DETERMINING OF INTEGRAL PERMEABILITY OF UNDERMINED COAL ROCK MASS IN CLOSED MINES

[1]Prykhodchenko O.V., [1]Prykhodchenko S.Yu., [2]Tokar L.O.

[1]*Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine, [2]National Technical University Dnipro Polytechnic*

ВИЗНАЧЕННЯ ІНТЕГРАЛЬНОЇ ПРОНИКНОСТІ ПІДРОБЛЕНОГО ВУГЛЕПОРОДНОГО МАСИВУ ЗАКРИТИХ ШАХТ

[1]Приходченко О.В., [1]Приходченко С.Ю., [2]Токар Л.О.

[1]*Інститут геотехнічної механіки ім. М.С. Полякова НАН України, [2]Національний технічний університет «Дніпровська політехніка»*

ОПРЕДЕЛЕНИЕ ИНТЕГРАЛЬНОЙ ПРОНИЦАЕМОСТИ ПОДРАБОТАННОГО УГЛЕПОРОДНОГО МАССИВА ЗАКРЫТЫХ ШАХТ

[1]Приходченко А.В., [1]Приходченко С.Ю., [2]Токарь Л.А.

[1]*Институт геотехнической механики им. Н.С. Полякова НАН Украины, [2]Национальный технический университет «Днепровская политехника»*

Annotation. Effect of mining on pressure variation in coal rock mass has been analyzed. Determination of pressure variation within rock mass is an important problem since it will help to identify the residual methane reserves, the rock mass permeability, and parameters of degassing holes. The studies were carried out in the context of series of the holes in the field of Public Joint Stock Company «Mine named after O.F. Zasiadka», which redrilled mined-out seam n_1. In the context of each hole, the height of undermining effect was calculated, the dependence of pressure decline relative to a mine working was determined as well as integral permeability; moreover, the hydrogeological data were applied to identify the coefficient of static pressure decline. Methods to determine the integral permeability as well as fluid pressure variations within undermined coal rock mass have been proposed. The method, intended to measure fluid pressure, is correct for a case when pressure in the neighbourhood of the mined-out seam floor is 0.1 MPa, i.e. during certain period after the coal seam development. With the course of time, migration of fluids takes place towards rock mining within the undermined coal rock mass; in this context, pressure is balanced in the rock mass disturbed by fissures. The pressure variation within the undermined rock mass can also be determined using a method based upon hydrostatic pressure and static pressure determination according to the water levels in a hole if hydrogeological observations during hole drilling involved registration of both static water levels and depths at which measurements were carried out. According to the methods, dependences of pressure variation as well as integral permeability of the undermined coal rock mass were determined in the context of series of holes drilled on the undermined coal rock mass. A technique to identify zones of "fast" gas and "slow" gas within undermined formation has been considered. Hence, the listed methods help to forecast integral permeability as well as fluid pressure variations within the undermined coal rock mass making it possible to identify zones of "fast" and "slow" gas, and determine parameters to evaluate and extract methane reserves from the undermined coal rock mass.

Keywords: methane, pressure, permeability, coal rock mass.

Introduction. It has been determined recently that while extracting methane from coal mines, maximum gas amount can be captured by means of holes from coal rock mass undermined in the process of coal mining. Formation of technogenic methane accumulations results from subsidence of roof rocks, their softening as well as free gas and liberated gas emission to mine workings, and fractured zones of the coal rock mass [1, 2]. Gas pressure declines and permeability of coal rock mass varies due to the undermined formation softening, and partial methane emission [3]. Determination of pressure variation within rock mass is an important problem [4] since it will help

identify residual methane reserves, the rock mass permeability, and parameters of degassing holes.

Methods. Direct measures by means of formation tests while hole drilling is the most accurate technique to determine pressure within undermined coal rock mass; however, they are rare event for practice.

Paper [5] proposes a method to measure gas pressure in the undermined coal rock formation. After subsidence of roof rocks, certain share of methane drains into mine workings from the undermined formation; certain share remains in the rock mass which results in pressure variation. As it has been demonstrated in paper [6], there is a tendency for the increase in pressure of fluids, saturating sandstones, up the open-cut from a coal seam mined previously. In the neighbourhood of the undermining zone, gas pressure should be 80-90 % of hydrostatical one; while approaching mined-out coal seam, pressure declines down to atmospheric one at the boundary of a mine working. Linear dependence of fluid pressure variation within the undermined rock mass $P_{u.r.m.}$ (Pa) has been proposed; the dependence is expressed as the function:

$$P_{u.r.m.} = f(h),$$

where h is distance along the normal from the mined-out coal seam floor up to the sandstone where pressure is measured.

