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Prediction of petrophysical characteristics of deposits in Kurovdagh field by use of attribute analysis of 3D data

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The paper is devoted to predicting petrophysical parameters of productive series of Kurovdagh field by use of attribute analysis of seismic data to define the direction of reconnaissance works in this field. The paper considers geographical position of the study area, its cover by geological and geophysical studies and underlines, in particular, the importance of 3D seismic data acquisition for more detailed study of Kurovdagh structure. Lithological and stratigraphic characteristics of the section is also given in the paper with detailed description of Productive Series deposits. In addition, tectonics of the area is considered in more detail. It is noted that the area is attributed to the Low Kur basin — the compound of the large tectonic unit. The tectonic zone of the south-eastern Shirvan is embracing four anticlinal zones: Pirsaat-Khamamdagh; Kharami—Mishovdag—Kalmas—Khydirly—Aghaevir-Byandovan; Kursangya; Padar—Kurovdagh—Karabaghly—Babazanan—Duzdagh-Neftchala. The latter anticlinal zone is characterized by a significant length. In the north-western part between the folds of Padar and Karabaghly the brachyanticline of Kurovdagh is located. In the north it has the border with M. Kharami uplift, in the north-east with Mishovdagh fold, it borders with Kursyanga anticline in the south-east and in the south-west with wide Salyan trough. In the Near-Kur depression the existence of two tectonic stripes has been established. One of them embraces the south-eastern Shirvan, the other covers the eastern Mughan and the western portion of Salyan steppe. The detailed description of fold setting is given on the basis of 3D seismic survey data. It has been indicated that the results of 3D data interpretation made it possible to study in more detail and make changes in the scheme of faults location accepted earlier. The other problem considered in the paper is the oil-and-gas presence in Kurovdagh field, which is related to the Absheron stage of Pleistocene, Akchagyl stage and Productive series (horizons of PS01—PS20) of Neogene, with lithology represented by sandy-clay rocks with various degrees of calcareousness. The structure of each of indicated horizons is rather complicated and variable in lateral. The most complicated of them is the Middle Absheron sub-stage, with identified 11 oil-bearing layers. Study results are given in the end of the paper. For prediction purposes within the study area we have prepared normalized curves of relative parameter of SP-ASP, gamma-log — dGR and resistivity by use of well logging data. The analysis of dependence of seismic attributes on petrophysical parameters within target interval, identified the low information bearing ability of SP method and gamma-log across the study area and established a good correlation between resistivity curve and instantaneous amplitudes, frequencies and dip angles. The clay cubes have been designed. To outline productive layers, we have applied multidimensional filters with cut offs for reservoir and as a result we have acquired a cube for supposed distribution of productive layers. It is emphasized that the conducted studies led to the conclusion that due to the complexity and interference nature of the observed wave pattern in some parts of the Kurovdagh structure, it was not possible to reliably convert the attributes of the seismic wave field into petrophysical parameters.

Key words: oil-and-gas presence, post Pliocene and Pliocene deposits, structure, oil-and-gas field, 3D seismic survey, horizons, seismic attributes.

Introduction. Kurovdagh field is located 120 km to the south-west of Baku, in the Low Kur depression in Shirvan steppe of Azerbaijan [Alizade et al., 2018]. The field is within the limits of Kur-South-Caspian oil-and-gas province (Fig. 1).

The field is located on the left bank of Kur river and extends along the river from the north-west to the south-east. The mud volcano ridge is located in this area and elongated parallel to the river channel starting from Hajigabul lake and further to the south. The ridge represents the plate, complicated by a small ledge of well-cemented limestone-sandy rocks of Absheron and Baku ages.

The first geophysical field-survey started in Azerbaijan in 1927. The survey resulted in development of general tectonic scheme of Near-Kur area. The area has been repeatedly covered by studies applying various geological and geophysical techniques, by 2D seismic survey, in particular. Some seismic lines were worked out by use of reflection wave method through the period of 1946—1948.

Initially oil-and-gas flows have been obtained in Kurovdagh field as a result of testing in appraisal wells in 1955, followed by a wide use of seismic survey applied for more detailed study of fold structure and commercial development of the field. In 1958 the seismic survey by reflection wave method and correlational method of refraction waves covered in general the north-west periclinal part of the structure, which is complicated by longitudinal faults. Three seismic lines have been worked out in 1975 in the north-east subsided part of Kurovdagh structure by CDP method. Starting from 1984 for approximately four years period (till 1987) the north-eastern part of the area has been covered by seismic CDP method, applied to reveal the elements of conjugation of Kurovdagh field with Mishovdagh structure. In 1987 it has been made clear that these structures are separated by a saddle. In 2002 for the first time, VSP technique was applied by «PetroAlliance» company in four wells located in the area. As a result, it became possible to design more accurate velocity model for investigated section and study in more detail the structure down to horizon PS07 (inclusively) of Productive Series. In 2002—2003 the seismic survey by use of 3D CDP technique has been applied within the borders of Kurovdagh field [Urupov, 2004].

Sedimentary cover across Kurovdagh field is represented by post-Pliocene and Pliocene deposits of Cenozoic era (Fig. 2). The modern and ancient Caspian deposits, deposits of Absheron stage show themselves at the surface. Akchagyl stage and Productive Series deposits were recovered by deep wells only [Abdullayev et al., 2012; Mamedov, 2008]. Productive Series, concentrating major oil and gas-bearing targets, were recovered by a large number of deep exploration and production wells. Productive Series is represented by alternation of sandy and clay formations. According to the drilling results, in total 23 productive horizons were outlined in Productive Series. The upper twelve of them derive the interest as the possible oil and gas-bearing targets.

