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Evaluation of the trends of secondary and tertiary hydrocarbon migration processes based on oil density–reservoir depths relationship in Hungary

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Depth of reservoirs of Hungarian oil fields and related oil density data were collected from the database of the Hungarian Mineral Resource Inventory. The purpose of the investigation was to point out the correlation between oil density and reservoir depth in some of the Hungarian hydrocarbon productive regions. Oil density related to reservoir depth in a particular area is generally linked to the migration mechanism. Zala Basin trends show a different migration process regionally and locally; tertiary migration by overflow mechanism can be supposed for the latter case. In the case of the Szeged–Kiskunság region, locally and regionally, migration along carrier beds through semipermeable sediments is present, with faults playing a significant role. In the Nagykunság region, the migration processes are similar to those in Zala, but the presence of faults seems more important. At depths below 2,000 m, the Bihar region trends are similar to those of the Szeged–Kiskunság region. In the shallower zone, hydrodynamic effects are recognizable. In two studied regions, the Battonya–Pusztaföldvár High and the Hungarian Paleogene Basin, the density of crude oil data does not show any significant variability and trend. Biodegradation and water washing were recognizable in the depth sections shallower than 2,000 m below surface. In karstic reservoirs of the Zala Basin (Nagylengyel, Sávoly), alteration is presumed at greater depths due to the karst water flow. The presented results show several trends of oil migration in the explored areas, which can be used for future estimation of the hydrocarbon potential in the Hungarian part of the Pannonian Basin.

Keywords: hydrocarbon migration, petroleum, secondary migration, crude oil alteration, oil density, dissolved gas, Zala Basin, Hungarian Great Plain, Hungarian Paleogene Basin

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Introduction

In Hungary, as in the most parts of the world, there is demand for the production of crude oil and natural gas. The discovery of prospective hydrocarbon resources is also expected based on different hydrocarbon play concepts. To estimate the hydrocarbon potential of the Pannonian Basin, it is necessary to understand the hydrocarbon generation–migration–accumulation process as thoroughly as possible. The spatial distribution of different petroleum density within a field or even within a geologically similar region contributes to the understanding of migration processes.

The record of hydrocarbon mineral resources in the Hungarian Mining and Geological Survey contains data on the quality parameters of crude oil accumulated in the hydrocarbon fields, in addition to data on resource quantity. Examples of such parameters are density, viscosity, sulfur content, dissolved gas content of the oil, and the qualitative composition of dissolved gas and the gas cap.

The density differences of oil in reservoirs located close to each other in a field indicate the changes that occur during the accumulation process, both in the migration path and in the reservoir. Spatial distribution of oil density specific to each subbasin may reflect regional sedimentary basin development processes. The aim of this work was to study secondary and tertiary oil migration processes and post-fill alterations in the reservoirs based on the depth and density distribution of crude oil accumulations. It is our hope that the results contribute to a better understanding of the hydrocarbon potential in Hungary and surrounding analogous areas within the Pannonian Basin.

Secondary migration is a process by which hydrocarbons are transported from the matured source rock to the places of accumulation (traps). This type of migration occurs through permeable and porous carrier beds and reservoir rocks, as opposed to primary migration (through dense, almost impermeable source rocks). Variations in crude oil composition are to a certain extent inherited from different source rocks. The primary driving force for secondary migration is the vertical buoyancy force due to the lower density of oil and gas compared with that of formation water, which can be modified by subsurface water potential gradient. Secondary migration terminates in hydrocarbon reservoirs, but tectonic events, such as folding, faulting, or uplifting, may be cause redistribution of filled oil or gas pools (tertiary migration, Fig. 1; Tissot and Welte 1984).

Hydrocarbon accumulations have survived extended periods of geologic time. During these periods, the physical and chemical conditions of the accumulation in the reservoir could have been changed. Since petroleum is thermodynamically metastable under geologic conditions, it responds to these changing conditions by adjusting its composition, which leads to the original composition becoming altered. Geologic processes, which lead to compositional alteration and their effects on oil density, are schematically illustrated in Fig. 2. Alteration of the hydrocarbon in the reservoir may affect the composition of a crude oil to a greater extent than does the character of the source material (Tissot and Welte 1984).

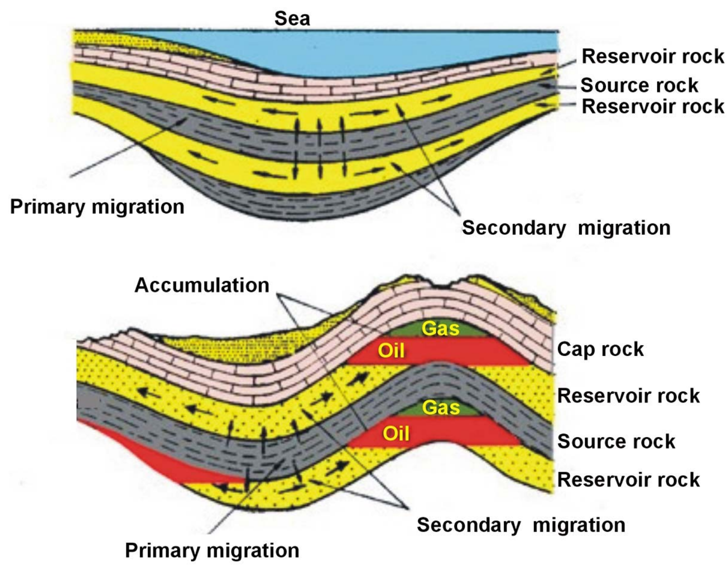

Fig. 1
Primary and secondary migration pathways (Tissot and Welte 1984)

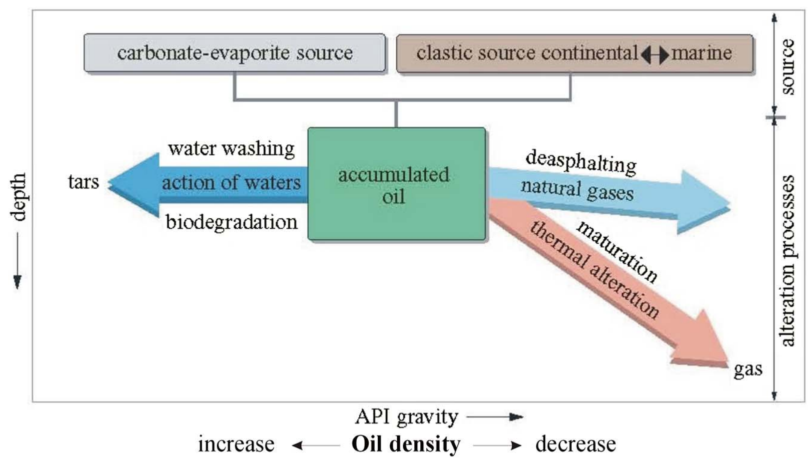

Fig. 2
Effects on a typical oil due to differences in source rock types and by alteration processes (Leythaeuser 2005, after Tissot and Welte 1984)

The driving philosophy of our work was that basically two migration mechanisms are known: overspill mechanism along carrier beds (Gussow 1954) and slow migration through lithologic barriers, in the form of semi-permeable sediments (Silverman 1965).