Pressure variation within the softened coal rock mass above the mined-out seam is shown using the dependence:

$$P_{u.r.m.} = a \cdot h \cdot \gamma_{\textit{в}} \cdot g,$$

where γ_v is water density being equal to 1000 kg/m^3; g is gravity factor, m/s^2; a is coefficient involving effect of undermining zone height.

a coefficient is identified for each hole; it depends upon undermined coal rock mass height as well as upon fluid pressure within a zone where the formation starts its softening:

$$a = \frac{0.85 \cdot H_n}{h_m},$$

where H_n is depth of upper boundary of a zone of undermining effect (from the surface), m; h_m is height of undermining zone effect (from the undermined seam), m.

Hence, when the method is used to determine dependence of pressure variation for each hole, it becomes possible to calculate values of integral permeability for the undermined coal rock mass.

The method, intended to measure fluid pressure, is correct for a case when pressure in the neighbourhood of the mined-out seam floor is 0.1 MPa, i.e. during certain period after the coal seam development. With the course of time, migration of fluids takes place towards rock mining within the undermined coal rock mass; in this context, pressure is balanced in the rock mass disturbed by fissures.

Pressure variation within the undermined rock mass can also be determined using a method based upon hydrostatic pressure and static pressure determination according

to water levels in a hole [5] if hydrogeological observations during hole drilling involved registration of both static water levels and depths at which measurements were carried out.

Static pressure in a hole (according to water level $P_{st.p.}$ (Pa) was determined on the formula:

$$P_{st.p.} = (H - h_{st.l.}) \cdot \gamma_{в} \cdot g,$$

where $h_{st.l.}$ is static water level in a hole, m; H is seam depth, m.

Hydrostatic pressure $P_{h.p.}$ (Pa) was measured in a hole for the depths where static levels were determined. Following formula was applied:

$$P_{h.p.} = H \cdot \gamma_{в} \cdot g.$$

Further coefficient of static pressure decline in a hole ($k_{s.p.d.}$) was determined. The coefficient demonstrates relative pressure deviation from hydrostatic pressure using the formula:

$$k_{s.p.d.} = \frac{P_{st.p.}}{P_{h.p.}}.$$

According to the methods, dependences of pressure variation as well as integral permeability of the undermined coal rock mass were determined in the context of series of holes drilled on the undermined coal rock mass.

Results and discussion. The studies were carried out in the context of series of holes in the field of O.F. Zasiadka mine which redrilled mined-out seam n_1.

In the context of each hole, height of undermining effect was calculated, dependence of pressure decline relative to a mine working was determined as well as integral permeability; moreover, hydrogeological data were applied to identify coefficient of static pressure decline.

Hole 3431. Mineable thickness of the undermined coal seam is 1.5 m. Volatile-matter content V^{daf} is 40.6 %. Height of undermining rock effect $h_{m.n.}$ is 97 m. Dependence of gas pressure variation within the undermined rock mass in the neighbourhood of a hole is expressed as follows:

$$P_{u.r.m} = 0.25 \cdot h \cdot \gamma_v \cdot g.$$

The generated equation makes it possible to calculate gas pressure within the undermined formation and, taking into consideration previously carried out studies [7], to observe changes in the rock mass permeability. As a graph demonstrates (Fig. 1, a), integral permeability increases dynamically from 310 m mark to 330 m mark being almost $100 \cdot 10^{-15}$ m^2.

