STUDY OF THE CAPABILITIES OF AVO-METHODS FOR THE DETECTION OF HYDROCARBON ACCUMULATIONS

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ABSTARCT. The AVO-methodology is based on the study and analysis of the wave field features related to the differing reflectance of the individual surfaces in the geological section. Several physical parameters of geological media are used: velocity of compressional wave, velocity of shear wave, density, acoustic impedance.
The software is based on the equation of Zoeppritz. This equation, re-processed by Aki-Richards, uses the linear relationship between the amplitudes of the reflected waves and $\sin^2\theta$, where θ is the angle of incidence of the seismic wave. The amplitude's change of reflected seismic waves, depending on the distance from the source point of seismic energy, has been investigated on real seismic data.
The presented study of the AVO-methodology possibilities for the identification of oil and gas deposits is based on the seismic, lithological and stratigraphic, and geological and geophysical data from the Galata gas field. In tectonic terms, the area falls on the southern board of the Varna Monocline, north of the Bliznatsi Fault. The data from a seismic line with south-north direction and materials from two wells were used. The AVO-anomalies studied are well correlated with the proven presence of hydrocarbon accumulations.

Keywords: AVO, incidence angle, acoustic impedance, anomalies.

ИЗСЛЕДВАНЕ НА ВЪЗМОЖНОСТИТЕ НА АВО-МЕТОДИТЕ ЗА ОТКРИВАНЕ НА ВЪГЛЕВОДОРОДНИ АКУМУЛАЦИИ

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РЕЗЮМЕ. АВО-методиката се основава на изучаване и анализ на особеностите на вълновото поле, свързани с различаващата се отражателна способност на отделните повърхнини в геоложкия разрез. Използват се няколко от физическите параметри на геоложките среди: скорост на разпространение на надлъжните вълни (Vp), скорост на разпространение на напречните вълни (Vs), плътност на скалите (ρ), акустичен импеданс (ρ.Vp и ρ.Vs).
В основата на използвания софтуер е уравнението на Zoeppritz, преработено от Aki-Richards, където е заложена линейна връзка между амплитудите на отразените вълни и $\sin^2\theta$, където θ е ъгъл на падане на сеизмичната вълна. Изменението на амплитудите на отразените сеизмични вълни в зависимост от отдалечението от пункта на възбуждане на сеизмичната енергия, е изследвано върху реални сеизмични данни .
Представеното изучаване на възможностите на АВО-методиката за установяване на нефтогазови залежи е базирано върху сеизмичните, литолого-стратиграфските и сондажно-геофизичните данни от района на газовото находище Галата. В тектонско отношение площта попада върху южния борд на Варненската моноклинала, северно от Близнашкия разлом. Използвани са данните от един сеизмичен профил с направление юг-север и сондажно-геофизичните данни от два сондажа. Изучените АВО-аномалии добре се корелират с доказаното наличие на въглеводородни натрупвания.

Ключови думи: АВО, ъгъл на падане, акустичен импеданс, аномалии.

Introduction

The AVO-methodology is based on the study and analysis of the wave field characteristics related to the differing reflectance of the individual surfaces in the geological section. Several physical parameters of geological media are used: velocity of compressional wave (Vp), velocity of shear wave (Vs), density (ρ), acoustic impedance (ρ.Vp and ρ.Vs).

The presented study uses professional specialized software. The development of all programs that are used to extract the listed parameters of seismic data is based on Zoeppritz (1919) equation, revised by Aki & Richards (1980), and later simplified by Shuey (1985), wherein is set a linear relationship between the amplitudes of the reflected waves and $\sin^2\theta$ (where θ is is the angle of incidence of the seismic wave).

The aim of the present study with data from proven hydrocarbon accumulations is to present the capabilities of the AVO-methodology for the establishment of oil-gas deposits. For this purpose, seismic, lithological and stratigraphic, and geological and geophysical materials were used from the area of the Galata gas field.

