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Migration Pathways of Hydracarbons in South-Caspian Basin

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Abstract

In paper features of migration of hydrocarbons (primary, secondary and tertiary) in geological conditions of the South-Caspian basin (SCB) are considered. On the assumption of non-uniform character of the industrial petroleum content, regularities of variation in space litho facial characteristics of rocks and development of overpressures, about various efficiency of expulsion of hydrocarbons from source rocks in various parts of SCB is concluded. Considering, that the layers generating and accumulating hydrocarbons, are shifted in a sedimentary section relative to each other, as well as the young age of petroleum fields, predominance in SCB sub vertical secondary migration along faults, cracks systems and channels of mud volcanoes is proved. Evidences of reformation and destruction of the subsurface hydrocarbon accumulations are: industrial petroleum content in young deposits (lying above the main basin reservoir), widely development at the earth surface a macro- and micro-seepages.

Keywords: Hydrocarbons; Primary/expulsion; Secondary; Tertiary migration; Pathways; Horizontal; Sub vertical; Mud volcano conduit; South caspian basin.

Introduction

Petroleum migration pathways control the distribution of oil and gas in sedimentary basins [1-4] and therefore it is one of the most important and controversial problems in oil and gas ontogenesis.

The complexity of this problem appears in full with regards to formation of oil fields in main reservoir in the South Caspian basin (SCB)-Productive series (PS, Lower Pliocene), especially in view of existing of predominant opinion that they are formed by migration from underlying Oligocene-Miocene source rocks. In this case it is necessary to identify the dominant form, direction and distance of oil migration. Primary oil migration is especially controversial topic in the geological conditions of the SCB because Oligocene-Miocene source rocks are massive shale sequences. The role of tectonic faults and mud volcano channel in migration and petroleum fields' formation in PS was not fully estimated.

Process of migration appears relatively simpler only with respect to syngenetic oil and gas formations such as in Maikop (Oligocene-Low Miocene) and Diatom (Middle-Upper Miocene) source rocks in SCB.

Until now has been no general analysis of spatial changes of properties and the degree of filling of the SCB structures that could spill light on the direction and scale of regional migration of petroleum.

The history of development of the SCB is characterized by change of several phases of tectonic activation of the subsurface that evidently regulates phases of the hydrocarbons migration. Therefore, the study of tectonic control of migration of hydrocarbons presents significant scientific and application interest.

The ideas and concepts of migration of hydrocarbons in sedimentary basins including the SCB developed with expansion of the knowledge about their evolution and modern structure, improvement of isotope-geochemical methods of studying of organic matter, oil and gas.

Some aspects of a considered problem though were touched in separate works, however, special, purposeful and generalizing researches on the given problem was not carried out till now.

A large scope of fundamental studies of rock, oil and gas of the SCB has been completed in the last twenty years. These studies formed a good basis for investigation of the hydrocarbons migration problem in SCB at new modern level.

Primary migration of hydrocarbons

The problem of expulsion of oil and gas generated in the source rocks for a long time has been a subject of debates among scientists. These debates touch upon the following aspects: mechanism, phase state of hydrocarbon fluids, driving force and migration pathways.

The history of geological development and geological structure of the SCB define the specific aspects of migration, especially of primary migration of hydrocarbons. These specific aspects are regulated by the following factors:

• Avalanche sedimentation rate due to which rate of squeezing-out of sediment waters was significantly lower than the rate of subsiding and sediments compaction. In other type of basins (for example in old cratonic basins) compaction and squeezing-out of bulk primordial pore waters occurs at the depths of up to 2 km, but in the SCB this processes is extended to depths of up to 4 km. Additionally, the oil window under abnormally low temperature conditions in SCB is shifted on the depth intervals of 5-9 km (in the central part of the basin). Therefore the transport of oil in the form of molecular solution in pore/sedimentation waters in the SCB cannot be considered as a potential mechanism of primary migration of oil because the intensive water squeeze-out and large-scale oil generation processes in the sedimentary section are shifted relative to each other (Figure 1).

