PALEO-RECONSTRUCTION MODELS AND GEOLOGICAL EVOLUTION OF THE NORTH-WESTERN PART OF THE THRACE BASIN

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ABSTRACT. In a tectonic aspect, the study area is located in the Madzharovo depression, which passes in the south-southeast to the large oil and gas Thrace basin in Turkey. This gives grounds to consider the region as its north-western board and to regard it in the context of the processes leading to the formation of the sedimentary complex in the entire Thrace basin. In the present study, based on stratigraphic and structural interpretation and analyses that present new information on the nature of the basin space, paleo-reconstruction models have been created, describing the basin filling and the geological evolution in the different stages of the basin system formation: the beginning of sedimentary complex deposition was during the Palaeocene and Early-Middle Eocene Age and it took place under strong tectonic influence; during the Priabonian Age, conditions for the formation of depressions with various shapes were created, as well as for the establishment of a marine environment all over; an approximate paleo-reconstruction has been created for the Oligocene Epoch, which illustrates the varied environment of the sediment formation and deposition. The created paleo-reconstruction models allow to trace back the stages of formation of the basin system, as well as to determine a mutual geological evolution of the sedimentary sequences on the Bulgarian and the Turkish territory. On a more global scale, the analysis of the basin space permits the identification of the main depocentres in this part of the basin and the correct and accurate assessment of the studied area regarding its oil and gas potential.

Key words: paleo-reconstruction models, north-western board of Thrace basin

МОДЕЛИ НА ПАЛЕОРЕКОНСТРУКЦИЯ И ГЕОЛОЖКО РАЗВИТИЕ НА СЗ ЧАСТ НА ТРАКИЙСКИЯ БАСЕЙН

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РЕЗЮМЕ. В тектонско отношение изследваният район е разположен в Маджаровското понижение, което на юг-югоизток преминава към големия нефтогазоносен Тракийски басейн в Турция. Това дава основание районът да се разглежда като негов северозападен борд и в контекста на процесите, водещи до образуване на седиментния комплекс на целия Тракийски басейн. В настоящото изследване, въз основа на стратиграфска и структурна интерпретация и анализи, представящи нови сведения за характеристиката на басейновото пространство, са създадени модели на палео-реконструкция, характеризиращи басейновото запълване и геоложкото развитие в различните етапи на формиране на басейновата система: през палеоцен-ранно-средноеоценската епоха е началото на отлагане на седиментния комплекс, което се извършва под силно тектонско влияние; през приабонския век се създават условия за образуване на различни по форма понижения и повсеместно налагане на морска обстановка; за времето на олигоценската епоха е създадена приблизителна палео-реконструкция, която илюстрира разнообразна обстановка на седиментоотлагане. Създадените модели на палео-реконструкция позволяват както да се проследят етапите на формиране на басейновата система, така и да се установи общото геоложко развитие на седиментния комплекс на българска и турска територия. Анализът на басейновото пространство, в по-глобален мащаб, дава възможност за идентифицирането на основните депоцентрове в СЗ част на Тракийския басейн и за съвременна оценка на изучаваната територия по отношение нефтогазоносната ѝ перспективност.

Ключови думи: модели на палео-реконструкция, северозападен борд на Тракийския басейн

Introduction

In a tectonics aspect, the study area is located in the Madzharovo foothill depression on the Bulgarian territory (Fig. 1), which passes in the south-southeast to the large oil and gas Thrace basin in Turkey and can be considered as its northwestern board (d’Atri et al., 2012; Cavazza et al., 2013). As an element of it, nature and the processes of sedimentation in the structural-tectonic units should be considered not only within the borders of our country, but in the whole Thrace basin. Due to its economic accent, the Thrace basin has been studied by many authors in different aspects - less in its Bulgarian part (Goranov and Atanasov, 1989; Doncheva et al., 2005; Balinov at al., 2013) and more beyond the border (Gorur and Okay, 1996; Coskun, 2000; Turgut and Eseller, 2002; Elmas, 2012; Cavazza et al., 2013).

In order to correctly and properly assess the study area, which is the subject of this research, in reference to both its oil and gas potential and sustainable extraction of ore and fuel raw materials in it, it is necessary to analyse the basin space on a more global scale. This is a result of the fact that the formation of the studied sedimentary basin, controlled by tectonic processes and depending on the interaction of tectonic movements and sedimentation processes, takes place on an area, including outside our state border.

