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Application of vertical seismic profile method for coal exploration in Red River delta, Vietnam

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ABSTRACT

Seismic method has recently been used in exploration for deep coal layers thanks to its capability to accurately map subsurface layers. The main issues are to recognize the coal signatures on seismic sections; moreover, seismic data are recorded in time while coal layers need to be defined in depth. The solution is to use Vertical seismic profile (VSP) method to identify the coal layers and to convert time sections to depth. In this paper, we describe an actual case of VSP application in Red River delta to define the characteristics of reflections from coal bearing layers on seismic data. The data acquisition and processing are also briefly demonstrated. In the results, coal bearing layers show strong amplitudes with lower frequency that can be identified on VSP. The information is important to tie with conventional seismic sections for coal layer mapping and time to depth conversion. The usefulness of VSP suggests that the method should be employed more in the future for coal exploration.

1. Introduction

Coal seams in Quang Ninh province, North Vietnam once were simple to discover and produce as they located in very shallow regions, or even on the surface (Le Dinh Thanh et al., 2012). However, after long time of production, the shallow coal in Quang Ninh is running out and the Department of Geology and Mineral of Vietnam recently stated that the coal exploration must reach the depth of 1000m (Decision No. 89/2008 / QDD-TTg, 2008).

With that target, seismic method naturally becomes an important exploration tool thanks to its capability to accurately map geological layers in the subsurface. Recently, a seismic survey has been carried out in Song Hong delta for coal exploration that allows defining several horizons at depth up to 1500m below the surface. The remaining significant issues are how to identify the coal bearing layers among the seismic horizons and correctly define the depth to them since the seismic sections are recorded in time domain. A suitable tool to solve these problems is VSP method, which records seismic signals traveling between a well bore and the surface

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(Lai Manh Giau, 2015). The technique provides a direct correlation between subsurface stratigraphy and seismic reflections measured at the surface and accurate velocity information. Despites these advantages, VSP is far from a routine geophysical method in coal exploration in Vietnam probably due to time and cost. This article describes one of the first applications of VSP method for coal exploration in Vietnam with encouraging results recommending that the method shall be used more in the future.

2. Vertical seismic profiling (VSP) method

Vertical seismic profiling (VSP) is a borehole seismic recording technique that measures the behavior of seismic wavefield as they propagate between a well bore and the surface. (Figure 1).

Three-component geophones are deployed in the borehole while the source is activated at the surface, at a certain distance away from the wellhead. Many shots are repeated for a certain depth level and then stacked together to produce one seismic trace. This procedure is repeated for different depth levels and, as a result, a group of traces are recorded in time yielding the VSP section.

There are several advantages of VSP method comparing with such as conventional surface seismic method.

1. First of all, in VSP the source is located quite close to the borehole therefore the distances between source and receivers are much shorter than in surface seismic method. Because the VSP recording geometry shortens the target-to-receiver path, the energy losses due to absorption are lower, and so the frequency content is generally higher. As a result, vertical and horizontal resolutions are improved.

2. The second advantage of the VSP is that both the downgoing and upgoing wavefield are measured during the receivers are located deep in the subsurface meanwhile conventional seismic has got only upcoming waves (Figure 2). Knowledge of the downgoing wavefield allows us to effectively deconvolve the upgoing wavefield to provide a broad-bandwidth, multiple-free measurement of the earth's reflectivity. Faults, angular unconformities, pinch outs, and weakly reflecting interfaces near a well can therefore generally be seen more clearly with VSP data from that well than with surface-recorded data.

3. Another benefit is that VSP details sequences stratigraphy. Because VSP receivers is located in the well bore so detailed image of the objectives near the well is received. Prediction of stratigraphy, lithology and the structure ahead of the bit to optimize drilling costs and reduce uncertainty.

