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COMPARATIVE ANALYSIS OF CATAGENETIC MATURITY MODELS FOR MAYKOP SEDIMENTS IN AZERBAIJAN

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Summary. Burial history, lithological composition of sediments, geochemical properties of organic matter and geothermal conditions were simulated for three different localities in Azerbaijan using basin modeling methods and software tools. Taking into account that this source interval can make voluminous contribution to hydrocarbon generation we have constructed catagenetic maturity models for these strata. Modeling of the temperature field from the beginning of sedimentation to the modern stage of basin formation is based on the principle of gradual reduction of temperature. In this way a good agreement between calculated temperature values and borehole temperature measurements has been obtained. The maximum paleotemperature of rocks is reflected in the reflectance values of vitrinite. To display the validity of temperature field modelling results we have provided a matching diagram plotting calculated vitrinite reflectance versus measured on core samples values. The catagenetic maturity models constructed suggest that in deeply buried Maykop strata of the Lower Kura, Yevlakh-Agjabadi depressions and Jalilabad trough oil window has subsided to different depths depending on geological evolution. Among localities considered the highest degree of catagenetic transformation has been reached in sediments within depocentral part of the Lower Kura depression. The deepest layers of the Oligocene – Lower Miocene interval have passed peak oil window and even more, realized complete hydrocarbon generation capability. In other areas thermal transformation ratio of the Maykop organic matter is estimated to be lower than that in the Lower Kura depression.

Introduction

From Eastern Georgia to Azerbaijan betweeen the Lesser and Greater Caucasus Mountains three large sedimentary troughs are located. The Meso-Cenozoic strata of these intermontane basins have different burial history, thickness, lithofacial, geothermal, geochemical and etc. characteristics due to various structural-tectonic conditions of their formation. Within mentioned troughs, the sedimentary filling covers a stratigraphic range from Jurassic to Quaternary age (Геология Азербайджана. Том VII, 2008).

In the Meso-Cenozoic there were favorable conditions for organic matter accumulation and its subsequent transformation into oil and gas. The Lower Kura, Yevlakh-Agjabadi depressions and Jalilabad trough are characterized with differing geological histories, while territorially being subunits of the South Caspian megabasin (Fig.1).

Relatively high organic matter content in the Oligocene-Miocene sediments has been noted in various publications devoted to hydrocarbon generative properties of the Meso-Cenozoic sedimentary complex within Azerbaijan. Starting with the first monographic works, in publications studying the source rock properties have shown that the Maykop's clayey rocks have favourable characteristics for generating hydrocarbons (Жабрев, Мехтиев, 1959; Али-Заде и др., 1975; Корчагина и др., 1988). Owing to Maykop unit's great thicknesses occupied in the sedimentary cover, its richness in organic matter compared to other sedimentary units and subsidence in many places to depths adequate for catagenesis allowed workers to consider it as a main hydrocarbon generator in the section, its oil and gas formation potential having been the study topic for a long period (Али-Заде, 1975; Feyzullayev et al., 2008; 2015; Katz et al., 2000). This paper deals with the modeling of catagenetic maturity in various onshore depressions located in Azerbaijan, considering the significance of the Maykop sediments as hydrocarbon source.

Evaluation of the thermal maturity of the Maikop strata in the Lower Kura, Yevlakh-Agjabadi oil and gas bearing regions and Jalilabad trough on the basis of quantitative simulation of geological evolu-

tion of the areas is of particular interest. The application of basin modeling methods made it possible to predict the geothermal conditions and organic maturity of sediments in a number of areas.

Geothermal conditions and the necessity for their modeling

Since every region has its own tectonic development history their present-day temperature fields differ from each other. Borehole temperature measurements present valuable information for understanding the formation of the geothermal regimes in the sedimentary basins. The average geothermal gradient is 1.57 in the Lower Kura, 1.7 – in the Yevlakh-Agjabadi depression and 2.2 ºC/100m – in the Jalilabad trough. Diversity of the temperature field at a 4 km depth level is demonstrated on the schematic map (see Fig. 1). The division of the oil and gas bearing regions and the distribution of isotherms are depicted according to: Карта месторождений нефти и газа.., 1984; Геотермическая карта Кавказа, 1989.