In the previous years the indexation of horizons has been done by use of Roman numerals (I—XXIII) or indices (ПТ1—ПТ23). Further with involvement of foreign companies in the projects, the indexation was changed and currently the productive horizons are given the indices PS01—PS23 (PS — Productive Series).

The study area is located in Low Kur depression — the compound of a huge tectonic unit Shamakhy-Gobystan marginal trough. The following are characteristics of evolution of the trough. The thickness of sedimentary cover in this area is about 15—16 km. The presence of two tectonic belts with echelon-like location of folds have been outlined in the Near-Kur trough. One of them embraces the south-east of Shirvan, the other — the eastern Mughan and the west part of Salyan steppe.

The anticlinal zone, including Kurovdagh, is characterized by a large extension. In the north-west part between the folds of Padar and Garabaghly the Kurovdagh brachianticline is located. In the north it borders with Small Kharami uplift, in the north-east with Mishovdagh fold, in the south-east with Kursyangya anticline and in the south-west with a huge Salyan depression (Fig. 3).

3D seismic survey applied in the area allowed to study the tectonics of the field through the all horizons. According to the structural map for the top of horizon PS01 of Productive Series the Kurovdagh field represents the brachianticline elongated from the north- north-west to the south- south-east with extensions 22 and 5 km. The fold is asymmetric with steeper south-west and gently-sloping north-eastern flanks. Dip angles in the north-western flank is about 5—10°, in the central portion is up to 55°, in the south-eastern flank is about 38°.

Subsided parts of flanks are severely complicated by faults. Tracing of reflection horizons across the area displayed that post-sedimentation tectonic movements and faulting systems have significant influence on their morphology.

Extension and compression deformations while large tectonic movements of the Earth's crust contributed to evolution of faults. Relief of stress zones led to destruction of the primary texture of layers and their spatial displacement relative to each other. Results of these processes are traced on time

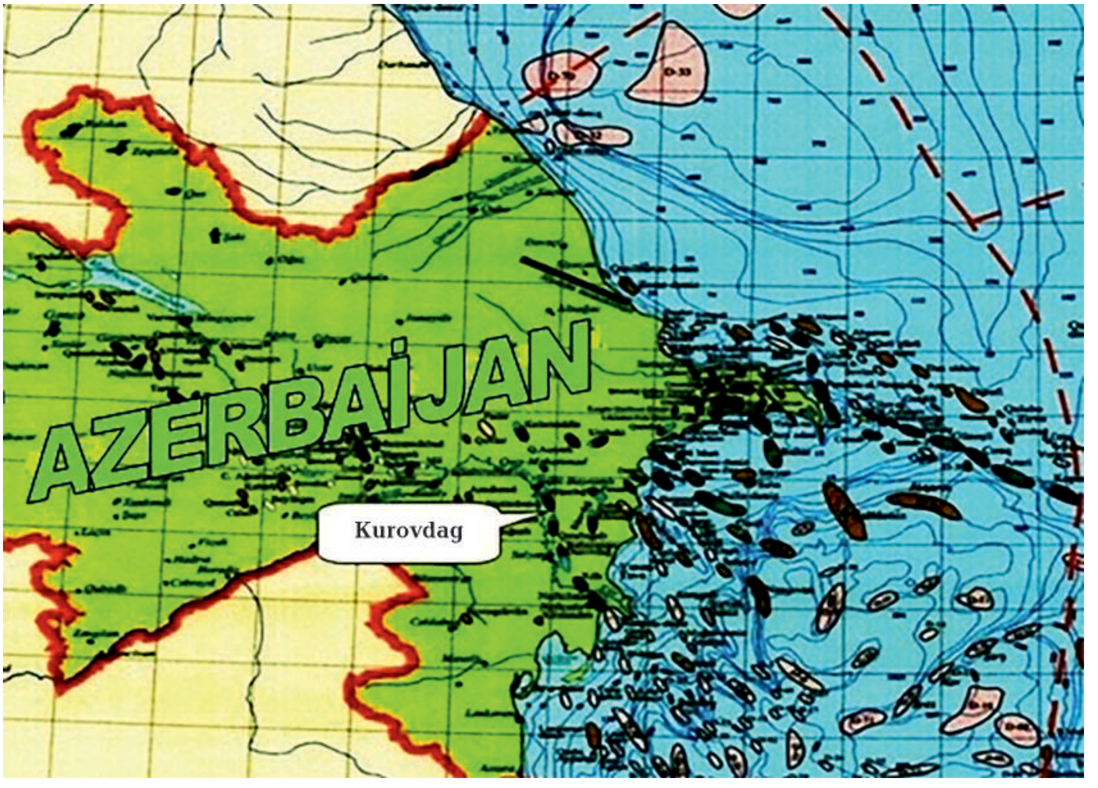


Fig. 1. Geographical position of Kurovdagh field.

sections by a change of seismic and facies features, break and displacement of synphase axes, which are used as the search criteria while tracing of individual faults along the seismic lines. The most elongated mapped faults are downthrown faults. Less elongated are cross faults, which are forming separate blocks.

In Kurovdagh field the presence of oil-and-gas is related to the Absheron stage of Pleistocene, Akchagyl stage and productive layers (horizons PS01—PS20) of Pliocene, represented by sandy-clay rocks with a various amount of limestone in them. Currently, the commercial oil-and-gas presence is related to the middle and lower sub-stages of Absheron stage, Akchagyl stage and horizons PS01, PS02, PS03, PS04, PS05, PS06, PS07, PS08, PS09, PS10 and PS12 of Productive Series. Statistics shows that except for listed horizons, the oil-and-gas flows were received from underlying horizons PS13, PS14, PS16, PS17 and PS19 of Productive Series.