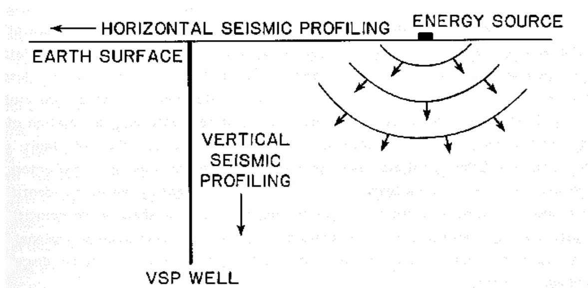

Figure 1. VSP schematic arrangement of source and borehole receiver.

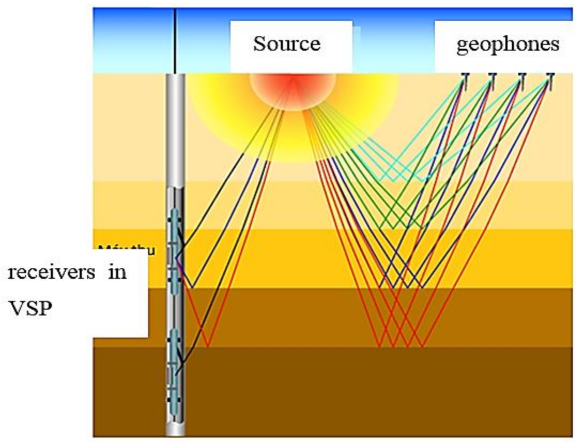

Figure 2. Schematic of VSP and conventional seismic.

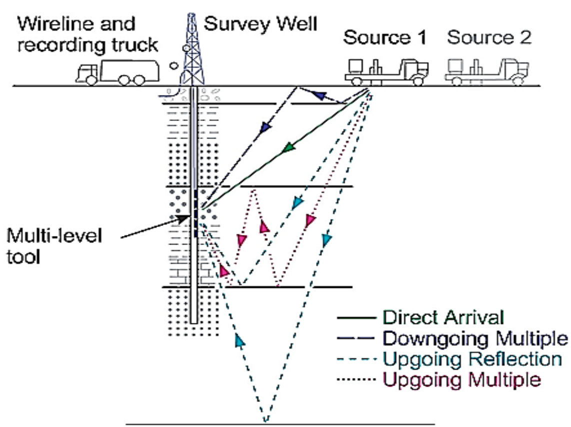

Figure 3. Schematic of different waves in conventional VSP method (Campbell et al., 2005).