• Formation of the massive Oligocene-Miocene source rocks sequence with significant thickness that exceeds 3,000 meters in the central part of the basin.

• Absolute prevalence (up to 80-90%) of fine-pelitic fraction in the source rocks with restricted presence of very think sand- and siltstone layers in the major part of the section (visible on outcrops and almost absence such layers on well LOG records).

In connection with the above mentioned the classical scheme of primary migration of oil (Figure 2) where oil is only sub-vertically

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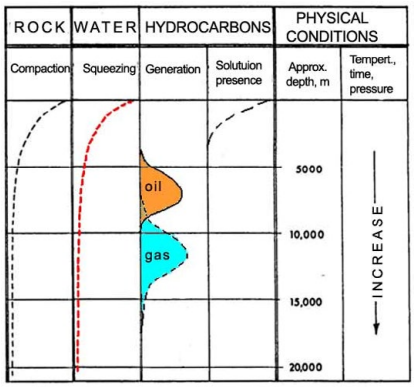

Figure 1: Relation of descharge peak of connate waters and oil and gas generation peaks in sedimentary section of the SCB.

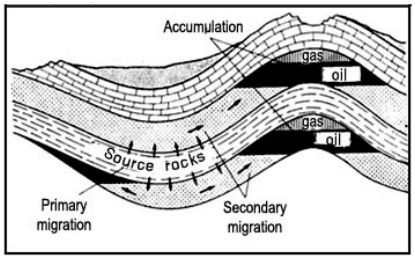

Figure 2: Classic scheme of primary migration of hydrocarbons [21].

squeezed out from the source rock into contacting upper and lower permeable carrier rocks that is acceptable for shale layers inter bedded with sand-and silt rocks (sandwich like section) is not applicable to geological conditions of the SCB.

Experiments proved that in case of large thickness of massive clayey source rocks the oil generated in its central part is locked and cannot be expelled into the carrier rocks. It is appeared by abnormally high pore pressure that provokes formation diapirism and mud volcanism.

Variable efficiency of expulsion of hydrocarbons from source rocks in different parts of the SCB is suggested proceeding from the irregular character of commercial oil and gas saturation of the SCB and concentration of the main hydrocarbon resources in the Absheron region (onshore and offshore), relationships of spatial variations of litho logical and facial composition of rocks and development of overpressures.

So, development of overpressures in the Baku Archipelago (Figure 3) is one of the obvious indicators of obstructed discharge of hydrocarbons formed in the source rocks. Possibly, this can explain the problem of commercial saturation of the structures in this area and relatively low efficiency of prospecting of commercial accumulations of hydrocarbons [5].

In this conditions primary migration unlike its classic concept will probably has pulsating- explosive character. When pressure will reach the critical level exceeding a threshold of strength of rock, hydrocarbons will be impulsively thrown out on the tripped system of horizontal and vertical cracks in carrier beds or fluidized clayey mass will be along fault squeezed out upwards in the form of diapir. The primary migration of hydrocarbons will have continuous-intermittent character mainly in the gas/gas condensate phase. However, it is necessary to take into account that the process of hydrocarbon migration in the SCB has short duration because assumed effective primary-secondary migration of oil started here in the Late Pliocene. Such kind primary migration should occur in the source rock many times over geological time to ensure movement of significant volumes of hydrocarbons sufficient for forming commercial accumulations. In this connection it is necessary to consider a role of seismicity of SCB in the hydrocarbons migration processes, characterized shallow hypocenters of earthquakes. Seismicity facilitates amplification of the pulse intensity of migration of fluids.