Oil-and-gas presence across the area is significantly influenced by complicated tectonic setting of the area. The total extension of oil-and-gas accumulation area is 20 km, the maximum width of the area is 3 km. However, oil-and-gas zones are significantly varying for some horizons. The major oil-and-gas saturation zones were outlined in the south-east part of the north-eastern flank and in the most uplifted blocks of the arch portion of the area. The commercial flow of gas has been obtained from horizons PS09, PS08, PS01, PS02, as well as from the targets of the Middle Absheron substage.

The present study aimed to solve the following tasks: outline productive layers, define prognostic distribution of the reservoir, evaluate the thickness of productive layers class in two intervals: Akchagyl + 200 msec and Akchagyl + 400—600 msec.

Research questions. In the framework of this study the tying up of the results of CDP-3D method for Kurovdagh field has been done. Data acquired by use of CDP-3D in Kurovdagh field have been applied for interpretation (Fig. 4). By use of the cubes we have done kinematic and dynamic analyses, which revealed the difference through the time shift, frequency spectrum and amplitude range (Fig. 5). The cubes were reduced to the same type for time, phase and amplitude.

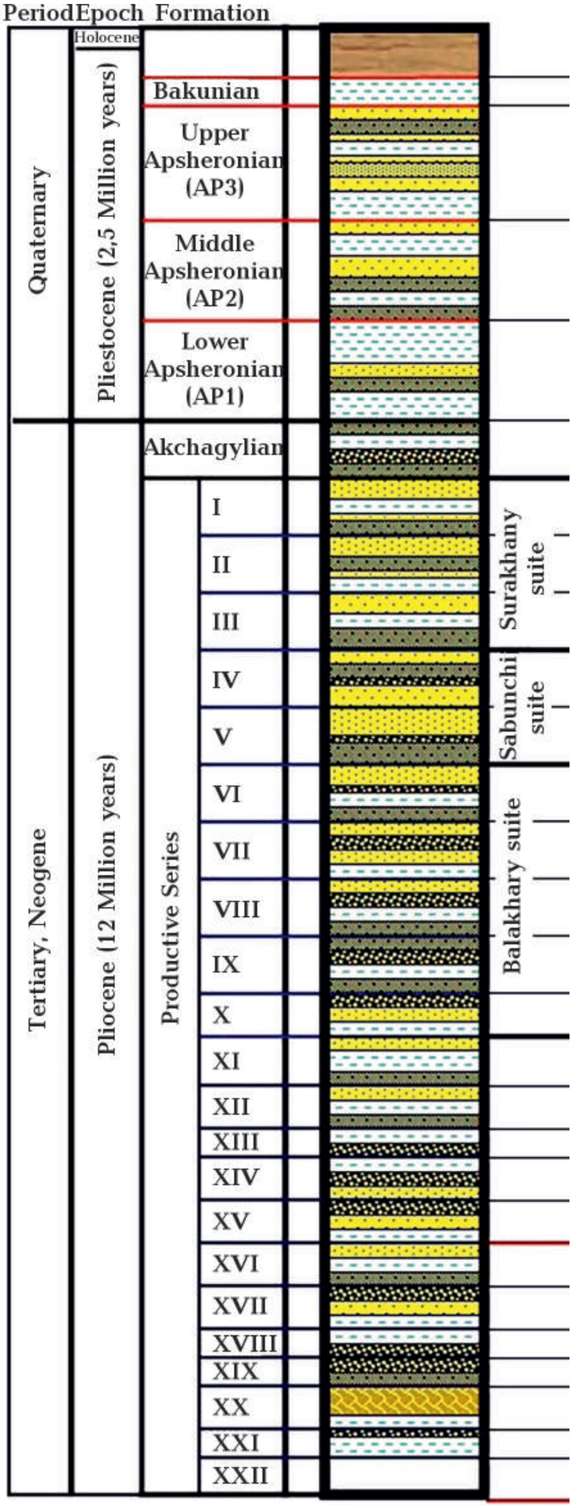


Fig. 2. Straticraphic column for the Kurovdagh field.

Since the acoustic log data are practically absent for Kurovdagh field and it is impossible to calculate the synthetic curves of Acoustic Log due to incomplete logging data from wells, the tying up was done on the basis of velocity model acquired by use of VSP data from well 598.

Aim of the study. The main aim of this study consists in prediction of petrophysical properties of deposits in the intervals, including prediction of target horizons in cross-hole area by use of seismic data.

Methodology. The researches applied the known procedures of dynamic analysis and PANGEYA methodology for dynamic analysis of seismic wave field. The methodology is based on the principle of use of multidimensional relations between seismic attributes and logging data, core analysis and well tests. In addition to standard procedures of dynamic analysis, such as the calculation of instantaneous attributes of seismic cube (Fig. 6), acoustic impedance, velocity-depth model of the cube, the cubes of Typification — Classification and Taxonomy have been calculated [Ovcharenko et al., 2002; Guliyev et al., 2010; Safanov et al., 2011; Akhmedov et al., 2016].

Results. Seismic cubes conversion into cubes of petrophysical parameters have been fulfilled by use of Topology software of PANGEYA® software package, which is based on multidimensional ties between geophysical fields attributes and the data, acquired by well logging data interpretation [Barnes, 1993; Haase, Stewart, 2005; Guliyev et al., 2010].

For study purposes within the study area by the available well logging data the normalized curves of relative SP-ASP (Spontaneous Polarization-gradient of Spontaneous Polarization) parameter, Gamma Ray — dGR (differential gamma-ray), and apparent resistivity (AR) were prepared. The analysis of dependence of seismic attributes on petrophysical parameters in the target interval has been done. The analysis established low efficiency of SP and GR in the area and established a good correlation between resistivity curve with instantaneous amplitudes, frequencies, and dip angles (Fig. 7—9).