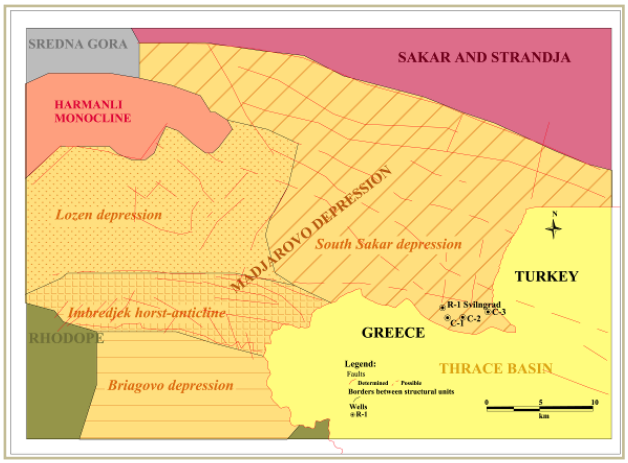

Fig. 1. Detailed tectonic scheme of the study area (according to Boyanov, 1971; Dabovski and Zagorchev, 2009, with author's additions)

Method of the research

The characteristics of the basin space are made on the basis of the information from geological and geophysical surveys carried out in the area and around it. To perform the geological interpretation, the data were used from the mapping at different scales, from gravimetric and magnetometry surveys, from 2D and 3D seismic surveys, from several instances of shallow explorational drilling for ore minerals, and also information from the scarce volume of drilling and geophysical surveys and gas exploration, all held in the area. The data and analyses from the field surveys in the geological mapping were compared with the data from the seismic surveys, which were useful in order to correlate the faults and the main stratigraphic boundaries and lithological units.

Analysis of the basin evolution

Despite numerous studies of theThrace basin in Turkey, the period of its initiation and subsequent geological evolution are still under discussion by Turkish researchers (Turgut and Eseller, 2002; Siyaco and Huvas, 2007; Elmas, 2012). A general conclusion is made that the beginning of sedimentation in different parts of the basin starts at different times. This is due to the different inherited forms of the paleo-relief, which are differentiated into distinctive structural highs. In the southwestern part of the basin, sedimentation began in the Early Eocene Age, in its central part - in the Early Middle Eocene Age, and in the northern and north-eastern parts - in the Late Lutetian Age, and continued until the Late Oligocene – Early-Middle Miocene Age.

The Paleocene-Early-Middle Eocene Age

In the central part of the Thrace basin, there is a clearly distinguished elevated structure - Central Thrace High (Coskun, 2000; Elmas, 2012), surrounded on the north and south by branching faults in the WNW-SSE direction. These faults control, on its northern side, the sedimentation of the rocks of the first Early-Middle Eocene sedimentary formation – Hamitabat. The lower part of the formation consists of coarse-grained sediments, which are dominated by conglomerates and breccias, with shallow-marine and lagoonal limestone intervals, while the upper part consists of the typical deep-marine turbidite facies, represented by dark shales with sandstone beddings (Siyaco and Huvas, 2007).

In the interpretations of the seismic surveys and the analyses of the data from the drillings and the field surveys carried out on Bulgarian territory, a similar high is observed in the area of R-1 Svilengrad well, which is assumed (Meracheva and Zaneva-Doranova, 2018) as a continuation of the one from theTurkish territory. To the north from this horst, differentiated by the basement, an additional sedimentary succession is observed, which is marked on the seismic section as a zone with unclear configuration, but with a typical sandy-conglomerate to turbidite facies with a clear lower boundary (Fig.2, dark purple colour) and an upper boundary (Fig. 2, bright purple colour). These rocks on lithological features can be classified as the Biserska and the Leshnikovska Formations with a Palaeocene-Eocene(?) Age and are accepted (Meracheva and Zaneva-Doranova, 2018) as an analogue of the Hamitabat formation.