In the first case, oil density increases along the migration route, whereas in the second case, density decreases. Interpretation of the migration processes and crude oil alterations detailed in this paper were based on the works of Gussow (1954), Silverman (1965), Tissot and Welte (1984), England et al. (1987), Verweij (1993), Leythaeuser (2005), and Bjørlykke (2010). Preliminary results were featured in the presentation abstract of Kovács and Zilahi-Sebess (2017).

Studied subbasins, data, and methods

In considering hydrocarbon exploration and production in Hungary, four geographic regions can be distinguished, along with some smaller units: (1) the Great Hungarian Plain (including Kiskunság, Szeged Basin, Battonya High, Nagykunság, Hajdúság, Nyírség, and Jászság); (2) the Zala and the Dráva Basin areas; (3) the Hungarian Paleogene Basin; and (4) the Danube Basin (Little Plain), as seen in Fig. 3.

The different reservoir and source rocks, generation, migration, and accumulation, as well as different styles of trap formation can be linked to each evolutionary stage of the basin formation. In Hungary, several Mesozoic and Cenozoic crude-oil-generating source rocks are known (Fig. 4).

In the Zala Basin, at least two different source rocks can be distinguished, based on the chemical composition of oils. The proven source of the Nagylengyel crude oil is the Upper Triassic Kössen Marl. Other sources include probable Upper Cretaceous

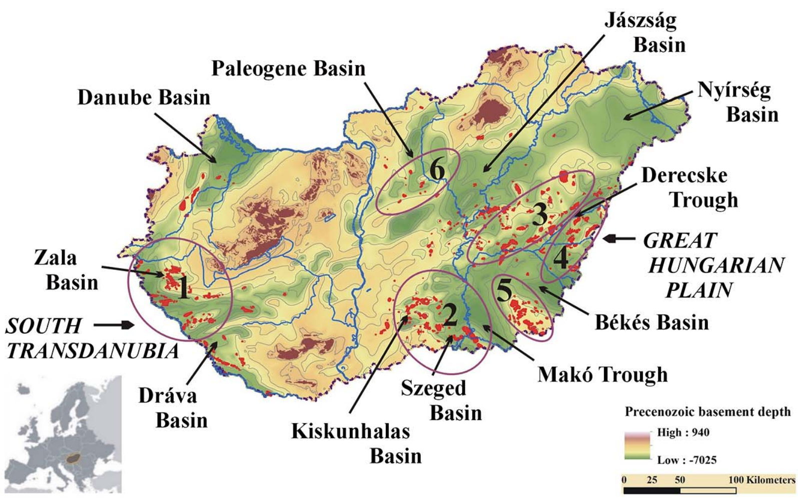

Fig. 3
Hydrocarbon-generating sedimentary basins and the studied crude oil accumulation areas (red patches: oil and gas fields). 1: Zala–Dráva Basin (South Transdanubia), 2: Szeged–Kiskunság, 3: Nagykunság, 4: Bihar, 5: Battonya–Pusztaföldvár High (2–5: Great Hungarian Plain), 6: Hungarian Paleogene Basin

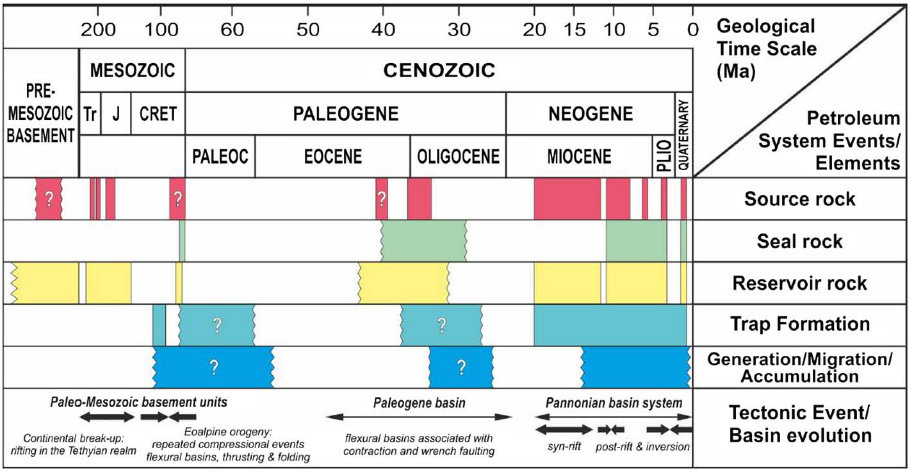

Fig. 4
Petroleum systems and events of the Pannonian Basin (Bada and Tari 2012)

(Jákó and Polány Marl) and Middle Miocene (Badenian–Sarmatian age) marls (Baden Fm., Szilágy Marl; Clayton and Koncz 1994a). Sources of Szeged–Kiskunság region oils are possibly Middle Miocene marls (Baden Fm., Badenian age) and the Upper Miocene (Lower Pannonian age) Tótkomlós Marl Member of the Endrőd Formation, along, especially, with Jurassic shale in the basement of Kiskunság (Milota 1991; Badics and Vető 2012). The main sources of the Hungarian Great Plain oils are also Middle and Upper Miocene marls, Jurassic shale in the middle part of the Hungarian Great Plain (Horváth et al. 1988; Szalay 1988; Clayton and Koncz 1994b; Koncz and Etler 1994; Horváth and Tari 1999). Upper Eocene–Lower/Middle Miocene marl (Buda Marl and Tard Clay) and shale (Kiscell Clay) are the sources of the oils of the Hungarian Paleogene Basin (Milota et al. 1995).