According to values of static pressure decline coefficient, a graph was plotted (Fig. 1, b). At 250 m mark, $k_{s.p.d.} = 0.97$; its values lower while the mined-out coal seam approaching. In such a way, within analytical boundary of undermining zone

beginning, $k_{s.p.d.} = 0.94$; it becomes $0.8 – 0.81$ at 342 m remaining invariable through to the mined-out seam.
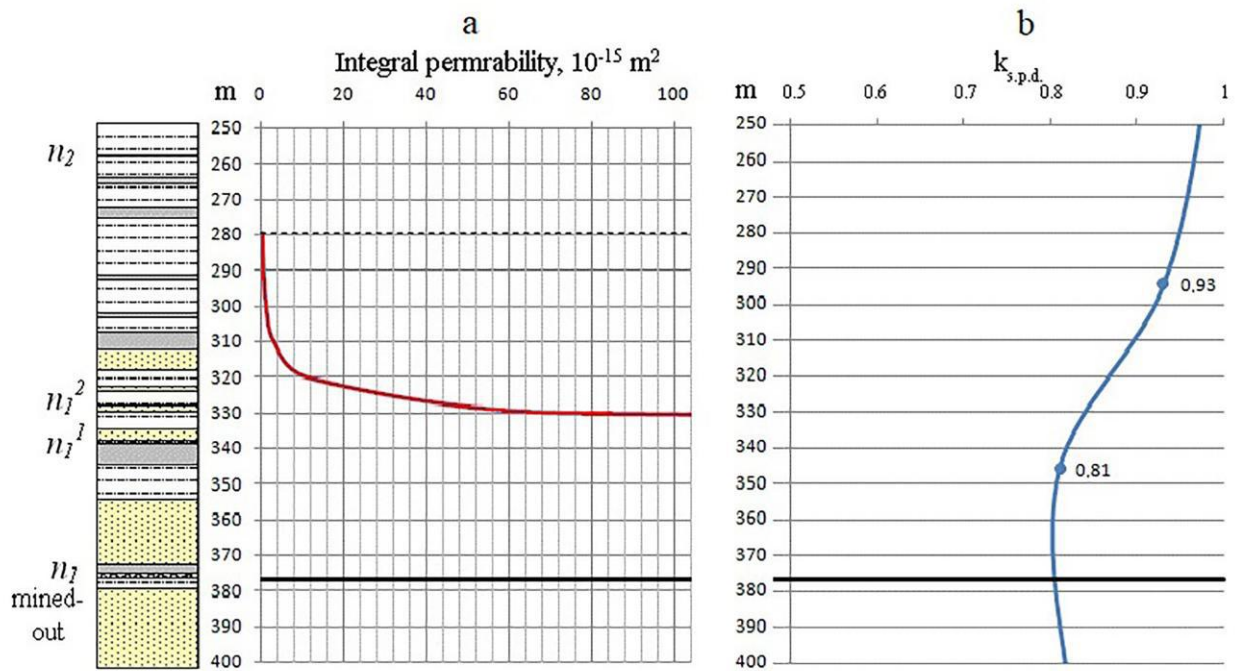

Figure 1 - Integral permeability (a) and static pressure decline coefficient (b) variation depending upon the depth of sandstones of the disturbed coal rock mass above the mined-out seam n_1 in the neighborhood of hole 3431 drilled in the field of O.F. Zasiadka mine

Thus, comparison of the graphs of changes in integral permeability and a graph of static pressure decline has explained that the values decrease in terms of the same intervals. That helps conclude that the both methods have identified two zones in the undermined coal rock mass: "slow gas" zone (280 to 320 m), corresponding to 3rd and 4th zones according to M.A. Iofis [8], and "fast gas" zone (320 to 378 m) corresponding to 1st and 2nd zones. In compliance with paper [9], methane from "fast gas" zone gets to operating longwall sometimes twice and more times increasing gas content; and methane from "slow" gas zone drains slowly to the mined-out area increasing background concentration.

Hole 3844 (Fig. 2). Mineable thickness of the undermined coal seam is 1.0 m. Volatile-matter content V^{daf} is 40.6 %. Height of undermining rock effect $h_{m.n.}$ is 65 m. Dependence of gas pressure variation within the undermined rock mass in the neighbourhood of a hole is expressed as follows:

$$P_{u.r.m} = 0.28 \cdot h \cdot \gamma_v \cdot g.$$

Integral permeability of rock mass (Fig.2) in the neighbourhood of the hole starts increasing vigorously from 240 m to 250 m becoming $250 \cdot 10^{-15}$ m^2. Hence, after 240 m, the undermined coal rock mass turns out to be more disturbed due to the increasing fissure number. The theoretical calculations have been substantiated by means of static pressure decline calculations. As graph in Fig. 2, b shows, $k_{s.p.d.}$ values do not vary down to 248 m depth being 0.95-0.96; then, they decrease rapidly