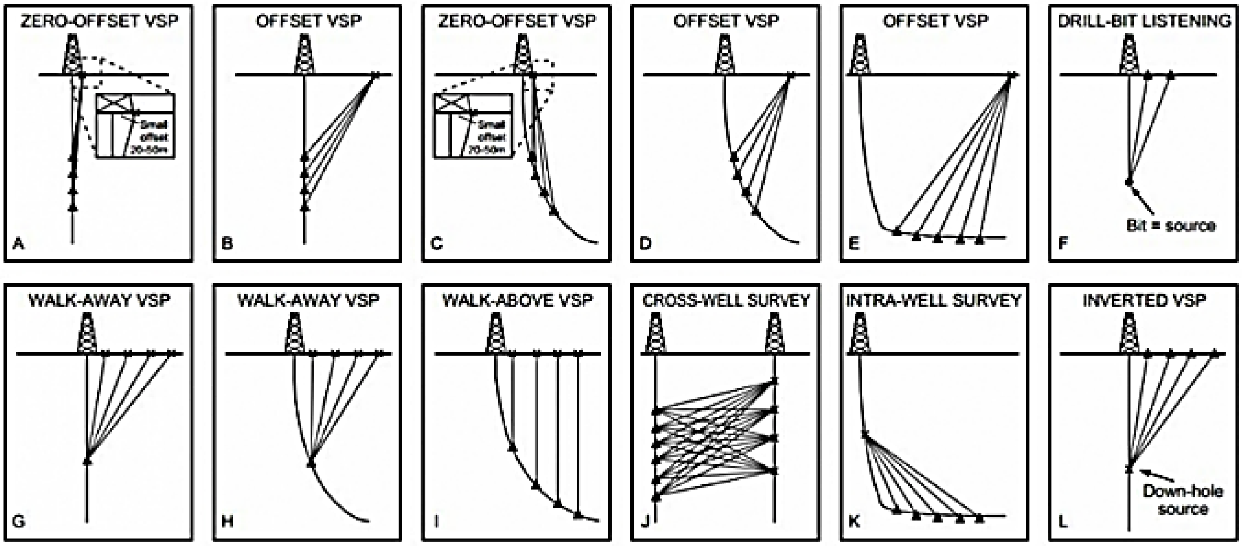

Figure 4. Well shoot and vertical seismic profile examples (Petroleum Geology forum).

4. Because VSP can provide the details of layers under surface and the corridor stack is very relative with surface seismic so the multiple on surface seismic can be recognized (Figure 3).

5. Depend on the deviation of well bores and location of sources, there are different figurations of conventional and unconventional VSP (Figure 4).

3. Geological characteristics of study area

The case study was carried out in the northwestern part of the Red River delta (blue shape in Figure 5). The stratigraphic column in the study area has different versions described by different authors (Pham Dinh Que et al., 1981; Vu Van Tien, 2002; Tran Van Tri, 2009). The one used in this article is proposed by Vu Xuan Danh, (1986). In general, the Quaternary sediments cover the surface that include Early Pleistocene(Q_1), Le Chi formation (Q_1^1lc); Middle and Late Pleistocene, Ha Noi formation ($Q_1^{2\text{-}3}hn$); Late Pleistocene, Vinh Phuc formation (Q_1^3vp); Holocene epoch Early-Middle Holocene, Hai Hung formation ($Q_2^{1\text{-}2}hh$); Late Holocene, Thai Binh formation (Q_2^3tb). Neogene sediment has an unstable thickness ranging from a few dozen meters to several hundred meters, even the thickness in some places can reach of over three thousand meters that include Early Miocene (N_1^1) Phong Chau Formation (N_1^1pch); Middle Miocene ($c^2{}_1$) Phu Cu Formation ($N^2{}_1pc$); Late Miocene ($h^3{}_1$) Tien Hung Formation ($N^3{}_1th$); Pliocene Epoch, Vinh Bao Formation (N_2vb); Underneath is the Paleogene sediments including Phu Tien Formation (E_2pt); Oligocene Epoch (E_3) Dinh Cao Formation (E_3*đc*).

Cenozoic deposits lies uncomformably over the older formations. Precambrian metamorphic rocks of Song Hong zone and some Triassic carbonate of Ninh Binh zone are outcropped in the west southwest edge of the Ha Noi trough; while Silurian sediment of Tan Mai formation, Devonian carbonate and Mesozoic sediments of Hon Gai and Ha Coi formations are observed.

Neogene sediments are the main coal bearing so the target in the study focused on Neogene period. Neogene sediments including sandstone, siltstone, clay and brown coal beds have unstable thicknesses ranging from a few dozen meters to several hundred meters, in some place it is up to more than 3000 meters. The target coal seam is part of the Tien Hung Formation that can be divided into 3 sets.

Tienhung formation set 1 ($N_1^3th_1$) is located at the bottom of the coal bearing formation, distributed at a depth from 400 m (Khoai Chau) to 4000 m (Quynh Phu, Thai Thuy - Thai Binh province). It is determined that there are about 20 coal seams with 5 economically mineable seams. The petrographic composition of the first set is mainly debris, coal clay, coal-forming materials of lakes, rivers, estuaries, delta plain. The first set of Tienhung Formations was formed in the environment of swamp or lagoon in some places.