Depth of oil–water contact data of oil field reservoirs and related oil density data were collected from the database of the Hungarian Mineral Resource Inventory. The data from 769 reservoirs of 142 oil fields were available from the inventory database. Original oil in place resources of reservoirs is 332 million tons, of which almost 100 million tons were produced in the past 80 years (Kovács and Fancsik 2015). The data from 308 reservoirs in 53 oil fields had been collected, which seemed to be suitable for the investigation. The main aspect of the selection was to provide as much data as possible within a given field. Finally, oil density and dissolved gas content data were collected: for the evaluation of the Zala region, 62 reservoirs in 7 fields; for the Szeged–Kiskunság region, 116 reservoirs in 9 fields; for the Nagykunság region, 32 reservoirs in 10 fields; for the Bihar region, 49 reservoirs in 5 fields; for Battonya, 29 reservoirs in 13 fields; and for the Paleogene Basin, 20 reservoirs in 9 fields.

Results

The plots defining the relationship of oil density versus reservoir depths, of dissolved gas versus reservoir depths, and of dissolved gas versus oil density can be studied in Figs 5–16.

For a better understanding of the migration mechanism, dissolved gas content versus depth and oil density versus dissolved gas content graphs were plotted. The dissolved gas content of the crude oils generally increases with depth, and the dissolved gas content is higher in the lower-density oils. Therefore, substantial deviations from the general trend may call attention to tertiary migration phenomena or to subsequent alterations in the reservoir.

Zala Basin

The prevailing oil density versus depth relationship in the Zala region (Fig. 5) is that generally lighter oils are in a shallower position. On a field scale, the relationship is that

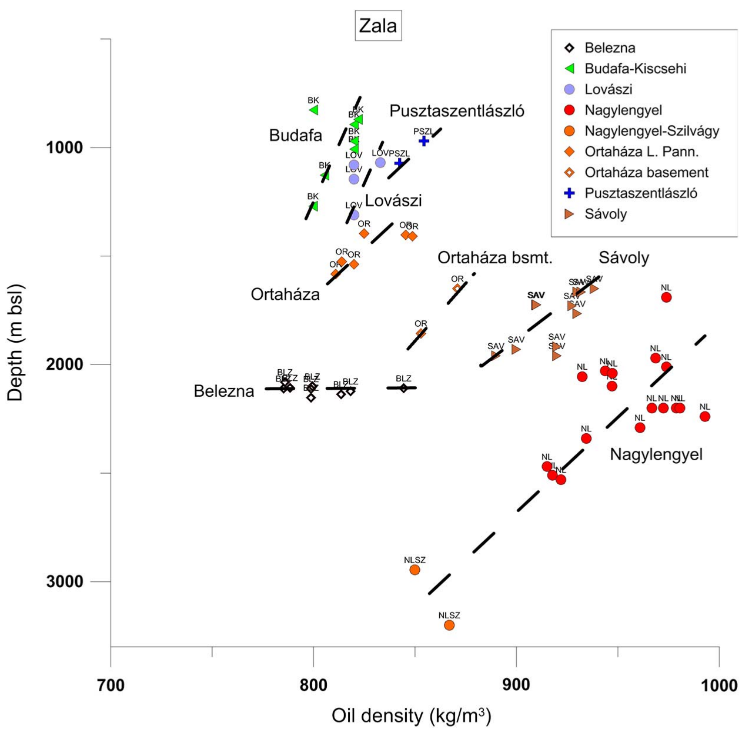

Fig. 5
Oil density versus depth relationship in the Zala Basin, South-West Transdanubia (differently colored marks are oil density–depth data values of reservoirs; possible trends were marked with dashed lines)

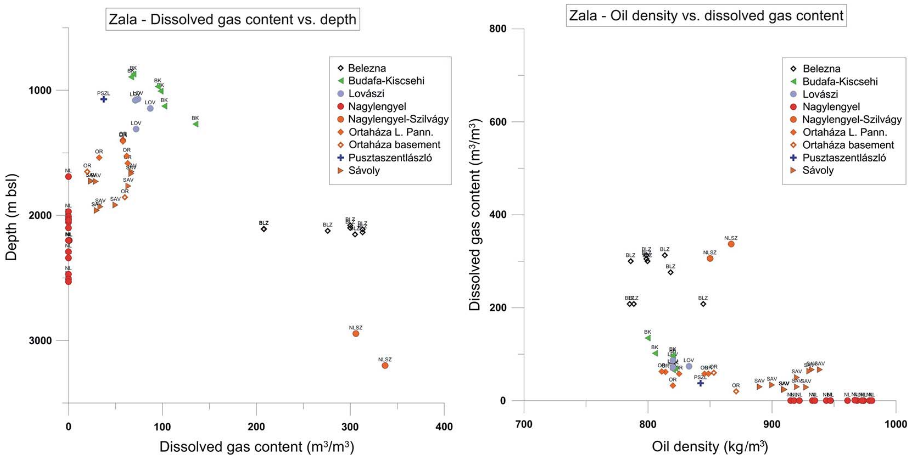

Fig. 6
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Zala Basin

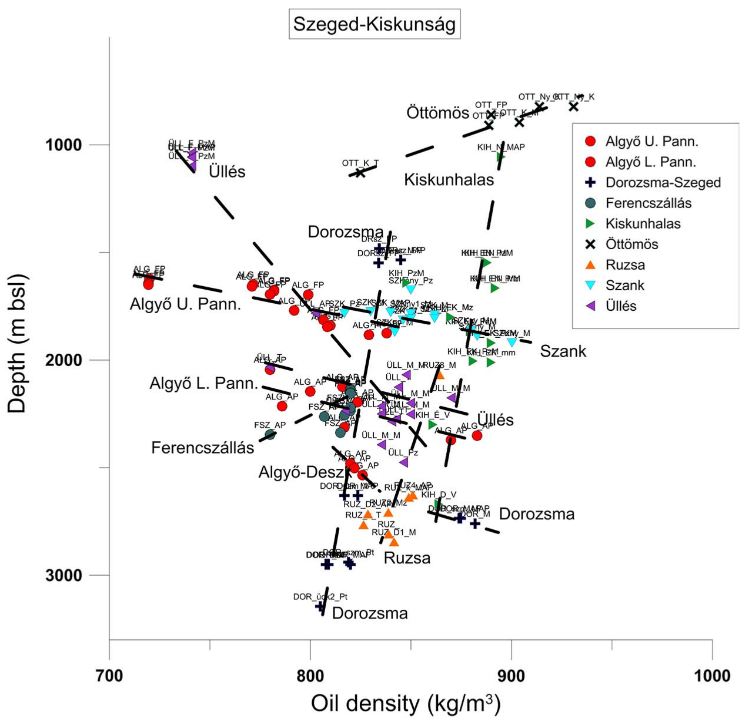

Fig. 7
Oil density versus depth relationship in the Szeged–Kiskunság region, South Great Plain