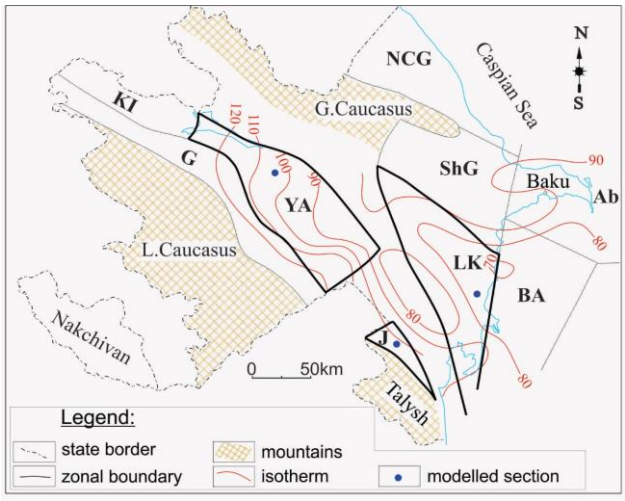

Fig. 1. Scheme of the study area and modelled sections
Zonation units: **Ab** – the Absheron area; **BA** – Baku Archipelago; **LK** – the Lower Kura basin; **ShG** – Shamakhy-Gobustan; **NCG** – Near Caspian-Guba; **G** –Ganja; **YA** – the Yevlakh-Aghjabadi basin; **KI** – the Kura-Iori interfluve area;
J – the Jalilabad hydrocarbon prospective area
Note: isotherms indicate temperature variation at 4km depth

Based on the data from scientific publications and research reports, lithostratigraphic features of the sedimentary cover in Azerbaijan have been analyzed and respective specific-to-region columns made up to be used in modelling process. According to the evidences from Saatly-1 super deep well, volcanites have a substantial presence in the Jurassic and Lower Cretaceous intervals.

The Paleogene section consists of clayey and siltstone rocks. These observations were taken into account in building the model. The Oligocene-Miocene sediments with dominant argillaceous rocks contain reservoir horizons though not very thick, yet capable of hosting commercial oil accumulations (Геология Азербайджана. Том VII. Нефть и газ, 2008).

Without taking into account the regularities in temperature variation, it would be impossible to address such important issues as hydrocarbon formation at great depths, fluid migration and accumulation in reservoirs, the hydrocarbon phase forecasting etc. Determination of the geological time-space relationship between formation of structures in which hydrocarbons can be accumulated and processes of oil generation and migration is among the main challenges facing petroleum geologists. To resolve the issue one needs to know whether the source rock interval had entered maturity phase by the time when structures and reservoirs were able to accomodate hydrocarbons migrating from the underlying strata. It is crucial to reconstruct the paleotemperature regime of the sedimentary cover, which plays a principal role in source rock maturation and determines time and depth occurrence of hydrocarbon generation processes. Thermal maturity is evaluated by geochemical indicators reflecting physical-chemical alteration of the kerogen – solid organic component of the sedimentary rocks (Miles, 1989). To understand the evolution of sedimentary basins and development of hydrocarbon generation along the section, it is necessary to quantify the relationship between these indicators and temperature field. On constructing basin models for petroleum bearing regions it is important to consider along with present-day temperatures paleotemperature conditions as well.

Modeling was carried out for the numerical description of oil and gas formation processes in synclinal parts of the depressions. It should be noted that individual units in presented lithostratigraphic columns are composed of the bodies of rocks, relative amounts of which are depicted as laterally adjoining rectangular blocks.