It can be assumed that the rocks deposited in this part of the examined area show the pattern of a typical turbidite system (Bouma, 2000), whose facies and geometry are determined by the morphology of the bottom of the basin and are strongly influenced by tectonic processes during the formation of the accommodation space. Along the faults, limiting the high from the south, several depocentres are formed, which continue and are best expressed in the central part of the basin in Turkey. When comparing the pattern of sedimentation observed in the present study with the classical models for turbidite systems, several distinguishing features can be established. In the western part of the Thrace basin, on the Bulgarian territory, the typical model of a coarse-grained turbidite system is observed. It is characterised by a narrow shelf and a steep slope, a source of sedimentation near the shoreline, represented by several smaller streams, short transport of sediments from the shelf to the bottom of the basin. Such sedimentary conditions are typical for the areas with transform faults, further complicated by the constant reactivation of the tectonic action. While in the central part of the Thrace Basin, the sedimentation model is a fine-grained turbidite system characterised by a relatively broad shelf and an oblique slope, long sediment transport provided by a major large river system. In the Turkish part of the basin, the turbidite system of the Hamitabat formation is deposited in separate depocenters, with its own sources and pathways of sedimentation, distribution area and nature of the filling sediments (Turgut, 1997; Sünnetçioğlu, 2008). In addition, due to the great influence of the morphology of the paleo-basin, different thickness of sediments with this age is observed.

Based on the analyses performed, it can be assumed that the sedimentation during the Early-Middle Eocene Age (Fig. 3), in the northern and north-eastern parts of the study area, is represented by terrestrial, fluvial-deltaic to shallow-marine and turbidite deposits of the succession correlated to the Hamitabat formation in Turkey, where conditions in the northern and central parts of the basin are similar. Lateral changes in the Hamitabat Formation show that the thickened layers of coarse-grained sediments in the north, in the lower and northern parts of the formation, are deposited under strong tectonic control and move south to shelf and deep-water depositional environment. This tectonic activity has a similar effect on sedimentation on the

Bulgarian territory. In the western part of the studied area, probably the depositional conditions change laterally to the fluvial and alluvial conditions of sedimentation of the rocks from the Biserska and the Leshnikovska formations. In the southern part of the study area, where the continuation of the Central Thrace High extends, in which the R-1 Svilengrad well is drilled and in the Imbredjek horst-anticline (Fig. 1), an absence of sedimentation during this stratigraphic interval is observed.

