ASEG-PESA 2015
Geophysics and Geology together for Discovery
24th International Geophysical Conference and Exhibition
15 – 18 February 2015 Perth, Western Australia

Near surface seismic investigation of the regolith in South Australia

Konstantin Tertyshnikov
DET CRC/Curtin University
Perth, Western Australia
Konstantin.Tertyshnikov@curtin.edu.au

Sinem Yavuz
DET CRC/Curtin University
Perth, Western Australia
Sinem.Yavuz@postgrad.curtin.edu.au

Bai Chun Sun
DET CRC/Curtin University
Perth, Western Australia
Baichun.Sun@postgrad.curtin.edu.au

SUMMARY

Investigation of the regolith is an important part of the mineral exploration. Large territories are overlaid by the regolith rocks and recent trends show a clear tendency of discovery major mineral deposits under the thick cover. Thorough regolith exploration involving geophysical techniques is required to push new deep mineral discoveries. Knowledge about the regolith structure and properties is necessary for designing the mine excavation and production as well.

A shot 2D seismic was acquired to investigate regolith's structure and properties at the Hillside prospect, situated on the Yorke Peninsula, South Australia. The small 3D dataset has been conducted to evaluate potential for seismic imaging of deep structures. The survey has been designed to be able to accommodate good data for various seismic methods simultaneously. Data analysis included processing and interpretation of surface, refracted and reflected waves. The study also involved an application of diffraction imaging to detect faults and fracture zones.

The experiment has demonstrated a cost effective near surface seismic setup that is capable to obtain a comprehensive set of information about undersurface. The results include imaging of the regolith structure, estimating of dynamic elastic properties of the ground and obtaining images of deep structures.

Key words: hard rock, seismic, near surface, regolith.

INTRODUCTION

The investigation of cover rocks in mining is an essential part of exploration. It is important from different perspectives: first of all research of regolith can lead to new discoveries under the cover; a regolith succession can act itself as a host for certain minerals; information about overburden rocks structure and properties is necessary for designing the pit excavation and for production planning. Regolith velocity information is also valuable for deep seismic imaging.

Generally, regolith represents a geological material of altered rocks that overlays fresh base successions. These rocks have been formed by erosion and/or re-deposition of the older formations and they are usually chemically weathered progressively towards the surface. Alteration processes in regolith can cause the formation of different mineral occurrences such as lateritic and saprolitic gold mineralizations, bauxites, lateritic nickel-copper deposits and others. The thickness of the regolith formation depends on tectonic and climate history and can vary from a few meters up to several hundred meters (Butt *et al.*, 2000; Scott and Pain, 2009).

Generally, regolith exploration has been carried out by geological prospecting, drilling, geochemical and geophysical surveys. Among geophysical techniques seismic methods are not often considered as a tool for near surface exploration in mining. The main reason is that these methods are more expensive than traditional electromagnetic surveys. Seismic acquisition requires much higher density data for shallow rocks investigation compare to deep mineral exploration. Seismic field setups have to be thoroughly designed to be able to achieve survey objectives and at the same time remained cost effective.

A seismic experiment has been conducted at the Hillside prospect, located on the Yorke Peninsula (South Australia). The main objectives were: to recover regolith structures, to obtain dynamic elastic properties of the overburden rocks and to estimate imaging capabilities of deep structures for particular geological settings in this area. Another important purpose of the survey was to design an appropriate acquisition setup to accommodate reliable data for various seismic techniques simultaneously and to provide an inexpensive seismic solution to the mining industry for regolith investigations. Processing and interpretation included analysis of surface, refracted and reflected seismic waves. Diffraction imaging technique has been applied to locate subvertical fault and fracture zones.

SEISMIC ACQUISITION AT THE HILLSIDE PROSPECT

Seismic data have been collected at the Hillside prospect over a 2D line and a mini-3D seismic survey to fulfil the research objectives. The acquisition site is located on the Yorke Peninsula (South Australia) 12 kilometres south of the Ardrossan township. The Hillside deposit is located in the Gawler Craton geological province. Most of the fresh rocks in the Gawler Craton are overlaid by a succession of regolith rocks. This overburden effectively hides deposits from the exploration. The Hillside mineral occurrence is one of many targets that can be found along the Pine Point Copper Belt on the Yorke Peninsula (Figure 1). The copper-gold mineralization is associated with main separate subvertical structures. The thickness of overburden is from 5 to 30 meters and represented by Tertiary and Cambrian altered calcareous sediments (Lowe, 2009).