In tectonic terms, the area falls on the southern board of the Varna Monocline, north of the Bliznatsi Fault (Fig. 1).Data from seismic line TX92-21 in direction south-north and well log materials of P-1 and P-2 Galata were used. It is interesting to note that the seismic line data used were recorded prior to the first well, discovered the deposits (late 1993 - early 1994) and before the start of its exploitation.

The Galata gas deposit is inserted in the platform carbonate sediments of the Paleocene, built by shallow algal limestones and in the Upper Cretaceous and Middle Eocene bio-clastic limestones.

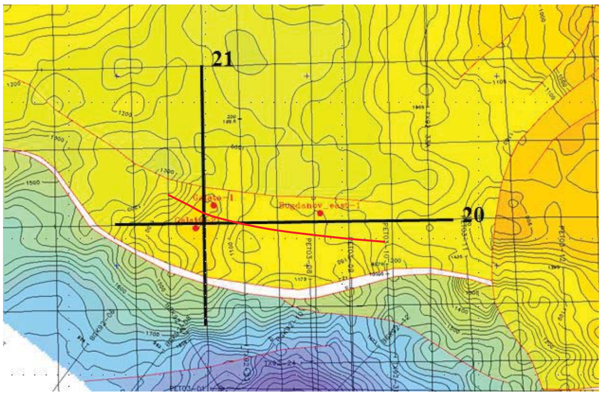

Fig. 1. Structural map of a seismic horizon attached to the top surface of the Paleocene

Figure 2 shows a fragment of the seismic section of line TX92-21 which crosses sequentially the Bliznatsi Fault from south to north, the area of the gas deposit and the F1 fault, limiting the Galata deposit from the north.

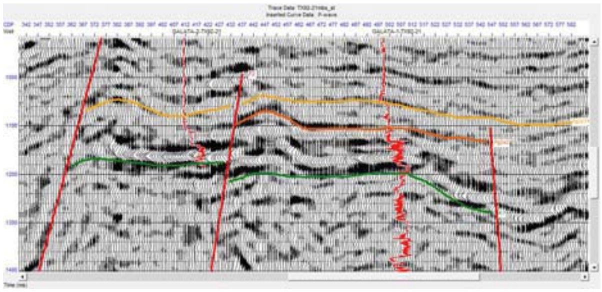

Fig. 2. Seismic section of a line TX92-21 with correlated P-wave curves from wells P-1 and P-2 in the Galata area

Across the line are correlated three seismic horizons attached to: the upper surface of Lower Cretaceous sediments (horizon K1), the upper surfaces of the Middle and Upper Eocene (horizons Pg2e2 and Pg2e3). Within the interval CDP-370 to CDP-515 of seismic line TX92-21 a local high amplitude anomaly was observed – a "bright spot". Anomalies of this type are so well-correlated with the existence of hydrocarbon accumulations that they are known as "direct hydrocarbon identifiers".

Methodology and preparation of data necessary for AVO study

The specialized profisional software used includes a set of programs for analysis of pre-stack seismic data for the purposes of evaluation and modeling of amplitude anomalies depending on offset. For AVO-processing of the Galata area chosen line TX92-21, the following seismic and well log information was used prepared in terms to be discoverable and matching the demands of AVO package:

- CDP Gathers records from seismic line TX92-21;
- Basic curve P-wave_corr_G1 (Fig. 3). This dependence of velocities of compression waves from the depth in P-1 Galata well was correlated with real seismic data from line TX92-21/CDP-505 with correlation coefficient 0.795 and frequency of impulse, with which is generated 28Hz synthetic trace;

