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Application of P & SH-waves for rock anisotropy studies: Genting Highlands case study

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Abstract: Seismic refraction surveys utilizing P & SH-waves were carried out over an abandoned quarry at Genting Highlands in order to study the anisotropy of the bedrock of that site. Shear (S) and compression (P) acoustic velocities of the subsurface refractor have shown significant variations in their spatial distribution. These variations in velocity values were compiled and then qualitatively correlated with surface fracture surveys conducted during the course of acquiring the field data.

Seismic P & SH-wave velocity values obtained from *in situ* measurements have been used for calculating the anisotropy percentage and slowness factor. The petrophysical parameters computed are then contoured to identify the orientation of fracture zones along the refractor surface.

INTRODUCTION

Seismic refraction method is a geophysical tool widely used for routine engineering site investigations (Redpath, 1973) whereby the subsurface structure of the surveyed area is inferred from interpretation of the seismic field data gathered from surface measurements. The SH-refraction method has found increasing use for seismic anisotropy studies since the velocity derived from such surveys are direction dependent (Danbom and Domenico, 1987).

In this study, a brief description of the field data acquisition and processing technique is given. Interpretations of geophysical results, the petrophysical parameters derived from the seismic attributes of the P & SH-waves refraction sections and their relationship with the discontinuity (surface fractures) results are described in some detail. Conclusions drawn from these surveys are given.

SEISMIC DATA ACQUISITION AND PROCESSING

The survey site is located in an abandoned quarry at Genting Highlands, Pahang State (Fig. 1), and the survey lines were set up on the floor of the quarry. The lithology of the site is made up mainly of two layers. The top layer consists of aggregate of rhyolite mixed with clayey silty coarse sand while the second layer or bedrock is made up of rhyolite.

The objective of this study is to delineate the topography of the rhyolite bedrock, determine petrophysical parameters of the bedrock (refractor layer) and to identify the orientation of the fractures in the rhyolite bedrock.

Seismic refraction surveys utilizing P & SH-waves were carried out on an overlapping radial patterns (Fig. 2). The azimuths between survey lines were kept small in order to secure good coverage for the spatial distribution of P & SH-velocities over the surveying area.

Field data collected from those surveys were then interpreted using the generalized reciprocal method (Palmer, 1980). The first arrivals of refracted signals were digitally picked (Hatherly, 1980) during data processing for further accuracy of arrival time measuring, thus decreasing the difference in reciprocal time estimated between the off-end shots.

The P-wave components in the opposite polarity field data records gathered from the shear wave surveys have been reduced by computer processing before picking first arrivals of the SH-refracted signals.

DISCONTINUITY SURVEYS

A discontinuity within a rock mass is considered as any plane of weakness having zero or very low tensile strength (ISRM, 1978). In this study, surface fractures surveys were involved, and these discontinuities were mapped along outcrops exposed at the site. At the investigation site, a detailed

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discontinuity survey using the scan-line method (Priest and Hudson, 1978) was carried out. The discontinuity orientations were then plotted as poles on an equal area stereographic Schmidt net and contoured (Fig. 3) to locate the orientation of the major discontinuity sets and also to determine the weak zones. The data set results of this analysis are presented in Table 1.

DATA INTERPRETATION

The P & SH-seismic refraction lines were processed using the generalized reciprocal method. This method keeps tracking on the change in velocity along the surface of the refractor (Palmer, 1981) and is also able to map the topography of refractors having large magnitudes of (> 10 degree) dip.

The P & SH-wave velocities derived from the seismic sections were compiled and then contoured. The slice section of Figure 4a depicts the distribution of P-wave velocity over the refractor surface. Note that a major fracture oriented in almost east-west direction. A high velocity plume located at the northwest side is surrounded by two minor fractures. The 3D view (Fig. 4b) of P-wave velocity shows the change in P-wave velocities over the refractor surface (rhyolite).

As shear wave has a short wavelength within a same frequency of the compression wave (Douma and Helbig, 1987); the change of SH-wave velocity over the refractor surface (Fig. 5) has been well resolved, and it has produced a high-resolution image of the subsurface structure. Therefore, the P & SH-velocity sections have located several sets of fractures that are represented by sharp boundary changes in velocity, along the rhyolite surface.

The 3D view of the absolute anisotropy percentage (Fig. 6) maps the major fracture which is indicated earlier in the slice section of P-wave

Table 1. Discontinuity distribution at the investigation site, Genting Highlands, Pahang.

