Introducing 3rd dimension into 2D reflective seismic exploration in the complex hard rock environment

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SUMMARY

In this paper, we are proposing a new methodology of 2D seismic acquisition and processing that aims to improve imaging of complex 3D geological environments. The method requires a simultaneous acquisition along two parallel receiver lines. The adapted processing highlights locations of the reflectors that are out of vertical plane by filtering the data by the apparent angle of incidence. This filtering also produces static and residual corrections as a function of this angle. Another benefit of the proposed pre-stack plane filtering is producing 3D velocity model as well as set of individually filtered and migrated sections that can be distributed in 3D volume for the visualisation proposes and interpretation free of conflicting events that would be present in conventional 2D imaging.

Key words: 2D hard rock seismic, seismic plain filtering, dip-attribute, 3D finite-difference modelling, 3D visualisation

INTRODUCTION

Difficulties of seismic exploration in complex hard rock environment has been documented by many researchers (Urosevic et al., 2007; Nedimovic and West, 2003; Juhlin et al., 2010; Malehmir and Bellefleur, 2009). Among the principal issues is poor Signal to Noise (S/N) ratio (Salisbury et al., 2003), since the strength of the reflected seismic signal recorded in high velocity crystalline rock formations results from relatively weak acoustic impedance contrast dominantly governed by density variations. Furthermore, targets are often very steep or sub-vertical, since mineralization occurs usually within heavily faulted (shear) zones (Urosevic et al. 2007). Another issue that significantly affects final result of the imaging is correct solution of the static corrections, since relatively low velocity weathered zone (regolith) is often defined by highly irregular refractor surface that has major role in the "blurring" of the already weakened reflection (Urosevic and Juhlin, 2007). Even with these issues resolved, the three dimensional complex environments cannot be imaged using a 2D acquisition and processing techniques due to ambiguity of out of vertical plane reflections (Biondi, 2006; Nedimovic and West 2003). In order to solve these problems, we are proposing a novel acquisition and processing methodology by deploying two parallel (straight or crooked) receiver lines (R2D). In this abstract we are demonstrating feasibility of the R2D concept by applying it to a dataset from a comprehensive 3D acoustic finite-difference modelling. In particular, the modelled data with R2D geometry are submitted to DIP-attribute calculation, seismic sections plane filtering (a function of reflection angle of incidence), as well as 3D visualisation (relocating the samples within the 3D cube according to the location of the reflectors).

Two Receiver Lines Methodology

The concept and technical design of the two receiver lines methodology (R2D) are presented in fig. 1. The conventional 2D fails to define the correct location of a reflector with strike parallel to the acquisition line (as illustrated in fig. 1b). By deploying two receiver lines (fig. 1a), we are able to detect time delays of emerging reflection wave (fig. 1c) and thus detecting the direction from which the reflection is arriving. While calculation of direction depends on accurate estimates of the velocity in the subsurface, the method separates the off plane reflections even without such velocity knowledge.
One of the most important steps in designing R2D acquisition is determining optimal receiver line distance, which is the function of frequency content of the signal and velocity of the weathering layer in order to provide sufficient distance (DIP detectability) while preventing potential cycle skipping (during DIP-attribute calculation), which can be treated to some extent by low-pass frequency filtering. To test the method and to tune acquisition parameters, we apply it to synthetic data, as discussed in the next section.