2D seismic line (600 m long) has been acquired using two different geophone spacing: 1 and 2 meter apart. The first 200 m were collected with 1 m spacing (Figure 1) and 2 m between the shot positions. Next 400 m were acquired with 2 m geophone spacing and 4 m shot increment. The 45 kg accelerated weight drop has been used as a seismic source. The 48-channel seismic system EX-6 with 10 Hz geophones was used to collect data. At the end of the line a mini-3D dense seismic cube (156 x 50 m) was acquired as well. The record length was 2 seconds; sample rate 0.5 ms. A small crew of 4 people has completed the survey in five days (including mobilization).

The acquisition geometry has provided the high density and good quality seismic records. Cooperative analysis of these data using different seismic methodologies allowed achieving the main objectives of the presented near surface seismic experiment.

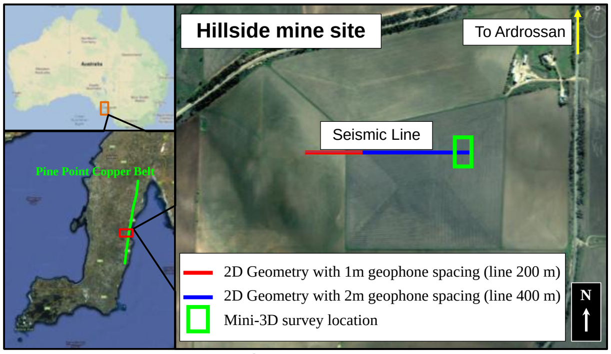

Figure 1. Location of the seismic line at the Hillside prospect (South Australia). Red and blue lines represent the position of a 2D seismic line with 1 m and 2 m geophone spacing respectively. Green box shows the position of the mini-3D seismic survey (modified from Tertyshnikov, 2014).

MULTICHANNEL ANALYSIS OF SURFACE WAVES (MASW) AND REFRACTION DATA ANALYSIS

Analysis of surface and refraction waves has been performed in order to estimate the thickness of the regolith, to obtain its internal structure and to define its dynamic elastic properties. Processing has been done separately for each geometry setup.

Information about shear-wave velocities were recovered from surface waves analysis. MASW is based on the dispersion of wave frequencies with depth (lower wave frequencies correspond to the deeper layer). The phase velocity spectra for every receiver position were computed using the slant-stack method in frequency domain (Park *et al.*, 1999); the stacking of slowness spectra for a given receiver window over all shot points was applied to improve signal to noise ratio (Neducza, 2007). To obtain shear-wave (S-wave) velocity depth sections, the dispersion curves have been inverted using the approach proposed by Xia *et al.* (1999).

Refraction wave's analysis is based on the measurement of travel time of seismic waves refracted from subsurface interfaces of different velocities. This method allows defining boundaries of layers and estimating propagation velocities of compressional waves (P-waves) of these layers. The first arrivals of the P-waves were picked for each shot record along the line. The trave-time curves were inverted utilizing the classical reciprocal method (Hagedoorn, 1959) to obtain depth and shape of the refraction interfaces. Distribution of P-wave velocities has been evaluated by performing the ray tracing tomography.

Figure 2 shows the S-velocity depth sections with overlaid interfaces which were obtained from the refracted waves processing. There is a reliable correlation between the inversion results of two seismic methods. For both cases the upper refraction boundary repeats the shape of the low-velocity layer observed in the S-velocity section.

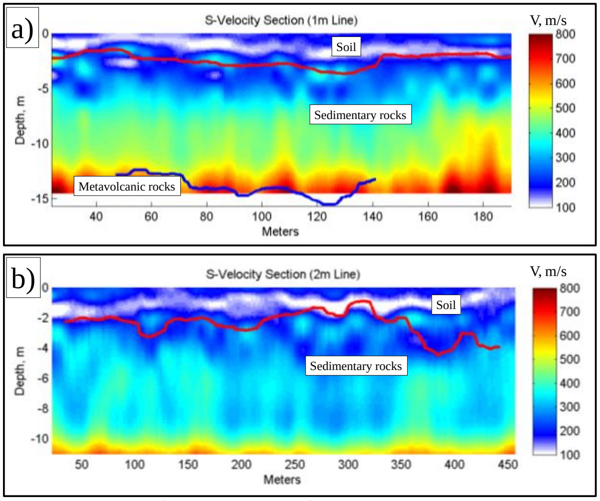

Figure 2. Refraction interfaces and S-velocity depth sections for a) 1 m geophone spacing geometry; b) 2 m geophone spacing geometry. Red line represents the bottom of the first soil layer; blue line shows the top of the third metasediment layer (modified from Tertyshnikov, 2014).

