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# THE BURIAL HISTORY OF PERMIAN SEDIMENTS IN THE CENTRAL PART OF THE DNIPRO-DONETS BASIN

# ІСТОРІЯ ЗАНУРЕННЯ ТА ТЕРМІЧНОГО РОЗВИТКУ ПЕРМСЬКИХ ВІДКЛАДІВ ЦЕНТРАЛЬНОЇ ЧАСТИНИ ДНІПРОВСЬКО-ДОНЕЦЬКОЇ ЗАПАДИНИ

**Ivanna O. Streltsova[1], Ivan V. Virshylo[2]**
**І.О. Стрельцова, І.В. Віршило**

[1]Institute of Geological Sciences, NAS of Ukraine, 55-b O. Honchara St., Kyiv, Ukraine, 01601 (ivanna.tit@gmail.com)
[2]Institute of Geology of Taras Shevchenko National University of Kyiv (ivirshylo@gmail.com)

The present paper deals with determination of the Permian paleodepositional environment in the central part of the Dnipro -Donets basin by simulating the burial history model on the basis of lithological, tectonic and paleogeographic data. The authors used the geological section of the wells Birykivska-653 and Cherepakivska-647 for 1D burial history models. Selected wells characterize various structural and tectonic conditions. Cherepakovskaya is semi-anticline and Biryukovsky is submerged block graben. Also, there are certain differences in the section of Permian sediments. The boundary conditions of the simulation were restored by interpreting the geological development history of the territory. The sea-level of the basin were interpreted at different times according to the lithological composition.

Paleodepositional environment in the early Permian are modeled as cyclic changes of paleodepths. The accumulation of a thick salt and sulfates layer is considered as evaporite origin. It is assumed that in the late Carboniferous and Early Peremian times this sedimentation basin was semi-isolated or isolated with a stagnant regime.

Late Permian time is characterized by continental conditions, which caused significant erosion and influenced the «heating» of this territory. Continental conditions have changed to the coastal one in the Triassic. The section ends with shelf conditions in Cretaceous and Paleogene.

In accordance to the burial history models, the moments of the largest heating of the basin is on the border of the upper Permian - Triassic, which coincide with the beginning of the hydrocarbon generation. It has been determined that the source rocks within these structures generated from 0.650 to 12 kilotons of hydrocarbons. Models of the burial history suggest a significant subsidence in this area during the late Cretaceous (up to 5 km in the well Birykivska-653). The obtained graphs of thermal conductivity and changes in the vitrinite reflections indicate a weak maturity of coal-bearing source rocks

*Keywords:* evaporites, paleodepositional environment, burial history, Dnipro-Donets Basin

Робота спрямована на уточнення умов осадконакопичення пермських відкладів у межах центральної частини Дніпровсько-Донецької западини шляхом моделювання історії занурення осадового басейну на основі літологічних, тектонічних та палеогеографічних даних. Автори використали геологічний розріз свердловин Бірюківська-653 та Черепаківська-647 для побудови 1D моделей історії занурення та термічного розвитку. Обрані свердловини характеризують різні структурно-тектонічні обстановки - Черепаківську напівантикліналь та Бірюківський занурений блок-грабен та певними відмінностями у розрізі пермських відкладів. Граничні умови моделювання було відновлено шляхом інтерпретації історії геологічного розвитку території. За літологічним складом було інтерпретовано палеоглибини басейну в різний час.

Умови осадконакопичення в ранній пермі змодельовані як циклічне коливання палеоглибин, при цьому накопичення потужної товщі солі та сульфатів розглядається з точки зору евапоритового походження. Припускається, що у пізньокам'яновугільний та ранньопермський час даний басейн осадконакопичення був напівізольованим або ізольованим з застійним режимом.

Пізньопермський час характеризується континентальними умовами, що спричинило значну ерозію і вплинуло на «прогрів» даної території. Континентальні умови змінились на прибережні у тріасі. Розріз закінчується шельфовими умовами у крейді та палеогені.

Відповідно до моделей термічного розвитку, виділено моменти найбільшого прогрівання басейну на границі верхня пермь – тріас, які співпадають з початком генерації вуглеводнів. Визначено, що материнські породи в межах даних структур генерували від 0,650 до 12 кілотон вуглеводнів. Моделі історії занурення припускають значне опускання на цій території протягом пізньої крейди (до 5 км у свердловині Бірюківська-653). Отримані графіки теплопровідності та змін відбиваючої здатності вітрініту вказують на слабку зрілість кам'яновугільних материнських порід ($R_0$ = 0.7%) в досліджених свердловинах, що може бути основним фактором неуспішності пробурених свердловин.

*Ключові слова:* евапорити, умови осадконакопичення, історія занурення, Дніпровсько-Донецька западина

## INTRODUCTION

Sedimentary basins studying require distinguishing not only dimensional distribution, but also the history of their transformation over geological time. Basin modeling is a crucial step in the regional and local hydrocarbon exploration. 1D simulation of the burial and thermal history includes all petroleum system elements. That is help to investigate sedimentary basins in detail. Today, petroleum geology has developed tools for evaluating the formation of a single layer in the context of the sedimentary basin developing. Investigation of the single strata role in the sedimentary basin formation requires careful study of accumulation and erosion processes. Moreover, erosion properties and the amount of eroded material give an opportunity to determine paleodepositional environment in the particular basin.