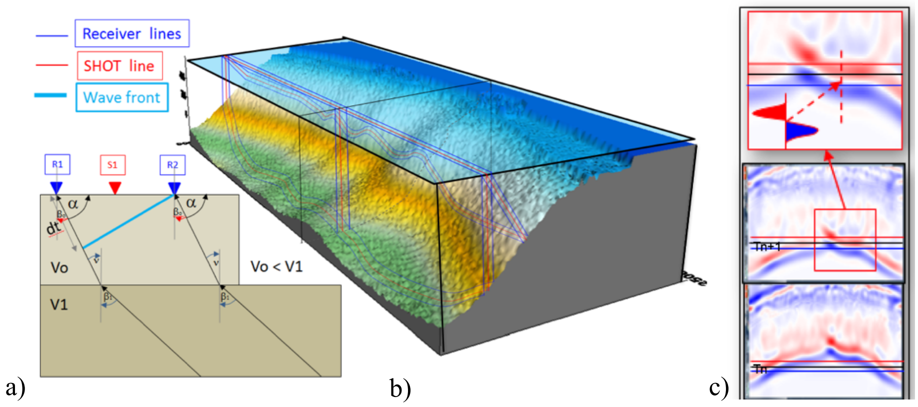

Fig. 1 R2D acquisition concept provides information of the reflector's location (b), based upon detected wave front delay on both receiver lines (a). Snapshots of the recorded wave front on the properly designed distance of the receiver lines (c).3D Numerical modelling of R2D line

Prior to application on the real data, 3D acoustic finite difference modelling was conducted on the relatively simple velocity model in order to test range of key parameters that could be important for potential application in the field (Fig. 2). Velocity model is made of 3 interfaces with velocities of the layers: 2000, 3000, 5000 and 6000 m/s with vertical gradients were 1.5 m/s, 0.25 and 0. 5 m/s per grid cell for the lower three layers respectively. R2D line is positioned diagonally over 3D velocity model with two receiver lines and one shot line in between. Grid cell size was 7 m and distance between receiver lines was 28 m and the distance between two stacked sections was 14 m.

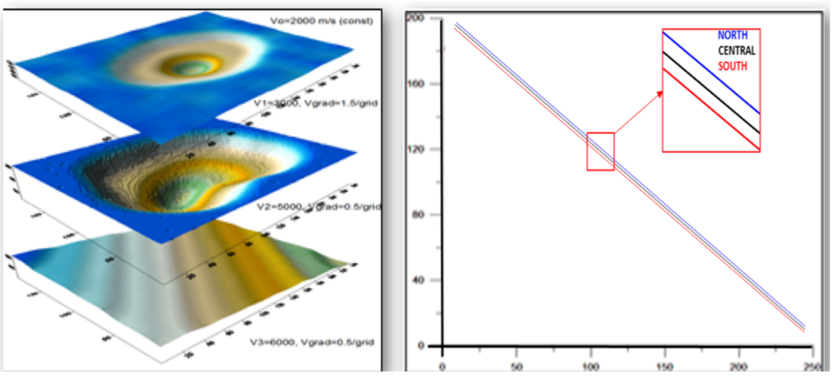

Fig. 2 Four-layer velocity model (left) and trajectory of the R2D line (right)

DIP – Attribute, Incidence Angle (DIP) Filtering-scanning and 3D 'SPRAYING'

Post-stack 3D modelling was conducted along the shot (central) line, 14 m apart from (north and south) receiver lines. Stacked sections are presented on Fig. 3.

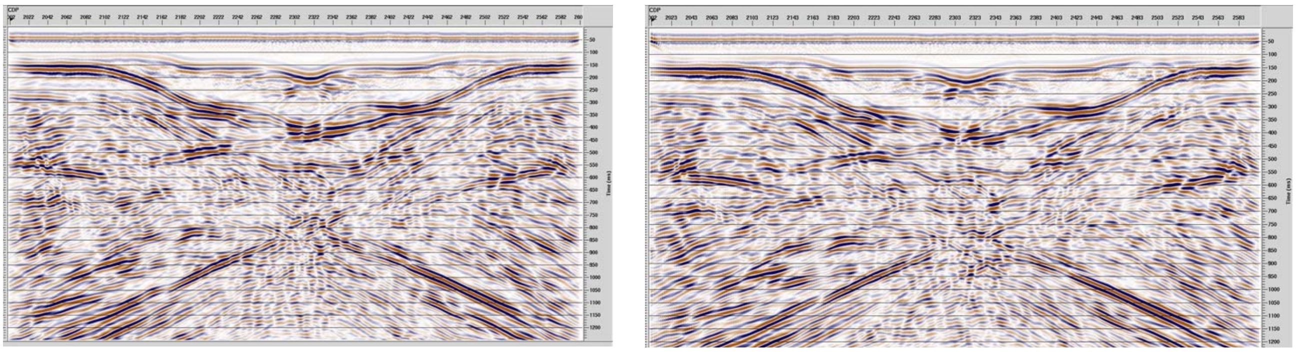

Fig. 3 Northern stacked section (left), Southern stacked section (right)

Based on known distance between stacked sections and time delays of analysed reflections along the opposite traces, DIP-attribute is calculated, expressed in angle of incidence (Fig. 4 left). Blue-white-red colour scale quantitatively shows the angle of incidence of the waves. In this particular arrangement of the lines, blue represents wave arrivals from north and red from south, respectively. Reflections in white came from the reflectors that are perpendicular to the seismic section plane.