Data set	Dip direction (deg. α)	Dip amount (deg. β)	Stereographic %
J_1	125	80	> 10
J_2	115	85	> 10
J_3	010	45	6–8
J_4	185	75	4–6

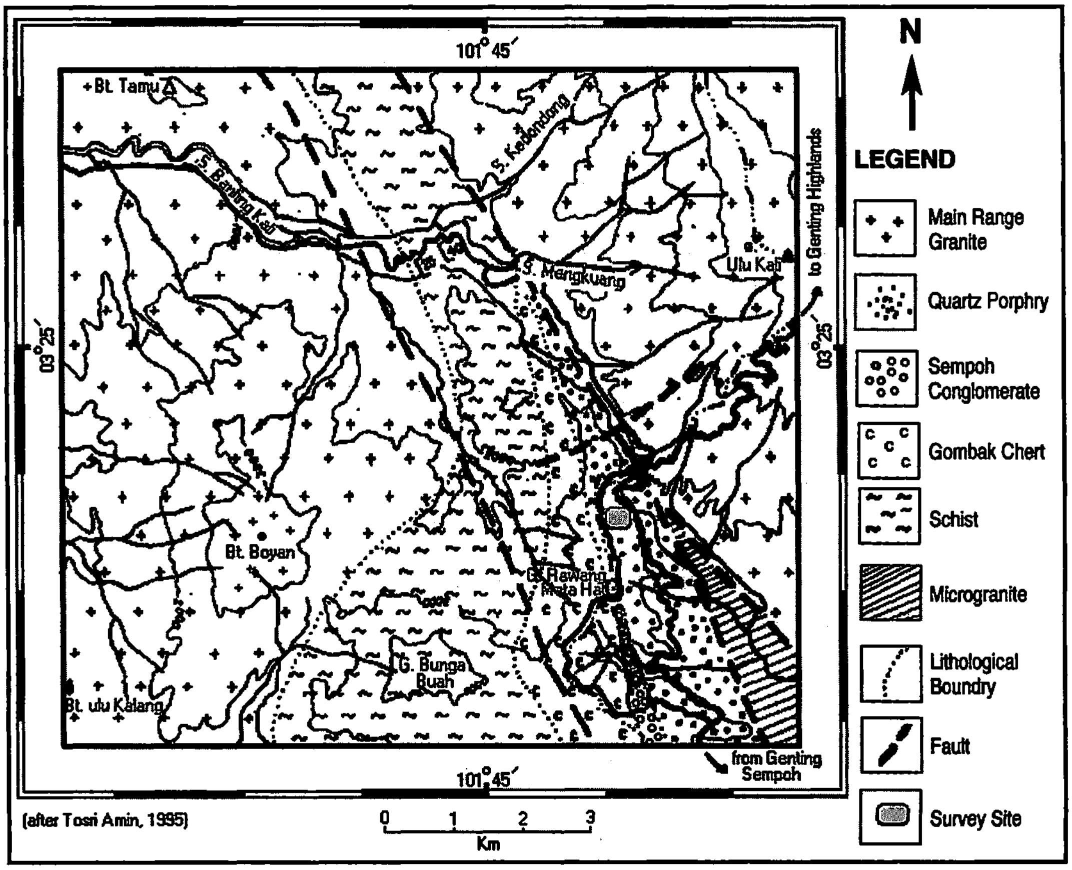

Figure 1. Map showing the location of area study and investigation site.

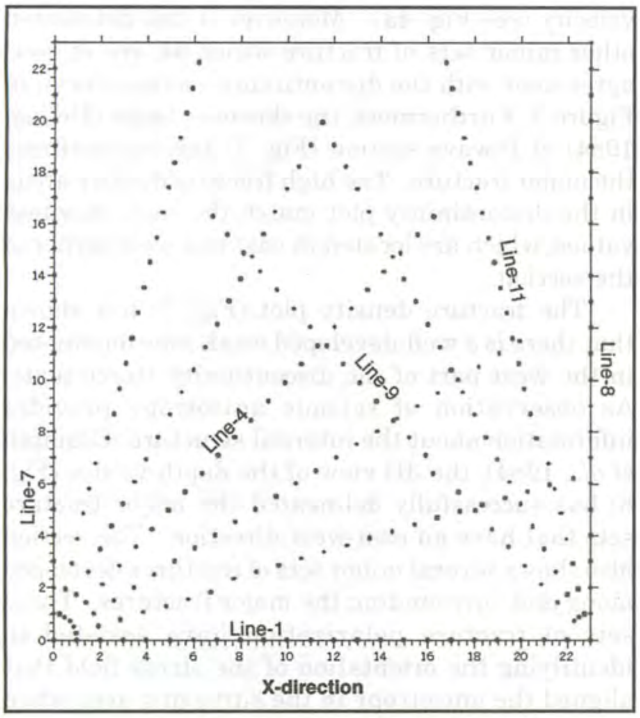

Figure 2. A schematic diagram depicts the overlapping radial patterns of the survey lines.