and $k_{s.p.d.}$ is 0.23 at 259 m mark. Thus, "slow" gas zone (i.e. 212-248 m), and "fast" gas zone (i.e. 248-277 m) can also be identified in the neighborhood of the hole.
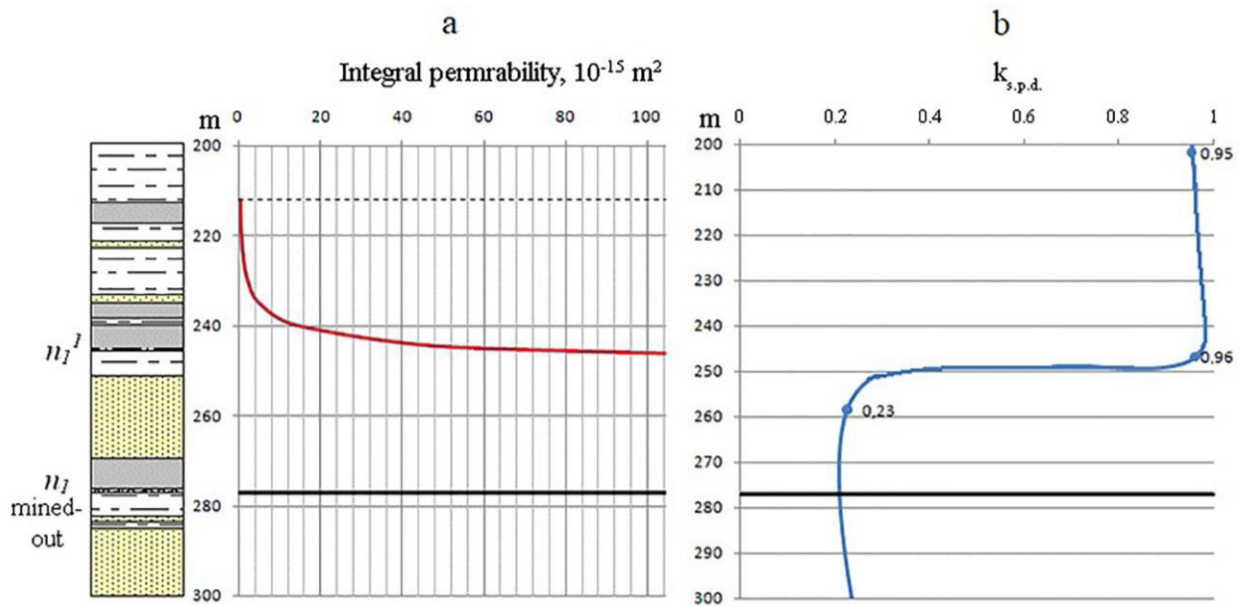

Figure 2 - Integral permeability variation (a) and static pressure decline coefficient (b) variation depending upon the depth of sandstones of the disturbed coal rock mass above the mined-out seam n_1 in the neighborhood of hole 3844 drilled in the field of *O.F. Zasiadka* mine

Hole D-5 (Fig. 3). Mineable thickness of the undermined coal seam is 1.5 m. Volatile-matter content V^{daf} is 40.6 %. Height of undermining rock effect $h_{m.n.}$ is 97 m. Dependence of gas pressure variation within the undermined rock mass in the neighborhood of a hole is expressed as follows:

