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V. Petruniak, postgraduate student
Geological Faculty
Taras Shevchenko National University of Kyiv
90 Vasylkivska Str., Kyiv, 03022 Ukraine
E-mail: petruniak@univ.kiev.ua

I. Ustenko, postgraduate student
Geological Faculty
Taras Shevchenko National University of Kyiv
90 Vasylkivska Str., Kyiv, 03022 Ukraine
E-mail: ustenko@univ.keiv.ua
Tel.: +380442597030

# MODEL OF SEISMIC VELOCITY DISTRIBUTION FOR COMPLETE COMPLEX OF PROCESSING AND INTERPRETATION OF SEISMIC DATA IN DNIEPER-DONETS BASIN

*(Reviewed by the editorial board member G. Prodaivoda)*

***Advanced understanding of geological structure of petroleum fields remains one of the main drivers of successful exploration and production. Due to limitations of seismic method we can acquire data only in time domain, while other data, like petrophysical or geological, are acquired in depth. Combining these main data sources in a single exploration project remains one of the main task of exploration geologist since it allows avoiding mistakes in depth estimation of prospects, and thus correct estimations for drilling.***

***The key for correlations between time and depth domain is vertical seismic profiling (VSP), which allows estimation of seismic waves' travel time with depth. Basically, so far this is the only direct measurement of time-depth relationship in petroleum fields. Correct processing and interpretation of this data will lead to correct interpretation and prospect evaluation.***

***In the paper VSP data processing workflow is being proposed. Calculation methods of interval, average and layer velocities and statistical methods to crosscheck obtained results are suggested. Statistical analysis allows avoiding subjective mistakes, and though in some situations might require later manual corrections for geological factors, nevertheless it allows to guarantee quality of the data and introduces unique approach to its interpretation.***

***Obtained seismic velocities later were incorporated in seismic data processing graph and an optimal graph for processing seismic data using VSP velocities is introduced. Applying well velocity data allows us to properly estimate velocity models for depth migration and to avoid uncertainties related to velocity estimation.***

***Seismic images, obtained after processing, were used for seismic interpretation, which helped to specify geological structure of the prospects in the cutoff part of the Dnieper-Donets Basin. Modern software and interpretation methods of seismic data allow significant improving of mapping accuracy and tracing tectonic faults.***

**Introduction.** Advanced understanding of geological structure of the fields of Dnieper-Donets Basin is one of the most important steps in modern geological exploration hence it allows increasing of oil and gas resources and reserves. In return, this challenge became unreachable without precise processing of acquired seismic data and detailed understanding of velocity model prior migration.

Significant amount of geological and geophysical studies were held at the area of interest, including electrometric, magnetic, gravity and seismic surveys. Wildcat, parametric, and some production wells are drilled.

Acquiring of these data allowed creating acceptable geological model of the area. Nevertheless, the most important issue related to depth conversion cannot be solved correctly solely by little amount of velocity data from certain fields, also we cannot rely completely on velocity models created based on velocity spectra analysis prior migration. Though such velocity cubes might be used later for depth conversion relatively easily using well-known Dix equation, we should take into account possible mistakes that might be introduced during velocity spectrum analysis. Thus, 5% mistake in velocity estimated from velocity spectra can result in about 20% mistake in interval velocities calculated via Dix equation. This is why using borehole seismic data is a crucial step for accurate depth models of petroleum prospects and leads.

Since most of well seismic data had being acquired in different time by different tools and processed by different methodologies, it was important to develop a methodology allowing processing and interpretation of the data and bringing it to one standard. Later these data, from more than 300 wells, were used to create interval, average and layer velocity models for central part of Dnieper-Donets Basin, helping to understand velocity distribution in the region based not only on onshore seismic, but on the well data.

These velocity data were introduced into processing workflow, allowing us to use additional information for velocity modeling and thus obtaining seismic images of higher quality and more accurate distribution of reflectors. And obviously, their correlation with geological strata.

A workflow to enhance processing graph using velocity model acquired from VSP data at the whole central part of DDB is being proposed in the paper.

Significant amount of geologic and geophysical surveys were held at the area of interest, including electric, magnetics, gravity and seismic surveys. Wildcat, parametric, and production wells are drilled.

Most of the fields at the area are linked to non-anticline traps – tectonic blocks with monoclines.

The processing was performed in a wide frequency range with preservation of kinematic and dynamic characteristics of the seismic record.