A geological section of the regolith structure reconstructed from 2D near surface seismic data is shown in Figure 3. The first layer represents unconsolidated soil deposits, which are characterized by low seismic velocities of P- and S-waves; the second layer corresponds to incoherent sediments; the third one represents metasediments-metavolcanics rocks. The results are consistent with the information from specific gravity and lithological logs from neighbouring boreholes.

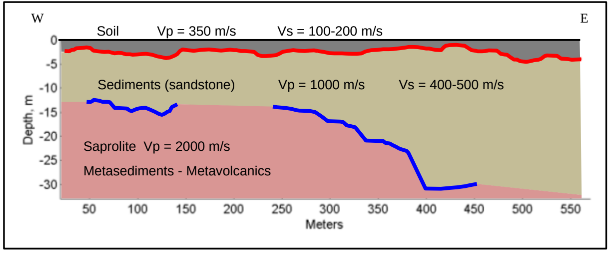

Figure 3. Geological section of the regolith structure at the Hillside prospect (modified from Tertyshnikov, 2014).

The dynamic elastic parameters of the regolith succession have been estimated using information about P- and S-waves velocity distribution (Yavuz *et al.*, 2012).

DIFFRACTION IMAGING FOR DETECTION OF SUBVERTICAL STRUCTURES

The diffractions occur when the radius of curvature of a layer's boundary is less than a few wavelengths. The presence of faults, fractures, truncated interfaces or any other types of heterogeneities is usually the cause of diffractions that appearing on seismic records. In case of scattering from edges the phase reversal is observed (Trorey, 1970). Despite the fact that diffracted waves are often considered as a noise in seismic processing, they can be used for imaging the subvertical geological features and scattering objects.

We applied the diffraction imaging approach for local heterogeneities detection (Landa and Keydar, 1998; Alonaizi *et al.*, 2013; Tertyshnikov *et al.*, 2013) to be able to locate faults and fracture zones at the Hillside prospect. The method is based on estimating of a local semblance along the diffraction traveltime curves. The technique forms sections of semblance's values that correspond to distribution of diffraction energy (so-called D-section). The phenomenon of the phase change from edges has been taken into account during the analysis as well. This phase reversal consideration allows us to produce two D-sections: one shows point diffractions, the other more sensitive to scattering from edges (Bóna *et al.*, 2013).

Firgure 4 shows a D-section (computed with phase change taken into account) overlaid with locations of fault/fracture zones from drilling data interpretation. The diffraction anomalies correlate with geological data; several potential locations of fault/fracture zones, which have not been intersected by boreholes, can be identified on the section.

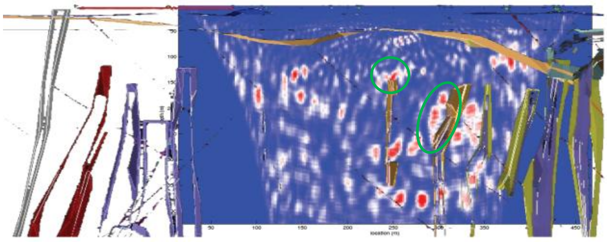

Figure 4. D-section that takes into account the phase change with overlaid geological section. Diffraction anomalies aligned with geological features are circle green (modified from Bóna *et al.*, 2013).

3D SEISMIC MINI-SURVEY

A mini 3D survey was also conducted at Hillside to test the potential for the application of this methodology for exploration. Maximum fold of 24 was achieved in the central part of the survey. Despite the low fold, good quality in-line and cross-line sections were produced. The mini-cube was processed using a conventional processing flow. Particular attention was devoted to static corrections which aim to remove variable time delays associated with regolith zone. Subsequently dynamic corrections were computed using old-fashion constant velocity stacks (CVS). Final corrections included removal of the effect of the layer dip on stacking velocities by applying dip-moveout corrections. Post-stack migration has been applied to the seismic volume at the last step of processing. Figure 5 show examples of in-line and cross-line seismic sections through the mini-3D cube.