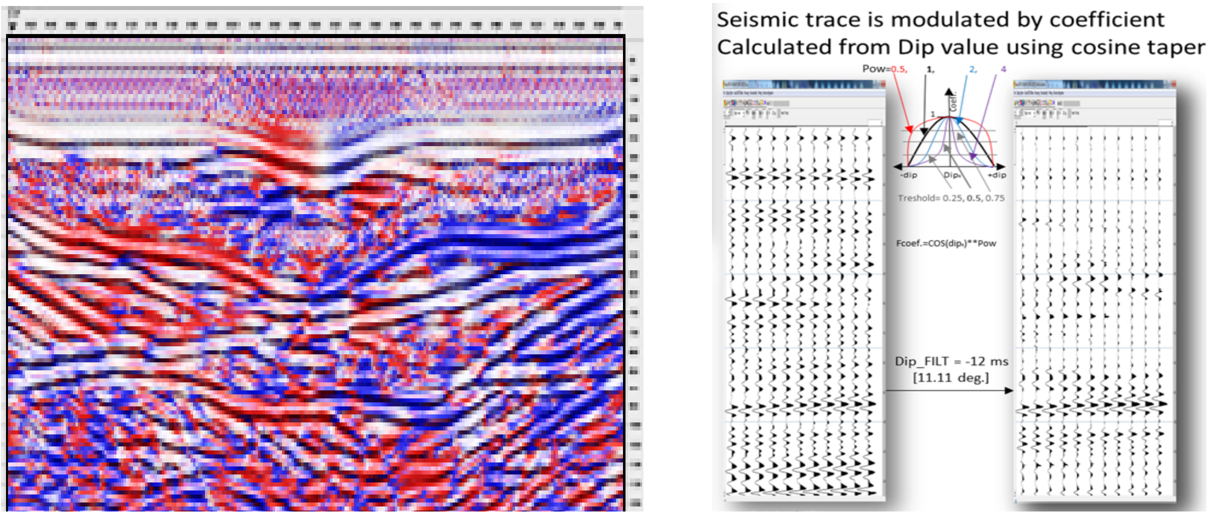

Fig 4 Dip-attribute superimposed on seismic section (left), Dip-filtering for the given angle (right)

Besides producing DIP-attribute for the final stacked/migrated sections, it is possible to create DIP-filtered post (or pre) stack data for the range of angles of incidence (Fig. 4 right).

Fig. 5 shows DIP filtered panels. On each filtered section 10% of original seismic section is added.