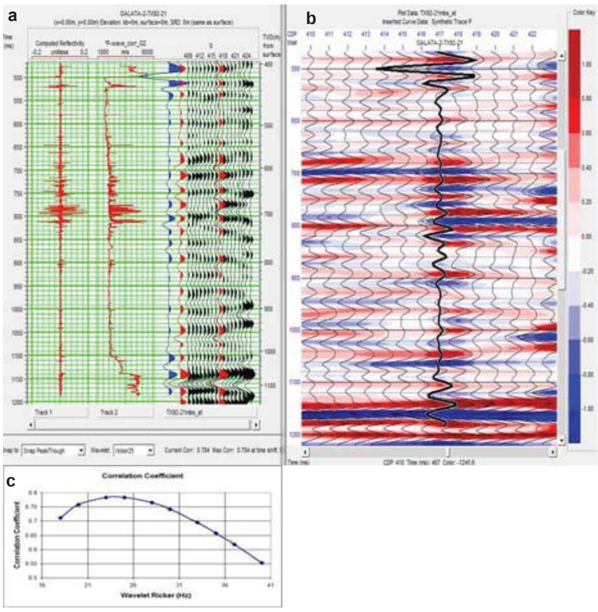

Fig. 3. Seismic line TX92-21
a/ Correlation between sonic log from P-1 Galata well and trace from the line; b/ Fragment of seismic section with synthetic trace generated from correlated P-wave curve of P-1 Galata; c/ Distribution of correlation coefficients for different frequencies of seismic impulse

- Basic curve P-wave_corr_G2 (Fig. 4). This dependence of velocities of compression waves from the depth in P-2 Galata well was correlated with real seismic data from line TX92-21/CDP-417 with correlation coefficient 0.784 and frequency of impulse, with which is generated 25 Hz synthetic trace;

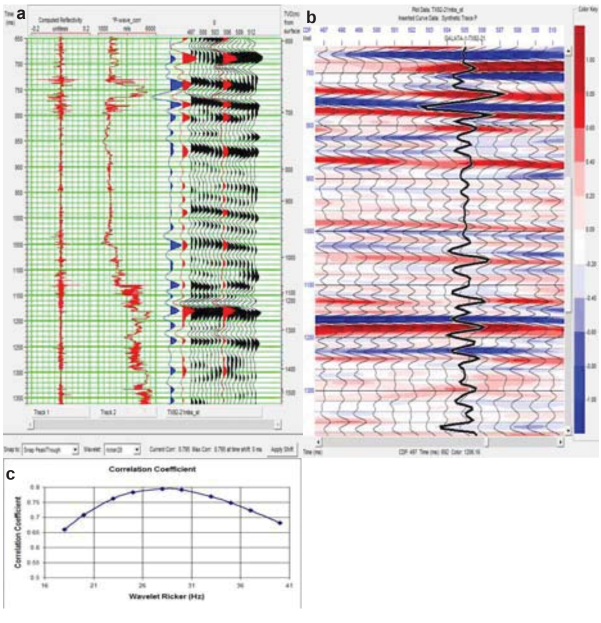

Fig. 4. Seismic line TX92-21
a/ Correlation between sonic log from P-2 Galata well and trace from the line; b/ Fragment of seismic section with synthetic trace generated from correlated P-wave curve of P-2 Galata; c/ Distribution of correlation coefficients for different frequencies of seismic impulse

- P-1 Galata well - original curve of natural Gamma ray (Fig. 5, a - Track1);
- P-1 Galata well - original curve of natural Gamma ray (Fig. 5,b - Track1)

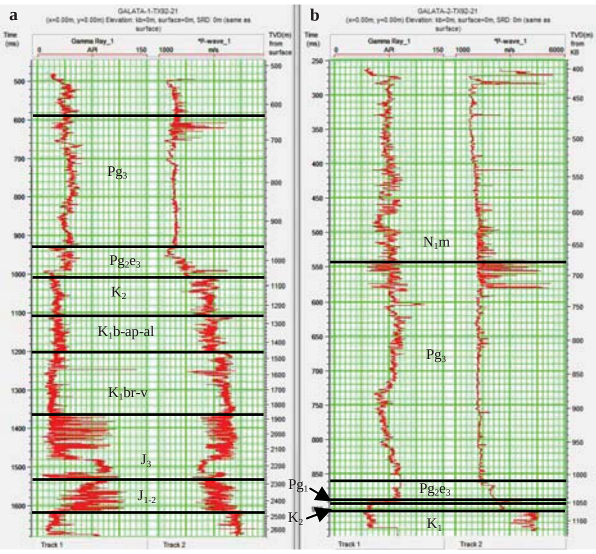

Fig. 5. Well log information, used for the current study; a/ **P**-1 Galata well; b/ **P**-2 Galata well)