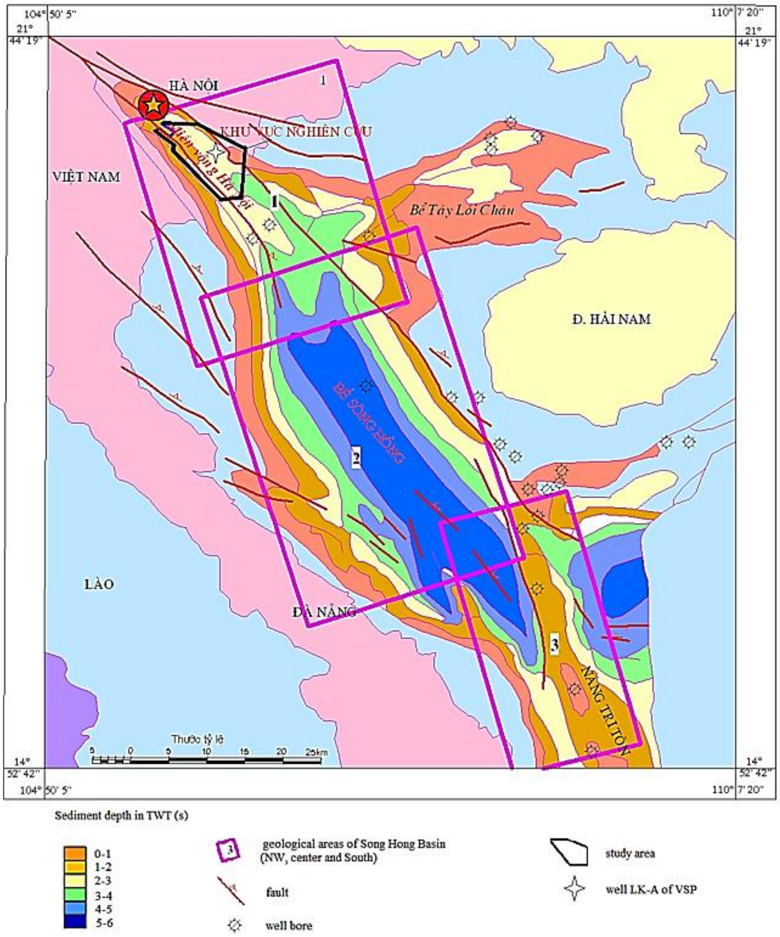

Figure 5. Location of the study area in the Red River valley's geological structure (Lai Manh Giau, 2012).

The set's thickness ranges from 250 to 650m.

Tienhung formation set 2 ($N_1^3th_2$) is located along Phucu - Hungyen province and Donghung - Thaibinh province to the coastal areas at a depth from 200 m (in Khoaichau) to 3400 m (in Thaithuy - Thaibinh province). There are about 15-20 coal seams. The petrographic composition of the second set is mainly terrigenous sediment containing interbedded sandstone, siltstone, claystone and coal seams. The set's thickness is from 590 to 1870m.

Tienhung formation set 3 ($N_1^3th_3$) is located between Songlo and Vinhninh faults, at a depth from 200 m to 1000 m and divided clearly into 2 parts. Lower part is sediments of lake, river and swamp environment. Upper part: coarse-grain deposits of river floods and streams including conglomerates, coal lenses interbedded with coarse sandstones. This set includes 5-27 coal seams. The set's thickness is from 250 to 700 m.

4. Data acquisition and processing

The VSP method was carried out in a well named LK-A located on the map in Figure 5. The frequency of explosive source about 80 Hz and weight is 300g and located in the depth 12m. The data is collected by 1 ms sample rate with frequency from 10 to 250 Hz. The receivers are geophones and the distance between receivers is 6m. Usually, explosive charges are efficient producers of seismic wave energy, but are not widely used as energy source in VSP because that it is difficult to shoot a large number of shots required in vertical seismic profiling and maintain consistent shot wavelets. Therefore, any VSP data application that demands invariant wavelets may be difficult to accomplish with dynamite. To get consistent shot wavelets, a constant diameter and depth during the shooting of multiple shots must be maintained.

