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Assessmemt of hydrocarbon potential of uplift structures in sedimentary basins from their geological history (Ateshgah structure in Baku Archipelago)

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Накопичений вміст органічної речовини в осадовому басейні сильно залежить від геологічних умов його формування, зокрема від темпу осадження відповідно з геологічними епохами. Літологічні і стратиграфічні розрізи та інші доступні пов'язані з темою геологічні дані дають змогу реконструювати палеографічні профілі структури, наприклад, складка або підняття для різних періодів часу. З відновлених палеопрофілей (техніка «backstripping» — зворотного моделювання) можуть бути наближено оцінені швидкості розвитку складки і швидкості осадження порід для минулих геологічних епох. Зроблено спробу встановити потенціал відповідних літологічних одиниць як материнських порід для родовищ вуглеводнів, визначаючи швидкості седиментації для декількох тимчасових періодів геологічної історії структури, що містить вуглеводень. В якості дослідно-методичного дослідження розглянуто підняття Атешгях як великої акваторіальної антиклынальної структури в центральній частині Бакинського архіпелагу в Каспійському морі. Швидкості росту складки для цієї структури монотонно збільшувалися в часі від 0,3—0,4 км/млн років до початку палеоцену, остаточно досягаючи значень 0,5—1,3 км/млн років. Цей результат узгоджується з подібними палеографічними реконструкціями, про які нещодавно повідомлялося для інших перспективних структур в цьому регіоні. Швидкість відкладення осадів, зазвичай, з часом збільшується з деякими варіаціями відповідно до змін палеогеографії. Існує деяке граничне значення швидкості відкладення порід, менше якої структура не здатна продукувати/акумулювати вуглеводневу речовину в істотних або промислово привабливих кількостях. Це спостереження може бути використано як практичний метод для зв'язку реконструкцій розвитку структури з очікуваннями, що стосуються її вуглеводневого потенціалу. За винятком палеоцену і еоцену інші стратиграфічні інтервали в структурі були сприятливі для нагромадження органічної речовини в потенційній материнській породі, принаймні, в концентраціях вище кларкових.

Ключові слова: вуглеводневий потенціал, зворотній демонтаж, палеопрофіль, темп відкладення, число Кларка.

Introduction. Ateshgah uplift is located in the open sea, in the central part of the Baku archipelago shelf, 30 km to the south-south-east of Bandovan uplift, in the river Kura outfall, within the continental slope of the Caspian Sea eastern shelf [Aliyev et al., 1985] (Fig. 1).

Since majority of mud volcanoes at either crestal or pericrestal parts of local uplifts were active in the recent geological past or are still active, their eruption products formed volcanic cones (positive elements of the seafloor) over corresponding uplifts [Aliyev, 2006; Aliyev et al., 2015]. The Ateshgah sandbank structure is similar, by its form and size, to the folds developed in the Kura depression and Baku archipelago and is of the short brachiform type. Correspondence of those cones to positive structures, i. e. local uplifts, beneath them gives grounds for a statement that the basin floor within the Baku archipelago is, in general, conforming. This instance could play a positive role in prospecting and exploration of local uplifts.

The structural map (Fig. 2) shows that the uplift has almost a symmetric form. Dip angles of limb layers vary between 18—30 °C. However, the north-eastern limb is slightly steeper than the south-western one.

The fold structure is modified by a network of longitudinal and latitudinal faults. The amplitude of the longitudinal fault reaches 100 m in south-east direction. The amplitude of the fault crossing the north-western pericline reaches 1000 m in the north-east and decreases towards the north-west reaching 500 m.

The amplitude of the three faults that transversely cross the eastern limb of the structure reaches 900 m in the south-western limb and 100 m in the north-eastern one. Another fault is located in the south-eastern wing and its amplitude is 100 m. The value is 200 m.

Methods. Sedimentary formations that make up a geological structure of any area are formed under certain paleogeographic environment and the study of such environmental conditions of formation of a sedimentary complex plays an important role in the estimation of hydrocarbon perspectives. To study paleogeographic and paleotectonic environments of formation of sedimentary complexes of the area we have built and analyzed the paleogeographic curves and deposition rate charts based on the normal lithologic and stratigraphic cross-section [Narimanov et al., 2019; Gurbanov et al., 2019].