Probably, primary migration of hydrocarbons is characterized by rather high efficiency in the Absheron oil and gas bearing region (onshore and offshore) where main hydrocarbon resources of SCB are concentrated. The sedimentary section in this region is characterized by frequent alternation of shale and sand-silt rocks existence of the thin sand-silt micro layers (millimeter and centimeter thickness visible in outcrops (Figure 4), but not detected by well logging) favorable for high efficiency of oil expulsion. Besides, Miocene shale of the Absheron area has laminated structure/flat organic matter network (Figure 5)) and the horizontal micro fractures existence. All the above mentioned could be facilitated by sub horizontal migration of hydrocarbons in the source rock up to the nearest vertical hydrocarbons discharge point (sub vertical tectonic fault).

It is important to note, that availability in the source rocks of the horizontal cracks network, serving favorable ways for sub horizontal migration of hydrocarbons, it is noted many researchers [6-9].

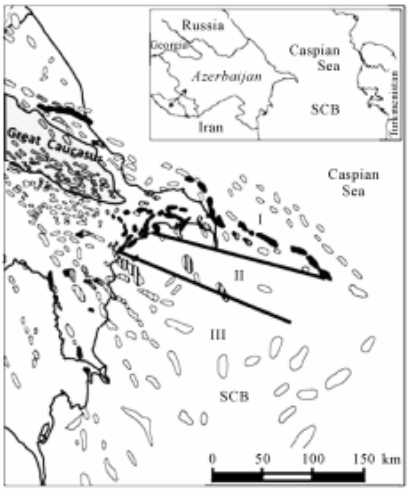

Figure 3: Formation pressure distribution zones in the SCB: I–hydrostatic pressures (Absheron p-la and Absheron archipelago); II–enhanced pressures (South Absheron water area); III–overpressures (Baku archipelago).

Figure 4: Fragment of some outcrops of Maikop Series in the SCB.

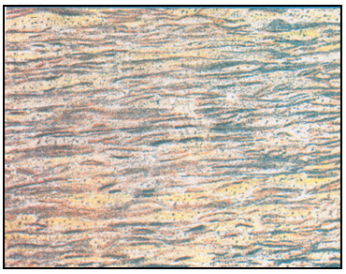

Figure 5: Microphotograph of thin-section (x90) showing characteristic texture of Miocene shale (well 132, 239-248 m) in the Absheron Peninsula.

Pressure on submerged rock layers will be decreasing from the central part of sedimentation basin to its margins. For this reason the fluids both in reservoirs and in massive source rock sequences will be mainly move towards the margins of the basin to highly permeable vertical fractures and dislocations. This is also facilitated by the fact that usually at the deeper depth lateral effective pressure is lower than vertical effective pressure (Figure 6).

Non-deep focus seismicity of the SCB facilitates pulse amplification of the intensity of hydrocarbon migration. It is known that after an earthquake horizontal stress and fluid pressure sharply decreases. Average decrease of statics stress during an earthquake is 3-6 MPa [10]. It indicates that repetitive seismic shock contributes to a pulse horizontal discharge of fluids.

Secondary migration

Unlike primary migration that occurs in tight low permeable source rock the secondary migration takes place in more permeable and porous carrier beds and reservoirs. Tracing of the petroleum migration process has been confirming very useful for optimizing of petroleum exploration.

Epigeneticity of the main portion of oil resources in the Productive strata (Lower Pliocene) of the South-Caspian Basin (SCB) currently is the prevalent point of view [11-17] that is based on the results of extensive isotopic and geochemical studies of organic matter, oil and gas, rock-rock, source rock-oil correlation and basin modeling.

Study of depth of generation of oil (based on biomarkers) and gas (based on carbon isotopic composition of ethane) demonstrated that their sources are shifted relative to each other (Figure 7).

Comparisons of the accumulation and generation depths in the SCB [18] of oil and gas (Figure 8), respectively, showed that there is no correlation between them.

Oligocene-Miocene sediments are considered to be the most real source of this oil. Assuming prevailing epigenetic concept of formation of hydrocarbon fields in the Productive series and taking into consideration their young age (it does not exceed 1 million. years) it is most likely that the main portion of hydrocarbons was supplied from the source to reservoirs by filtrational mass transfer (subvertical migration along deep faults, tectonic dislocations, channels of mud volcanoes). The range of vertical migration of main portion of oils supposedly is around 4 km, but it is greater for hydrocarbon gases and reaches up to 10-11 km (Figure 7).