Basin modeling allows us to evaluate the prospects with a minimum amount of data. Generally the 1D model is based on the layers well-tops and ages (which allowing creation of burial history model) and lithology, which defines paleodepositional environment, petrophysical properties, and petroleum system role of each layer as well as boundary conditions for the basin

PREVIOUS STUDIES

Geology and geochemistry in sedimentary basins have been established sciences for centuries. Important textbooks, such as (Tissot, Welte, 1984), (Hunt, 1996), (Gluyas, Swarbrick, 2004), (Peters et al., 2005), (Allen and Allen, 2005), summarize the knowledge especially related to petroleum geosciences. The first basin modeling computer programs were developed around 1980 (Yukler et al., 1979). The main concept encompassed multi–1D heat flow simulation and subsequent geochemical models to construct petroleum generation and expulsion maps for the evaluation of source rock maturity. One of the key tasks was to calculate and calibrate the temperature history during the evolution of a geological basin. Heat flow calculation is one of the best-investigated problems in applied engineering. A formulation and solution of the corresponding differential equations can be easily achieved. Once the paleo– temperatures were known, equations for chemical kinetics could be used to evaluate the cracking rates of petroleum generation. Textbook (Nikishin et al., 1999) is equally important to understand modeling procedure. It describes in detail the basic principles of modeling and analysis of the sedimentary basins development. Another work (Galushkin, 2007), shows the role of temperature, heat flow and tectonic processes in the simulation. The burial history model for the Dnipro-Donets Basin (DDB) was shown in (Gonchar, 2008) abstract. This work clearly describes the necessity of the most accurate paleo water depths data for simulation.

MAIN ISSUES

The Dnipro-Donets Basin geological history is studied for a long time, however a lot of white spots left. An example of this is the Permian - Triassic and Permian – Carboniferous boundaries. The Permian – Triassic border shows significant erosion that caused some confusion in stratigraphy of this region. From another stand point there is Permian – Carboniferous border. It is characterized by the similar lithology in both cases. Mainly, these strata consist of alteration of shales and sandstones. Besides, Permian sediments in the central part of the Dnipro-Donets Basin are petroleum reservoir. That is why studying their lithology and distribution is a fundamentally important issue. The lithological variations in Permian sediments form stratigraphic traps. They are perspective for hydrocarbon production. For instance, the gas and condensate extracted from stratigraphic trap on Kotlyarivka gas and condensate field.

GOALS OF THIS STUDY

The purpose of this work was to examinate the thermal history of the Permian sediments in the central part of the Dnipro-Donets Basin. To achieve this purpose we have analyzed.the lithological section and built the 1D burial and thermal history models for two wells – Birykivska-653 and Cherapakivska-647. The data was taken from report (Tkachenko, 1990). Gas and condensate fields, such as Western Khrestyshche, Chervonoyarske, Western Starovirivka, Vedmedivka, Kegychivka, Shebelynka are widespread at this territory (Arsiriy et al., 1999). The main feature of these fields is the productive horizons in the Permian sediments. The main reservoir is Kartamysh and Mykytivka formation of the Lower Permian. This area is important for studying because of the lithological variation of the stratigraphic traps. Analysis of paleodepositonal environment and basin modeling can lead to discovering new hydrocarbon deposits.

MAIN METHODS AND APPROACHES

Basin modeling is dynamic modeling of geological processes in sedimentary basins over geological time spans. A basin model is simulated forward through geological time starting with the sedimentation of the oldest layer until the entire sequence of layers has been deposited and present day is reached (Hantschel, Kauerauf, 2009). Today, computer simulation is one of the main methods for visualizing the geologic history of the sedimentary basins. At the same time, geological models are inverse. In other words, by the given results, we have to determine the processes leading to them. Simulation is based on the very complex theory, which integrate mechanical and chemical behavior of rocks. But most of the sowtware developed for such simulation consists of powerful databases with petrophysical and petrochemical properties of rocks and «hides» the many parts of calculations from the scientist.

The main data required for computer simulation are:

- Modern geological section with well-tops of layers boundaries and selected lithology of each layer from the database, which consist of related properties;

- Interpretation of erosion and hiatus parameters (time, duration and thickness of eroded rocks)

- Absolute dating of the geological boundaries

- Basin boundary conditions such as paleo water depth, paleoclimate and paleo heat flow

The basin modeling relay on the following factors:

1. Geological section is a sequence of layers, and the history of subsidence is a sequence of geological events. To switch from one description to another it is necessary to determine boundary dates, erosion and hiatus.