- Density curve (Fig. 6,b), obtained from basic curve through Gardner's transformation;
- S-wave curve of the velocities of shear waves according to depth (Fig. 6,c), obtained through - Krief's - transformation of basic curves;
- Curve of Poisson's ratio coefficients (Fig. 6,d);
- Distribution of reflection coefficients, calculated from basic curve (Fig. 6,e);

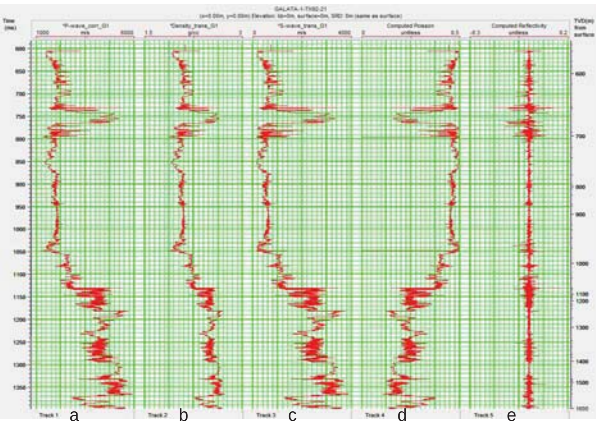

Fig. 6. **P**-1 Galata well– curves created by the correlated P-wave for the purposes of AVO developed methodologies
a/ basic curve P-wave_corr; b/ density curve from Gardner's – transformation of basic curve; c/ curve of velocities of S-wave from Krief's – transformation of basic curve; d/ curve of Poisson's ratio coefficient; **e**/ Distribution of reflection coefficients calculated of basic curve

The last four described curves are transformations of P-wave_corr_G-1 curve used for P-1 Galata. Analogical set of curves (not presented here) was prepared and used for P-2 Galata well.

AVO-technology gives the opportunity to perform three group of researches:

- AVO-modeling of gas or oil saturation;
- AVO-technics based on reflection capability of seismic boarders in geological section;
- AVO-analysis of rock properties in the section.

AVO-modeling of gas saturation

AVO-modeling precedes possible AVO area studies aiming at prediction of changes which would occur in the characteristics of the wave field with change of the fluid filling collectors in the geological section.

Figure 7 presents AVO-modeling on well data P-1 Galata. The correlated P-wave_corr_G1 is used at constant density ρ = 2.22 g/cm^3 and porosity ϕ = 24% for water saturation 5%, 30% и 100%.

On the curve obtained at the lowest water saturation (5%), there was a significant decrease of the velocities in the target area (interval with Middle Eocene aged) by about 17% compared to the 100% water saturation velocity. This would create anomalous impedance values approximate 1100 m/s. g/cm^3.

For each AVO model in Figure 7 were presented also synthetic records with a maximum offset of 1996m, as is the maximum offset in line TX92-21, which significantly exceeds incidence angle 30º. The nature of the resulting synthetic records largely explains the deep Mute applied to standard seismic data processing in the line.

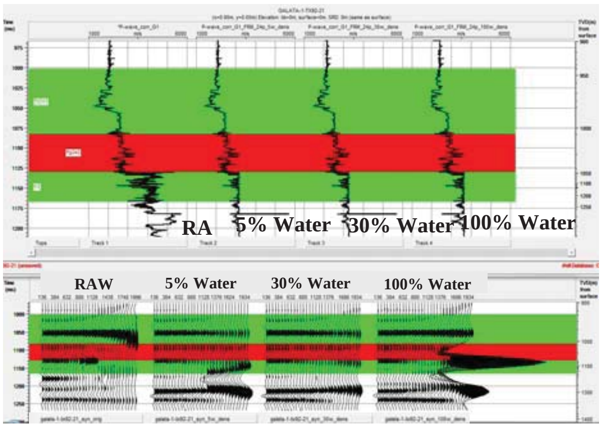

Fig. 7. AVO-modeling at water saturation 5, 30, 100%, constant density 2.22g/cm^3 for target area and porosity 24% (P-1 Galata well)