In view of the above it is logical to suggest existence of the conduits feeding by hydrocarbons the structures in Productive series, generated in underlying sediments. Intrusion into structures of hydrocarbons from relatively greater depths, owing to their sub vertical migration on these conduits, undoubtedly, should be reflected in physical, isotope-geochemical, hydrochemical, etc. fields. This theoretical postulate was tested based on the example of huge offshore Gyuneshli field (shallow part), that have rather statistically representative data base.

Gyuneshli field is situated in asymmetric structure, with sharp S-W

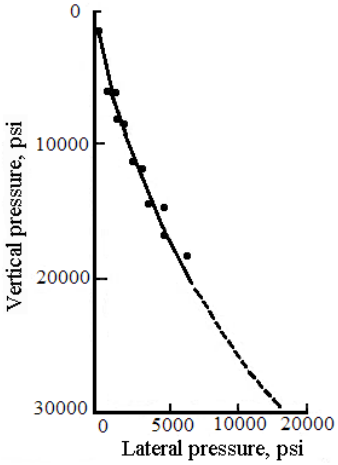

Figure 6: Relationship between vertical and horizontal pressure in sedimentary section [22].

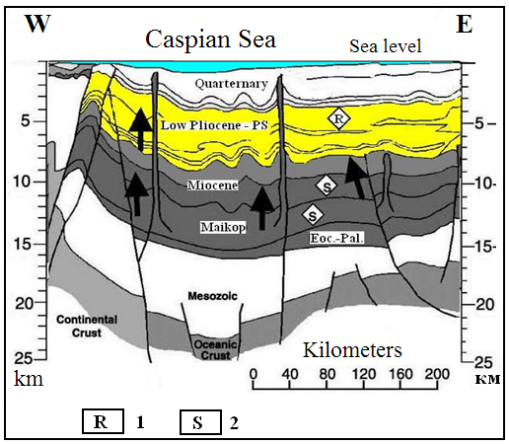

Figure 7: Model of petroleum systems in the SCB: 1-reservoir; 2-source rocks.

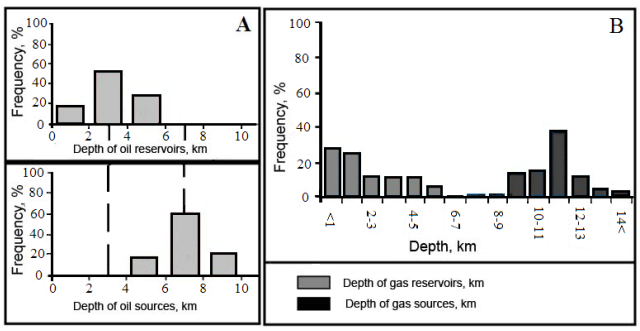

Figure 8: The scheme of comparison of the oil and gas generation (estimated) and accumulation depths in the SCB.

and more gentle N-E limbs. It is dissected by numerous faults and has a block structure. Commercial accumulations of hydrocarbons are situated in Productive series and attributed to arch and tectonically screened type. The relationships of areal distribution of formation pressure and temperature at Gyuneshli structure based on the data measured in more than 60 wells (depths 2600-3800 m) and recalculated to the depths of 3 km are shown on Figure 9b and 9c) [19].

Certain similarity of distribution of both parameters is seen on the schemes shown on Figure 9b and 9c: presence of local areas with high pressure and temperature values on the background of relatively moderate values. The location of areas with high formation pressures and temperatures is very well aligned reflecting their common nature. The most significant zone of high values of both parameters is observed in the S-E part of the structure. Significantly smaller local areas with high pressure and temperature are observed in the west of central part of structure.