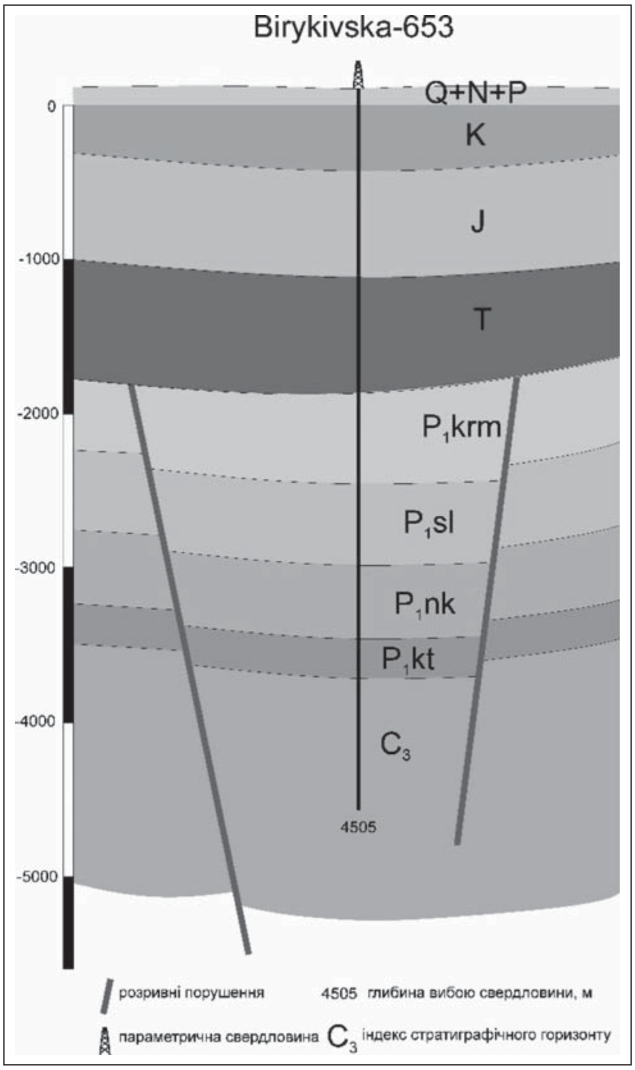


**Fig. 1.** Section of the Birykivska structure (Tkachenko, 1990).

2. The position of the upper boundary of the section in the each moments of the past establishing on the eustatic sea-level data.

3. The subsidence causes compressions of the rocks.

Basin modeling helps measure the importance of events, as well as uses the obtained data for graphical visualization and numerical modeling of geological processes (Nikishin et al, 1999). In the 1D approach, it is assumed that all heat flow vectors are directed vertically.1D solutions often provide a good estimate for temperatures since the boundary values define radial core to surface aligned paths. They are especially used for well–based calibrations of basal heat flow trends. Exceptions, which cannot be modeled with 1D approaches are local areas of extraordinarily high thermal conductivities like salt domes, which bundle heat flow vectors from adjacent areas along highly conductive avenues (Hantschel, Kauerauf, 2009).

## GEOLOGICAL SETTINGS AND INPUT DATA

In the process of studying the Permian sediments, the main task was to analyze the role of these strata in the Dnipro-Donets basin developing in the context of the petroleum system. For analysis, the central part of the Dnipro-Donets basin was selected. During the study, the main regional petroleum system elements were identified: source rocks, reservoirs, seals, which are representative for this territory. The lithological section was also analyzed and paleodepositional environment were determined. In the result of the analysis we created 1D burial history model, shown in Fig. 1 with boundary conditions of paleo water depths, SWIT (sediment-water-interface temperature) and heat flow (Fig. 2-4). These data provide an opportunity to analyze the formation of the Dnipro-Donets basin and draw conclusions about the hydrocarbon perspectives.

*Tectono-Stratigraphic Development*. The correlation of geological events and sedimentary strata is described in (Ulmishek, 2001) abstract. The sedimentary succession of the DDB consists of four sequences that reflect major stages in tectonic development of the basin. The pre-rift platform sequence is poorly known in much of the DDB because of great burial depths, but different parts of this sequence have been penetrated by wells in the marginal zones of the basin. The sequence includes Middle Devonian–Lower Frasnian clastic and carbonate rocks. These rocks were deposited in platform conditions. Judging from the absence of