All processing consisted of three main steps:

1. Time processing of seismograms.
2. Prestack time migration.
3. Processing of the 3D volume.

The first and third stages of processing were performed in the Echos software package. The second stage was performed in GeoDepth.

Along with loading seismic profiles in geologic database of the project, well log data was entered – coordinates of wells in the area of study, stratigraphy markers, their depth marks, VSP data, acoustic and radioactive logs, well deviations and others.

Results of interpretation of seismic images build using suggested processing graph allowed obtaining much more detailed geological structure, with more accurate depth correlation of the strata. Correct understanding of depth relations can foster petroleum production from the field and will be essential for well planning.

**Methodology of VSP data interpretation.** Collection and analysis of wellbore seismic data, mainly results of VSP research was the first step in preparation data for velocity modeling. Authors have collected the data from more than 300 wells. Most of these wells are located at the area of research, while some wells are located outside the area, but in "immediate" vicinity. These wells were incorporated into model in order to control extrapolation process at the borders of the research area.

About 5% of these data were not conditional – it was not possible neither to re-interpret the data, nor even understand the readings. Therefore, we made conclusion that such oil fields may be considered as the ones without well velocity data.

Since all the VSP surveys were conducted in different time by different methodologies, we have decided to re-interpret the data – in order to bring it to one standard.

In order to have all the VSP interpretation results we have developed following workflow:

- at the first stage vertical time travel curves were referenced to absolute depth level (sea level) and correction of an a priori mistakes was made.

- at the second stage corrected time travel curve was recalculated in the time travel curve with constant increment. If input time travel curve was reordered with a step of 20 meters and more, step of an output curve was set to 20 meters. If input time travel curve was reordered with increment of 10-15 meters and more, increment in the output curve was set to 10 meters.

- at the third stage obtained data was transferred in digital and graphical form for further processing.

A section of vertical time travel curve with location of reading points is presented at Figure 1. Figure 2 shows time travel curve with reading points (A) and interval velocities calculated in the well. Red arrow indicates a layer with anomalously high velocities, which corresponds to one reading point at the time travel curve and most likely is a result of measurement mistake.

Average and interval velocities based on VSP data were calculated according to the following workflow:

$$Vp\_av = \frac{H}{Tp}, \quad (1)$$

were $V_{p\_av}$ – average velocity for primary wave, $H$ – vertical depth from the reference datum, $T_p$ – wave transit time.

For interval velocity:

$$V\,\text{int} = \frac{\Delta H}{\Delta Tp}, \quad (2)$$

were $V_{int}$ – interval velocity of primary wave, $\Delta H$ – depth differential, $\Delta T_p$ – primary wave transit time.

Figure 3 presents an example of layer velocity modeling.