Evaluation of initial wave field and procedure for improvement of signal/noise ratio enabled us to obtain good seismic record in Productive Series and made it possible to acquire the above-mentioned cubes of seismic parameters within the interval of Productive Series with discretization step 2 msec [Crawford, Medwedeff, 1999; Lees, 1999; Pedersen et al., 2002; Korneev et al., 2004; Iske, Randen, 2005]. With some assumptions we have used the normali-

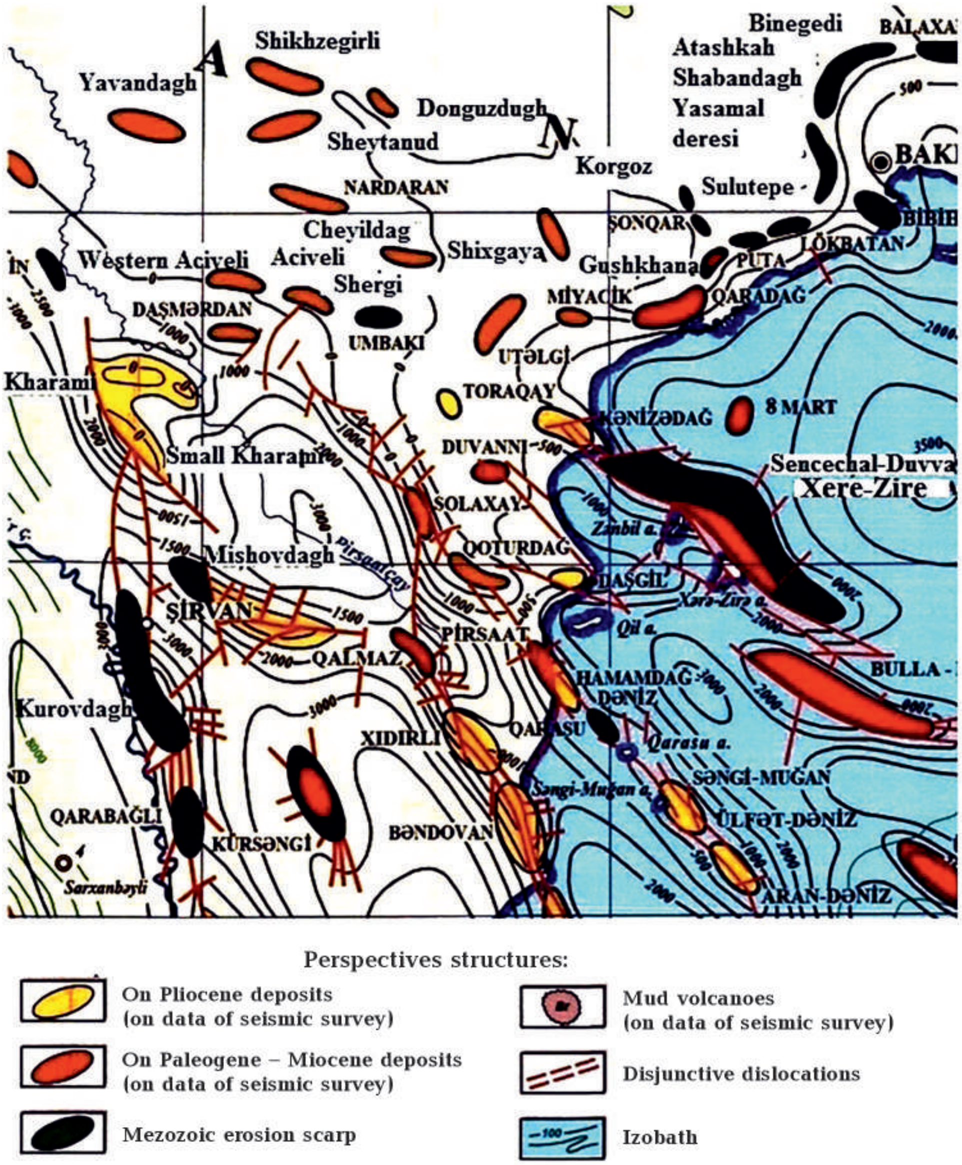
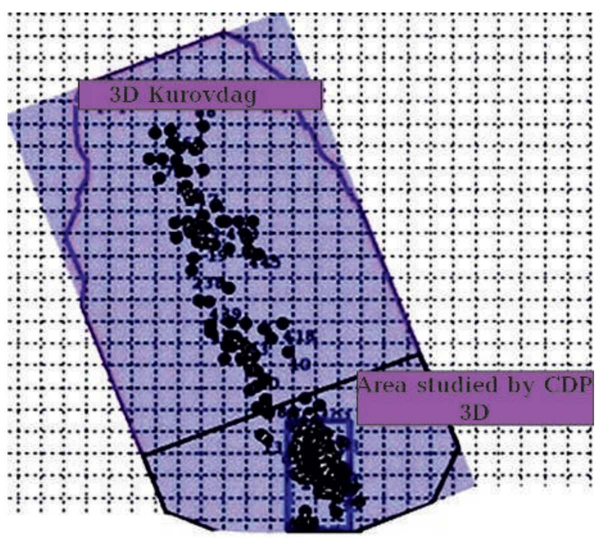


Fig. 3. The echelon arrangement of folds in the southeast of Shirvan.

zed curve of gamma-log — dGR to outline the sandy part of the section.

Prediction results by use of well data made it possible to derive clay cubes (Fig. 10).

To define productive layers class by integration of these two methods we have applied multidimensional filter [Ampilov, 2004; Shimansky et al., 2011] and obtained the cube of supposed distribution of productive layers class.



→ Fig. 4. General map of the area studied by seismic survey CDP-3D.