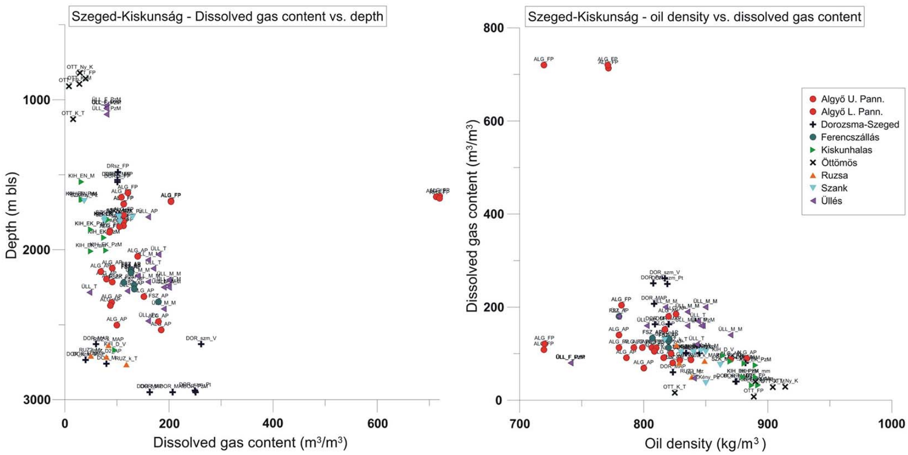

Fig. 8
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Szeged–Kiskunság region

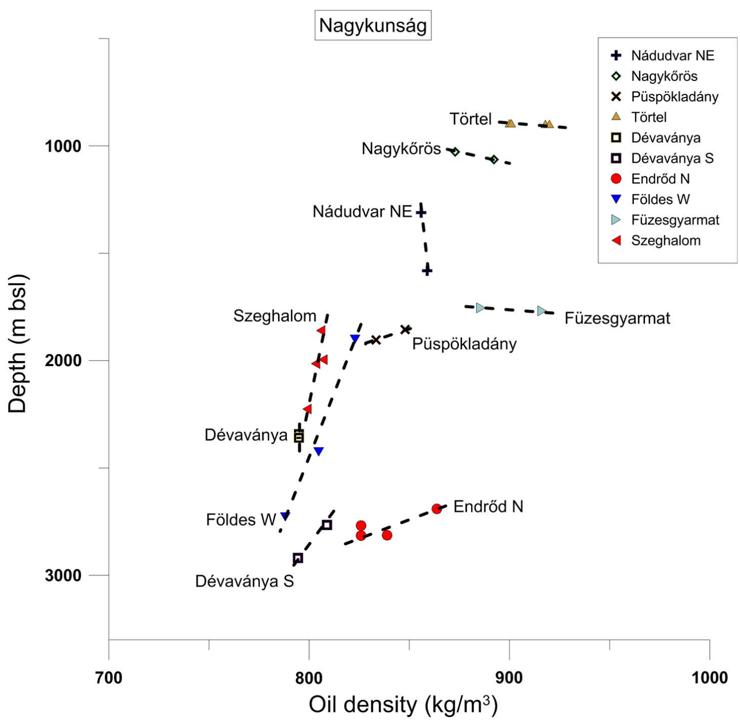

Fig. 9
Oil density versus depth relationship in the Nagykunság region, middle part of Hungarian Great Plain

