shown as the directional diagram of the velocity for each rock (Fig. 5).

In Fig. 5, velocity (V) is defined as follows:

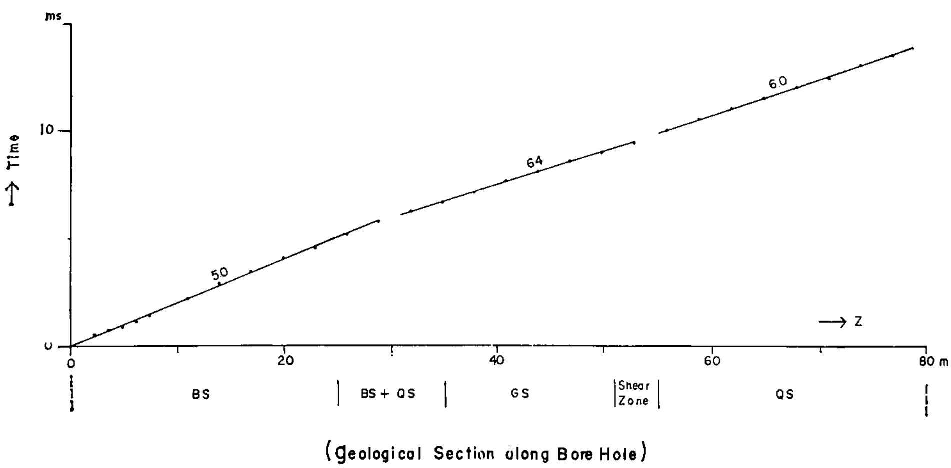
$$V = \frac{X}{t},$$

where X is the distance between the shot and the detector, t is the time interval from the shot to detection of the first kick. In anisotropic media the velocity defined as above is not always identical to the propagation velocity, because the wave front generated from a point source is not necessarily perpendicular to the direction from the source to the detector. Only in the direction perpendicular or parallel to the horizon they are identical. Such figure as Fig. 5 is called as the wave surface (Postma, [1955]).

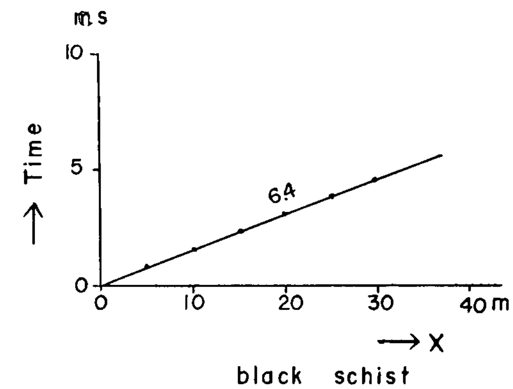
The measurements were also carried out in other places of this mine. These results are shown by broken lines in Fig. 5 for convenience sake.



(a) Experimental place (Drift: 21L, Kazukimuke).

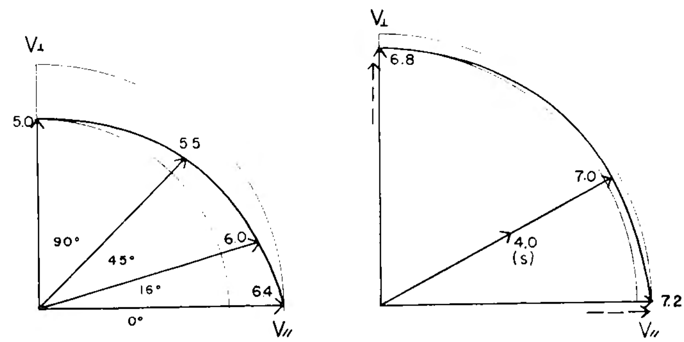


(b) Travel time curve of P wave propagating in the direction perpendicular to schistosity plane.
BS: Black schist, QS: Quartz schist, GS: Green schist



(c) Travel time curve of P wave propagating in the direction parallel to schistosity plane.

Fig. 4. An example of the field condition and the experimental result obtained there.



(a) Black schist (bore hole No. 144)