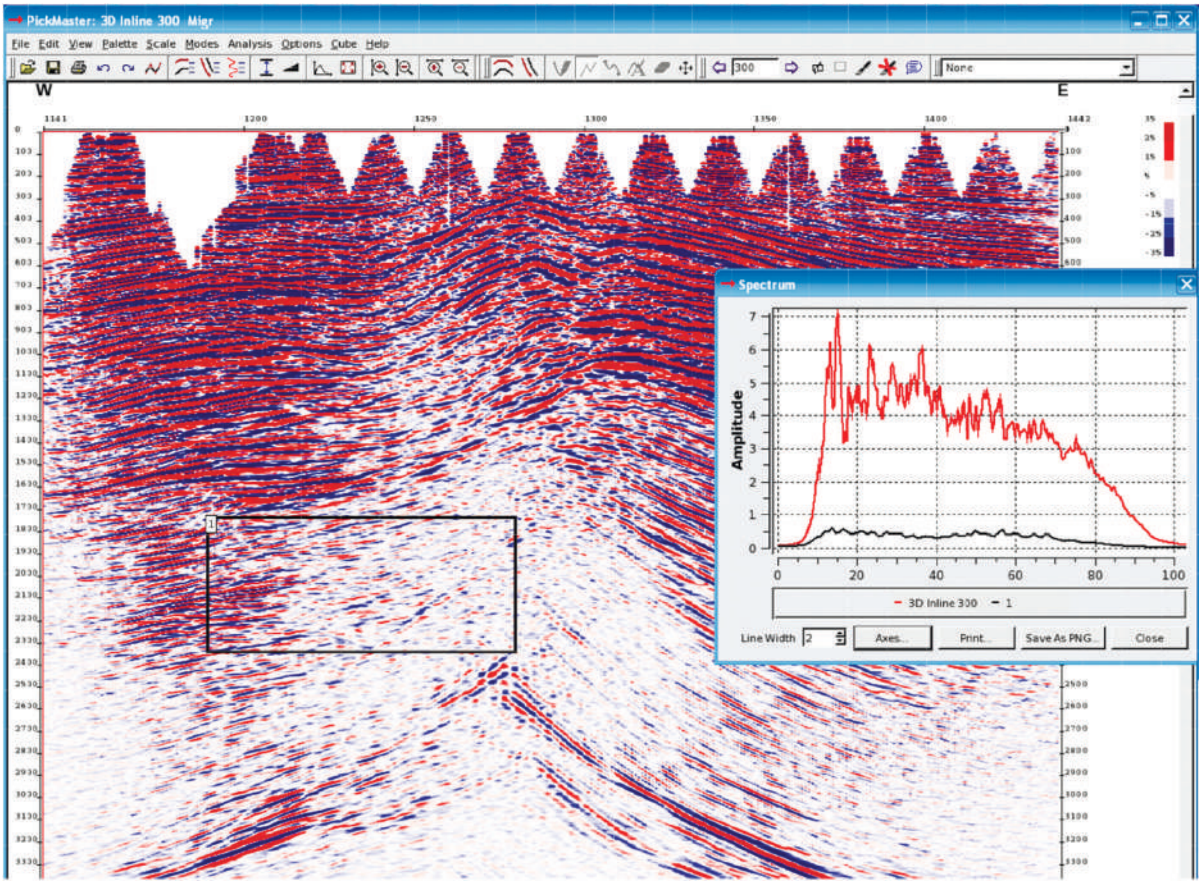


Fig. 5. Tie up of CDP-3D data for Kurovdagh field.