AVO-techniques based on the reflectivity of seismic boundaries in the geological section

All theoretical developments (the equations of Zoeppritz, 1919; Aki & Richards, 1980 etc.) which serve as the basis for applied AVO-techniques are proven to be valid for incidence angle up to 30º. In order to determine the range of offsets to meet the limitation condition described, a gradient analysis was made on a real record (CDP-470) by seismic line TX92-21 (Fig. 8.a). The same procedure is repeated on a synthetic record by data from the P-wave_corr_G1 curve from the P-1 Galata well (Fig. 8.b). In both cases it can be seen that the offset satisfying the condition of the incidence angle does not exceed 30º, is small - no more than 1150 m. This does not allow us to use such well-functioning AVO-techniques based on the reflectance of reflective surfaces in the geological section, such as near and far sections, and angle stacks for different incidence angles.

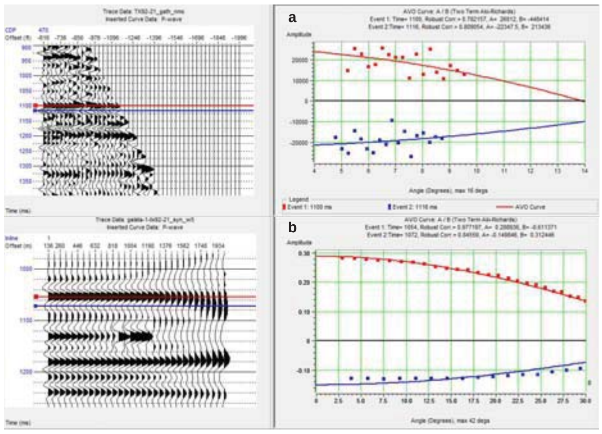

Fig. 8. Gradient analysis
a/ on real data from CDP-470 on line TX92-21; b / on synthetic data from P-wave curve P-1 Galata well

AVO-analysis of the properties of the rocks in the section

In areas with favorable rock features, it is possible to detect hydrocarbons directly - using standard seismic data. However, not all areas have so favorable physical properties on the rocks that the seismic amplitudes in the Post-Stack Migrating data provide information on the reservoir quality and the presence of hydrocarbons. In such cases, it is useful to apply complex AVO-techniques to see how the amplitudes of pre-stack data vary depending on the offset. Here are shown the sections of four AVO-properties of the rocks in Galata area: Intercept (A) (Fig. 9), Gradient (B) (Fig. 10), Poisson's Ratio (Fig. 12) and Fluid Factor (Fig. 13).

AVO-Property Intercept (A) and Gradient (B)

The intercept is the intersection of the best match line with axis at zero distance source-receiver (zero offset) or the zero incidence angle. This is the amplitude of the zero offset directly related to the reflection coefficient (Ostrander, 1984). In this sense, the section of the property Intercept (A) represents the variation of the reflection coefficient of the P-waves on the line induced by the lateral variation of the physical parameters of the geological media contacting the reflecting surface. For a simple cumulative trace, the amplitude value of a certain time is averaged for the amplitudes of all offsets. Thus, this averaging eliminates the amplitude of information that is carried by each offset. On the other hand, however, information about the change of offset amplitude is used in the calculation of the "intercept-trace". In this sense, the intercept-section can be considered as a more informative section than the conventional one in the sense of amplitude anomalies.

The gradient is the slope of the best match line. A section of AVO-property Gradient (B) describes from CDP-trace to the next CDP-trace, along the line, the reflection coefficient is changed according to the offset. The anomalous values are related to the local variation of the wave velocities above and below the reflecting surface. The large change in the Vp / Vs ratio causes high gradient values. Since the presence of gas in porous rocks strongly influences the Vp / Vs ratio, the gradient section is a good indicator of such reservoirs.