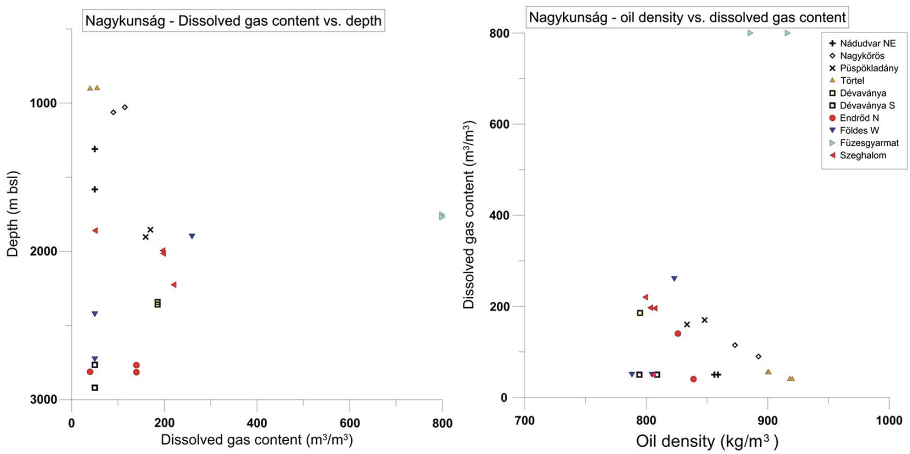

Fig. 10
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Nagykunság region

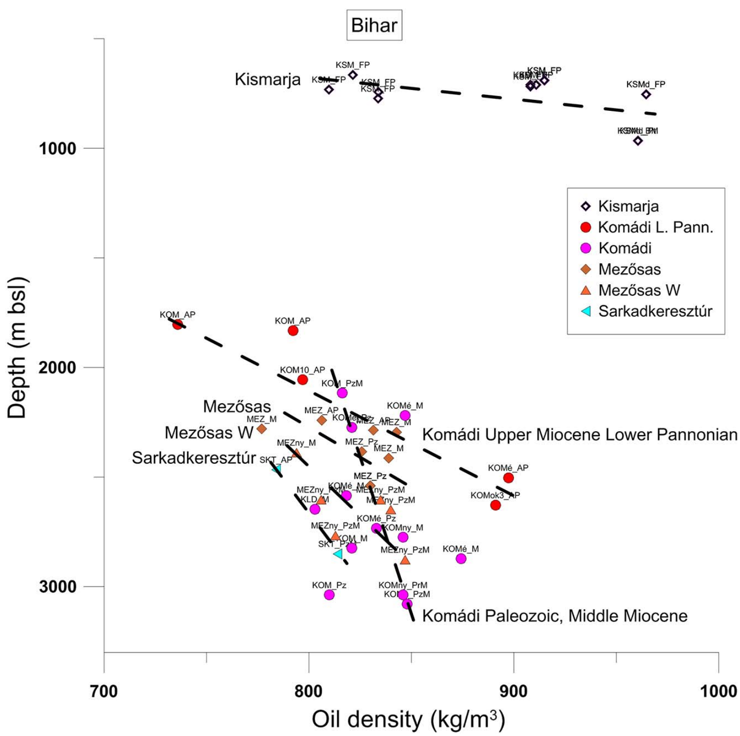

Fig. 11
Oil density versus depth relationship in the Bihar region, South-East Great Plain

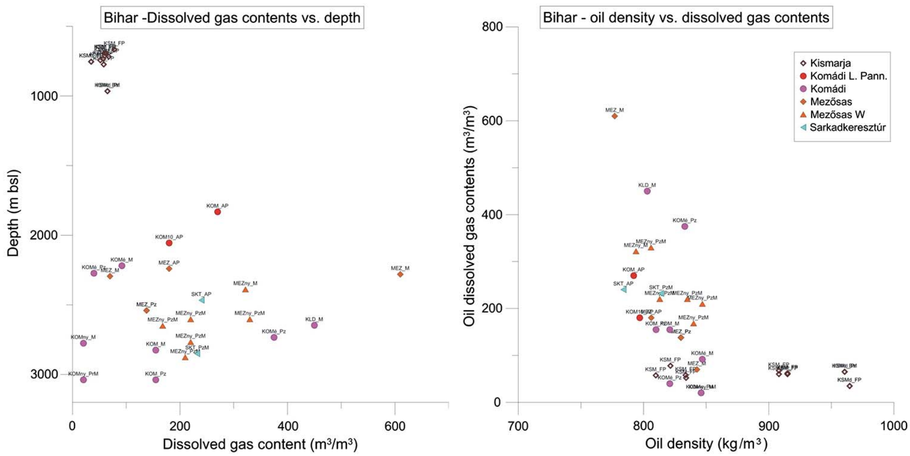

Fig. 12
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Bihar region

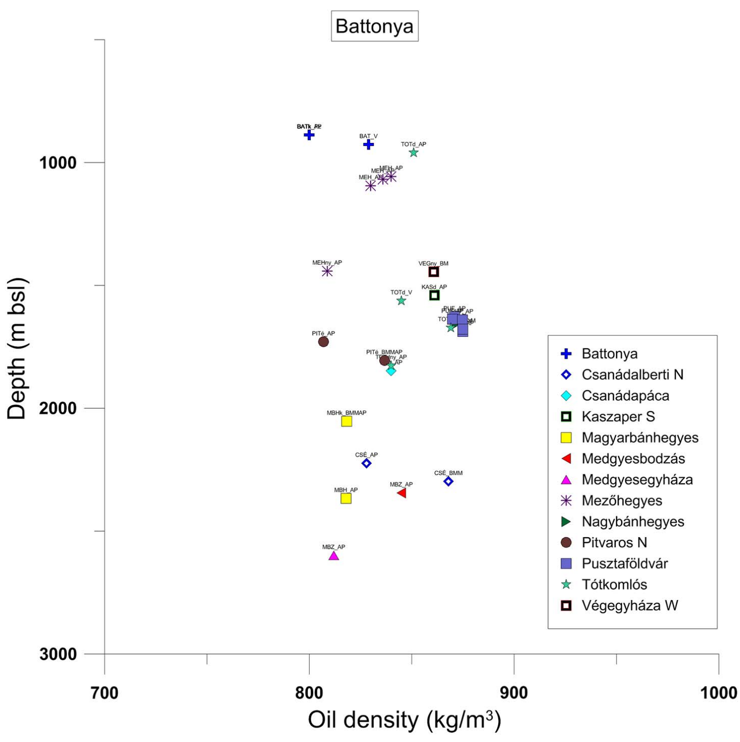

Fig. 13
Oil density versus depth relationship in the Battonya–Pusztaföldvár High region, South Great Plain

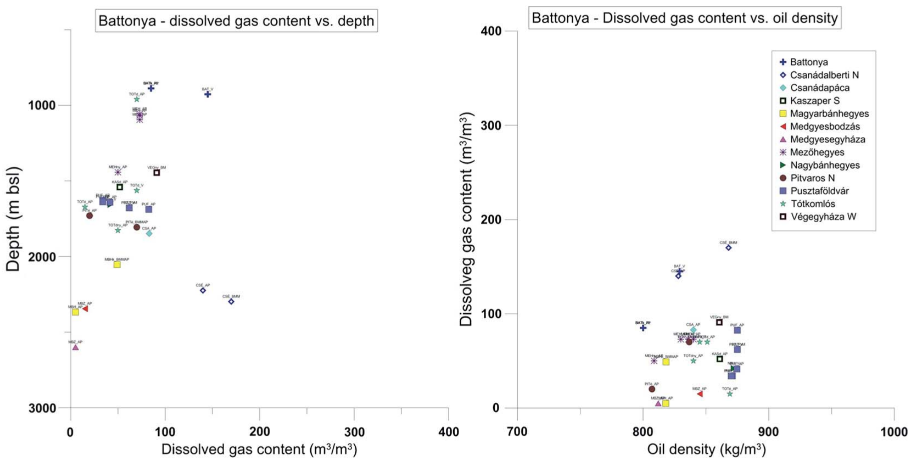

Fig. 14
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Battonya–Pusztaföldvár High region