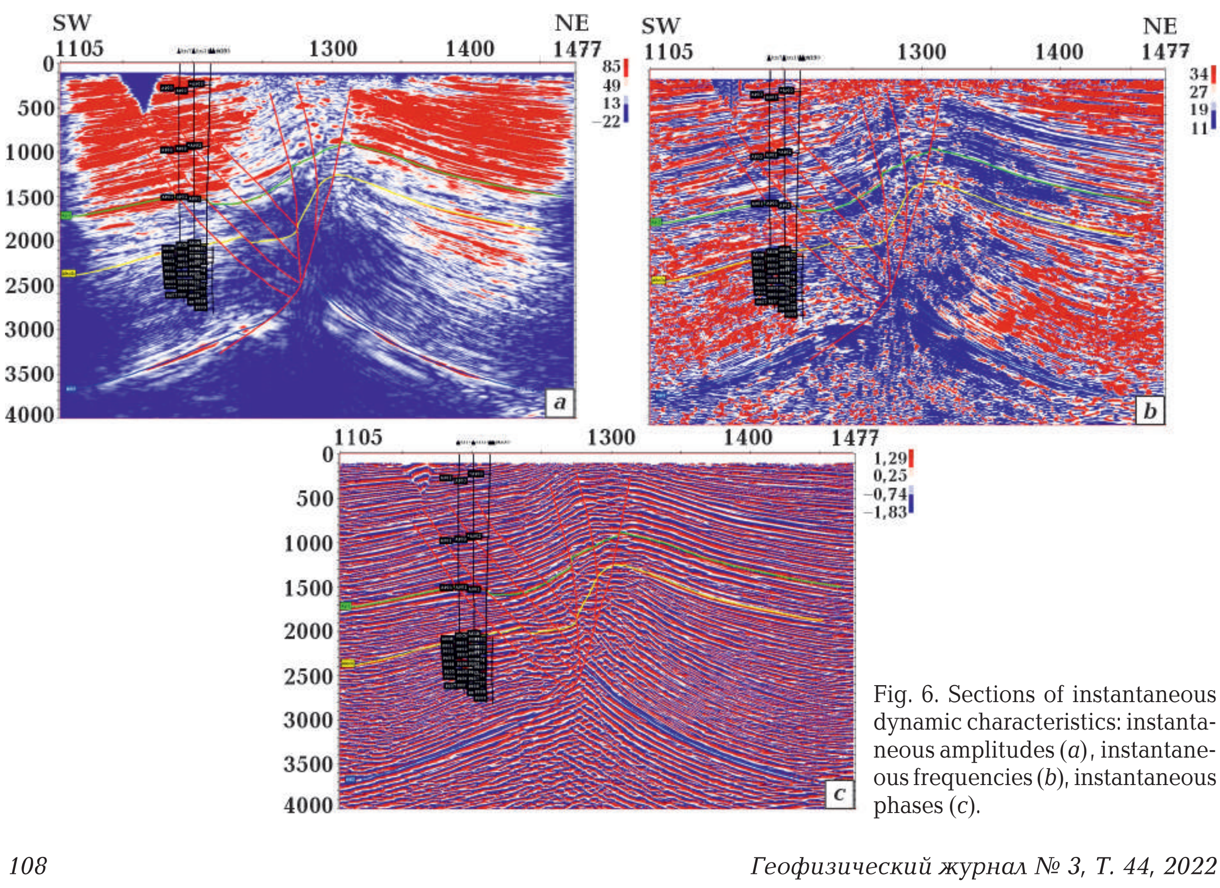


Fig. 6. Sections of instantaneous dynamic characteristics: instantaneous amplitudes (*a*), instantaneous frequencies (*b*), instantaneous phases (*c*).

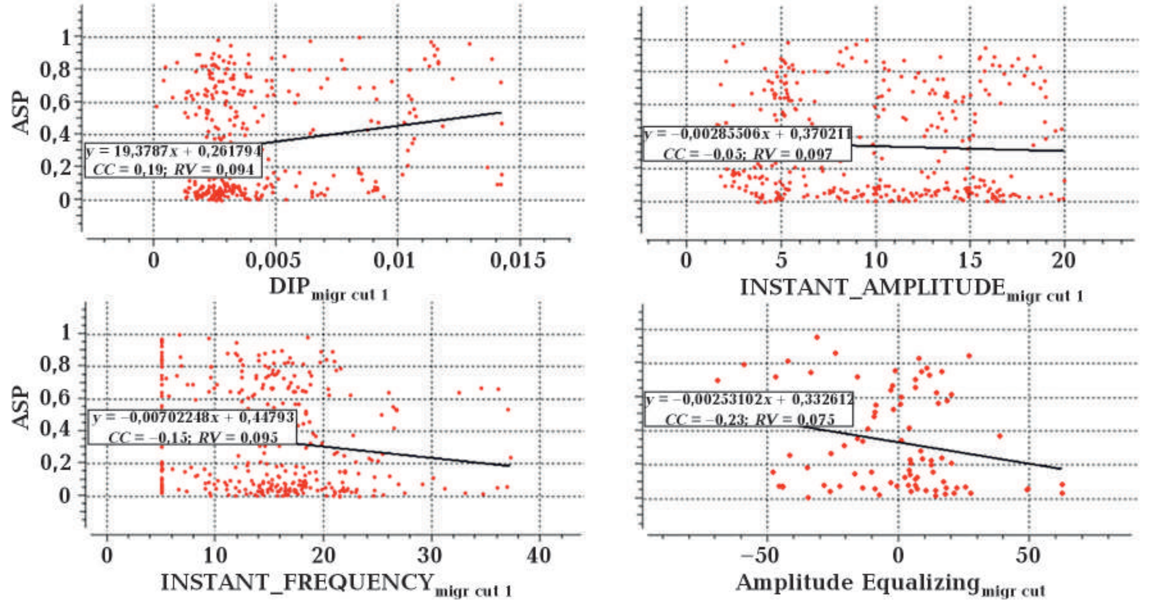


Fig. 7. Dependence of ASP curve on seismic attributes.

Conclusion. The independent system analysis of all data available for the field made it possible to valuate the importance of various assumptions allowed in petrophysical model.

There has been developed an approach to the elements of procedure applied for setting of structure and parameters of algorithms of optimization inversion. It should be noted, that the spatial prediction in productive interval made it possible to reliably fulfill the inversion of features of analyzed seismic wave field into petrophysical parameters and more accurately define the setting (geometry) of reservoir layers. It is impossible to say the same about the arc and near-arc portions of the structure,