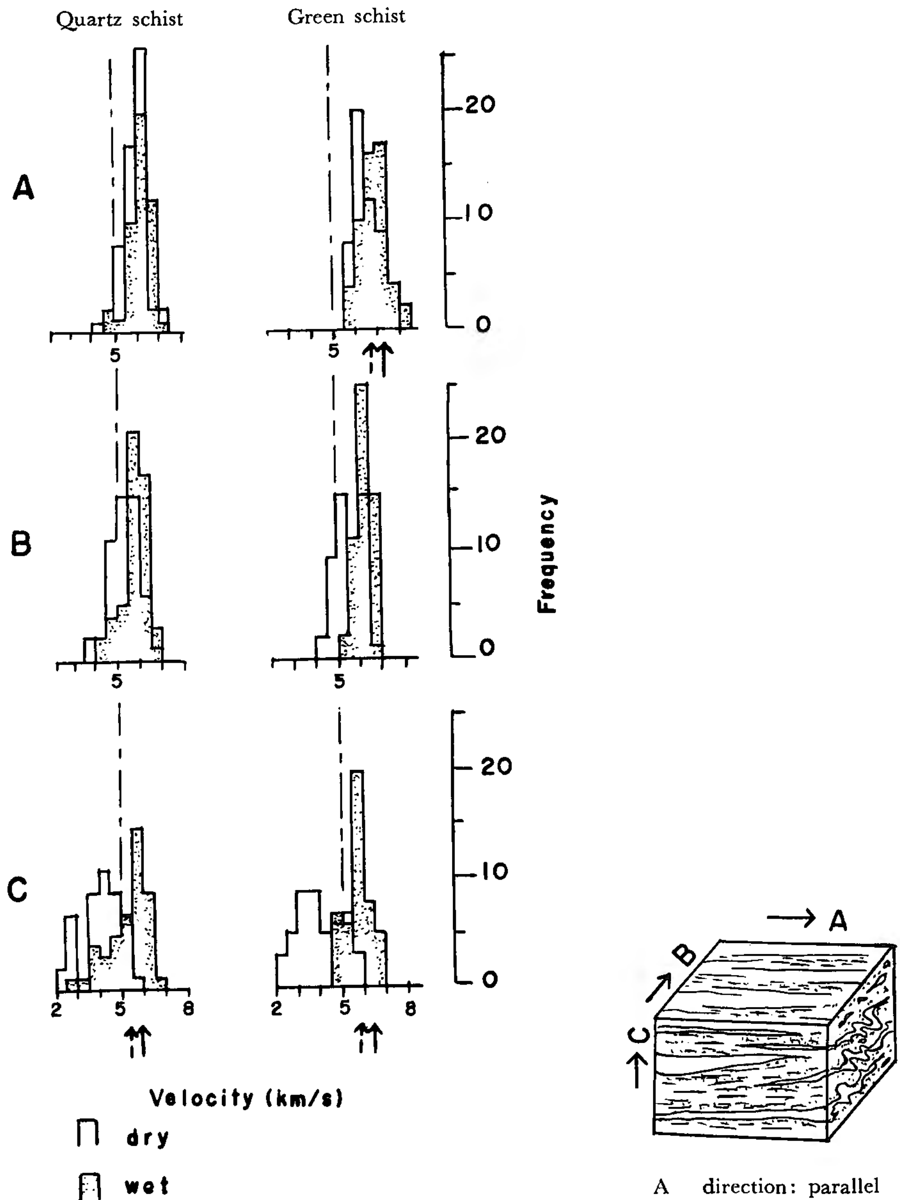
(b) Green schist (bore hole No. 131)

Fig. 5. Representation of anisotropy by wave surface. They are the results on the measurements of velocity of P wave, except the value "S" which means velocity of S wave.

Discussion

Generally, the measurement of velocity of rock specimen by the supersonic method is applied for such purpose in this case. Regarding the rock specimens sampled in the same drift of the Sazare Mine, K. Hirasawa [1962] carried out the supersonic measurement before the author's experiment. The important results obtained by Hirasawa are cited in Fig. 6(a) from his paper.

In Hirasawa's experiment, each rock specimen was examined both in a dry and wet condition. Rocks were classified into green schist and quartz schist in which black schist is included. (This does not considerably affect the result on quartz schist, because the number of black schist specimens is few).



↑ mean value of the velocity (wet) of the supersonic method

↑ velocity determined in natural conditions

(a)

A direction: parallel to liniation

AB plane: schistosity plane

A⊥B⊥C

(b)

Fig. 6. The P wave velocity of specimens by the supersonic method (cited from K. Hirasawa's paper). It is shown in comparison with the velocity in natural conditions.

The measurement was carried out for the three directions which are illustrated in Fig. 6(b). In Fig. 6(a), the following data are added by the author to the original figure; mean velocity in a wet condition (based on Hirasawa's paper) and the velocities obtained by the author (A and B directions are not distinguished in the author's experiment. The datum is tentatively treated as A direction.) The author also examined some specimens of the rocks in this mine by the supersonic method and obtained nearly the same results. Therefore, it is believed that the Hirasawa's data show the typical results of supersonic measurement. In Fig. 6(a), following points are noted: broad distribution of the velocity of rocks in similar kind under the same condition, and dependency of the velocity on the experimental condition (dry or wet). In such a kind of measurement, it is difficult to select a condition reasonable as natural and to appoint a representative value in that conditions. So they cannot be directly applied for the interpretation of seismic observation in fields. The direct measurement in natural conditions is free from the faults above mentioned. The wide distribution of velocities obtained by the supersonic method would be partly attributed to the fact that the wave length is too short. If the frequency of the supersonic wave is 500 kc and the velocity is 5 km/s, then the wave length becomes 1 cm. This value of wave length corresponds to mineral grains or domains in some rocks. In the relevant rocks of this mine, many lenticular minerals (0.5~2 cm in thickness) are contained. In order to dertermine the velocity in rock, it is essentially important to select the wave length larger enough than the dimension of discontinuity in media and shorter enough than the thickness of an unit of the media (layer).

In the supersonic measurement, the velocities in a dry condition distribute in very wide range and are generally lower than that in a wet condition. The author's measurement reveals that mean values of velocities in natural conditions roughly correspond to that in a wet condition. But the former is more larger than the mean value of the latter (12~15% larger in C direction, 5~8% in A direction). This means that the effect of the pressure cannot be neglected. The experimental field was about 800~1,000 m below the ground surface.

In the region of the author's experiment, the largest anisotropy is recognized in black schist whose value is 20%. If an exact measurement is done in A direction, somewhat larger anisotropy may be observed in those schists, because A and B directions are not distinguished in this experiment.

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