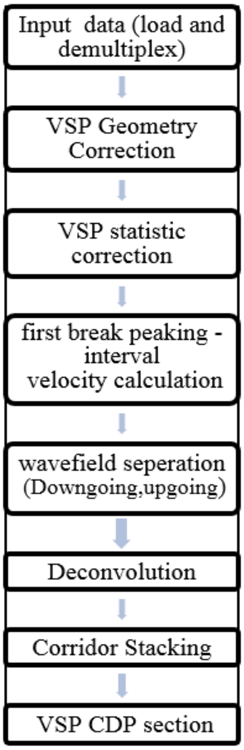

Figure 6. Workflow for processing VSP data.

The workflow of data processing is displayed in Figure 6 including spherical divergence corrections, up and down wavefield separation, wave-shaping deconvolution and corridor stacking, according to Hardage and others (Hardage et al., 1985; Campbell et al., 2005; Bubshait et al., 2009).

The basic processing results were valuable and provided the link between the high-resolution logs and low-frequency surface seismic. Picking of first break is one step of processing work flow (Figure 7).

5. Results and interpretation

The results of VSP data processing is shown in Figure 8. The main reflections are considered (Perz, 2001). There are 8 reflecting boundaries from H1 to H8, the interval velocities can be defined by time and depth values shown in Figure 8. The black lines correspondent with coal seam in the borehole. The results match quite well with core samples (NguyenVan Hanh, 2017). Layer 1 locating above H1 has low interval velocity (about 817 m/s); according to the core sample, it consists of clay, claystone, siltstone and powder. Layer 2 covering H2 is mainly sandy, due to the delimitation of the boundary of Kien Xuong formation with Hai Duong according to the geological database of boreholes.

The H2 boundary according to the VSP is a strongly reflective surface. Layer 2 between H1 and H2 has interval velocity of 1679m/s.

Layer 3 between H2 and H3 has interval velocity of 2215m/s.

From the stratigraphic column, this layer includes sandy having size from small to large seed, the lower part is mainly siltstone.

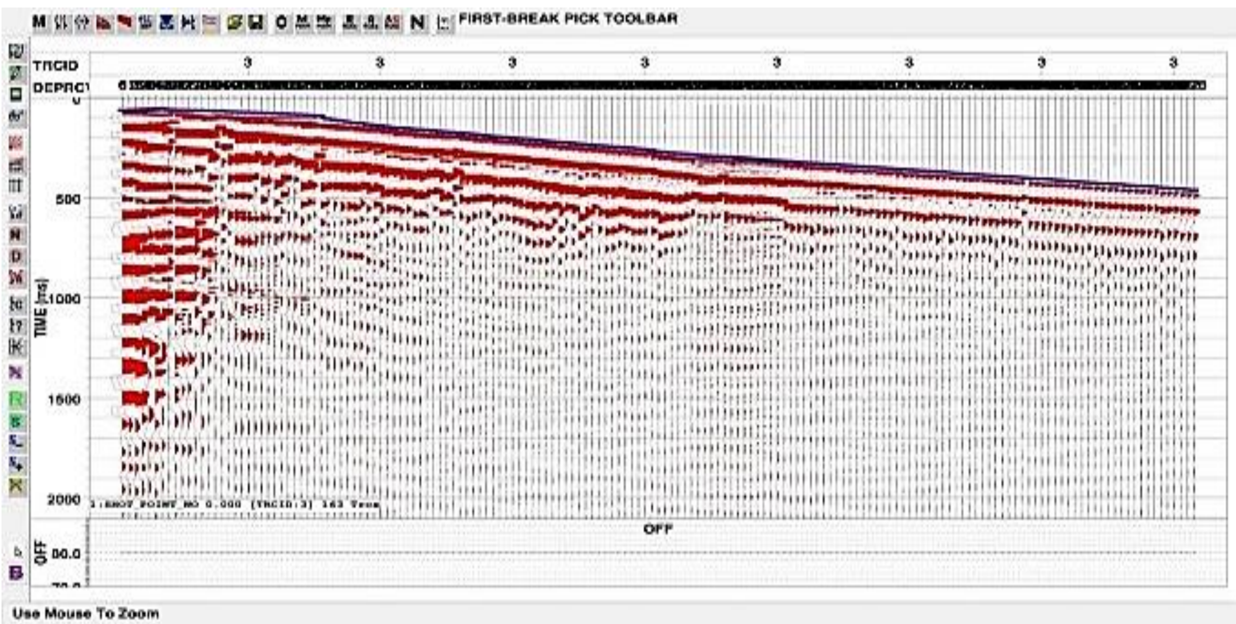

Figure 7. Zero offset VSP with first break times.