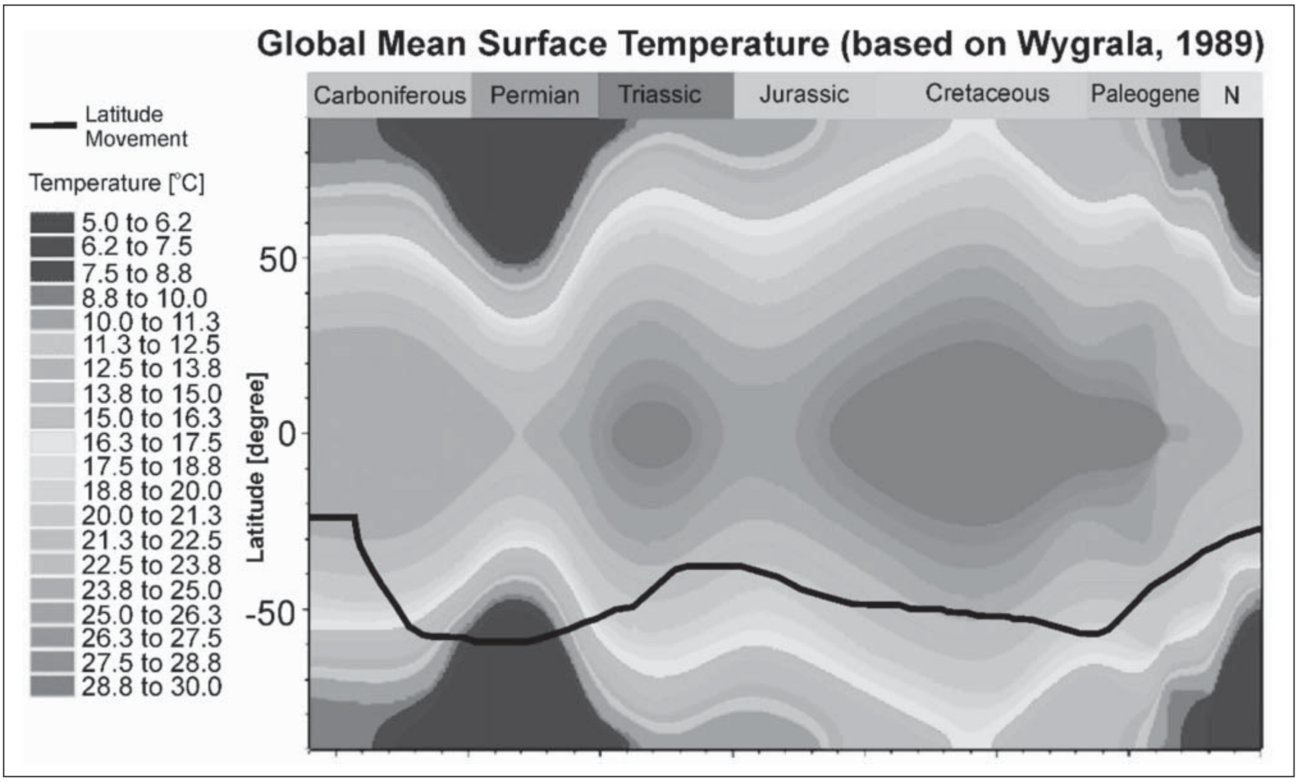


**Fig. 2.** Global Mean Surface Temperature (Wygrala, 1989).

marginal facies, the platform originally extended far beyond the present limits of the formations.

Establishing of the rift began in Middle Frasnian time and continued until the end of the Devonian period. During rift development, the Ukrainian shield was uplifted; it became a major source of terrigenous clastic material that formed fans in proximal areas along the southern rift margin. Analogy with the Pripyat basin indicates that both salt formations probably filled deep-water basins, in which organic-rich anoxic shales and carbonates were deposited prior to evaporite sedimentation. The total thickness of the synrift sequence is estimated to 4–5 km.

The post-rift sag sequence is bounded by the pre-Carboniferous and pre-Triassic unconformities (fig. 3). The tectonic regime and paleodepositional environment of deposition of this sequence differ markedly from those that existed earlier in Devonian time. Termination of rifting was accompanied by cessation of uplift of the Ukrainian shield. The shield probably was covered by a thin veneer of Carboniferous sediments. A large volume of fluvial clastic material was transported by a river from the northwest along the basin strike. The river delta prograded into the deep-water basin that existed from Devonian time. The basin probably was filled in Middle Visean time; Late Visean and younger sediments were deposited on the previously existing rift shoulders. Serpukhovian and younger Carboniferous sediments commonly consist of cyclothems of marine limestone or shale at the bottom to coal and paleosol beds at the top.

During Carboniferous the Dnipro-Donets basin subsided isostatically and under the sediment load. The rate of subsidence was high. The rocks are dominantly clastics; some limestones were deposited on the northern margin, and occasionally also in the basin center during transgressions and retreat of the delta. Increased aridity during Asselian-Sakmarian (Early Permian) time resulted in deposition of red beds, carbonates and evaporites (including salt).

The post-rift sag stage was terminated in Artinskian (Early Permian) time by compression related to Hercynian collision of continental blocks with the southern margin of the Russian craton. Shortening of the crust increased southeastward, and in the Donbas foldbelt the shortening resulted in thrusting, folding, and partial inversion of the basin. A shallow foredeep formed along the northern boundary of the foldbelt. In the DDB, the intensity of uplift and erosion increased southeastward along the basin strike and from the northern to the southern basin margins.

Sedimentation in the basin resumed in Triassic time, when continental red and variegated gypsiferous shales and some fresh-water carbonates were deposited on the truncated surface of older