Paleogeographic environment of deposition. The paleogeographic curve (Fig. 3) shows that the depth of the sedimentary basin of the area under study had varied within a relatively wide range during the geologic span of time from Paleocene to Quaternary. From this point of view, psammitic and pelitic facies of the section in Paleocene are caused by the deposition process that mainly covered low and moderate depths. Taking into account the depositional environment in Eocene, the basin floor relatively subsided and the depositional process occurred in a deep marine environment. In Lower Maykopian, that is, in Oligocene, deposition took place in alternating average depth and deep marine environments. As a result, alternation of coarse and fine-grained rocks in the section is observed during this period. In Upper Oligocene and Lower Miocene, however, the depositional environment had altered to relatively average and shallow depth environments. This notwithstanding, two depositional processes took place in the marine environment during this period and carbonate facies sediments formed here.

Vertical tectonic movements drastically changed their direction later on, from Lower Miocene to Middle Miocene. That is, the deposition process occurred in alternating shallow and deep marine environments. Relative uplift of the basin floor was observed from Upper Miocene to the beginning of Lower Pliocene and the depositional environment altered to average depth and shallow marine environments.

The environmental conditions that lasted till the end of the Lower Pliocene show a similarity to those during the geologic time span from Lower Miocene to Middle Miocene, i. e. this is a frequent alternation of shallow and deep marine environments occurred. Favorable conditions for the formation of psammitic facies during Upper Pliocene are due to prevailing average and shallow depth marine environments. By the end of Upper Pliocene, a shallow marine environment alternates with average and deep marine environments. Later on, the deposition process continued till the end of the period in shallow and average depth marine environments. However, a deep marine environment prevailed one more time in the cross section till the end of the period.

Depositional rate analysis. There is a direct relationship between the deposition rate in a basin and the amount of accumulated organic matter [Sokolov, 1985; Vassoyevich, 1988]. We have tried to establish the potential of relevant lithologic units as hydrocarbon source rocks and to estimate the deposition rates within several geologic time spans based on the available lithologic and stratigraphic sections of the area. Mother rock

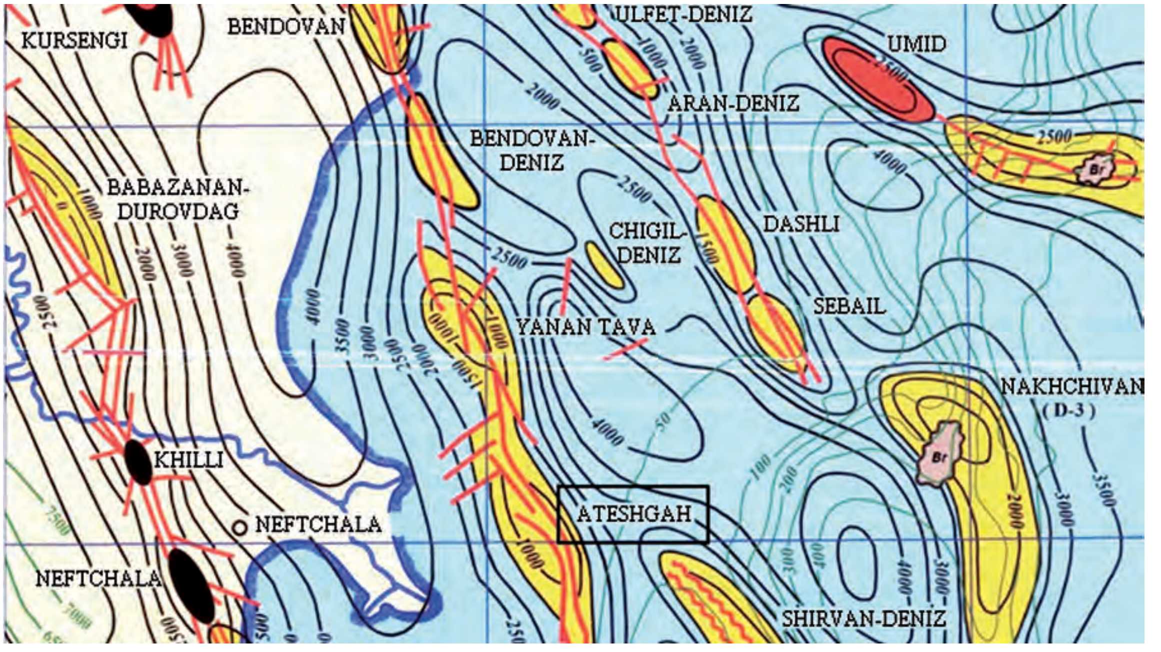

Fig. 1. Generalized map of the area.
Рис. 1. Обобщенная карта местности.