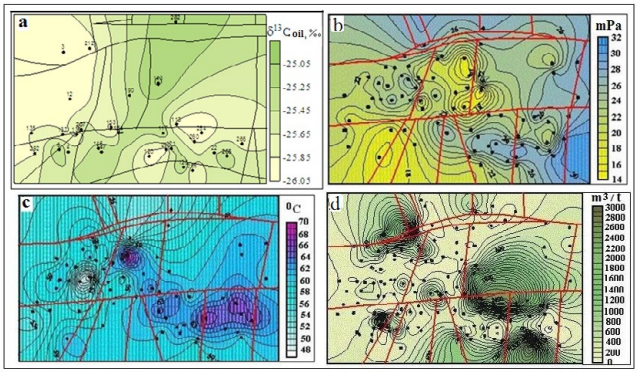

Figure 9: Scheme of areal distribution of isotopic composition of carbon in oil (a), formation pressure (b), temperature (c) and GOR (d) in Productive series (at the depth of around 3 km) in Gyuneshli field.

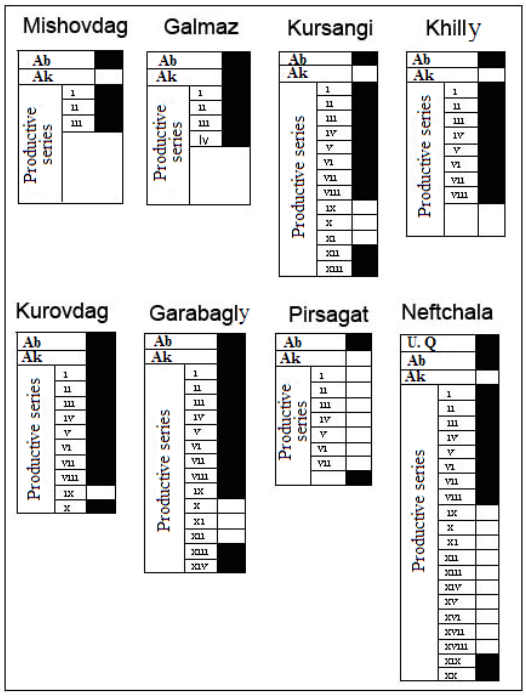

Figure 10: Petroleum bearing intervals of Absheron and Akchagyl suits of Productive series in the Low Kura depression.

Regularities of variations of isotope composition of carbon (ICC) in oil are especially interesting. Previously carried out studies of ICC of kerogen in source rocks and oil-source rock correlation [14,15] revealed that this genetic parameter is very clearly reflects presence of two main genetic oil groups. The first genetic oil group, characterized by relatively light ICC, is a derivative mainly of the kerogen of Oligocene-Lower Miocene source rocks (Maikop Series) and the second group is the derivative of kerogen of Upper-Middle Miocene (Diatom suite). Oils of Productive series is a mixture of these two genetic groups. But towards deeply submerged part of the SCB the share of the second oil group is increasing [20].

According to Figure 8a it possible note, that here local sites both light and heavy ICC of oils are allocated. This indicates that there are favorable conditions for vertical migration in this area and oil migrates into the structure from different genetic sources. However, the large anomaly in the S-E part of the structure that is characterized by relatively light ICC of oil is more deeply rooted.

Tertiary migration

The other aspect of migration in connection with preservation of the hydrocarbon accumulations are the process that is named tertiary migration. It can start in the result of a natural breakdown of cap rocks due to faulting or fracturing. This process can lead to re-formation (re-allocation) and even to destruction of hydrocarbon accumulations. As a rule, process of tertiary migration leads to more significant changes of quantitative and qualitative composition of hydrocarbons than secondary migration.

Discovering of commercial petroleum accumulations of hydrocarbons in the Absheron (Quaternary) and Akchagyl (Upper Pliocene) suites in a several fields of Low Kura (Figure 10) and Absheron petroleum bearing regions in SCB is a evident indicator of process of re-formation of underlying hydrocarbon accumulations in main reservoir of SCB-Productive series.

