High Resolution VSP in Outokumpu

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Summary

In order to assist in determining detailed structure of bedrock nearby the Outokumpu deep drill hole and combine straight measurements done in deep drill hole to surface measurements, a zero-offset vertical seismic profile was acquired near the Outokumpu deep drill hole. In this new survey, 2 m depth increment was applied to obtain high resolution information. Using the first break picking, the interval P-wave velocities were determined and that match the sonics well. And from the stack result, it showed detailed information about sequence structure which also can be used for the interpretation of surface reflection seismic profiles.

Introduction

Outokumpu is one of the most important and interesting ore areas in Finland, and it is well known for its unconventional Precambrian sulphide deposits (~1.97 Ga). In 2004-2005, a 2.5 km deep research borehole of ICDP (International Continental Scientific Drilling Program) was drilled on the south-east side of the main ore belt. The hole reveals that thicknesses and velocities of rocks change in depth in Outokumpu.

In order to determine detailed structure of the bedrock nearby the deep drill hole and combine straight measurements done in deep drill hole to surface measurements, in May 2006, University of Alberta, GTK and Institute of Seismology of University of Helsinki did a seismic VSP- (Vertical Seismic Profile) and surface seismic surveys near the Outokumpu deep drill hole. One of the purposes is to create an anisotropic velocity model for future micro-seism studies as well as to provide a higher resolution reflection profile through the area. This paper introduces the processing of zero-offset VSP data and the velocity profile derived from VSP data.

Geology of the Deep Drill Hole

The Outokumpu rocks are relevant to the Archaean oceanic crust and subsequent Paleoproterozoic closure of ocean basin, thrust and deformation. An ophiolite formation was thrusted on the Archaean continental margin. The lithologies revealed by the deep drill hole mainly include mica schist with biotite-gneiss layers (upper 2 km) underlain by pegmatitic granites. The ophiolite-related Outokumpu assemblage rocks were observed at depth range of 1.3-1.5 km (Figure 1).

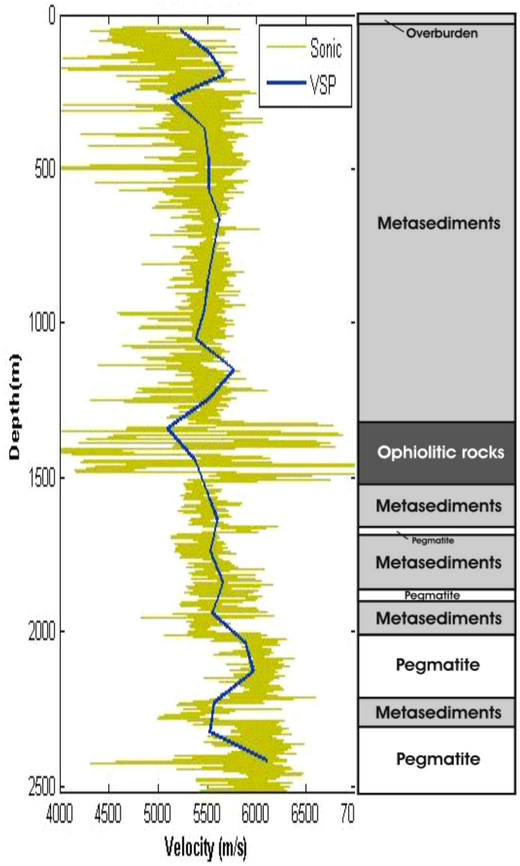

Figure 1: Sonic and VSP velocity and Outokumpu geology

Data Acquisition

This new survey consisted of several parts, including a series of multi-azimuth multi-depth walk-away VSPs, a zero-offset VSP, and a surface seismic component.

Zero-offset VSP is a measurement procedure that the source is placed at a single point at the surface close to the borehole and geophones secured at various depths to the wall of a drilled well. So the seismic ray paths from the source to the receiver are consequently nearly vertical and have lengths that are very close to the depth of the receiver. The conventional zero-offset VSPs are typically recorded at relatively large receiver gaps of 10m or more. In this new survey, zero-offset VSP was acquired every two meters, starting at 2500m and ending at 50m (bottom of casing) from April 28 2006 to April 30 2006. The source (IVI Minvib®) was 33.5m away from the borehole. Fold ranges from 1 to 5. The sampling rate is 1 ms and the total final recording length is 5 s.

Processing and Results

VSP data are often used to find the depths at which seismic reflections originate and hence assist in the interpretation of surface reflection seismic profiles. However, when an interpreter is confronted with a set of unprocessed VSP field data, several problems are apparent. On this zero-offset VSP profile, that is easy to see that there are several kinds of interference waves which include random noise, tube wave and harmonic interference with 50 Hz and 150 Hz which make the S/N ratio of the data quite low (Fig 2a). And it is difficult to separate the signal with the noise. Moreover another big challenge, which is confronted by most interpreters, is that the downgoing wavefield is so strong that any interpretation involving upgoing primary reflection is difficult and often impossible to make. To overcome these problems, a series of processing techniques were applied to this Outokumpu high resolution seismic reflection data. The main key methods include pick up the first break, f-k filter to attenuate tube wave, remove the harmonic noise by seeking a linear combination of sinusoids that are harmonics of one or more fundamental frequencies to fit the data in a least-squares sense, separate the wave field (Fig 2b) deconvolution and finally corridor stacking of the remaining upgoing wavefield (Fig. 2c). Compete removal of the downgoing tube waves was difficult due to aliasing even with the large small receiver spacing employed.