is a bed of rock capable of generating commercial hydrocarbons in a favorable thermal and pressure environment. The deposition rate chart (see Fig. 3) shows that the rate of deposition was 72 m/MA (MA — million years) in Paleocene—Eocene. It increased in Oligocene—Lower Miocene and was approximately two times higher, i. e. 141 m/MA. The depositional rate increased even more in Middle—Upper Miocene up to 336 m/MA. Next, the rate of deposition drastically increased in Lower Pliocene and, as a result, reached 1371 m/MA. An abrupt decrease followed in Quaternary down to 678 m/MA. According to [Sokolov, 1985; Vassoyevich, 1988] and other researchers, if the deposition rate in a basin is up to 50 m/MA, the amount of organic matter accumulated in potential mother rock is, as a rule, below the Clarke number. In other words, this category of mother rock is unable to generate commercially productive hydrocarbons. If the rate of deposition in a favorable (subaquatic) paleogeographic environment reaches 20—130 m/MA, the content of organic matter accumulated in potential mother rocks may be up to 0.1—2 %. If the depositional rate is 140—660 m/MA, the amount of organic

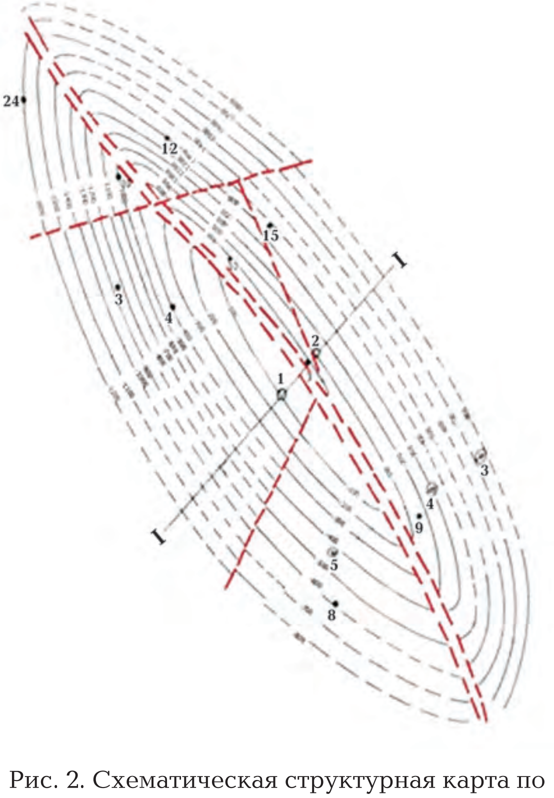

Рис. 2. Схематическая структурная карта по кровле VII горизонта поднятия Аташгях.

Fig. 2. Schematic structural map of the Ateshgah uplift for the top of horizon VII.