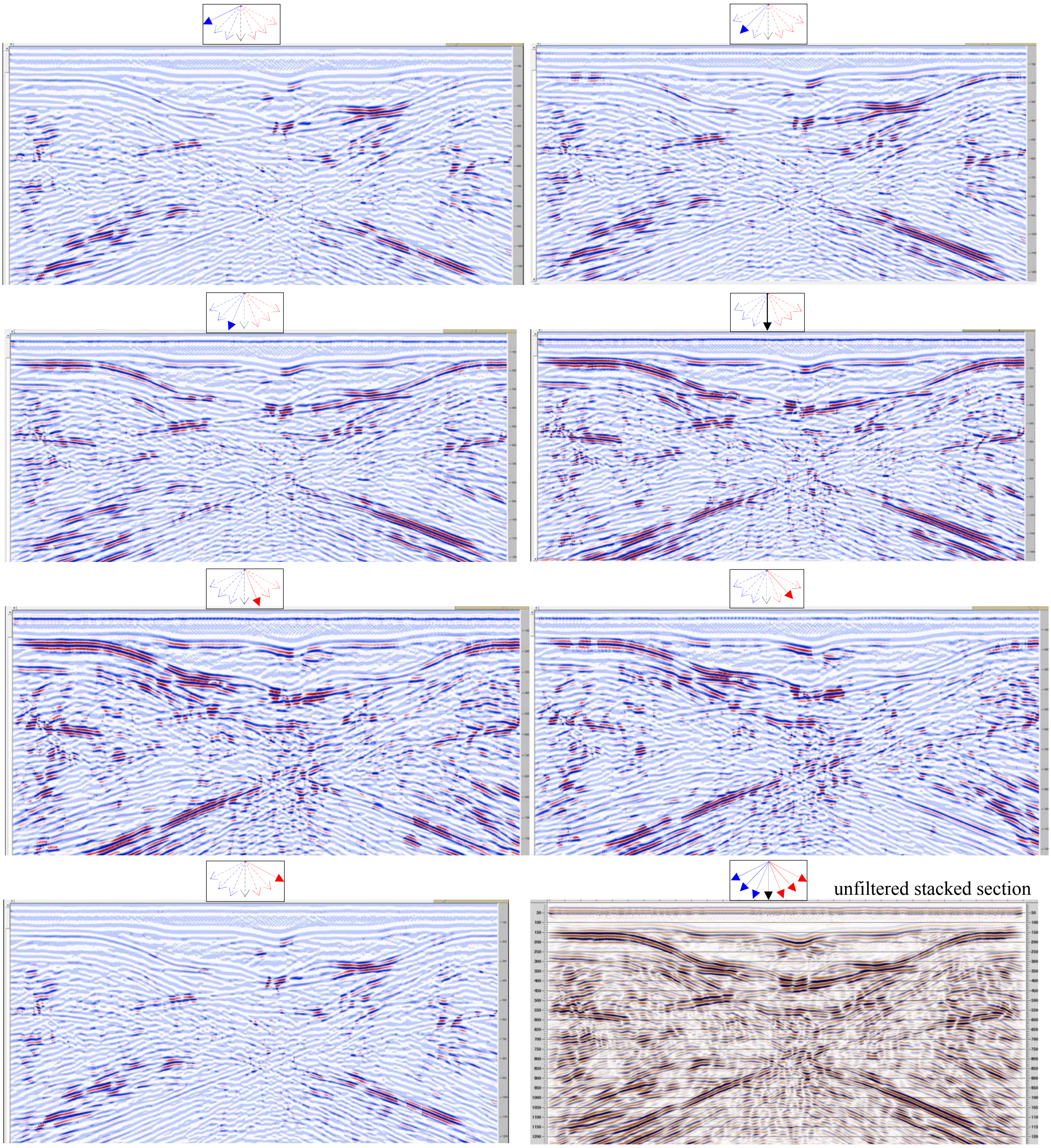

Fig. 5 DIP filtered panels with unfiltered version of the stack

Instead of a 2D section and the corresponding 2D velocity model, R2D enables separating the events in 3D space and performs independent processing sequences as a function of angle of incidence. By doing this, we are preventing the interference of the reflection arrivals from different locations in space. After creating multiple filter panels within a given DIP range, we are practically performing relocation of the seismic energy within a perpendicular plane to the direction of the seismic line. This process could be considered as migration (second pass) in cross line direction, which was regular procedure of 3D processing, due to hardware limitations back in '70 -'80. Independently processed DIP filtered planes are then migrated to the correct location in 3D space. Therefore, it is possible to visualise the imaged data in 3D cube (Fig 6).