A vertical seismic profile is closely related to a velocity survey since the source and receiver geometry is the same for both measurements. First break times are the critical information needed to determine the P-wave velocity. Thus, in order to estimate the interval velocities, the first break time picking was done. And a polynomial fit method was applied to obtain a good

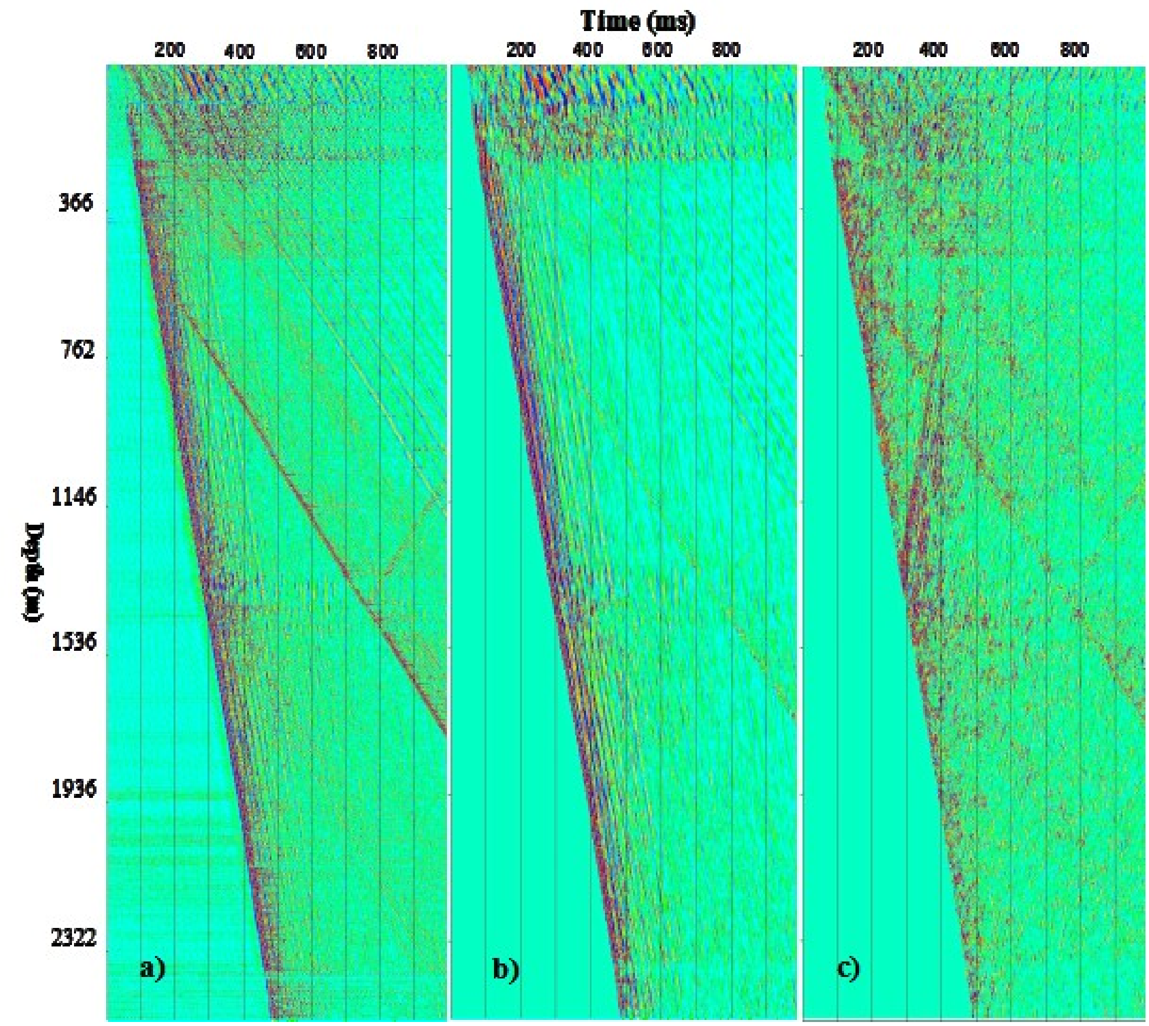

Figure 2: The result of wavefields separation. a) Full wavefield after removing noise. b) Down-going wave field. c) Up-going wave field

approximation for the changes in velocity with the depth. Figure 1 shows the comparison between the VSP velocity and the sonic result. We can see the P wave velocity (by polynomial fit) agree well with the sonics, but obviously does not represent velocity variations on the same scale as sonics do. That is because the sonic logs measure the P wave velocity using higher frequencies (~ 20 kHz) than does the seismic results here (20 Hz to 250 Hz).