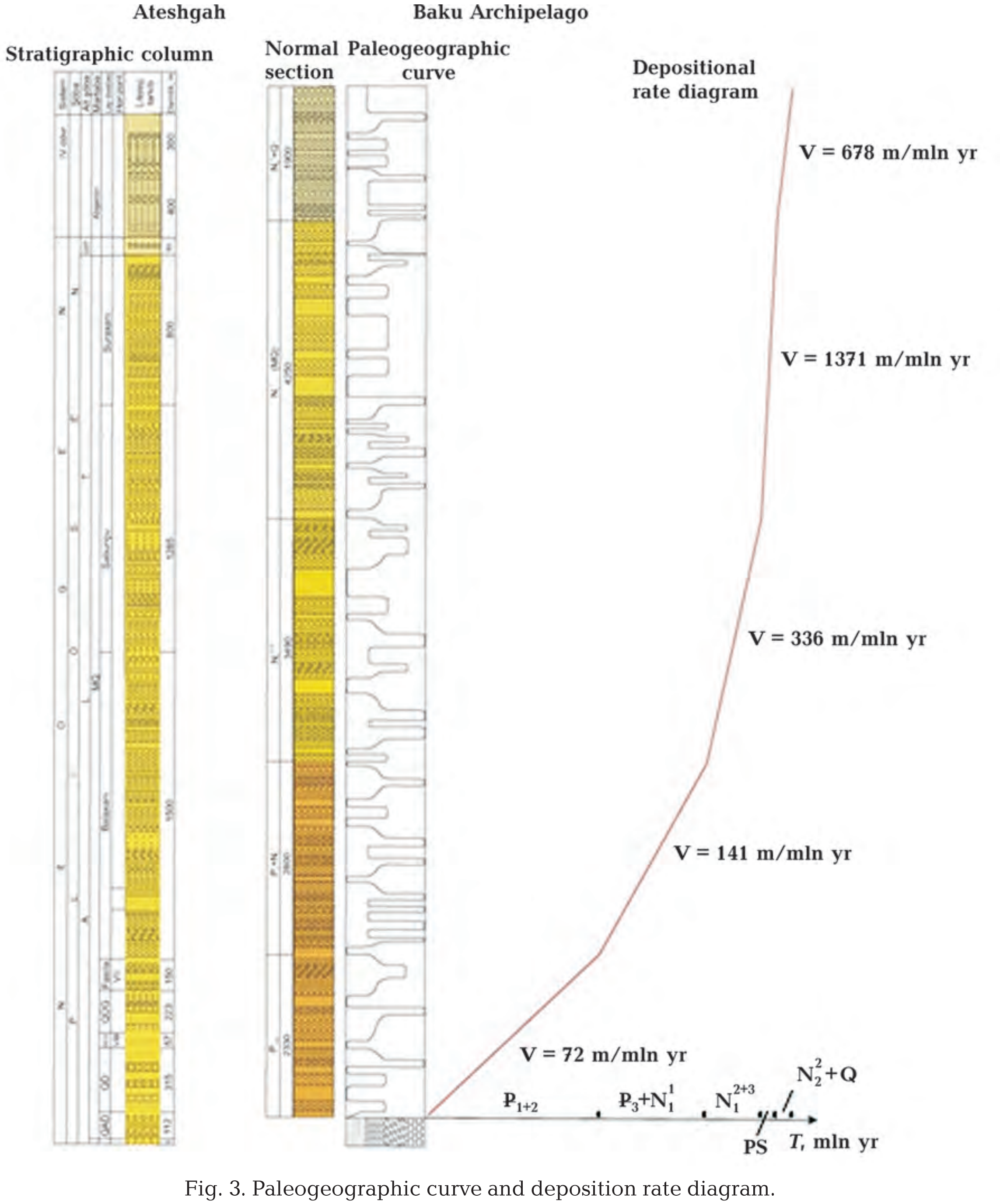

Fig. 3. Paleogeographic curve and deposition rate diagram.
Рис. 3. Палеогеографическая кривая и график скорости осадконакопления.

matter in potential mother rock beds is up to 2—10 %, that is, up to 10 % of organic matter can be accumulated in favorable conditions. If the depositional rate in a sedimentary basin reaches 1400 m/MA, the amount of organic matter accumulated in potential mother rocks can reach 11—18 %.

Thus, having correlated the rate of deposition for various time spans within the study area with other observed properties, one can state that with the exception of Paleocene and Eocene epochs, the remaining stratigraphic time intervals were favorable for accumulation of organic matter in potential mother rock at least above the Clarke number. Lower Pliocene should be especially mentioned from that point of view since the rate of deposition in the basin during that geological time was over 1300 m/MA (see Fig. 3). Therefore, as analysis of the paleogeographic curve and the depositional rate shows, paleotectonic and paleogeographic environment was sufficiently favorable for the accumulation and preservation of sufficient amount of organic matter in the region.

Paleostructural and paleotectonic environment for fold formation. Structural, paleostructural and paleotectonic conditions play an important role in the estimation of hydrocarbon perspectives of the area. It should be noted that paleographic reconstructions (backstripping techniques) are considered as the most detailed and profound method for a successful accomplishment of prospection and exploration works. In order to develop a fair assessment of the hydrocarbon perspectives of the area and to identify the time of formation and further development history of the fold under investigation we have built a series of paleoprofiles and constructed the growth rate chart of the uplift on their base (Fig. 4, see p. 103). This method, which is a kind of a simple backstripping on the base of available seismic profiles, was recently used [Narimanov et al., 2019] to systematically assess the growth rates of the prominent onshore and offshore anticline structures of Baku Archipelago and Lower Kura depression. Further details and guidelines for this technique can be found in this article (and references therein).