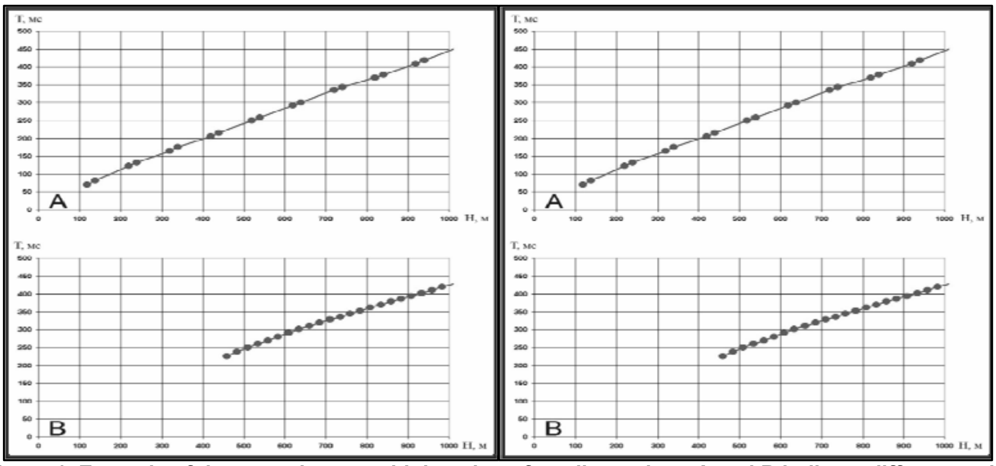


**Figure 1. Example of time travel curve with location of reading points. A and B indicate different wells**

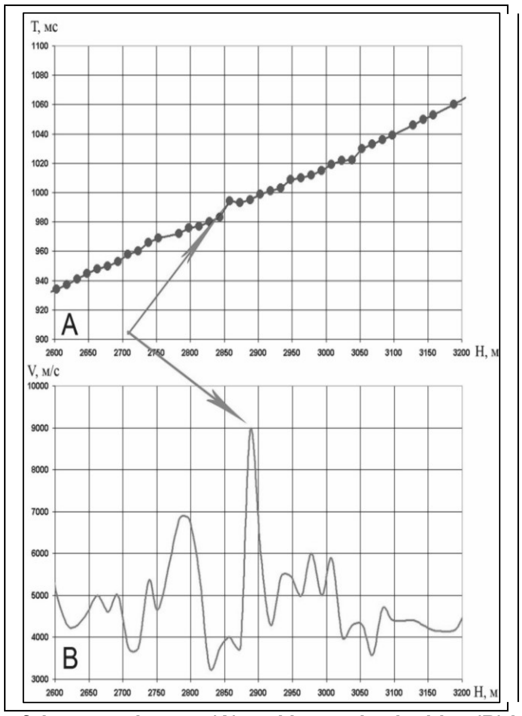


**Figure 2. Example of time travel curve (A) and interval velocities (B) before corrections. Arrows indicate errors of the first arrival readings**

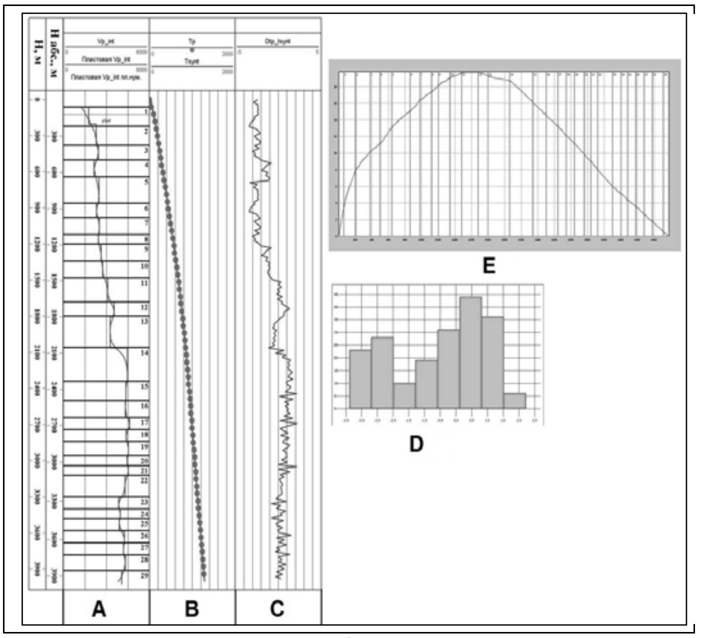

**Figure 3. An example of layer velocity modeling.**
A – interval and layer velocities, B – forward modeling – calculation of vertical time travel curve, which is later compared to real time travel curve (B, C). E – correction of the model with reduced time travel curve, D – statistical control of the data

Calculation of layer velocity based on traditional methods (choosing breakpoints of time travel curve) is the most subjective and open to errors since interpreter's point of view is the main criteria in this approach. At the other hand, suggested methodology allows calculating layer velocities automatically, reducing human factor.

To calculate layer velocities authors have used not time travel curves, but interval velocities. Based on common petrophysical algorithms [2, 3] these data were converted into layers and layer velocities were calculated based on the equation (3):

$$Vp = \frac{\Delta H}{\Delta Tp}, \quad (3)$$

were $V_p$ – layer velocity, $\Delta H$ – thickness of the layer, $\Delta T_p$ – wave transit time in the layer.

Calculated layer velocities were used for forward geophysical modeling – calculation of time travel curves, which were compared to recorded ones. If qualitatively both curves matched, the process was finished. If qualitatively curves did not match – model was corrected solving inverse problem of reduced time travel curve with additional quality control, both visual and statistical.