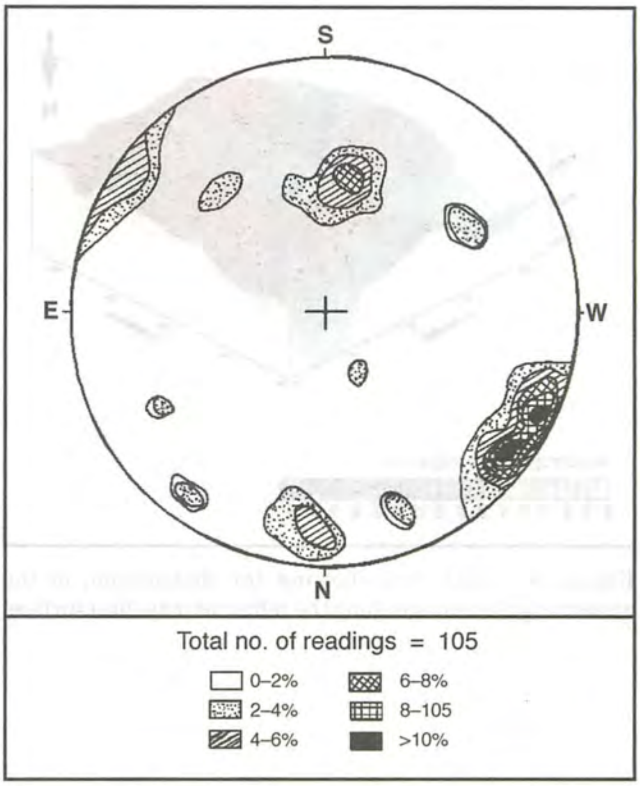

Figure 3. A Stereographic plot of discontinuity distribution at the investigation site.

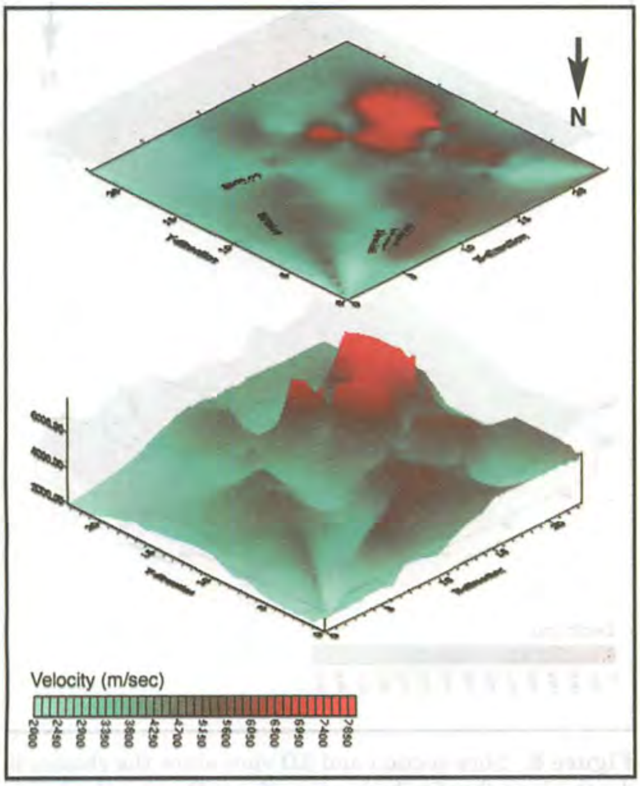

Figure 4. Slice section and 3D view for P-wave velocity of the rhyolite bedrock.