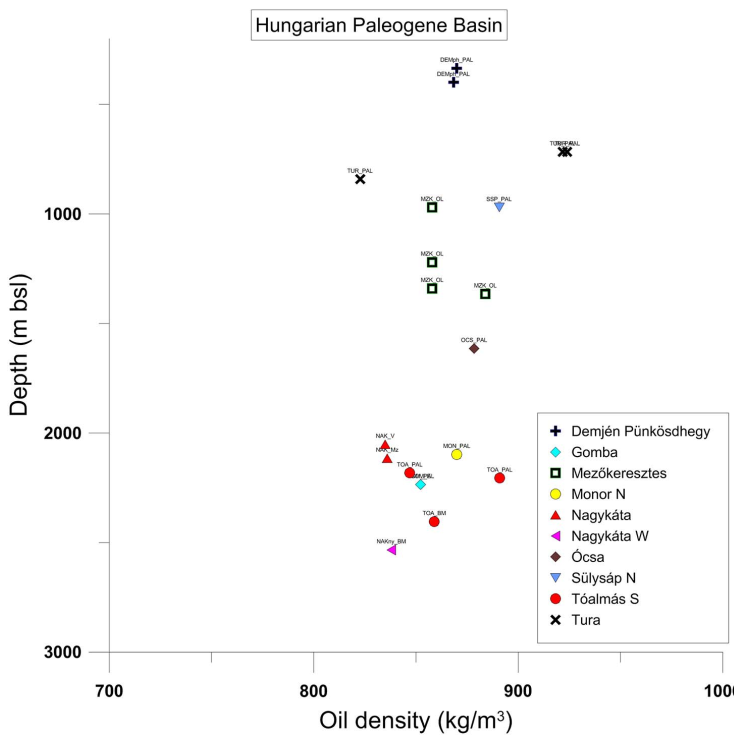

Fig. 15
Oil density versus depth relationship in the Hungarian Paleogene Basin, North Hungary

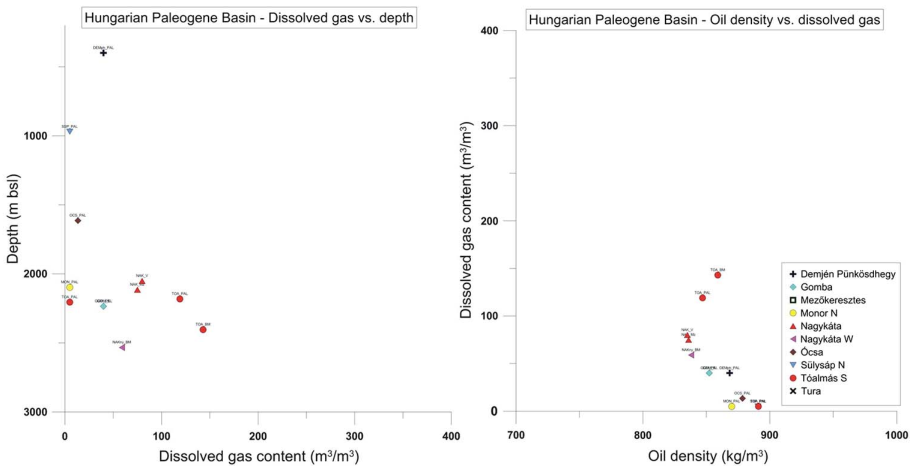

Fig. 16
Dissolved gas content versus depth and oil density versus dissolved gas content data relationships in the Hungarian Paleogene Bain

the shallower the depth, the greater the oil density. The deeper the average depth where migration is taking place, the stronger is the tendency of inversely proportional change of oil density with depth. This suggests that the primary segregation process was a kind of separation mechanism according to carbon-chain length through semi-permeable sediments. Overflow mechanism is indicated by the density distribution of crude oils. The increasing density with decreasing depth trends occurs only locally and suggests tertiary migration mechanisms within earlier formed reservoir groups, in which the individual reservoirs within a group were hydraulically connected to each other.

Reservoirs of Nagylengyel, Sávoly, and partly Ortaháza and Pusztaszentlászló are in the Mesozoic (Upper Triassic, Upper Cretaceous limestone, and dolomite formations of the pre-Cainozoic) basement. Some upper reservoirs of Nagylengyel, Sávoly Pusztaszentlászló, and Ortaháza, all of the reservoirs of Belezna, Budafa, and Lovászi are located in Middle–Upper Miocene sandstone or coarse-grained limestone.

The Nagylengyel–Szilvágy and Belezna reservoirs can be distinguished with regard to high-dissolved gas content (Fig. 6). In the case of Szilvágy, this can be explained by thermal maturation, whereas for Belezna, the type of generating source rock and the compactness of the seal rocks are the key elements. For Nagylengyel and Sávoly fields, low-dissolved gas content and high oil density values can be explained by water washing; gas and light hydrocarbon components may have been washed out from the karstic reservoirs by deep karst water flow.

Szeged–Kiskunság

Reservoirs of this region are situated in varied Paleozoic–Mesozoic magmatites and carbonates (the Öttömös, Dorozsma, Kiskunhalas, Ruzsa, and Üllés fields), Middle Miocene conglomerates, calcareous marl, coarse-grained limestone (the Öttömös, Kiskunhalas, Dorozsma, Ruzsa, Szank, and Szank-West fields), Upper Miocene (Lower Pannonian), conglomerates, turbiditic, and delta slope sandstone (the Algyő, Dorozsma, Ferencszállás, Szank, and Ruzsa fields), and Upper Miocene (Upper Pannonian) sandstone (the Algyő, Dorozsma, and Öttömös fields). In the case of Algyő, Szank, and Üllés, the specific trend is that the shallower the depth, the lower the oil density (Fig. 7). This may have been caused by a separation mechanism of oil migrating through fine-grained shaly sediments. The steep trends of Dorozsma, Ruzsa, and Kiskunhalas can have been caused by the oil migrating along tectonic surfaces. In the opposite trend of Öttömös, post-trapping alteration (degassing, water washing, and biodegradation) of crude oil can be supposed because of the relatively near-surface position. In some cases, in the Algyő Upper Pannonian reservoirs, the dissolved gas content of oils is much higher than in other oils in this field (Fig. 8). Otherwise, the distribution of dissolved gas content versus depth and dissolved gas content versus oil density trends is normal. This means the greater the depth, the higher the dissolved gas content; the lower the oil density, the higher the dissolved gas content.