**Optimal graph of seismic data processing**

1. Reading of field seismic data in SEG-Y format and recording them on magnetic disk of the workstation.
2. Formation, linking and verification of the array of source points and receiver points positions for further development of the project database in the processing system ProMAX 3D, obtaining position schemes of the source and receiving points.
3. Binning points of CDP. Obtaining multiplicity distribution in the area of interest.
4. Entering parametric information required for the system processing ProMAX 3D in the headers lines.
5. Quality control of assigned geometry by visual control of seismogram first entries in the records.
6. Calculation of static corrections using data of explosive seismic investigations CDP method of previous surveys and SRM data.
7. Formation of tables of static corrections for source and receiving points and entering them into project database.
8. Editing of input seismographic records. Making changes to the tables of the database.
9. Calculating of an a priori 3D cube.
10. Analysis of seismic characteristics of the input data.
11. Selecting parameters and restoring the values of the amplitudes.
12. Attenuation of sound waves.
13. Testing of the parameters and performance of FK filtering by source points.
14. Testing of parameters and deconvolution of input data.
15. Calculating of control 3D cube after FK filtering and deconvolution.
16. The first cycle analysis of stacked 3D velocity grid by 2.5 by 2.5 km.
17. The first cycle of the automatic 3D static corrections and editing of results.
18. Calculating of the control 3D cube using the first cycle static and kinematic corrections.
19. Weakening of multiple waves of seismographic records.
20. The second cycle of velocity stacking on the 1.25 x1, 25 km grid.
21. The second cycle of the automatic 3D static corrections.
22. Calculating control 3D cube using second cycle of static and kinematic corrections.
23. DMO-transformation in the high-speed analysis points.
24. Adjustment of velocity stacking using data corrected by DMO.
25. DMO transformation.
26. Zero-phase deconvolution of stacked data.
27. Weakening of incoherent noise.
28. Building of the velocity model for 3D time migration.
29. Time 3D migration of the stacked data.

**Data interpretation.** Reinterpretation of 3D seismic data and formation properties at the Southern border of Dnieper-Donets Basin led to revealing new aspect of geological structure of the area, determine areas of petroleum leads and re-estimate formation properties of key productive horizons.

**Interpretation workflow**

Today, when new technologies and equipment are developed, both for seismic data acquisition and its processing and interpretation, it has become possible further research of Southern part of Dnieper-Donets Basin border. Interpretation was carried out on 20 seismic profiles, which forms fairly uniform grid. For alignment of wells two profiles of past years – 19-43-81 and 70-43-90 were used. After processing of seismic data, and also reprocessing of profiles from previous years, in the ProMAX system, all materials were loaded into the database of "Integral Plus" interpretation package. The seismic reference datum of profiles is 150 m.

For tying seismic boundaries with geological data at all deep drilling wells, as well as to determine the characteristics of the complex nature reflectors, seismic modelling was carried out.

For convolution of impulse traces 23 Hz Ricker wavelet was used, determined from seismic profiles 77-2-02. Calculations of synthetic traces were performed based on an acoustic borehole logging and generalized velocity curves. Results of seismic modelling showed that the lower and upper borders of Visean formations correspond to an acoustically hard surface. Stratigraphic boundaries coincide with the top of seismic vibrations' wavetrain. This conclusion is also confirmed by comparing calculated seismic traces with the real wave field.

**Conclusions.** Modern software and interpretation methods of seismic data allow significant improving of mapping accuracy and tracing tectonic faults. Application of new techniques for the interpretation of data makes it possible to create 3D geological models, defining distribution of zones with better reservoir properties, predict values of porosity and zones of lithological substitutions. Using algorithms of seismic facies analysis allows much more reliable establishment of lithological substitution zones and estimate distribution of formations with similar porosity and permeability properties. As a result of seismic studies the geological structure of southern border of Dnieper-Donets Basin was clarified.

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**В. Петруняк, асп., petruniak@univ.kiev.ua,**
**Є. Устенко, асп., ustenko@gmail.com,**
**Київський національний університет імені Тараса Шевченка,**
**Геологічний факультет, вул. Васильківська, 90, м. Київ, Україна, 03022,**
**Тел.: +380442597030**

## ВИКОРИСТАННЯ МОДЕЛІ РОЗПОДІЛУ ШВИДКОСТЕЙ СЕЙСМІЧНИХ ХВИЛЬ ПРИ ПОВНОМУ КОМПЛЕКСІ ОБРОБКИ ТА ІНТЕРПРЕТАЦІЇ СЕЙСМІЧНОЇ ІНФОРМАЦІЇ НА ПРИКЛАДІ ПЛОЩ ДНІПРОВСЬКО-ДОНЕЦЬКОЇ ЗАПАДИНИ