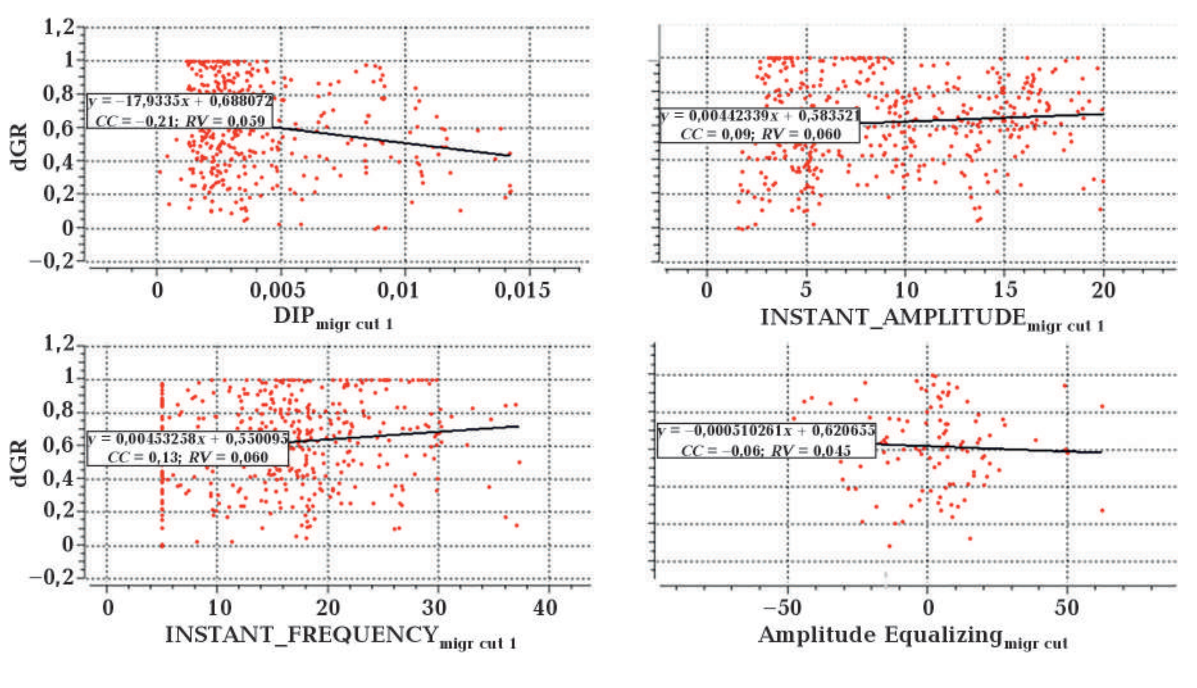


Fig. 8. Dependence of clay curve on seismic attributes.

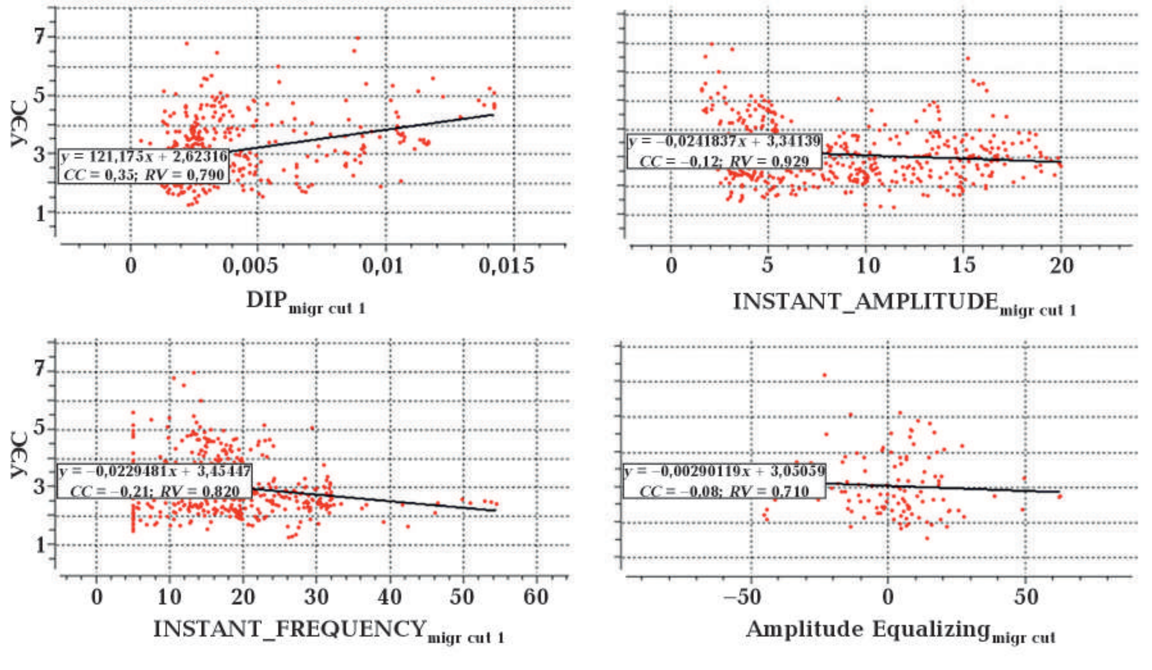


Fig. 9. Dependence of electric resistivity on seismic attributes.