A paleoprofile constructed for the end of the Pliocene lower Productive Series has been built based on a seismic transect transversally crossing the crestal part of the Ateshgah uplift in SW-NE direction. We deduce that the Ateshgah uplift started developing no later than in early Pliocene, most probably, the formation of the structure is associated with Miocene.

The paleoprofile shows that the fold height reached 175 m by the end of the accumulation of the lower strata of the Productive Series. It should be noted that the fold had already been complicated by a longitudinal fault during the lower Productive Series age. Nonetheless, it is almost impossible to substantiate the formation of this fault based on the fold development rate during the geologic span of time under consideration. That is why it is reasonable to regard it as a more longstanding one, taking into consideration, in particular, that this fault is longitudinal. It is well known that folds developed in Azerbaijan both offshore and onshore are, in most cases, complicated by longitudinal faults. These faults are normally syndepositional or have periodically recurring development properties. This fault possibly belongs to the same type of faults. The paleoprofile shows that Productive Series sediments developed throughout the area.

There is a decrease in thickness of sediments towards the central, i. e. crestal part of the structure. This is the evidence of the Ateshgah uplift being simultaneously developed with sediment accumulation during the time of the lower Productive Series. Nevertheless, accumulation of lower Productive Series sediments all over the area of the uplift (crestal part included) shows that the rate of deposition was significantly higher than the fold development rate during the geological span of time under consideration.

A paleoprofile built for the end of the upper Productive Series shows that the Ateshgah uplift continued its development during this geological time span and by the end of Productive Series age its height already reached 1250 m. The paleoprofile indicates that the deposition process during the upper Productive Series was as intense as during the lower Productive Series all over the area. This is the cause of formation of Productive Series sediments of relatively great thickness. Nonetheless, decrease in thickness of Productive Series sediments towards the crestal part of the fold is observed. This decrease is sharper than the one that previously occurred. Despite all of that it should be noted that during the Productive Series age the depositional rate was significantly higher than the fold development rate as well.

The paleoprofile shows that during the upper Productive Series the crestal part of the Ateshgah uplift was complicated by a second fault. Unlike the first one, it complicates the fold in diagonal direction. As a result, a system of these two faults formed a horst in the fold crest. As follows from the above mentioned, the fold itself and the faults that complicate it developed simultaneously with the deposition process during the upper Productive Series age.

The paleoprofile built for the end of the Absheron age shows that the fold development was more intense in upper Pliocene rather than in lower Pliocene. For this reason, the height of the Ateshgah uplift already reached 2900 m by the end of Pliocene. This is indicative of more intense development in comparison with previous time intervals. The seismogeologic profile shows that the Aqjagil stage sediments have, in general, significantly less thickness. Nonetheless, they pinch out towards the crest of the fold in the north-eastern limb. In connection with that it should be noted that the Aqjagil stage does not stand out for its tectonic activity within the South Caspian depression. For this reason, pinching-out of these sediments towards the crest of the fold is related to an injective type of fold and is associated with its individual development. As for the Absheron stage, it should be noted that the deposition process occurred throughout the entire area. Since the fold development rate was relatively high thickness of sediments of this age drastically decrease towards the crest of the fold. This, in turn, shows higher fold development rates during the upper Pliocene in comparison with previous time intervals. Nevertheless, the deposition rate during the Absheron age was higher than the fold development rate too. As for the Agjagil stage — this bear opposite properties. The fold development rate was slightly higher that the deposition rate.

A recent seismogeologic profile shows that the Ateshgah uplift continued its development during this geologic time span. It was 3550 m high and Productive Series sediments cropped out on the basin floor within the crestal part of the Ateshgah uplift. This is indicative of the high development rate for the Ateshgah uplift, that was higher than the depositional rate during Quaternary. That is why there are no Quaternary sediments on its crest, even formed Absheron and Agjagil sediments were completely eroded and Productive Series sediments cropped out on the basin floor as a result. A paleoprofile and a seismogeologic profile show that the faults that complicate the fold continued there development simultaneously with the fold.