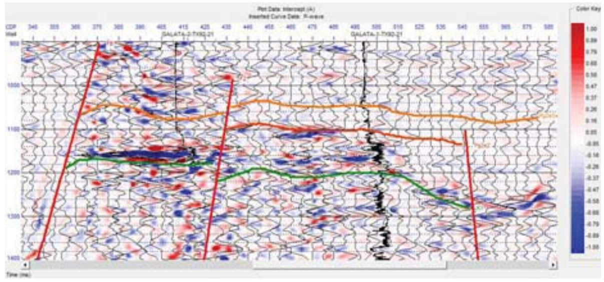

Fig. 9. Section of AVO-property Intercept (A)

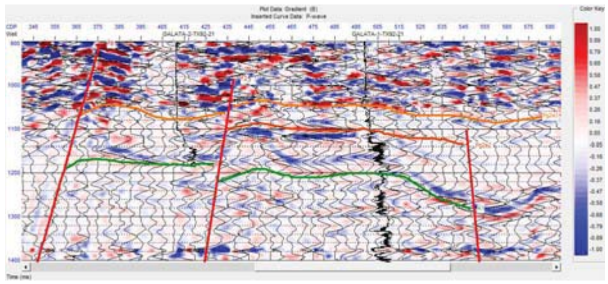

Fig. 10. Section of AVO-property Gradient (B)

AVO-Analysis - Crossplot (A / B)

Figure 11 present the result of the AVO-analysis Crossplot that implements the interconnection between AVO-properties Intercept (A) and Gradient (B). Reflections from the upper surface of water-saturated sediments are plotted around linear dependence (wet trend), passing through the start of the coordinate system. Its slope depends on the average Poisson's coefficient. Reflections from the upper surface of hydrocarbon accumulations are grouped under the wet trend, and reflections from the lower surface of the reservoir - above it (Castagna, & Swan, 1997). The two marked areas –blue (F) and yellow (E) - correlate very well with the gas-saturated intervals on the cross-section shown on Fig. 11,d, where the two wells P-1 and P-2 Galata are located.

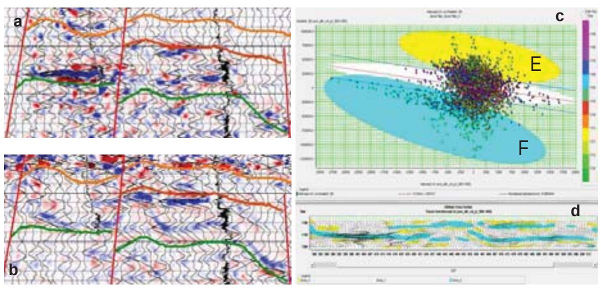

Fig. 11. AVO - analysis crossplot A/B
a/ Fragment of AVO-property Intercept (A) in target zone (line TX92-21);
b/ Fragment of AVO-property Gradient (B) in target zone (line TX92-21);
c/ AVO - Crossplot in target zone (line TX92-21); d/ AVO Cross-section in target zone (line TX92-21)

AVO-Property Poisson's Ratio

In Figure 12, the AVO-indicator Poisson's Ratio Coefficients are considered for the "bright spot" anomaly only. Generally, the velocities of clays and sandstones are not significantly different. The presence of fluid in a collector can cause a difference in the velocities of the P- and S- waves, and hence the anomalous values of the Poisson's Ratio coefficient (Koefoed, 1955).

AVO - Property Fluid Factor

Figure 13 shows the AVO-indicator Fluid Factor. The AVO-property Fluid Factor is defined by Castagna (Castagna, 1993) as a deviation from the calculated on drilling data dependence Vp/Vs for water-saturated clayey rocks and sandstones.