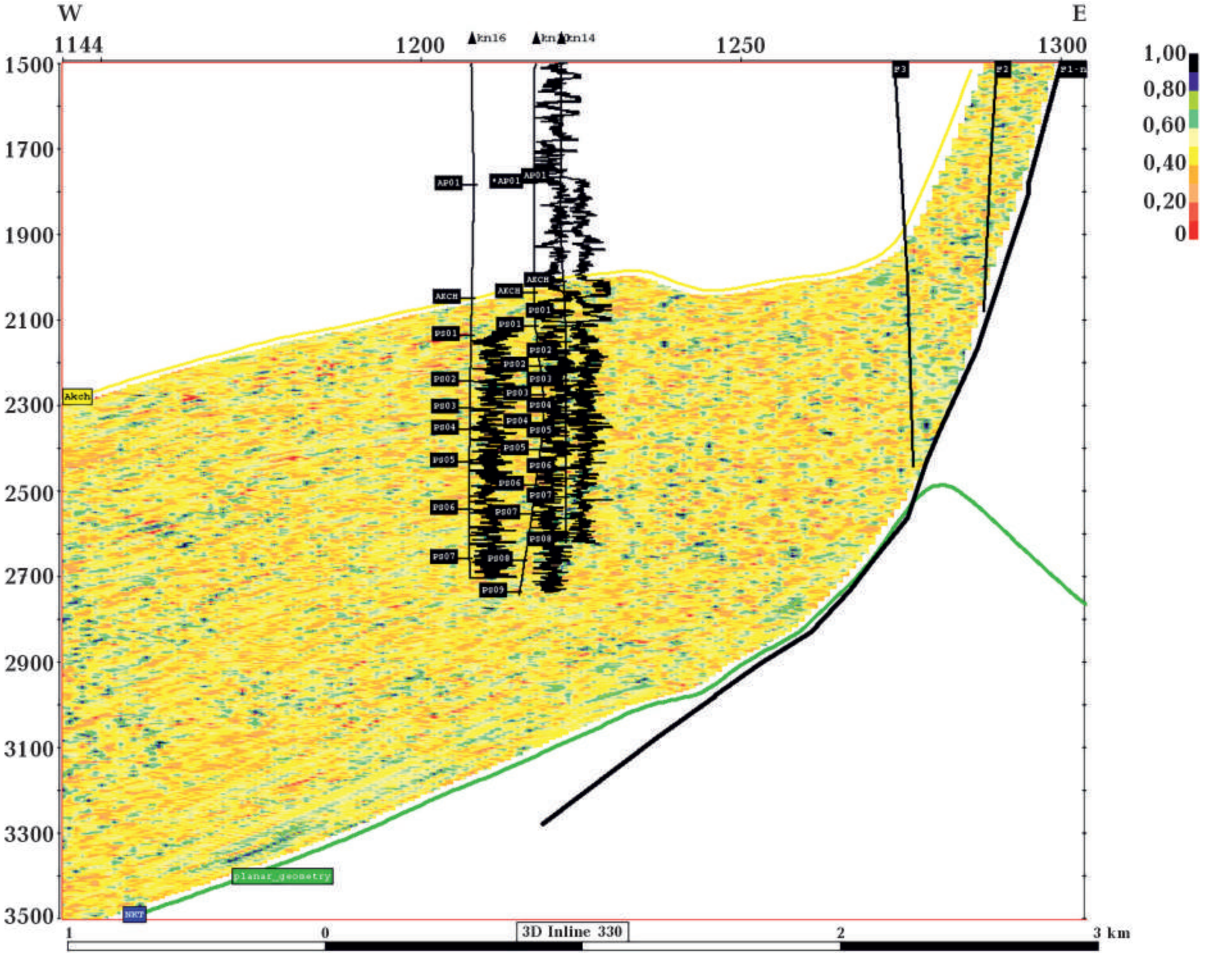


Fig. 10. Quantitative prediction of clayness cube for wells.

where due to fragmentation of these parts of the fold and complex interferential nature of observed wave pattern the dynamic range in the target interval is characterized by exceptionally low resolution, low amplitude values and by practical absence of reflections and strong interference in some places.

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Прогнозування нафтофізичних властивостей відкладів Кюровдагського родовища у результаті атрибутного аналізу 3D сейсмічних даних

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У статті наведено прогнозування нафтофізичних властивостей продуктивних родовищ Кюровдагського родовища за атрибутним аналізом сейсмічних даних з метою визначення напрямів додаткової розвідки. Розглянуто географічне положення досліджуваної місцевості, її геолого-геофізичне вивчення, тектоніку, показано важливість 3D сейсмічної розвідки при уточненні будови Кюровдагської структури. Описано літологічно-стратиграфічну будову ділянки, схарактеризовано поклади продуктивного шару. Площа досліджень знаходиться у межах Нижньокуринської западини — складової частини великої тектонічної одиниці. Тектонічна зона південно-східного Ширвану включає чотири антиклінальні пояси: Пірсагат-Хамамдаг; Харамі—Мішоводаг—Кальмас—Хайдирлі—Агаєвір-Бяндован; Курсанга; Падар—Кюровдаг—Карабагли—Бабазанан—Дуздаг-Нефтехала. У північно-західній частині Ширвану між складками Падара і Карабаглі розміщується Кюровдагська брахіантикліналь. На півночі вона межує з підняттям Малий Харамі, на північному сході — з Мішоводською складкою, на південному сході — з антикліналлю Курсанга, а на південному заході — з великою Сальянською депресією. Детальний опис структури складки Кюровдаг наведено за даними сейсмічної розвідки 3D. Зазначено, що результати інтерпретації матеріалів 3D-знімання дали можливість істотно уточнити раніше прийняту схему розломів цієї структури. Наведено короткий опис вмісту нафти і газу на Кюровдагському родовищі. На досліджуваній площі поширені нафто- і газоносні відклади абшеронського ярусу плейстоцену, а також акчагильського ярусу і продуктивної товщі пліоцену, які літологічно репрезентовані піщано-глинистими породами з різним ступенем вапняності. Структура кожного з цих горизонтів досить складна і за латераллю мінлива. Найскладнішим з них є середньоабшеронський під'ярус, у межах якого встановлено 11 нафтоносних шарів. Сформульовано мету дослідження та методологію проведеної науково-дослідної роботи. Для прогнозування у межах зазначеної площі з використанням наявних матеріалів геофізичного дослідження свердловин (ГДС) були підготовлені нормалізовані криві відносного параметра, гамма-каротажу — dGR і опору. Аналіз залежності сейсмічних атрибутів від петрофізичних параметрів у цільовому інтервалі показав низький інформаційний вміст методу ПС і гамма-каротажу за площею, а також виявлено хороший зв'язок кривої опору з миттєвими амплітудами, частотами і кутами нахилу. Отримано куби глинистості. Багатовимірний фільтр з колекторними відсічками було використано для ізоляції продуктивного класу за комплексом цих двох методів — отримано куб розрахункового розподілу вказаного класу. В результаті досліджень зроблено висновок, що через складність і інтерференційний характер спостережуваного хвильового малюнка в деяких частинах структури Кюровдага не вдалося надійно перетворити атрибути сейсмічного хвильового поля у петрофізичні параметри.

Ключові слова: вміст нафти і газу, постпліоценові і пліоценові родовища, структура, нафтогазове родовище, 3D сейсмічна розвідка, світло відбивні горизонти, сейсмічні атрибути.