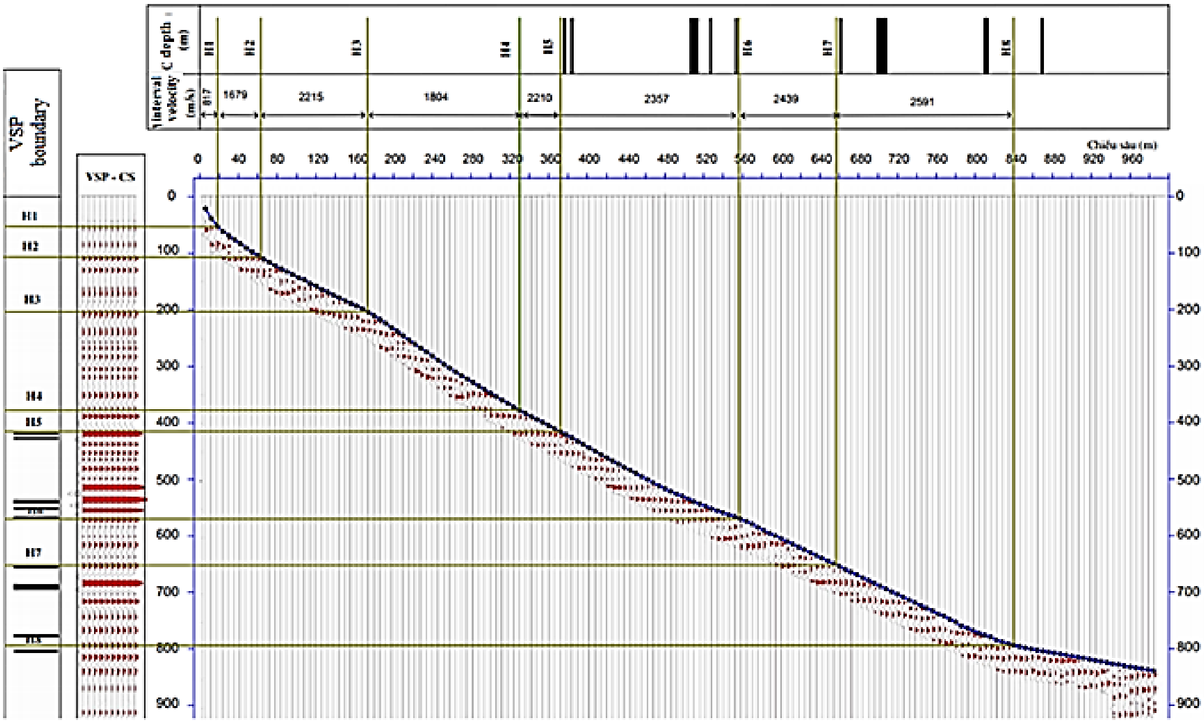

Figure 8. Corridor stacking of VSP section.

Layer 4 between H3 and H4 has interval velocity of 1804m/s. It is the intersection between high speed zones. From the stratigraphic column base on sample core, the upper part of the H4 boundary is dominated by gravel, pebbles and gravel, while the lower part consists mainly of fine to large sand grains. This shows the matching between VSP and core data too.

Layer 8 between H7 and H8 has interval velocity of about 2591m/s with strong reflections that may relate to coal seams (Nguyen Van Hanh, 2017). The drilling report shows that in the Tien Hung Formation 2, the seams of coal and dirt were identified intermixture with the coal seams is thicker than 2m. This layer includes mainly sandy granules to large particles mixing with gravel and sandstone, below is sand mixing with clay, siltstone.