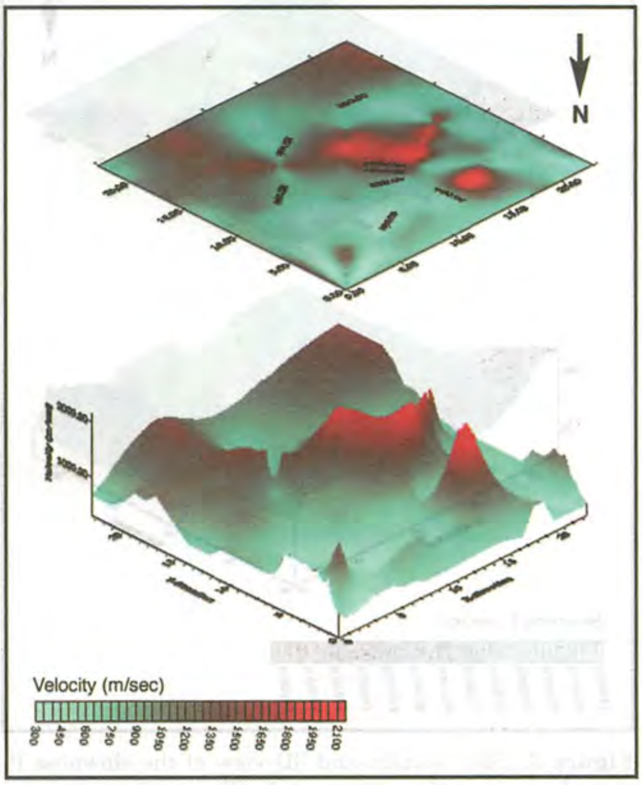

Figure 5. Slice section and 3D view for SH-wave velocity of the rhyolite bedrock.

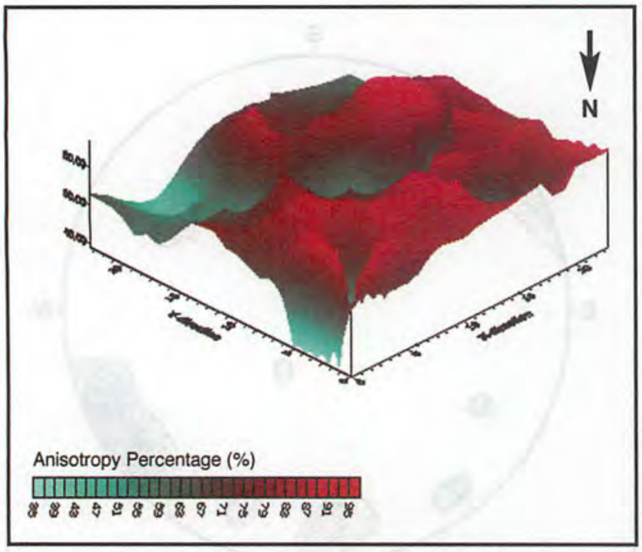

Figure 6. A 3D view showing the distribution of the anisotropy percentage along the refractor (rhyolite) surface.

velocity (see Fig. 4a). Moreover it has delineated other minor sets of fracture which all are in good agreement with the discontinuity section shown in Figure 3. Furthermore, the slowness factor (Helbig, 1984) of P-wave section (Fig. 7) further confirms the major fracture. The high fracture density areas in the discontinuity plot match the high slowness values, which are located in east and west corner of the section.

The fracture density plot (Fig. 3) has shown that there is a well-developed weak zone dominated in the west part of the discontinuity stereo plate. As observation of seismic anisotropy provides information about the internal structure (Crampin *et al.*, 1984), the 3D view of the depth values (Fig. 8) has successfully delineated the major fracture sets that have an east-west direction. The section also shows several minor sets of fractures developed along and surrounding the major fractures. These sets of fracture polarization have assisted in identifying the orientation of the stress field that aligned the anisotropy in the surveying area when it was last fixed. The major field stresses that aligned those fractures in the survey area have produced several narrow trenches between these main fractures.

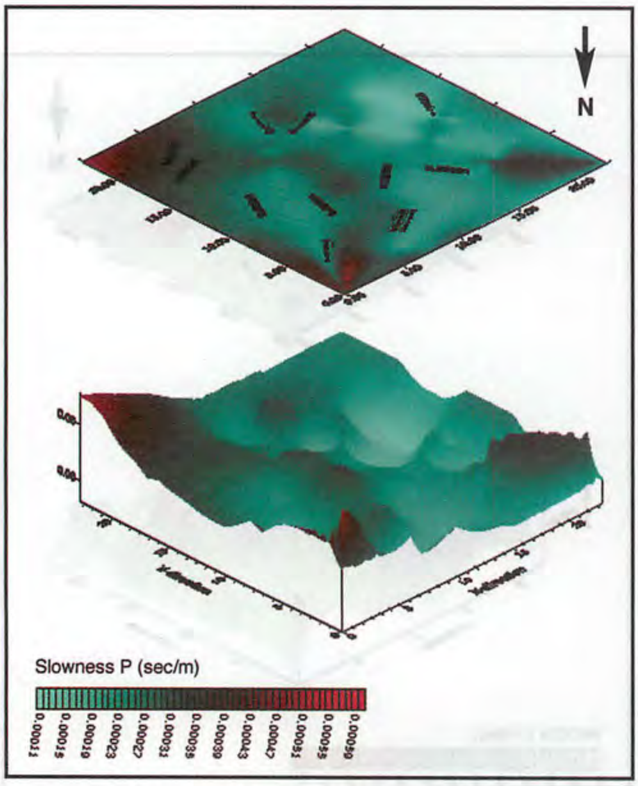

Figure 7. Slice section and 3D view of the slowness P-wave factor over the refractor (rhyolite) surface.