Nagykunság

There were only few data available to evaluate the migration processes of the area, because the reservoirs of natural gas are significantly more frequent than oil reservoirs. Fields with one or two reservoirs are common. Oils were trapped in the pre-Cenozoic basement rocks (the Dévaványa, Dévaványa South, Endrőd North, Szeghalom, and Püspökladány fields), in Middle Miocene conglomerates, limestone, and sandstone (the Dévaványa, Endrőd North, Szeghalom, Füzesgyarmat, Püspökladány, and Nagykőrős fields), Upper Miocene (Lower Pannonian) sandstone and marl (Nádudvar Field), and Upper Miocene–Pliocene (Upper Pannonian) sandstone (Törtel Field). Reservoirs of Szeghalom, Dévaványa, Földes, and Endrőd are situated in the southern part of the region, whereas Püspökladány, Füzesgyarmat, Nádudvar, Nagykőrös, and Törtel are in the northern sub-region.

In the deeper parts of the Nagykunság region subbasin, the main trend is that the denser oils are in a shallower position (Fig. 9). This can have been caused by degassing, by overflow mechanism of the oil flow, by migration along fault surfaces, and possibly by biodegradation at depths above 2,000 m.

In the case of reservoirs at moderate depth, an opposite, slightly sloping trend can be seen. It can be explained by migration through semi-permeable, low compaction, horizontally interconnected, coarser-grained carrier-bed sandstone, with better porosity–permeability properties.

Southern reservoirs below 1,800 m are different in the density-to-depth relationship and in dissolved gas content (Fig. 10). The oil of Szeghalom, Dévavénya, Földes W, and Endrőd shows an increasing upward trend, and the dissolved gas content increases with the density of oils. The dissolved gas content of the top reservoirs does not show any trend; the gas contain is low, and degassing in the direction of surface occurs.

Bihar

It seems to be a clear trend, in the case of the reservoirs of the Komádi, Mezősas, and Sarkadkeresztúr fields, that the higher the average depth, the higher the density of oils (Fig. 11). These oils were trapped in the pre-Cenozoic basement rocks (the Komádi, Mezősas, Mezősas West, and Sarkadkeresztúr fields), in Middle Miocene argillitic sandstone (Komádi Field) and in Upper Miocene (Lower Pannonian) turbiditic sandstone (the Komádi, Mezősas, and Sarkadkeresztúr fields). Separation during the migration process can have occurred when oils had migrated along the carrier bed in fine-grained, shaly sandstone and turbiditic sandstone. In the case of migration from near basement reservoirs of Komádi to shallower depths, the role of migration along faults and fractures can be significant. Oils in the Upper Miocene/Upper Pannonian silty sandstone reservoirs in the Kismarja Field migrated up from the deeper part of the basin, where the mature source rocks had been situated. In the Kismarja Field, the alteration of trapped oil may be supposed as having been caused by biodegradation or water washing. At depths below 2,000 m, the mostly argillitic sediments and randomly deposited turbiditic sandstone may not be interconnected to each other, whereas in the case of Kismarja, the relatively younger sandstones are presumably horizontally interconnected. At this shallower depth, the rate of compaction is low, and the horizontal groundwater flow effect may be more significant compared with the deeper-situated argillitic sandstone.

Dissolved gas versus depth and versus oil density figures (Fig. 12) show that the oils of Kismarja were degassed, and that the density of oils in some reservoirs increased, presumably because of biodegradation and/or water washing. Dissolved gas contents have low to intermediate values, without any significant trends.

Battonya–Pusztaföldvár High

Oil density data of reservoirs in the Battonya–Pusztaföldvár High vary within a relatively narrow range in the area. Significant differentiation cannot be observed (Fig. 13). The depths of the accumulations are in correlation with the local elevation of the Paleo–Mesozoic basement high; the reservoirs are usually directly in the fractured basement rocks or in the basal conglomerate, as well as in the overlying limestone and fractured marl. In the case of a few reservoir data pairs, lighter oils are located in a higher position, suggesting migration through semipermeable shaly rocks.

The density–depth data suggest that the oil probably comes from a single source rock, presumably from the Middle–Upper Miocene (Lower Pannonian) Tótkomlós Member of the Endrőd Marl (Clayton and Koncz 1994b); hydrocarbon traps were reached through lateral migration in the carrier bed. In some cases, the reservoirs were situated in the natural fractures of the marly source rocks. Post-trapping alterations of oils are unlikely, due to the thick, shaly overburden rocks; the dissolved gas values do not exhibit any extreme values (Fig. 14).

Hungarian Paleogene Basin

The density of crude oils in the reservoirs of the basin lies within a narrow range (Fig. 15). Traps were likely reached through short migration paths for the oils. Tura Field oils, at shallower depths, are denser, which could be a result of biodegradation.

The shallow depth of Demjén Field, which is situated on the southern edge of the Bükk Mountains, indicates a significant, possibly even 1,000 m, uplift of the Paleo–Mesozoic basement, based on the fact that mature source rocks can be found near the depth of the accumulation.

The oils contain a small amount of dissolved gas, presumably because of degassing and water washing (Fig. 16).

Conclusions

The scope of our work was the investigation of trends between the depth of reservoirs and the density of crude oils in six characteristic hydrocarbon subbasins, to identify the dominant trend, and the possible migration mechanisms, for each studied area.

Zala Basin trends show a different migration process regionally and locally; tertiary migration by overflow mechanism can be supposed for the latter case. In the case of the Szeged–Kiskunság region, locally and regionally migration along carrier beds through semipermeable sediments occurred, but the role of faults is very significant. In the Nagykunság region, the migration processes are similar to those in Zala, but the presence of faults seems more important. At a depth below 2,000 m, the Bihar region oil versus depth trends are similar to those of the Szeged–Kiskunság region. In the shallower zone, hydrodynamic effects are recognizable.

In two studied regions, the Battonya–Pusztaföldvár High and the Hungarian Paleogene Basin, the density of crude oil data does not show and significant variability or trend. The reason is presumably the short distance between the mature source rock and the place of trapping, and the limited migration distances along faults.

The general regional trends are summarized in Fig. 17.

The possible oil density–depth trends and the assumed physicochemical processes of the studied subbasins are summarized in Fig. 18.