Thus, the paleoanalysis shows that the Ateshgah uplift development (from the onset of its formation) occurred simultaneously with the deposition process during the entire geologic time span throughout the section. Despite increasing development rate till the end of the Absheron age, this factor was less than the deposition rate. Only during the Agjagil age the fold development rate was slightly higher than the deposition rate. This predominance was drastic during the Quaternary, that is why Absheron, Agjagil and partially Productive Series sediments had been eroded in the crestal part. Based on the abovementioned we can conclude that the Ateshgah uplift is a syndepositional type of structure.

In order to track the fold development rate of the uplift under investigation during geologic time spans we have built the fold development rate chart (Fig. 5) from the reconstructed paleoprofiles. As the chart shows the fold development rates varied throughout geologic time. For instance, the fold development rate for the Ateshgah uplift was 390 m/Ma during the lower Productive Series (0.5 Ma).

With regard to upper Productive Series — the fold height reached 1250 m by the end of the time span. Its development rate was 414 m/Ma.

The height of the fold by the end of the upper Pliocene was 2900 m. The fold development rate reached 717 m/Ma.

Finally, it was 3550 m in Quaternary. The fold development rate was 1300 m/Ma. Thus, the chart shows that the fold development rate, since its formation, kept increasing throughout geologic time. The most intense fold development was observed in Quaternary.

Conclusion. Ateshgah uplift is a syndepositional fold complicated with faults appearing during each time interval of its development. The most intense fold growth is observed in Quaternary. The Ateshgah uplift was separated into 6 tectonic blocks by latitudinal and