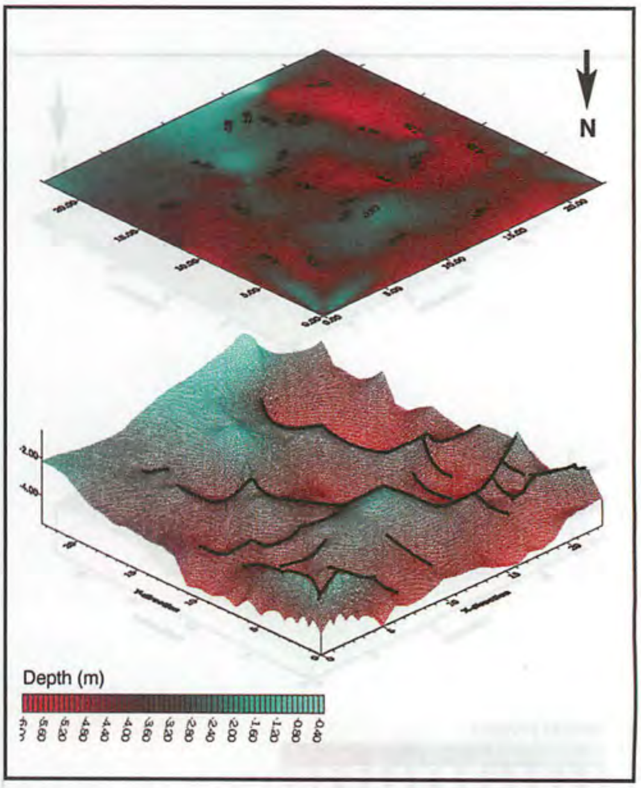

Figure 8. Slice section and 3D view show the change in depth along rhyolite bedrock surface. Depth values used are obtained after merging of depth values of seismic P & SH-waves refraction lines.

CONCLUSION

The anisotropy of acoustic velocity, measured horizontally along several azimuths within narrow angles between refraction survey lines, provides high quality data that can be used for fracture density studies. Petrophysical parameters derived from the acoustic velocities of P & SH-waves assist in locating the trend of fractures.

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REFERENCES

CRAMPIN, S., CHESNOKOV, E.M. AND HIPKIN, R.A., 1984. Seismic anisotropy — the state of the art. *First Break, 2*, 9–21.

DANBOM, S.H. AND DOMENICO, S.N., 1987. *Shear-Wave Exploration*. SEG Publisher, Tulsa.

DOUMA, J. AND HELBIG, K., 1987. What can the polarization of shear wave tell us. *First Break, 5*, 95–104.

HATHERLY, P.J., 1980. Digital Processing of Seismic Refraction Data. *Bull. Austral. SEG., 11*, 69–74.

HELBIG, K., 1984. Foundation of Anisotropy for Exploration Seismics, 22. *In:* Helbig, K., and Treitel, S. (Eds.), *Handbook of Geophysical Exploration, Section 1 — Seismic exploration*. Geophysical Press, London, 486p.

INTERNATIONAL SOCIETY OF ROCK MECHANICS, ISRM, 1978. Suggested methods for the quantitative description of discontinuities in rock mass. *Int. J. Rock Mech. Min. Sci, and Geomech. Abstract, 15*, 319–368.

PALMER, D., 1980. *The Generalized Reciprocal Method of Seismic Refraction Interpretation*. SEG Publisher, Tulsa.

PALMER, D., 1981. An introduction to the generalized reciprocal method of seismic refraction interpretation. *Geophysics, 46*, 1508–1518.

PRIEST, S.D.K. AND HUDSON, J.A., 1978. Estimation of discontinuity spacing and trace length using Scan-line surveys. *Int. J. Rock mech. Min. Sci, and Geomech. Abstract, 18*, 183–197.

REDPATH, B.B., 1973. Seismic Refraction Exploration for Engineering Site Investigations. *U.S. Army Engineer Waterways Experiment Station Explosive Excavation Research Laboratory, Technical Report E-73-4*.

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