The recognition of the dominant migration mechanism is a characteristic element of the hydrocarbon system of each subbasin. Knowledge of the hydrocarbon migration

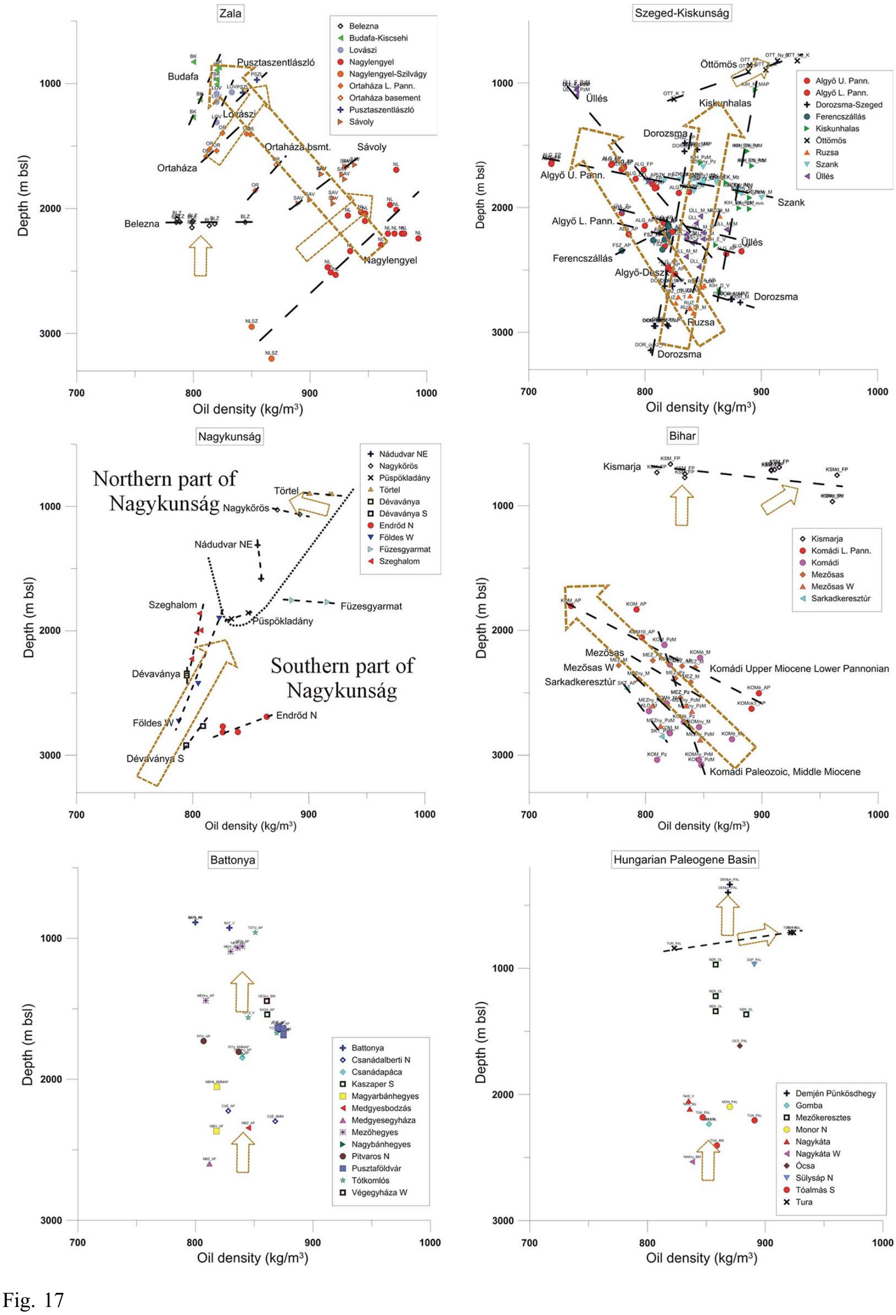

Fig. 17
The main oil density–depth trends of migration processes in the studied regions (large arrows: regional trends, small arrows: local trends)

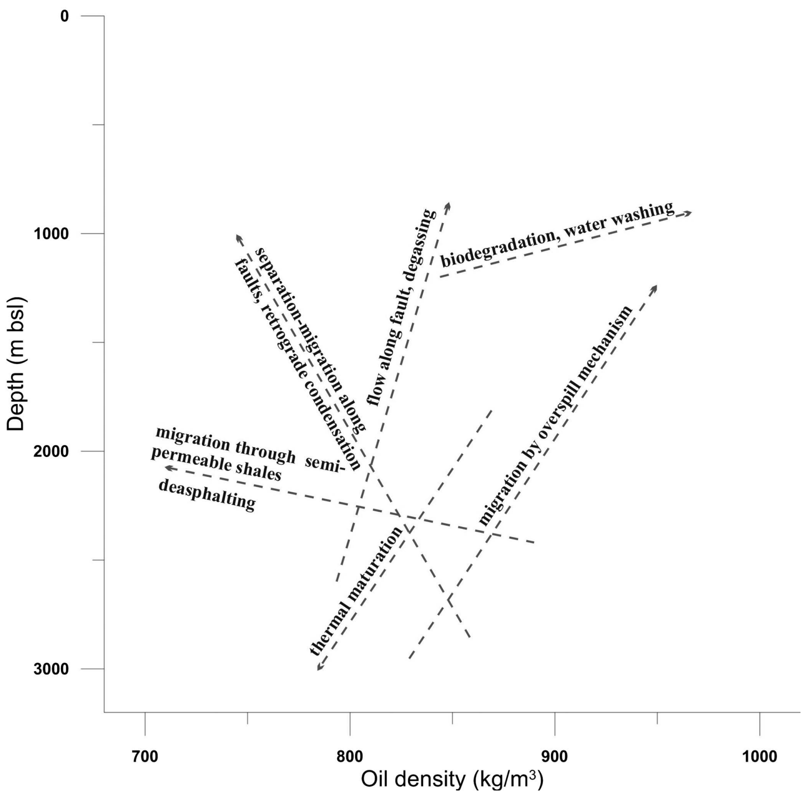

Fig. 18
Possible oil density changes in the studied hydrocarbon subbasins

process and of the oil density–reservoir depth trend evaluation results help us understand the situation in the different locations of hydrocarbon accumulations in the Pannonian Basin. A similar published comparative study has never been published for the Hungarian part of the subbasins, so this scope of studying migration processes can be considered as a pioneer attempt. A second stage of the study is planned, which would incorporate hydrocarbon generation type and maturity data of possible source rocks within subbasins.

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