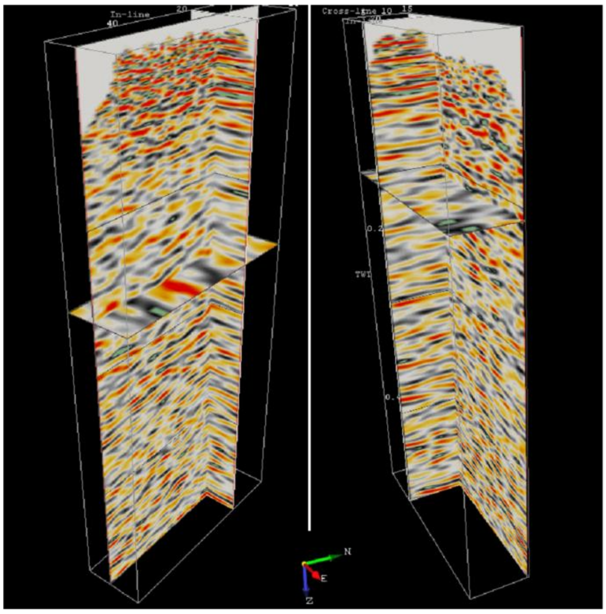

Figure 5. 3D seismic sections. An in-line section is in left panel and a cross-line section is in the right panel.

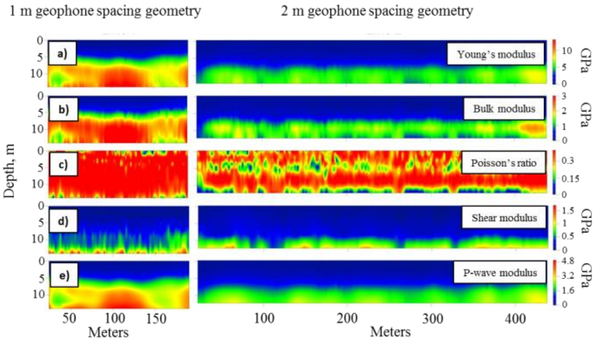

Figure 6. Dynamic geotechnical parameters of the 2D lines recovered from P- and S-wave velocities: a) Young's Modulus, b) Bulk Modulus, c) Poisson's ratio, d) Shear Modulus and e) P wave Modulus (modified from Yavuz *et al.*, 2012).

CONCLUSIONS

The main objective of the Hillside seismic experimental survey was to test the performance of high resolution seismic methods when using a small number of active seismic channels and a portable weight-drop to image regolith structure. Proving such a concept would enable implementing rapid and inexpensive seismic surveys for exploration of mineral deposits and could lead to its widespread applications.

Cooperative analysis of both refraction and surface wave data proved to be useful for the regolith investigation. Good agreements were achieved between P- and S-wave velocity sections. Moreover, geotechnical parameters of regolith were recovered using the refraction tomographic inversion results (Figure 6). Such comprehensive information about regolith can support exploration of new shallow deposits and designing of mining construction as well. Considering the quality of the results with low channel count the application of dynamic acquisition systems, such as land streamers or draggable geophone strings, might be proposed as a cost–effective setup for the near surface exploration at hard rock prospects.

Application of the diffraction imaging has shown a good potential to support delineation of subvertical geological features in hard rock environments. This approach can be used to detect small mineral bodies, which would appear as scattered objects on seismic sections, and edges of the relatively large ones.

Depth penetration greater than 400 m was achieved with reflection seismic. High quality mini-3D seismic cube with exceptionally low fold was acquired and processed. Based on the results a subsequent 3D seismic survey has been designed for deep exploration of the Hillside prospect.

ACKNOWLEDGMENTS

The research is carried out at the Department of Exploration Geophysics, Curtin University. The work has been supported by the Deep Exploration Technologies Cooperative Research Centre whose activities are funded by the Australian Government's Cooperative Research Centre Programme. This is DET CRC Document 2014/537. We would like to thank RexMinerals for permission to publish the results. We thank Dr Andrew Greenwood, Dr Simon Van Der Wielen and Dr David Giles for their help to organize this experiment. We thank Dr Roman Pevzner, Dr Milovan Urosevic and Alexandar Dzunic for their help in data processing.

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