A model reflecting temperature evolution throughout the burial history of the Lower Kura depression and the Jalilabad trough is given in the Fig. 2. In the result of post-Sarmatian overthrusting the Miocene clayey sediments in the Jalilabad syncline occurred in themodynamic conditions that turned them into oil generating strata. Structural-tectonic conditions formed beneath the thrust might have become favorable for hydrocarbon fluids to accumulate within the traps. The Upper Eocene tuffogenous deposits participating in the Arkivan thrust are likely to have sealing capacity for potential petroleum system. It seems likely that within the Jalilabad syncline zone, formation of oil accumulations in sandy reservoirs underneath the thrust could have taken place

(Алиев, Байрамов, 2011). Depth and time characteristics of the oil formation zone are closely related with the temperature regime of sediments. It can be concluded that in the deeply buried Oligocene-Miocene interval of the study area there have been adequate heating conditions for hydrocarbon generation.

In the Lower Kura depression the most subsided Jurassic rocks attained the highest temperature conditions. Because the study area is characterized with the lowered temperature gradient it is appropriate to expect location of oil deposits at relatively greater depths.

The chemical reactions providing thermal transformation of kerogen into hydrocarbons depend on time, pressure and temperature parameters. Geological age of sediments is biostratigraphically dated, less influencing pressure is measured or calculated. However, a major factor determining the rate and scale of hydrocarbon formation processes – paleo status of temperature field – is one of the least known factors.

Paleotemperatures and maturity models

Organic maturation rate is directly correlated with temperature increase. Transformation of organic matter into hydrocarbons commences at 50-60°C, at advanced temperatures (150-175°C) generation of dry gas composed of over 90% of methane takes place (Miles, 1989). Potential source rocks that have not been impacted by geotemperatures required for hydrocarbon generation are ranked as immature, while those generating oil and wet gas are considered as mature. Rocks that have passed the first two stages of thermal transformation and presently occur in conditions where only dry gas is generated are considered as being at post-mature stage.

Organic material of marine and lacustrine origin includes some input of plant remnants too. Vitrinite being an organic mineral of higher plant origin and major constituent of coal is observed in sedimentary rocks in the form of scattered small particles. A physical property of vitrinite, its ability to reflect polarized light, is widely used as a maturation indicator of organic matter. Vitrinite reflectance is regarded as the most reliable paleo-temperature indicator. Increase of vitrinite reflectance is concomitant to geotemperature growth in the rocks, therefore it indirectly records the highest temperatures that hosting sediments have been exposed to during their subsidence. The maximum paleo-temperature experienced by the rocks is believed to leave "an imprint" on this indicator. The parameter's (R_o) 0.5-0.6% values are commonly considered as indicative of oil window onset, or in other words a top of oil formation zone. The bottom of oil window, otherwise the end of oil formation zone, is constrained with 1.4-1.5% values (Miles, 1989). In a special case R_o values may help to reveal if tectonic inversion has occurred in the basin in ancient geological times, because erosion brought up by uplifting leads to thermal cooling of the older non-eroded strata.

In a number of international and local publications (Klosterman et al., 1997; Inan et al., 1997; Abrams, Narimanov, 1997) dedicated to Azerbaijani basins as a part of organic geochemical studies, data on vitrinite reflectance were reported as well. We have used these data in order to control our simulations.