The interpretation of the VSP data described above helps to identify the coal rich layers, tie them to the seismic data as well as provides the time-depth function to convert the time horizons and time maps generated from seismic data to depth maps.

6. Conclusion

A VSP method has been applied for deep coal exploration in Song Hong delta. After being processing, the VSP data allow confident identification of coal layers on seismic data as well as provide reliable time-depth conversion information. The correlation of the VSP seismogram to the conventional seismic data will help to map coal layers accurately. It is therefore recommended that VSP method shall be applied routinely with conventional seismic surveys not only for exploration of coal but also of other mineral resources.

Acknowledgements

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References

Bubshait, K. S. and Lawton, C. D., 2009. VSP Processing For Coal Reflections. *CREWES Research* (21), pp 1-21.

Campbell, A., Fryer, A., Wakeman S., 2005. Vertical seismic profiles- more than just a corridor stack. *Leading Edge* (July), pp 694-697.

Decision No. 89/2008 / QDD-TTg, 2015. Strategy of Vietnam's coal industry to 2015 and orientation to 2025 (in Vietnamese).

DiSiena, J. P., Byun, B. S., Fix, J. E., and Gaiser, J. E., 1984. F-K analysis and tube wave filtering, in Eds. Toksoz, N.M. and Stewart, R.R., Vertical Seismic Profiling, Part B-Advanced Concepts, *Geophysical Press.*

Hardage, B. A., Helbig, K., and Treitel, S., 1985. Vertical Seismic Profiling. Handbook of Geophysical Exploration. Seismic Exploration: *Geophysical Press*. Elsevier Science Ltd, The Boulevard, Langford Lane, Kidlington, Oxford, OX5, GB, UK.

http://www.epgeology.com/gallery/image_page.php?Album_id=4&image_id=116.

Lai Manh Giau, 2012. Investigation and general appraisal of coal resource in Red River Basin's Mainland, *Report of Ministry of Natural Resources and Environment project*, Center for Information and Archives of Geology, Hanoi (in Vietnamese).

Lai Manh Giau, 2015. Geophysical results from investigation and assessment of coal resources in the Red River Basin. Geology and resources in Vietnam, *Natural science and technology publisher*, Hanoi (in Vietnamese).

Le Dinh Thanh and Nguyen The Bau, 2012. Study and propose the measures for environmental rehabilitation and recovery of Lotri coal mine in Quangninh province, *Journal of water resources and environmental engineering* 39 (12-2012), 34-40 (in Vietnamese).

Nguyen Van Hanh, 2017. Interpretation of vertical seismic profile (VSP) to determine reflection horizons in the area X of Red River Trough, *MSc.Thesis*, Hanoi University of Minning and Geology (in Vietnamese).

Perz, M., 2001. Coal and their confounding effects, CSEG Recorder, 26 (10), pp 34-53.

Well Shoot and Vertical Seismic Profile (VSP) Examples, 2018. *Petroleum Geology forum*, http://www.epgeology.com/gallery/image_page.php?Album_id=4&image_id=116

Pham Dinh Que, Do Bat, 1981. The stratigraphic complex of the Tertiary sediments of Hanoi, *Report*, Petroleum Institute of Hanoi (in Vietnamese).

Tran Van Tri, Vu Khuc (editors), 2009. Geology and resources in Vietnam, *Natural science and technology publisher*, Hanoi (in Vietnamese).

Vu Van Tien, 2002. Results of the coal survey in Red River trough project from 1998 to 2002 between the Vietnam National Coal Corporation and NEDO (Japan), *Report*, Vietnam Coal and Mineral Industries Group (in Vietnamese).

Vu Xuan Danh, 1986. Report of coal reservoir in Hanoi (Hung Yen - Thai Binh), *Center for Information and Archives of Geology*, Hanoi (in Vietnamese).