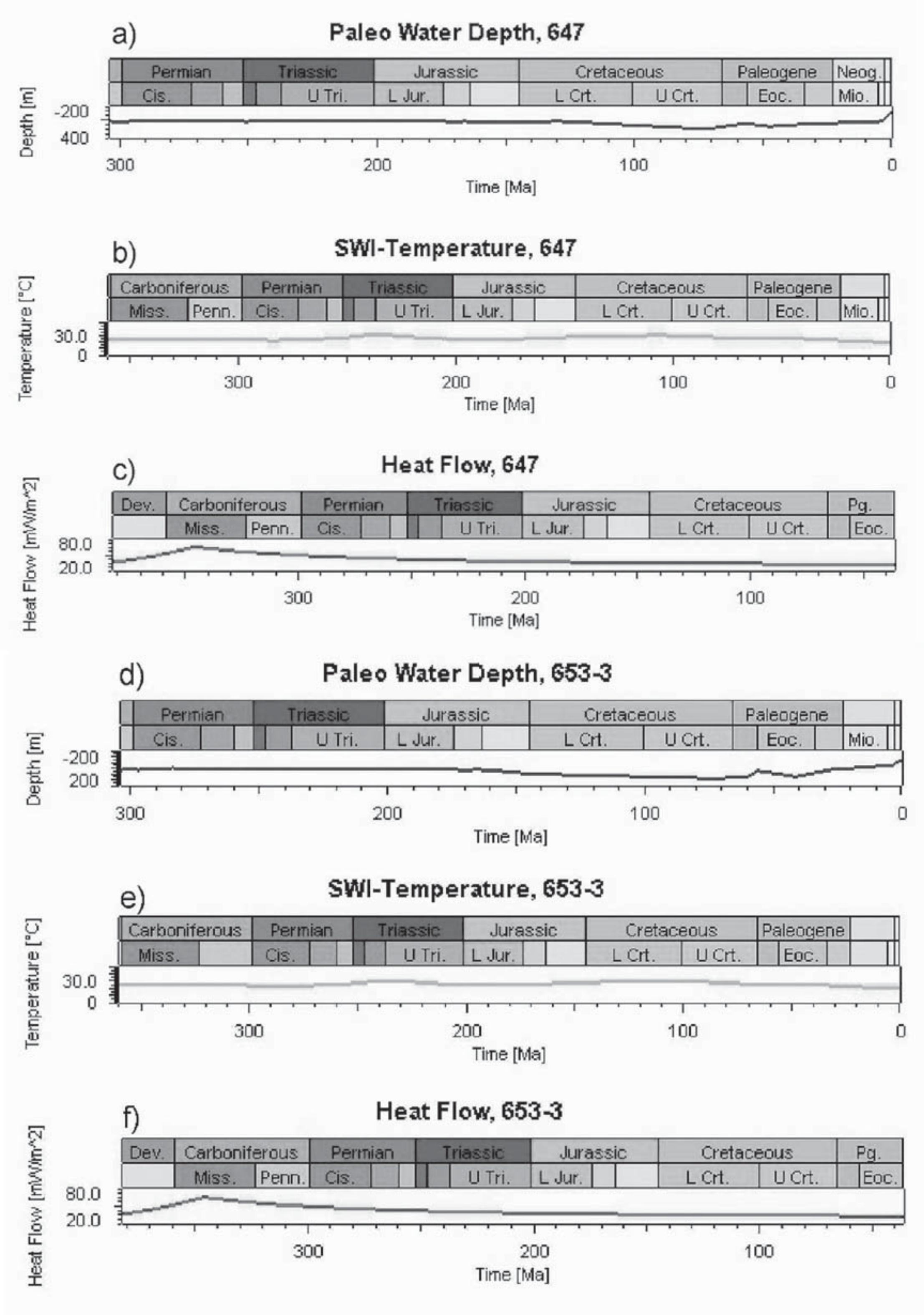


**Fig. 3.** Boundary conditions tables for
a)Paleo Water Depth in 647 well;
b) SWIT in 647 wel;
c ) Heat Flow in 647 well;
d) Paleo Water Depth in 653 well;
e) SWIT in 653 wel;
f ) Heat Flow in 653 well.