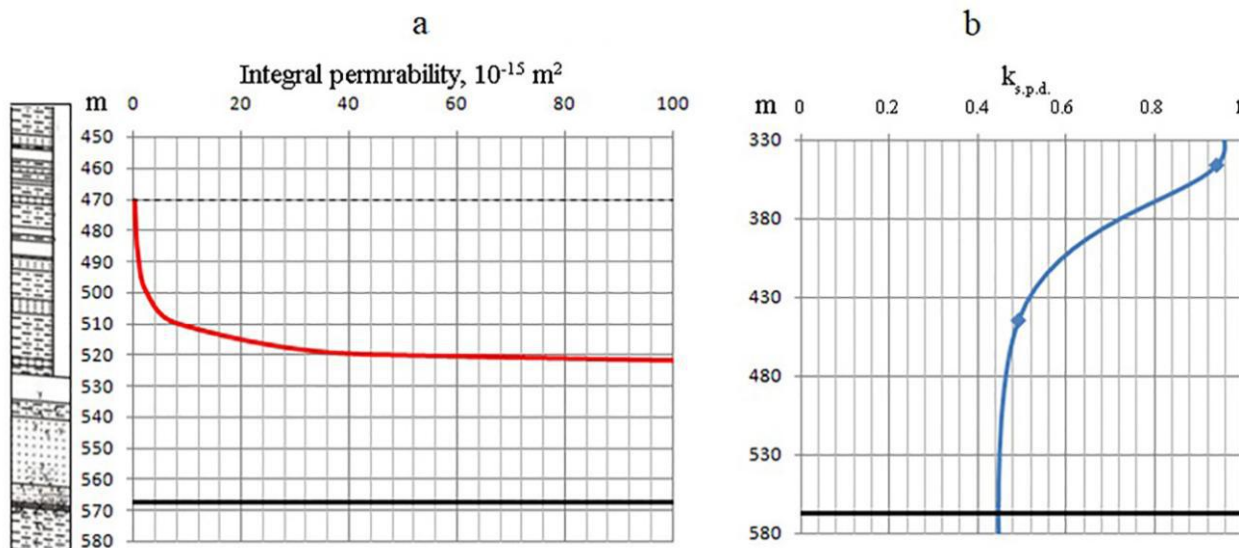$$P_{u.r.m} = 0.25 \cdot h \cdot \gamma_v \cdot g.$$

Figure 3 - Integral permeability variation (a) and static pressure decline coefficient (b) variation depending upon the depth of sandstones of the disturbed coal rock mass above the mined-out seam n_1 in the neighborhood of hole 3431 drilled within a site of *Kalmiusski Rudnik* of *O.F. Zasiadka* mine field

Analytical values of integral permeability within the undermined formation in the neighborhood of D-5 hole have shown that the fastest permeability increase starts from 520 m depth (Fig. 3, a). The calculations are supported by the fact that while hole drilling, 100 % lost returns began starting from 530 m depth. However, comparison of permeability variation graph and statistic level decrease graph (Fig. 3, b) has shown that the zones do not coincide to compare with the two previous holes. In the context of the hole, $k_{s.p.d.}$ B deviation from values, close to 0.9, starts from 350 m mark; decrease in the coefficient values stop approaching 0.45-0.5. Such a variation can be explained by the differences between analytical height of undermining effect zone, and natural one.

Conclusions. Hence, the listed methods help forecast integral permeability as well as fluid pressure variations within the undermined coal rock mass making it possible to identify zones of "fast" and "slow" gas zones, and determine parameters to evaluate and extract methane reserves from the undermined coal rock mass.

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About the authors

Prykhodchenko Oleksii Vasylovych, Candidate of Technical Sciences (Ph.D), Researcher in the Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine (IGTM, NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Prykhodchenko Svitlana Yuriivna, Candidate of Technical Sciences (Ph.D), Senior Researcher, Senior Researcher in the Department of Geology of Coal Beds at Great Depths, Institute of Geotechnical Mechanics named by N. Poliakov of National Academy of Sciences of Ukraine (IGTM, NAS of Ukraine), Dnipro, Ukraine, gvrvg@meta.ua

Tokar Larysa Oleksandrivna, Senior Lecturer in Department of Foreign Languages, *National Technical University Dnipro Polytechnic* (NTU "DP"), Dnipro, Ukraine, lrstokar@gmail.com

Про авторів

Приходченко Олексій Васильович, кандидат геологічних наук, науковий співробітник відділу геології вугільних родовищ великих глибин, Інститут геотехнічної механіки ім. М.С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна, gvrvg@meta.ua

Приходченко Світлана Юріївна, кандидат геологічних наук, старший науковий співробітник, старший науковий співробітник відділу геології вугільних родовищ великих глибин, Інститут геотехнічної механіки ім. М.С. Полякова Національної академії наук України (ІГТМ НАН України), Дніпро, Україна, gvrvg@meta.ua