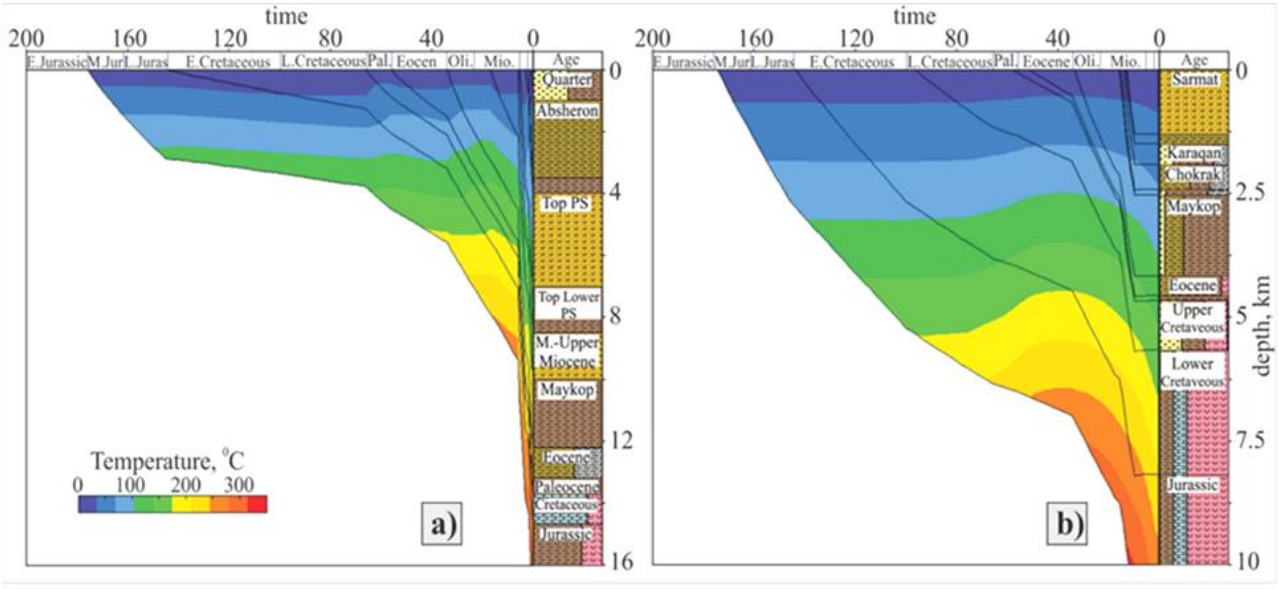

Fig. 2. Modelled temperature field over geological history in a) the Lower Kura depression; b) the Jalilabad trough

Depending on sedimentation and burial rates, stratigraphic units composing the section in question pass thermal maturity stages at different periods of geological time. From this point of view, it is of interest to look at comparative study of the vitrinite reflectance (VR) evolution curves for selected localities in the Lower Kura and Yevlakh-Agjabadi, doing so model outcomes are depicted on the same plot with measured reflectance values (Fig. 3). According to the measured on core samples VR values in a number of fields in the Lower Kura, the R_o values show an increasing trend with depth (see Fig.3). The largest value 0.65% R_o was reported at 5200 m within the Lower Pliocene strata in the Kalameddin field, which points to an early stage in oil window. At Sovetler locality in Yevlakh-Agjabadi, the Eocene sediments at a depth of 3680 m were reported to have R_o value at 0.6%. According to the simulations, in the present-day Lower Kura and Yevlakh-Agjabadi sections the value of 1.0% R_o occurs respectively at the top layers of the Miocene and Cretaceous. On depth axis this reflectance value is associated with 9.0 km and 6.5 km, accordingly.

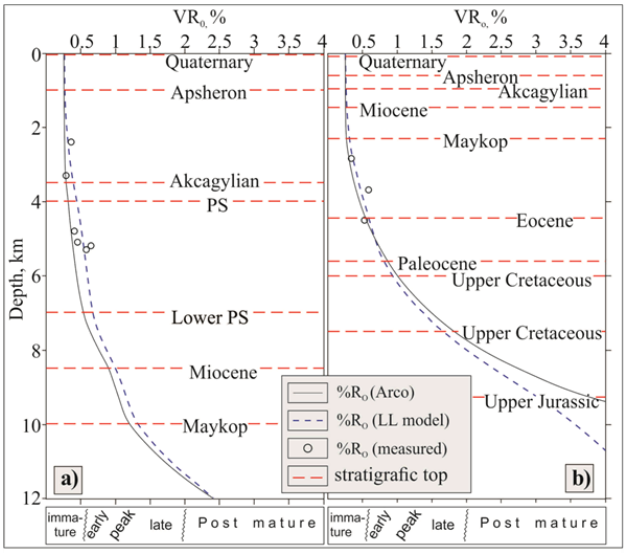

Fig. 3. Vitrinite reflectance values: calculated versus measured. a) the Lower Kura depression; b) the Yevlakh-Aghjabadi depression