***Комплексне уявлення про геологічну будову родовищ нафти та газу є основним інструментом, що забезпечує успішну розвідку родовища та видобування корисних копалин. Відомим обмеженням сейсморозвідки є те, що отримані дані знаходяться в часовій області, в той час як більшість інших методів, таких як геофізичні дослідження свердловин чи петрофізика, мають глибинну розмірність. Інтеграція цих типів даних в єдиному геологорозвідувальному проекті є однією з першочергових задач геофізика-інтерпретатора оскільки дозволяє уникнути помилок у визначенні глибин родовища та прогнозах при бурінні.***

***Основним інструментом при кореляції часових та глибинних даних є результати вертикального сейсмічного профілювання, що дозволяють оцінити час проходження сейсмічних хвиль з глибиною. Коректна обробка та інтерпретація цих даних є ключовою для коректної інтерпретації сейсмічних даних та побудови геологічних моделей.***

***В даній роботі автори пропонують методику обробки даних вертикального сейсмічного профілювання, розрахунку інтервальних, середніх та пластових швидкостей. Для контролю якості отриманих результатів було використано статистичні методи. Статистичний аналіз дозволяє уникнути суб'єктивних помилок інтерпретатора, хоча, безперечно, в подальшому може знадобитись коректування отриманих результатів з врахуванням наявних геологічних умов.***

***Розраховані швидкості сейсмічних хвиль були використані для розробки оптимального графу обробки сейсмічних даних. Використання свердловинних даних дозволяє створити більш точну швидкісну модель для глибинної міграції та уникнути невизначеностей в оцінці швидкостей.***

***Сейсмічні зображення, отримані в результаті обробки та міграції, були використані при інтерпретації та дозволили уточнити геологічну структуру родовищ прибортової частини Дніпровсько-Донецької западини. Сучасне програмне забезпечення та методи інтерпретації сейсмічних даних дозволяють значно підвищити точність картування та коректність визначення тектонічних порушень.***

**В. Петруняк, асп., petruniak@univ.kiev.ua,**
**Е. Устенко, асп., ustenko@gmail.com,**
**Киевский национальный университет имени Тараса Шевченко,**
**Геологический факультет, ул. Васильковская, 90, г. Киев, Украина, 03022,**
**Тел.: +380442597030**

## ИСПОЛЬЗОВАНИЕ МОДЕЛИ РАСПРЕДЕЛЕНИЯ СКОРОСТЕЙ СЕЙСМИЧЕСКИХ ВОЛН ПРИ ПОЛНОМ КОМПЛЕКСЕ ОБРАБОТКИ И ИНТЕРПРЕТАЦИИ СЕЙСМИЧЕСКОЙ ИНФОРМАЦИИ НА ПРИМЕРЕ ПЛОЩАДЕЙ ДНЕПРОВСКО-ДОНЕЦКОЙ ВПАДИНЫ

***Комплексное понимание геологического строения месторождений нефти и газа является основным инструментом обеспечивающим успешную разведку месторождения и добычу полезных ископаемых. Известным ограничением сейсморазведки является то, что полученные данные находятся во временной области, в то время как большинство других методов, таких как геофизические исследования скважин или петрофизика, имеют глубинную размерность. Интеграция этих типов данных в едином геологоразведочном проекте является одной из первоочередных задач геофизика-интерпретатора поскольку позволяет избежать ошибок в определении глубин месторождения и прогнозах при бурении.***

***Основным инструментом при корреляции временных и глубинных данных являются результаты вертикального сейсмического профилирования, которые позволяют оценить время прохождения сейсмических волн с глубиной. Корректная обработка и интерпретация этих данных является ключевой для корректной интерпретации сейсмических данных и построения геологической модели.***

***В данной работе авторы предлагают методику обработки данных вертикального сейсмического профилирования, расчета интервальных, средних и пластовых скоростей. Для контроля качества полученных результатов были использованы статистические методы. Статистический анализ позволяет избежать субъективных ошибок интерпретатора, хотя безусловно в дальнейшем может потребоваться корректировка полученных данных с учетом наявных геологических условий.***

***Рассчитанные скорости сейсмических волн были использованы для разработки оптимального графа обработки сейсмических данных. Использование скважинных данных позволяет создать более точную скоростную модель для глубинной миграции и избежать неопределенностей в оценке скоростей.***

***Сейсмические изображения, полученные в результате обработки и миграции, были использованы при интерпретации и помогли уточнить геологическую структуру месторождений прибортовой части Днепровско-Донецкой впадины. Современное программное обеспечение и методы интерпретации сейсмических данный позволяют значительно повысить точность картирования и корректность определения тектонических нарушений.***