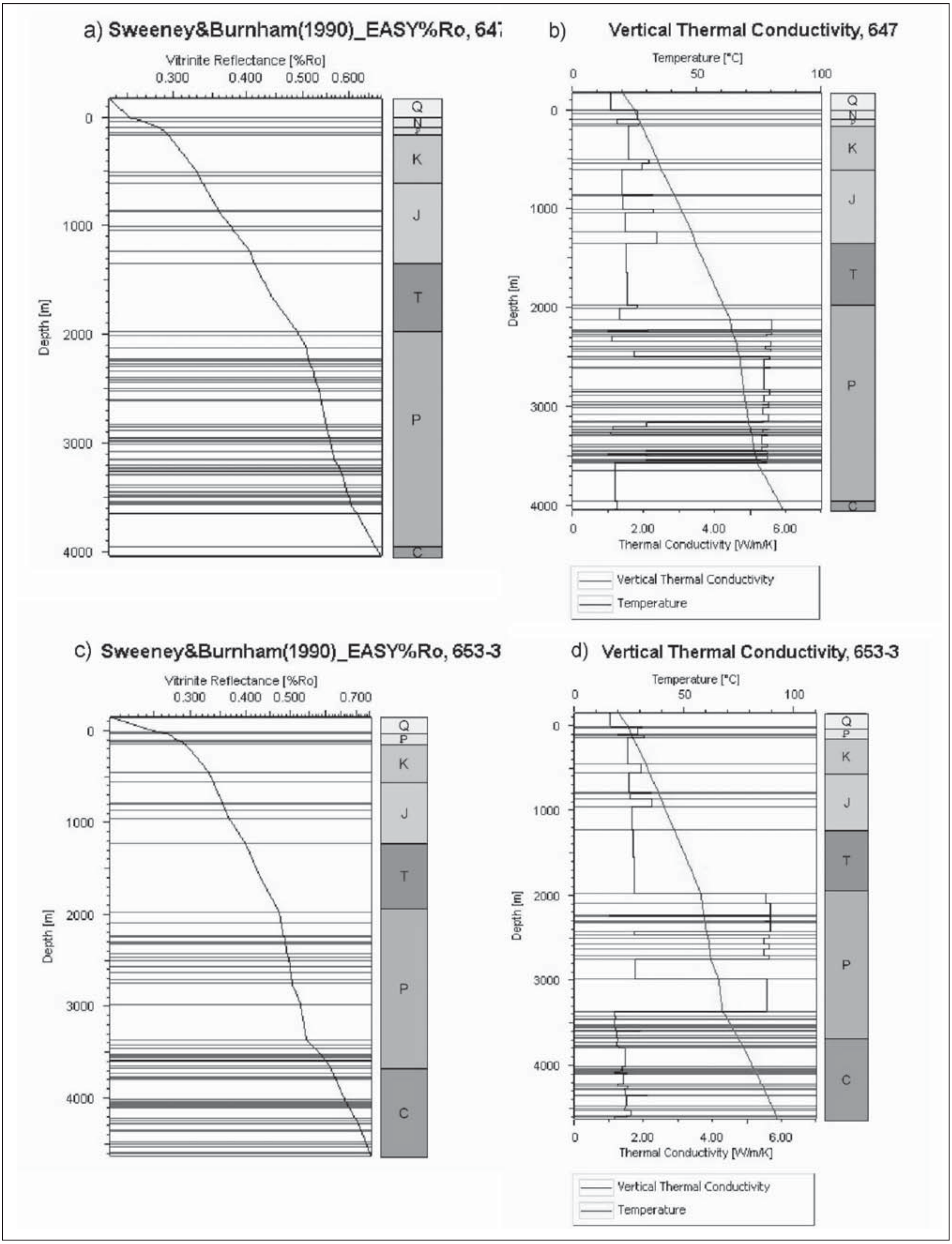


**Fig. 4.** Depth plot for
a) Vitrinite Reflectance in 647 well;
b) Vertical Thermal Conductivity in 647 well;
c) Vitrinite Reflectance in 653 well;
d) Vertical Thermal Conductivity in 653 well.

strata. Rocks of the post-rift sequence are Triassic, lower-Middle Jurassic, Cretaceous and Upper Jurassic carbonates. The sediments were deposited in a gentle platform-type depression that extended far beyond the boundaries of the Paleozoic basin.

*Tectonic structure*. The blocks penetrated by wells Birykivska-653 and Cherapakivska-647 have a different tectonic structure. The results of the Cherapakivska-647 drilling confirm anticline structure. The Cherapakivska structure on the top of the Kartamysh formation is a semi-anticline, limited from the north by fault. But in fact, the hypsometric position of the Permian and Carboniferous perspective horizons was deeper than predicted. The nature of the penetrated section shows a significant subsidence. Birykivska structure is a submerged block graben with Permian sediments monoclinal bedding (Fig.1).

*Lithology*. Deposits of the Lower Permian are represented by evaporite and terrigenous formations. The Kartamysh formation of the lower Permian is composed of terrigenous sediments. It is mainly an alternating layers of shales and siltstone with thin layers of sandstone.

Evaporite formation is divided into two subformations: rock-salt-bearing (Mykytivka and Slovyanska formation) and K-Mg-salt-bearing (Kramatorska formation) (Shekhunova, 2015). The first one is represented by the alternating layers of rock salt, anhydrite, dolomite, limestone and gallopelites. In rock-salt-bearing subformation 5 cycles are distinguish, which begin with rock salt, and end with the interlayers of anhydrites, dolomites and gallopelites. The second subformation is represented by rock salt with layers of anhydrite, salted siltstones, clay and sandstones, potassium and magnesium salts. There are 2 cycles that begin with rock salt and end with terrigenous rocks.

*Source rocks.* In general, the main source rocks in the Dnipro-Donets basin are represented by the following Carboniferous formation. 1) Serpukhovian rocks composed of argillites with carbonated plant detritus. It contain near 2% of TOC (Total Organic Carbon) and 300.0 mgHC / gTOC of the HI (Hydrogen Index). 2) The Moscowian formation composed of coal-terrigenous rocks with layers of coal and limestone. TOC is 1.5% and HI is 300.0 mgHC / gTOC (Misch et al., 2015). Organic matter in the source rocks belongs to the second and third type of kerogen. It confirmed by production data. The main extracting hydrocarbon in this region is gas and condensate (Arsiriy et al., 1999). Source rock is represented by Kartamysh formation in Cherapakivska-647 well. These are limestones with the interlayers of brown organic matter. TOC is 1.5% and HI is 80.0 mgHC / gTOC taken by analogy to work (Misch et al., 2015). Source rock from the Birykivska-653 well was deposited in the Upper Carboniferous. These are black, carbonaceous argillites. The TOC is 1.1% and HI is 80.0 mgHC / gTOC also taken by analogy to work (Misch et al., 2015).

## RESULTS

Birykivska-653 and Cherapakivska-647 have a similar lithological section. Neogene deposits are represented by sand with clay layers. This may indicate coastal paleodepositional environment up to 30 meters deep.

Paleogene sediments consist of sandstones and marls. Marls accumulates in the open shelf with up to 200 m depth. The Cretaceous system is represented by white chalk with interlayers of marl. Cretaceous sediments are formed in pelagic conditions, separated from the coast, at a depth from 200 m. The Jurassic system consists of alternating layers of sandstones and shale with rare interlayers of limestone. This indicates the dynamic, coastal environment. Accepted depth is 20 m. Triassic is represented by shales with rare layers of sandstones. Shales can be accumulated in the deepest parts of the oceanic shelf and the depth was taken at 150 m. There is erosion on the Permian-Triassic border. So, it is believed that in the Guadalupian and Lopingian series were continental arid conditions, and the deposits did not accumulate, but eroded. The Permian system is represented by evaporite and terrigenous formations. In general, salt sediments are formed by the evaporation of brines. Brine can be formed directly from sea water when it is evaporated in a semi-isolated or completely isolated sea in the arid region. The depth of such an isolated basin was adopted at 30 m depth.