Depth and timing evolution of hydrocarbon formation centers are in certain relationship with the type of organic matter contained in a source rock. In this respect modeling of thermal maturation of the Maykop source rocks in the Lower Kura, Yevlakh-Agjabadi and Jalilabad regions is of both theoretical and practical interest. Throughout its geohistory, from the Middle Jurassic to the Quaternary period, the Lower Kura has experienced steady subsidence. During the Pleistocene-Holocene time uplifting and erosion at the flanks of the depression accelerated, nevertheless sedimentation was not disrupted in the central parts. In the parts of the depression extending towards the South Caspian offshore the sedimentation continued even at faster rates during the Pliocene and the Pleistocene epochs.

The extreme increase in sedimentation rates in Late Miocene resulted in burial of the Oligocene – Lower Miocene Maykop strata as deep as 10-12 km in the depocentral part of the Lower Kura (see Fig.4). According to the modeling results at the present day section of the Lower Kura, VR values at top and base layers of the Maykop sediments are expected to be within a range of 1.2 to 2.4%. This implies that top horizons of the unit reside at the peak of oil window and the base layers do at post-maturity stage. As to generation products in the Maykop strata they are likely to be presented by a wide range of hydrocarbons. While the deeply seated horizons occur in the intensive gas formation zone, the shallow buried ones have been in conditions conducive to liquid hydrocarbon preservation. It may be suggested that gaseous hydrocarbons formed in the deep horizons subvertically move into upper layers, and doing so disssolve and transport with themselves significant volumes of long-chain hydrocarbons, in this way enhancing fluid mobility.

As it is known, the Jalilabad trough is located at the north-eastern foothills of the Talysh mountain range. The Eocene volcanism played an important role in formation of lithological, structural-tectonic and other geological features of the region. In particular, volcanogeneous rocks (tuffs and their mixtures with other terrigenous rocks) are widespread in the sedimentary strata. Geothermal regime of the region has formed under influence of volcanic processes, and modern temperature field is characterized with elevated gradients. For this reason, not so deeply buried Maykop strata (2.8-4.4 km) have entered oil window and transformation of organic matter has considerably moved forward.

In Maykop deposits the share of terrestrial organic matter is prevailing accounting for 60-70% of the organic content (Feyzullayev et al., 2008). It is common knowledge that in layers where terrestrial organic debris is dominant, thermal breakdown requires higher temperatures compared to the rocks containing essentially marine organic input. In this respect in the base layers relatively high VR values are noted, accordingly thermal transformation has reached 90% level.

Lopatin's TTI index for the Maykop sediments in Yevlakh-Agjabadi is represented by a value lower than that for the Eocene strata. Variation of "$\sum\tau$" in the range of 70-80 in Naftalan, Shirvanli, Gulluja, Agjabadi, Terter and other areas allows one to conclude that currently Maykop occurs at early stage of oil and gas formation (Гусейнов и др., 2015).