The analysis of up-going wave mode is particularly important and also complicated by the fact that down-going wave affect the up-going waves seriously. As a result, it is necessary to separate the up-going modes from the down-going modes. In this processing, the median filter technique was chose. From the result (Figure 2), after the separation, the up-going wave field can obviously be seen on the profile.

Additionally, as it is mentioned above, the receiver gap in this survey for zero-offset VSP is 2m. That is quite small depth increment relative to conventional industrial surveys. And this makes it possible to generate a high resolution stack profile which is showed on a) of Figure 3. This corridor stack reveals a number of reflections and particularly the strong set of events at 550 ms (~1.3 km) associated with ophiolite complex that is potentially ore bearing.

A further test was carried for two different receiver gaps at more conventional 10 m and 20 m receiver increments. The same processing flow and parameters were used in the analysis of these more sparsely sampled wave fields. This was achieved by extracting the traces in different interval. And the results are showed on b) and c) of Figure 3. By the comparison, it is obvious that the stack profile with 2m depth increment shows more detail than the other two stack profiles.

A somewhat unsettling result of this analysis is that the three different corridor stacks, while mostly all showing the major events, have somewhat different character in terms of the apparent waveforms observed. This may be partly due to aliasing effects in the larger receiver spacing.

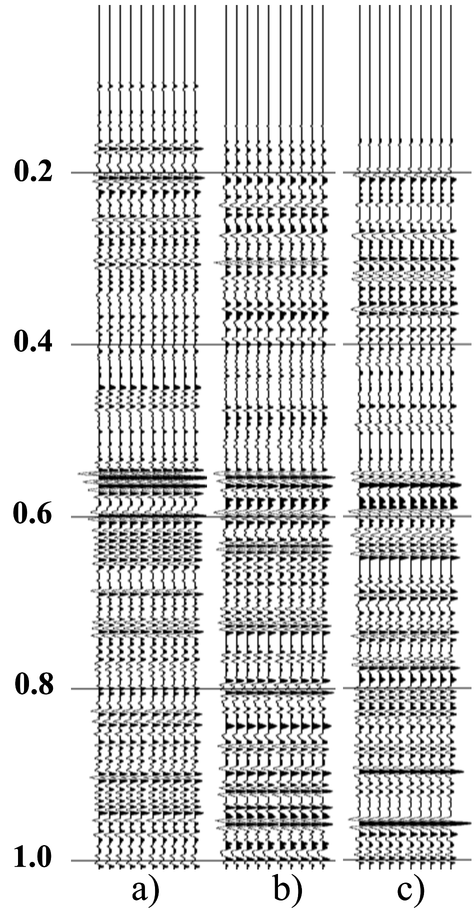

Figure 3: Stack results. a) 2m depth increment. b) 10m depth increment. c) 20m depth increment.

Conclusions

The zero-offset VSP survey was done to assist in the determination of the detailed structure of bedrock near the deep drill hole. A 2m depth increment was applied in this new survey to get high resolution data. The P-wave velocity was determined from the first break picking. By comparison with the sonic log, they match well although they did not represent velocity variations on the same scale. A series of processing techniques were employed to obtain a high resolution result based on the 2 m depth increment which was also used to compare with two different depth increments. From the results, the stack profile showed detailed information about sequence structure which also can be used for the interpretation of surface reflection seismic profiles. The 2 m spacing also allows for a better determination of the in situ seismic band velocities.

References

Butler, K. E. and Russell, R. D., 2003, Cancellation of multiple harmonic noise series in geophysical records: Geophysics, **68**, 1083-1090.

Elbra, T. and Pesonen, L. J., 2004, Physical properties and palaeomagnetism of the drill core from Outokumpu, C-E Finland: International Workshop Espoo, Programme and Expanded Abstracts, 38-41.

Hardage, B. A., 2000, Vertical seismic profiling principles: Handbook of geophysical exploration, Seismic Exploration, **14**, Pergamon, Elsevier Science Ltd.

Heikkinen, P., Kukkonen, I. T., Koivisto, E. and FIRE Working Group, 2004, Seismic reflection images in Outokumpu: International Workshop Espoo, Programme and Expanded Abstracts, 16.

Heinonen, S., 2008, Processing of high resolution seismic reflection data and correlating it with deep drill hole data, Outokumpu, Finland, Thesis

Hinds, R. C., Anderson, N. L. and Kuzmiski, R.D., 1998, VSP interpretive processing: Theory and practice, Society of exploration geophysicists.

Schmitt, D. R., Milkereit, B., Karp, T., Scholz, C., Danuor, S., Meillieux, D. and Welz, M., 2007, In situ seismic measurements in borehole LB-08A in the Bosumtwi impact structure, Ghana: Preliminary interpretation: Meteoritics & Planetary Science, **42**, 755-768.

Stewart, R. R., 1985, Median filtering: Review and a new F/K analogue design, Journal of the Canadian society of exploration geophysicists, **21**, No. 1, 54-63.