*Basin modeling*. The Kartamysh formation of the lower Permian is completely replaced by the terrigenous component: the alternation layers of argillites, siltstones and rarely sandstones. A similar section, but with the predominance of argillites observed in the Upper Carboniferous. There is a significant amount of mica, as well as brown argillites and siltstones. This suggests that in the Upper Carboniferous and Early Permian times there was zone of lakes, or even stagnant swamps. Formation depth of these deposits was accepted from 10 to 30 m.

The basis of basin modeling is the lithology and stratigraphy of penetrated sediments. Paleo water depth (PWD), heat flow (HF) and sediment water interface temperature (SWIT) data are used for burial history simulation. The heat flow is determined from the main tectonic events. The highest rate of heat flow was at the rift event in the Dnipro-Donets basin. Sediment water interface temperature can be selected from Petromod databases. It lays on the distribution of temperatures around the globe developed by Bjorn Wygrala (Schlumberger, Aachen, Germany) in 1989 (Fig. 2).

The bulk thermal conductivity is controlled by conductivity values of rock and fluid components. Mixing rules for rock and fluid components are generally complex and depend on whether the mixture is homogeneous or layered (Fig. 4a, Fig. 4c) (Hantschel, Kauerauf, 2009).

The results of simulation are time plots of the PWD, HF, SWIT and the generation mass (Fig. 3). Moreover, depth plots are simulated too. There are plots of pressure, thermal conductivity and vitrinite reflection. Combination of SWIT, PWD and HF makes possible to link subsidence with sedimentary basin heating.

OVERALL CONCLUSION

The obtained results point to the dynamic history of the Dnipro-Donets basin development. The thickness of Permian section is up to 2 km. Moreover, there is cyclicity in the evaporite and terrigeneous formation. The cyclicity related with dynamic paleodepositional environment with regular sea level changes. In conclusion, this basin of sedimentation was semi-isolated during Permian time. Such a powerful layer of salt could be formed in the presence of a constant source of brine. Probably, there was a channel connecting the East European evaporate basin with the Dnipro-Donets basin.

It is clear that burial history model of Cherapakivska-647 well is more matured than model of Birykivska-653 (Fig. 5a, Fig. 5b). This difference may lead to the location of the source rock in the section. On the other hand, main source rock wasn't penetrated because of significantly deep bedding. Maximum burial occurred around late Cretaceous in 653 well. At the same time, this well was not drilled to the foundation. So the actual depth of