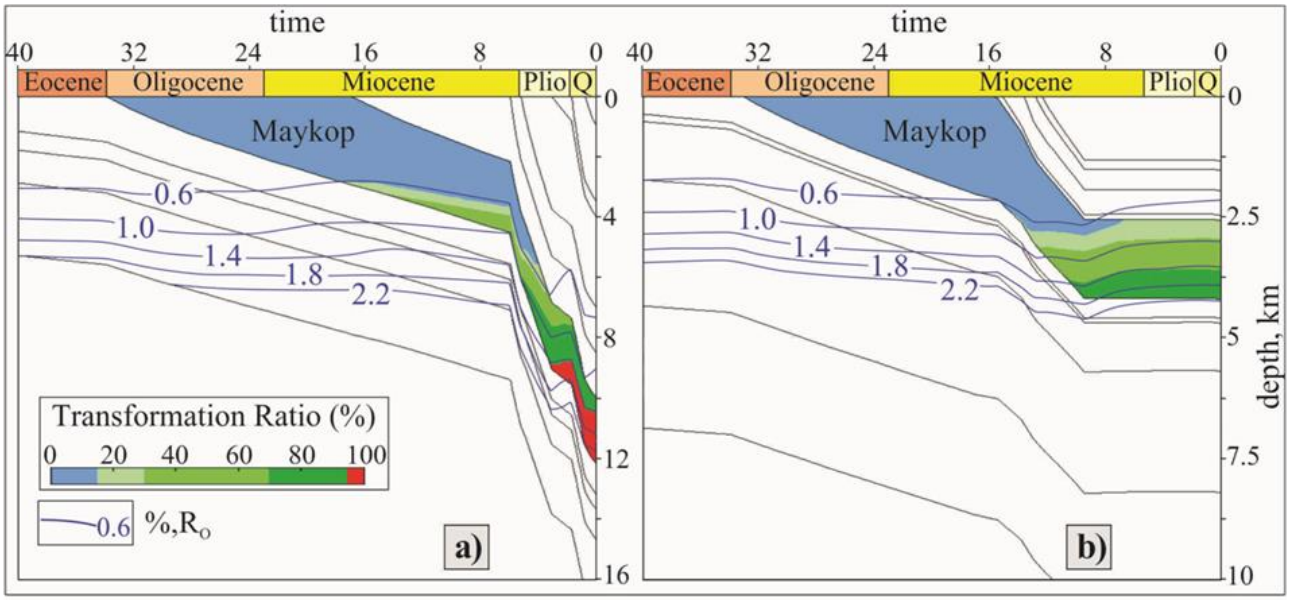

Fig. 4. Burial history charts for Maykop sediments in a) the Lower Kura depression and b) the Jalilabad trough

Conclusion

The modelling study allowed revealing different time-depth characteristics of catagenetic processes in Maykop sediments in regions with dissimilar geothermal regimes, which are the Lower Kura, Yevlakh-Agjabadi depressions and Jalilabad trough.

The maturity models indicate that in deeply buried Maikop strata of the Lower Kura, Yevlakh-Agjabedi depressions and Jalilabad trough oil window occurs at different depths depending on geological evolution of the area.

Onset of oil generation in the depocentral part of the Lower Kura is estimated to begin in Early Miocene, while in the Jalilabad trough it is dated as Middle Miocene.

Maikop strata deeply buried in the Yevlakh-Agjabadi have reached just the onset of oil window.

Among the localities considered, the highest degree of catagenetic transformation has been reached in sediments occuring within depocentral part of the Lower Kura depression. The deepest layers of the Oligocene – Lower Miocene interval have passed peak oil window and even more, realized complete hydrocarbon generation capability. In other areas thermal transformation ratio of the Maykop organic matter is estimated to be lower than that in the Lower Kura depression.

Depending on the local geological conditions, presence of reservoirs, their lithophysical properties and presence of traps are critical conditions for the accumulation of formed hydrocarbons.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ МОДЕЛЕЙ КАТАГЕНЕТИЧЕСКОЙ ЗРЕЛОСТИ МАЙКОПСКИХ ОТЛОЖЕНИЙ АЗЕРБАЙДЖАНА

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Резюме. На основе применения программных средств бассейнового моделирования осуществлена симуляция истории погружения, литологического состава, геохимических особенностей органического вещества и геотермической обстановки для трех разных участков на территории Азербайджана. Учитывая роль майкопской свиты, как регионально распространенной нефтематеринской толщи, и ее потенциальный вклад в объемы генерации, были построены модели катагенетического созревания для данного интервала. При построении бассейновых моделей для нефтегазоперспективных районов палеотемпературные условия, как правило, наименее известные. Тем не менее, их исследование и уточнение считается необходимым. Моделирование температурного поля с начала осадконакопления до современного этапа становления бассейна основано на принципе постепенного снижения градиентов температуры. Таким способом удалось достичь хорошей аппроксимации между значениями рассчитанного температурного поля и его современными скважинными замерами. Хорошо известно, что максимальные палеотемпературы, испытанные породами отражаются на величинах отражательной способности витринита. Достоверность модели эволюции температурного поля иллюстрируется на построенной диаграмме подгонки вычисленных значений отражательной способности витринита к ее значениям, инструментально измеренным на образцах породы. Построенные модели катагенетической зрелости указывают на то, что в зависимости от геологической эволюции в глубокопогруженных частях Нижнекуринского, Евлах-Агджабединского и Джалилабадского прогибов майкопские отложения и вместе с ними нефтяное окно погрузились на различные глубины. Среди рассматриваемых районов наиболее высокий уровень катагенетической превращенности в пределах майкопских отложений достигнут в депоцентральной части Нижнекуринской впадины. Здесь подошвенные слои олигоцен-нижнего миоцена прошли пик «нефтяного окна», тем самым полностью реализовав свой генерационный потенциал. Для других районов степень катагенетической превращенности органического вещества в майкопской толще несколько ниже по сравнению с Нижнекуринской впадиной.