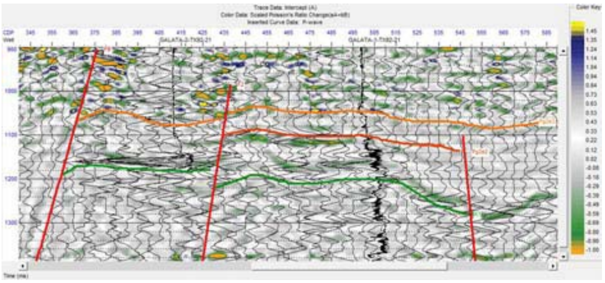

Fig. 12. Section of AVO-property Poisson's Ratio

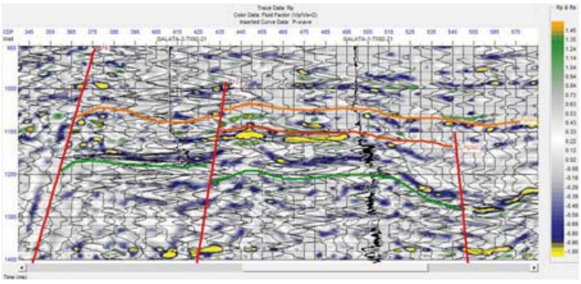

Fig. 13. Section of AVO-property Fluid Factor

Conclusion

The results of all AVO-techniques give rise to several important conclusions:

- At each section of the AVO-properties, it is noticeable that the anomalies appear on a lower noisy background than the standard section;
- The described amplitude anomaly "bright spot" in the standard seismic section TX92-21 appears to be an anomalous area of the Intercept (A) and Gradient (B) sections, in view of the fact that both are related to variations in the reflection coefficient;
- The sections of the AVO-properties show a more detailed division of the gas-saturated interval and an uneven distribution of the rocks collector properties in the target zone, including sediments of the following periods: Upper Cretaceous, Paleocene, and Middle Eocene. The gas-saturated section interval in the tectonic block P-2 Galata well is one attached to the limestone of the Paleocene and Upper Cretaceous, while in the northern block (the area of P-1 Galata), the main anomalous zone is attached to the upper part of the Middle Eocene, but a significant improvement in the capacity characteristics of the collector is also recorded at the lower part of the Eocene;
- An important result is obtained from the AVO-technology AVO-analysis Crossplot, where the upper and lower surface of the intervals with a substantial gas-saturation is observed well on the image of Figure 11,d- Cross-section
- The anomalous zones in the tectonic block, where is located P-1 Galata well around the CDP-450, mark an area, where a future well would be in a more favorable structural position and as collector quality as compared to the P-1 Galata well position. This is particularly well illustrated by the sections from AVO-properties: Poisson's Ratio (Fig. 12) and Fluid Factor (Fig. 13).

In conclusion, it can be noted that the interpretation of amplitudes of pre-stack data is extremely effective in reducing the risk when choosing a location for a search or exploitation drilling.

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References

Aki, K. & P.G. Richards. Quantitative Seismology. - W.H. Freeman and Co., 1980. - 202-228.

Castagna, J. P. Rock physics - the link between rock properties and AVO response. - In: Offset dependent reflectivity – theory and practice of AVO analysis (eds. J. P. Castagna & M. M. Backus). Investigations in Geophysics, 8, 1993. Society of Exploration Geophy-sicists.

Castagna, J. P. & H. W. Swan. Principles of AVO. Crossplotting. The Leading Edge, 16, 1997. - 337-42.

Koefoed, O. On the effect of Poisson's ratios of rock strata on the reflection coefficients of plane waves. - Geophysical Prospecting, 3, 1955. - 381-387.

Ostrander, W.J. Plane-wave reflection coefficients for gas sands at nonnormal angles of incidence. - Geophysics, 49, 1984. - 1637-1648.

Shuey, R. T. A simplification of the Zoeppritz equations. - Geophysics, 50, 1985. - 609-14.

Zoeppritz, K. Uber reflexion und durchgang seismischer Wellen durch Unstetigkerlsflaschen. Uber Erdbebenwellen VIIB. Nachrichten der Koniglichen Gesellschaft der Wissenschaften zu Gottingen. - Math. Phys., K1, 1919. - 57-84.

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