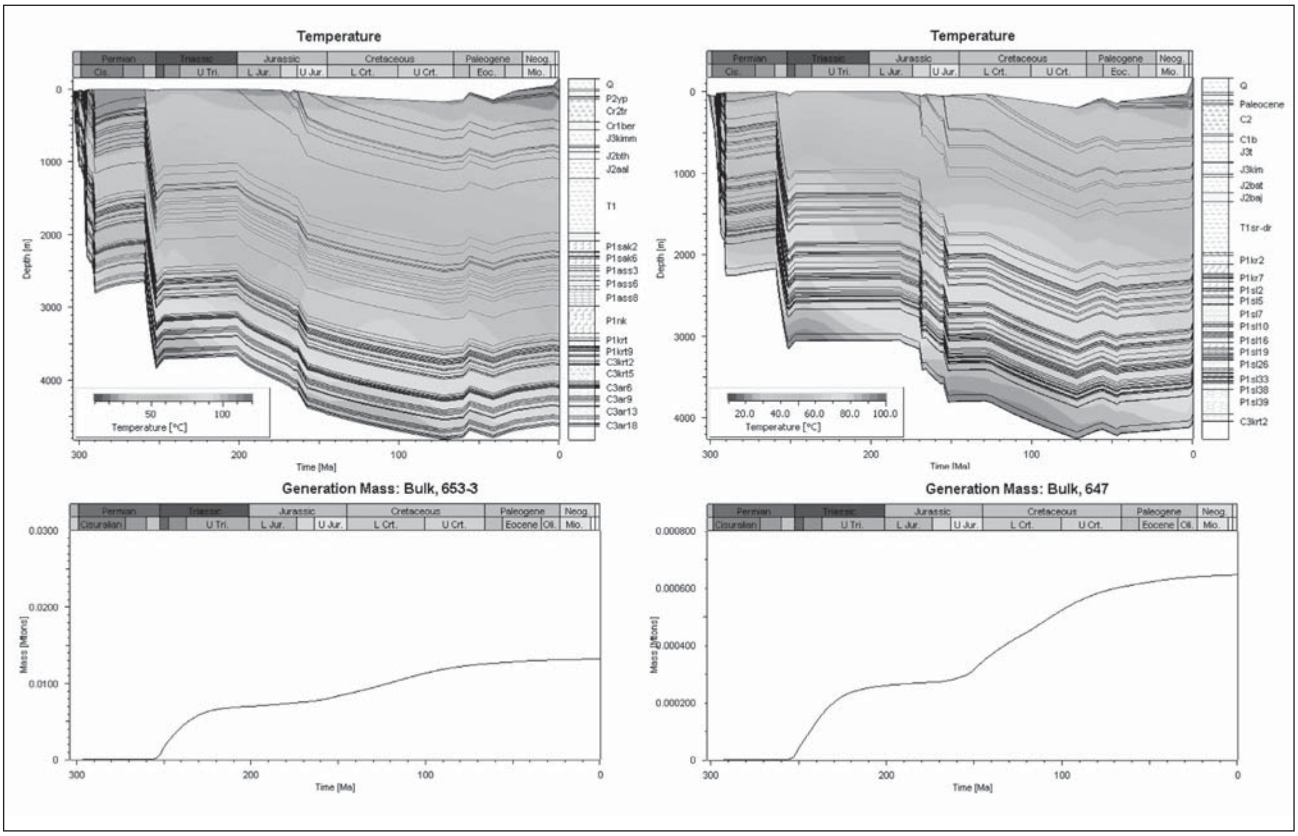


**Fig. 5.**
a) 1D Burial history model for 653 well;
b) 1D burial history model for 647 well;
c) Time plot of generation mass in 653 well;
d) Time plot of generation mass in 647 well.

the subsidence is even greater. The largest heating of the basin is observed on the Permian-Triassic border and during Cretaceous time. These events involve the beginning of the hydrocarbons generation. The resulting generation plots indicate that the discovered source rocks could generate up to 0,000650 mega-tons of hydrocarbons in 647 wells and up to 0,0120 mega-tons of hydrocarbons in 653 wells (Fig. 5c, Fig. 5d).

The key point is that wells did not get hydrocarbon production during drilling. This may occur because of the lack of paths or time for hydrocarbon migration due to the significant subsidence of the main gas generating rocks. We can estimate maturity of source rock by obtained plots of vitrinite reflection changes. Models for both wells are not mature enough ($R_0$ = 0.7%) (Fig. 4, Fig. 4b). It could also affect the absence of hydrocarbons in these wells.

In summary, the studied areas are not perspective in terms of hydrocarbon production. The presence of such a thick layer of Permian sediments formed in 10 million years is important for analyzing geologic history of the Dnipro-Donets basin. This may indicate a high rate of sedimentation at this time. Such sedimentation may be related with climate and the presence of a constant brine source.

The further perspective is the construction of a 3D burial history model with the inclusion of more wells and the spatial distribution of the main petroleum system elements data. Such a model will determine not only stratigraphic traps for hydrocarbons, but also analyze their prospects for oil and gas production.

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[1]Інститут геологічних наук НАН України,
Київ, Україна
[2]Київський національний університет імені Тараса Шевченка,
Київ, Україна

## ИСТОРИЯ ПОГРУЖЕНИЯ И ТЕРМИЧЕСКОГО РАЗВИТИЯ ПЕРМСКИХ ОТЛОЖЕНИЙ ЦЕНТРАЛЬНОЙ ЧАСТИ ДНЕПРОВСКО-ДОНЕЦКОЙ ВПАДИНЫ

**И.А. Стрельцова, И.В. Виршило**

Работа направлена на уточнение условий осадконакопления пермских отложений в пределах центральной части Днепровско-Донецкой впадины путем моделирования истории погружения осадочного бассейна на основе литологических, тектонических и палеогеографических данных. Авторы использовали геологический разрез скважин Бирюковськая-653 и Черепаковская-647 для построения 1D моделей истории погружения и термического развития. Избранные скважины характеризуют различные структурно-тектонические обстановки - Черепаковскую полуантиклиналь и Бирюковский погруженный блок-грабен и определенными различиями в разрезе пермских отложений. Граничные условия моделирования было восстановлено путем интерпретации истории геологического развития территории. По литологическому составу было интерпретировано палеоглубины бассейна в разное время.

Условия осадконакопления в ранней перми смоделированы как циклическое колебание палеоглибин, при этом накопление мощной толщи соли и сульфатов рассматривается с точки зрения евапоритового происхождения. Предполагается, что в позднекаменоугольное и раннепермское время данный бассейн осадконакопления был полуизолированный или изолированный с застойным режимом.

Позднепермское время характеризуется континентальными условиями, которые повлекли значительную эрозию и повлияли на «прогрев» данной территории. Континентальные условия изменились на прибрежные в триасе. Разрез заканчивается шельфовыми условиями в мелу и палеогене.

Согласно моделям термического развития, выделены моменты наибольшего прогрева бассейна на границе верхняя пермь - триас, которые совпадают с началом генерации углеводородов. Определено, что материнские породы в пределах данных структур генерировали от 0,650 до 12 килотонн углеводородов. Модели истории погружения предполагают значительное опускание на этой территории в течение позднего мела (до 5 км в скважине Бирюкивська-653). Полученные графики теплопроводности и изменений отражательной способности витринита указывают на слабую зрелость каменноугольных материнских пород ($R_0$ = 0.7%) в исследованных скважинах, может быть основным фактором непродуктивности пробуренных скважин.

*Ключевые слова:* эвапориты, условия осадконакопления, история погружения, Днепровско-Донецкая впадина.