Токар Лариса Олександрівна, стрший викладач кафедри іноземних мов, Національний технічний університет «Дніпровська політехніка» МОН України (НТУ «ДП» МОН України), Дніпро, Україна, lrstokar@gmail.com

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Анотація. Досліджено вплив гірничих робіт на зміну тиску у вуглепородному масиві. Визначення зміни тиску в масиві є важливим завданням, оскільки дозволить визначити залишкові ресурси метану, проникність масиву і параметри дегазаційних свердловин. Дані дослідження виконувалися по ряду свердловин на полі шахти ім. О.Ф. Засядька, що перебурили відпрацьований пласт n_1. По кожній свердловині розраховувалася висота впливу підробки, визначалася залежність зменшення тиску щодо гірничої виробки і визначалася інтегральна проникність, а за гідрогеологічними даними визначався коефіцієнт пониження статичного тиску. Запропоновано методи визначення інтегральної проникності і зміни тиску флюїдів в підробленому вуглепородному масиві. Метод, призначений для вимірювання тиску флюїду, є правильним у випадку, коли тиск рідини в околиці відпрацьованого шару пласта становить 0,1 МПа, тобто протягом певного періоду після відробки вугільного пласта. З плином часу відбувається міграція флюїдів у бік видобутку гірських порід у межах підробленого вуглепородного масиву; у цьому випадку тиск врівноважується в гірській масі, порушеній тріщинами. Встановити зміну тиску в підробленому масиві можна по методу, заснованому на визначенні гідростатичного і статичного тиску за рівнем води в свердловині, якщо під час гідрогеологічних спостережень при бурінні свердловини відмічалися статичні рівні води, а також фіксувалися відмітки глибин, на яких проводилися виміри. По цих двох методах по ряду свердловин, що пробурені на підроблений вуглепородний масив були визначені залежності зміни тиску і інтегральна проникність підробленого вуглепородного масиву. Розглянутий спосіб виділення в підробленій товщі зон «швидкого» і «повільного» газу. Таким чином, застосувавши вказані вище методи можна прогнозувати інтегральну проникність і зміни тиску флюїдів у підробленому вуглепородному масиві, що дозволить виділяти в товщі зони «швидкого» і «повільного» газу, визначати параметри оцінки і вилучення запасів метану в підробленій вуглепородній товщі.

Ключові слова: метан, тиск, проникність, вуглепородний масив.

Аннотация. Исследовано влияние горных работ на изменение давления в углепородном массиве. Определение изменения давления в массиве является важной задачей, поскольку позволит определить остаточные ресурсы метана, проницаемость массива и параметры дегазационных скважин. Данные исследования выполнялись по ряду скважин на поле шахты им. А.Ф. Засядько, перебуривших отработанный пласт n_1. По каждой скважине рассчитывалась высота влияния подработки, определялась зависимость понижения давления относительно горной выработки и определялась интегральная проницаемость, а по гидрогеологическим данным определялся коэффициент понижения статического давления. Предложены методы определения интегральной проницаемости и изменения давлений флюидов в подработанном углепородном массиве. Метод, предназначенный для измерения давления флюида, является правильным в случае, когда давление жидкости в окрестности отработанного слоя пласта составляет 0,1 МПа, то есть в течение определенного периода после отработки угольного пласта. С течением времени происходит миграция флюидов в сторону добычи горных пород в пределах подработанного углепородного массива; в этом случае давление уравновешивается в горном массиве, нарушенном трещинами. Установить изменение давления в подработанном массиве можно по методу, основанному на определении гидростатического и статического давлений по уровням воды в скважине, если во время гидрогеологических наблюдений при бурении скважины отмечались статические уровни воды, а также фиксировались отметки глубин, на которых проводились замеры.

По этим двум методам по ряду скважин, пробуренным на подработанный углепородный массив были определены зависимости изменения давлений и интегральная проницаемость подработанного углепородного массива. Рассмотрен способ выделения в подработанной толще зон «быстрого» и «медленного» газа. Таким образом, применив указанные выше методы можно прогнозировать интегральную проницаемость и изменения давлений флюидов в подработанном углепородном массиве, что позволит выделять в толще зоны «быстрого» и «медленного» газа, определять параметры оценки и извлечения запасов метана в подработанной углепородной толще.