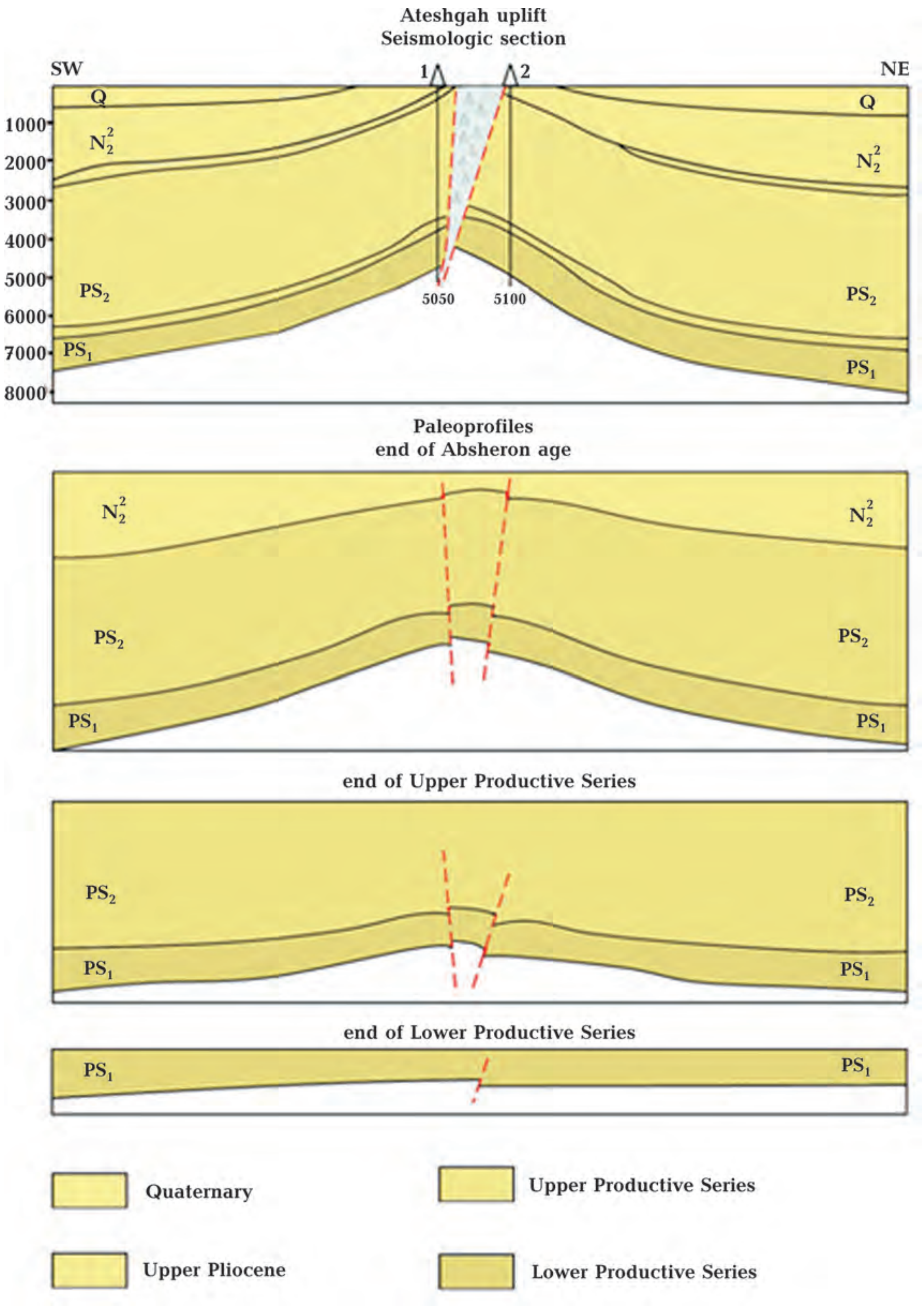

Fig. 4. Backstripped paleoprofiles of Ateshgah local uplift.

Рис. 4. Палеопрофили к локальным поднятиям Аташгях.

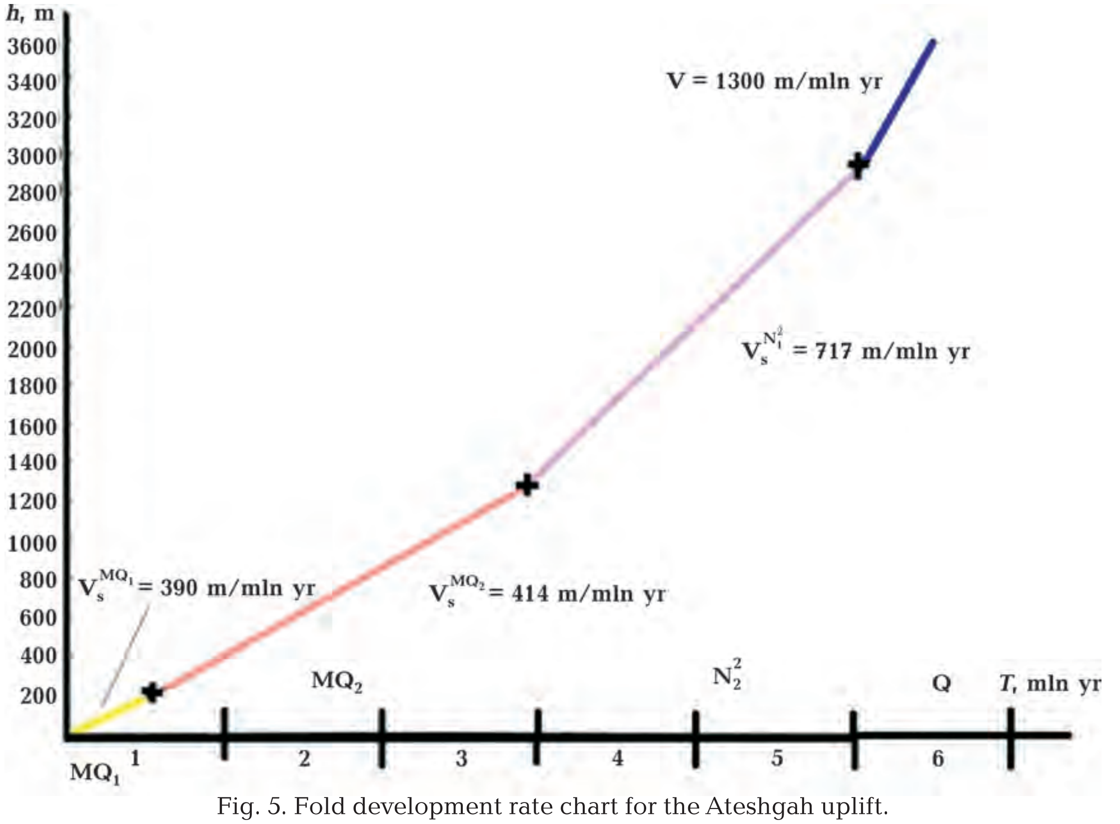

Fig. 5. Fold development rate chart for the Ateshgah uplift.