The explosive primary/secondary migration of hydrocarbons in the form of fluidized shale moving upward along the fault up to reservoirs (diapir-shaped) is transformed into a mud volcano at the surface. From this moment the migration is characterized as tertiary migration because hydrocarbon gases (sometimes oils) are continuously and explosively discharged into the atmosphere (hydrosphere in offshore) facilitating destruction of subsurface hydrocarbon accumulations (Figure 11). The tertiary micro flows of hydrocarbons are manifested by formation of epigenetic gas anomalies above commercial petroleum accumulations (Figure 12).

Figure 11: Examples of surface discharge of gas and oil along the channels of mud volcanoes.

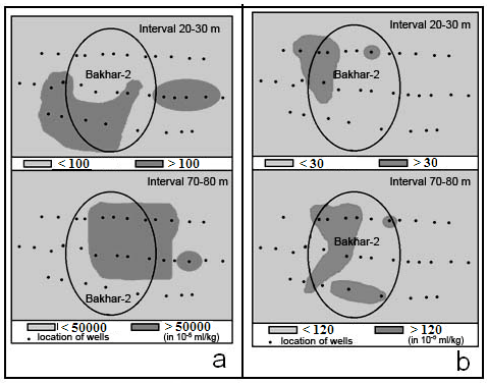

Figure 12: Distribution of methane (a) and sum of its homologous (b) at different depths in sea bottom over Bakhar-2 offsore fields.

Conclusion

Based on gathering and generalization of results of theoretical and experimental worldwide studies, analyses of litho facial characteristics of the Oligocene-Miocene source rocks both in well sections and at outcrops, macro and micro features of texture of these rocks, thermo-dynamic conditions of their occurrence main forms, phases, directions and distance of migration of hydrocarbons in geological conditions of the SCB were examined. These comprehensive studies allowed to obtain a more complete understanding of formation of hydrocarbon fields in the geological conditions of the SCB and to draw the following basic conclusions:

• The transport of oil in the form of molecular solution in connate waters cannot be considered in the SCB as a potential mechanism of primary migration of oil because bulk of these waters was discarded up to the depth of 3-4 km, but oil window is situated at depths interval 5-9 km.

• The Absheron petroleum bearing region (onshore and offshore) where the primary hydrocarbon resources are concentrated have more favorable conditions for primary migration of hydrocarbons in comparison with Baku archipelago. Occurring of overpressures in the Baku archipelago is one of the evident signatures of hindered expulsion of hydrocarbons generated in the source rocks. Possibly, this can explain the low efficiency of prospecting of commercial accumulations of hydrocarbons in this area. In this conditions primary oil migration unlike the classic concept will probably has pulse/explosive character. This kind of continuous-intermittent process of the primary migration of oils is assumed mainly in the gas/gas-condensate phase.

• Pressure on submerged rock layers will be decreasing from the central part of sedimentation basin to its margins. For this reason the fluids both in reservoirs and in massive source rock sequences will be mainly move laterally towards the margins of the basin to highly permeable vertical fracture, faults, conduit of mud volcanoes and then due sub vertical migration along this pathways to reservoir.

• Case study of one of larges in SCB Gyuneshli petroleum field, based on spatial distribution of formation pressures and temperatures, isotopic composition of oil carbon and GOR in Productive series presence of the fault systems, feeding structures by hydrocarbons from underlying sediments was established.

• Discovering of commercial petroleum accumulations of hydrocarbons in the Absheron (Quaternary) and Akchagyl (Upper Pliocene) suites in a several fields of Low Kura and Absheron petroleum bearing regions in SCB is an evident indicator of process of re-formation of underlying hydrocarbon accumulations in main reservoir in SCB-Productive series.

• The process of destruction of hydrocarbon accumulations in the SCB is expressed by multiple large-scale hydrocarbon macro seepages, related with deep faults and mud volcanoes. The tertiary micro flows of hydrocarbons are manifested by formation of epigenetic gas anomalies above commercial petroleum accumulations

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