Ключевые слова*: майкопская свита, органическое вещество, отражательная способность витринита, температура, моделирование зрелости*

AZƏRBAYCANDA MAYKOP ÇÖKÜNTÜLƏRİNİN KATAGENETİK YETKİNLİK MODELLƏRİNİN MÜQAYİSƏLİ TƏHLİLİ

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Xülasə. Təqdim edilən məqalədə hövzə modellənməsi üsulları və proqram vasitələrinin tətbiqi əsasında tədqiqat sahələrinin gömülmə tarixi, çöküntülərin litoloji tərkibi, onlarda üzvi maddənin geokimyəvi xüsusiyyətləri və geotermik şərait simulyasiya edilmişdir. Kəsilişdə əsas neft-ana süxurları hesab olunan Maykopun karbohidrogen generatoru kimi əhəmiyyətini nəzərə alaraq, bu intervalın katagenetik yetkinlik modelləri qurulmuşdur. Neftli-qazlı rayonlarda hövzə modelləri qurarkən paleotemperatur şəraiti ən az məlum faktorlardan biri olsa da, bu haqda məlumatların təhlili vacib hesab olunur. Hövzədə çöküntütoplanma başladığı dövrdən indiyədək temperatur sahəsinin dəyişilməsinin modellənməsi məqsədilə temperatur qradiyentinin tədricən azalma prinsipi tətbiq edilmişdir. Bu üsulla hesablanmış temperatur qiymətləri və müasir quyu temperatur ölçmələri arasında yaxşı approksimasiya əldə etmək mümkün olmuşdur. Məlum olduğu kimi, süxurların məruz qaldığı maksimal paleotemperatur vitrinitin əksetdirmə qabiliyyətində öz əksini tapır. Temperatur sahəsinin təkamül modelinin etibarlılığı vitrinitin əksetdirmə qabiliyyətinin hesablanmış və onun süxur nümunələrində cihazla ölçülmüş qiymətləri arasında uyğunluq qrafiki şəklində göstərilmişdir. Qurulmuş katagenetik yetkinlik modelləri Aşağı Kür, Yevlax-Ağcabədi və Cəlilabad ön çökəkliklərinin dərinə gömülmüş hissələrində Maykop çöküntülərinin geoloji təkamülündən asılı olaraq neft pəncərəsinin müxtəlif səviyyələrdə yerləşdiyini göstərir. Baxılan sahələr arasında Maykopun ən yüksək katagenetik çevrilmə dərəcəsi Aşağı Kür çökəkliyinin deposentral hissəsində qeyd edilir. Burada Oliqosen-Alt Miosen intervalının ən dərin layları neft pəncərəsinin zirvə həddini keçmiş və KH əmələgətirmə potensialını tam realizə etmişdir. Digər ərazilərdə üzvi maddənin katagenetik çevrilmə dərəcəsi Aşağı Kür kəsilişi ilə müqayisədə nisbətən aşağı rəqəmlərlə səciyyələnir.

Açar sözlər: *Maikop lay dəstəsi, üzvi maddə, vitrinitin əksetdirmə qabiliyyəti, temperatur, katagenetik yetkinliyin modellənməsi*