Рис. 5. График скорости развития поднятия Аташгях.

longitudinal faults. Blocks I, II and VI are the most perspective ones because of their hypsometric level. Oil-and-gas signs were observed during prospecting works in most of pilot wells drilled within these blocks. That is why prospect and exploratory wells have to be drilled on separate blocks. Wells to be drilled in blocks II and VI will enable assessment of hydrocarbon content of all of the Productive Series horizons they are going to cut.

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Assessmemt of hydrocarbon potential of uplift structures in sedimentary basins from their geological history (Ateshgah structure in Baku Archipelago)

M.S. Babayev, 2020

The accumulated content of organic matter in a sedimentary basin strongly depends on the geological conditions of its formation, in particular, on the deposition rate according to geological epochs. Lithological and stratigraphical cross sections and other available relevant geological data allow us to reconstruct paleographic profiles of a structure, for example, a fold or uplift, for different time periods. From the reconstructed paleoprofiles (backstripping technique), the rates of the fold development and deposition rates for past geological epochs can be approximately assessed. We try to establish the potential of relevant lithological units as source rocks for hydrocarbon deposits, determining the rates of sedimentation for several time spans of the geological history of a hydrocarbon-bearing structure. As case study, Ateshgah uplift is considered as a large offshore anticline structure in the central part of Baku archipelago in the Caspian Sea. Fold growth rates for this structure steadily increased throughout the time from the rate of 0.3—0.4 km/mln yr by the beginning of Paleocene eventually reaching the values of 0.5—1.3 km/mln yr. This result is in agreement with similar paleographic reconstructions, recently reported for other prospective structures in the region. The deposition rate of sediments generally increased with time with certain variations following the changes in the paleogeography. There is a certain threshold value of the deposition rate, below which the structure is not capable of producing/accumulating hydrocarbon matter in substantial or commercially interesting amounts. This observation can be used as a rule of thumb for linking the reconstructions of the structure development with the anticipations about its hydrocarbon potential. With the exception of Paleocene and Eocene, the remaining stratigraphic intervals in the structure were favorable for the accumulation of organic matter in potential mother rock at least exceeding the Clarke number.

Key words: hydrocarbon potential, backstripping, paleoprofile, deposition rate, Clarke number.

Оценка углеводородного потенциала поднятий в осадочных бассейнах по данным изучения их геологической истории (на примере структуры Атешгях на Бакинском архипелаге)

М.С. Бабаев, 2020

Накопленное содержание органического вещества в осадочном бассейне сильно зависит от геологических условий его формирования, в частности, от темпа осаждения в соответствии с геологическими эпохами. Литологические и стратиграфические разрезы и прочие доступные относящиеся к теме геологические данные позволяют реконструировать палеографические профили структуры, например, складка или поднятие для различных периодов времени. Из восстановленных палеопрофилей (техника «backstripping» — обратного моделирования) могут быть приближенно оценены скорости развития складки и скорости осаждения пород для прошедших геологических эпох. Делана попытка установить потенциал соответствующих литологических единиц как материнских пород для месторождений углеводородов, определяя скорости седиментации для нескольких временных периодов геологической истории углеводород содержащей структуры. В качестве опытно-методического исследования рассматрено поднятие Атешгях как крупная акваториальная антиклинальная структура в центральной части Бакинского архипелага в Каспийском море. Скорости роста складки для этой структуры монотонно увеличивались во времени от 0,3—0,4 км/млн лет к началу палеоцена, окончательно достигая значений 0,5—1,3 км/млн лет. Этот результат согласуется с подобными палеографическими реконструкциями, о которых недавно сообщалось для других перспективных структур в этом регионе. Скорость отложения осадков, как правило, со временем увеличивается с некоторыми вариациями в соответствии с изменениями палеогеографии. Существует некоторое предельное значение скорости отложения пород, меньше которой структура не способна продуцировать /аккумулировать углеводородное вещество в существенных или промышленно привлекательных количествах. Это наблюдение может быть использовано как практический метод для связи реконструкций развития структуры с ожиданиями, касающимися ее углеводородного потенциала. За исключением палеоцена и эоцена остальные стратиграфические интервалы в структуре были благоприятны для накопления органического вещества в потенциальной материнской породе, по крайней мере, в концентрациях выше кларковых.

Ключевые слова: углеводородный потенциал, обратный демонтаж, палеопрофиль, темп отложения, число Кларка.