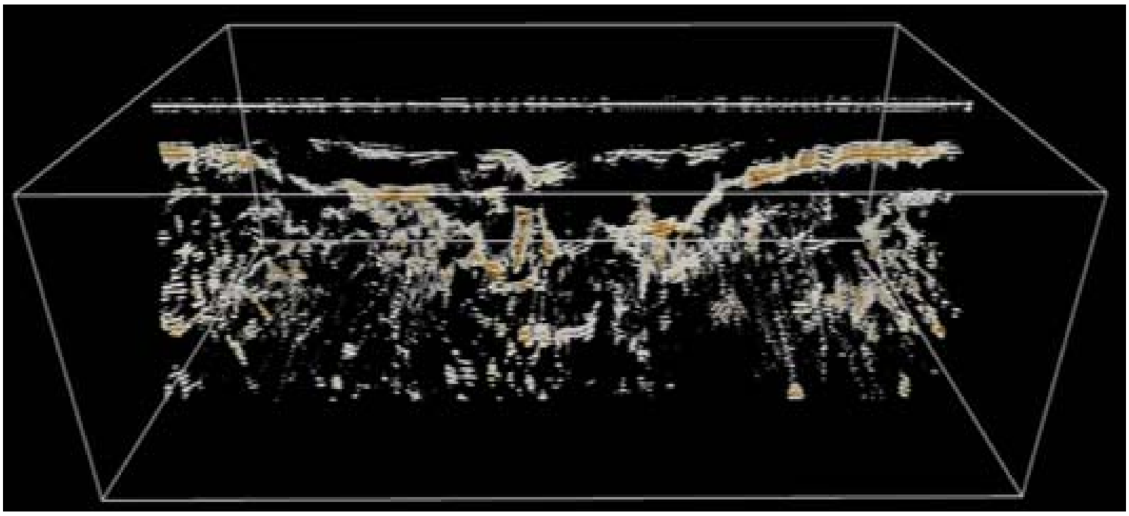

Fig. 6 Relocation of the seismic energy based on DIP parameter within a 3D volume

CONCLUSIONS AND DISCUSSION

R2D methodology for reflection seismic in complex environments has the potential to address various problems encountered by the processors and interpreters. The main features and possible extensions are:

- Obtaining information about the location of the reflectors out of the vertical plane.
- Performing post-stack dip-filtering and avoiding superposition of out of plane events that can affect processing and will be migrated wrongly.
- Ideally, dip-filtering should be performed on pre-stack data with the following benefits: a) first break picking and refraction statics calculation for each set of pre-stack filtered data set (resolving issues due to 3D nature of the refractor); b) velocity analysis as a function of filtered plane, as well as residual statics correction; c) each processing flow will be repeated for each plane individually. Such approach besides post-stack filtering advantages, produces a 3D velocity model that provides better migration for particular filtered plain.
- Possibility of applying the methodology on already conventionally processed crooked lines (applicable for selected segments that fulfil minimum requirements, i.e. sufficient CDP scattering and applying 3D geometry for the parallel line extraction procedure).
- After obtaining migrated seismic sections, we can relocate individual samples within 3D volume using appropriate "velocity plane" for depth conversion, that can be corrected according to available data from wells, even in the wider area of interest within the 3D volume.
- The same concept could be applied to VSP.
- Source locations do not necessarily have to be symmetric with respect to the receiver lines.

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REFERENCES

Biondi, B., 2006. 3D seismic imaging (No. 14). Tulsa: Society of Exploration Geophysicists.

Juhlin, C., Dehghannejad, M., Lund, B., Malehmir, A. and Pratt, G., 2010. Reflection seismic imaging of the end-glacial Pärvie Fault system, northern Sweden. Journal of Applied Geophysics, 70(4), pp.307-316.

Malehmir, A. and Bellefleur, G., 2009. 3D seismic reflection imaging of volcanic-hosted massive sulfide deposits: Insights from reprocessing Halfmile Lake data, New Brunswick, Canada. Geophysics, 74(6), pp.B209-B219.

Nedimovic, M.R. and West, G.F., 2003. Crooked-line 2D seismic reflection imaging in crystalline terrains: Part 1, data processing. Geophysics, 68(1), pp.274-285.

Salisbury, M.H., Harvey, C.W. and Matthews, L., 2003. The acoustic properties of ores and host rocks in hardrock terranes. Hardrock seismic exploration: SEG, pp.9-19.

Urosevic, M. and Juhlin, C., 2007, June. An analysis of seismic information obtained from crooked line seismic surveys in crystalline rocks, Australia. In 69th EAGE Conference and Exhibition incorporating SPE EUROPEC 2007.

Urosevic, M., Kepic, A., Stolz, E. and Juhlin, C., 2007. Seismic exploration of ore deposits in Western Australia. In Exploration in the new millennium: Proceedings of the Fifth Decennial International Conference on Mineral Exploration (pp. 525-534).