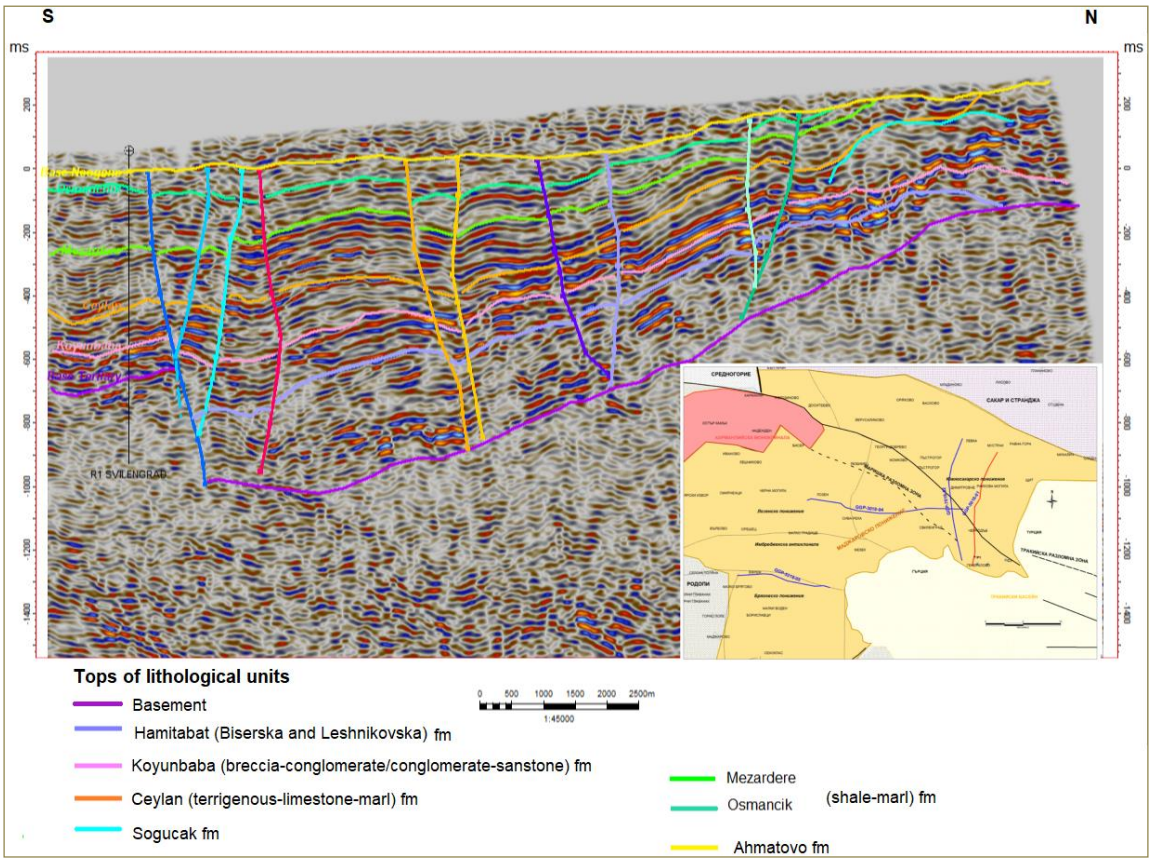

Fig. 2. Interpreted seismic section (in time), illustrating the tops of the main horizons

The Late Eocene (Priabonian) Age

In the elevated structures on the Turkish territory - the southernmost parts of the Strandzha Mountain and the Central Thrace High - directly on the basement, are deposited respectively chaotic coarse-grained clastic sediments with widespread debris flows and olistrostrome horizons of the Akalan Formation, and breccia conglomerates and sandstones of the Koyunbaba Formation. The sediments of the Akalan Formation are interpreted as alluvial-fan and are characterised by block, breccia-conglomerate facies to the north, and fine-grained to the south, correlating with the Koyunbaba Formation. The depositional conditions of the sediments of the formation are shallow-marine, and the age is Early-Priabonian. The observed flow direction of fluvial deposits in the western part of the basin is to the south, and in the east - to the southwest-west.

On the Bulgarian territory, on the basis of field research, in the northern part of the studied area and according to the data from the R-1 Svilengrad well (the region of the South Sakar Depression), sedimentation of the Breccia-conglomerate-sandstone and Breccia-conglomerate formations is observed. At the foot of the Sakar Mountain, the rocks are overlain transgressively and discordantly on the basal parts of the Priabonian succession, especially the areas with a clear onlap. This can be interpreted as onlap to a slope of a paleo-relief or a syn-sedimentary fault. On the seismic sections, this discordant overlying of the rocks can clearly be traced by these Formations, with a distinctive angular unconformity both directly on the basement and on the analogue to the Hamitabat Formation (Fig. 2, top, in pink colour). This sequence shows a strong syn-tectonic evolution of the layers against the main fault, located north of the R-1 Svilengrad well, and in the places of non-conformity to the basement, a distinctive thinning is observed. The conglomerates of the Breccia-conglomerate-sandstone formation, characterised by debris flow and tempestites and obscure layers of sandstone, with poorly sorting, which are outcropping in this northernmost part of the region, indicate fast sedimentation and short transport. Large pieces and blocks of sandstones and marls are an indication of active tectonics and continued expansion of the accommodation space. On the other hand, the established foraminifers in the sandstones of the Breccia-conglomerate formation in the horst, where the deep well is set, prove not only the Priabonian Age, but also the establishment of a marine environment. On the seismic sections, in the considered stratigraphic interval, distinctive reflections are observed, which could be interpreted as fan-shaped sediment bodies (Fig. 2).

In the most south-western part of the study area (the Imbredjek Horst Anticline and the Bryagovo Depression) the Breccia-conglomerate formation is characterised by complex

lateral relationships of lithotypes. From west to east, a better sorting and greater roundness of the pieces is observed, as well as a transition from conglomerate to gravelly-sandy facies. Indications for supply from the south or east-west direction and temporary establishment of alluvial-brackish environment exist. In this region, on the seismic sections with a west-east direction, well-formed channel systems are identified.

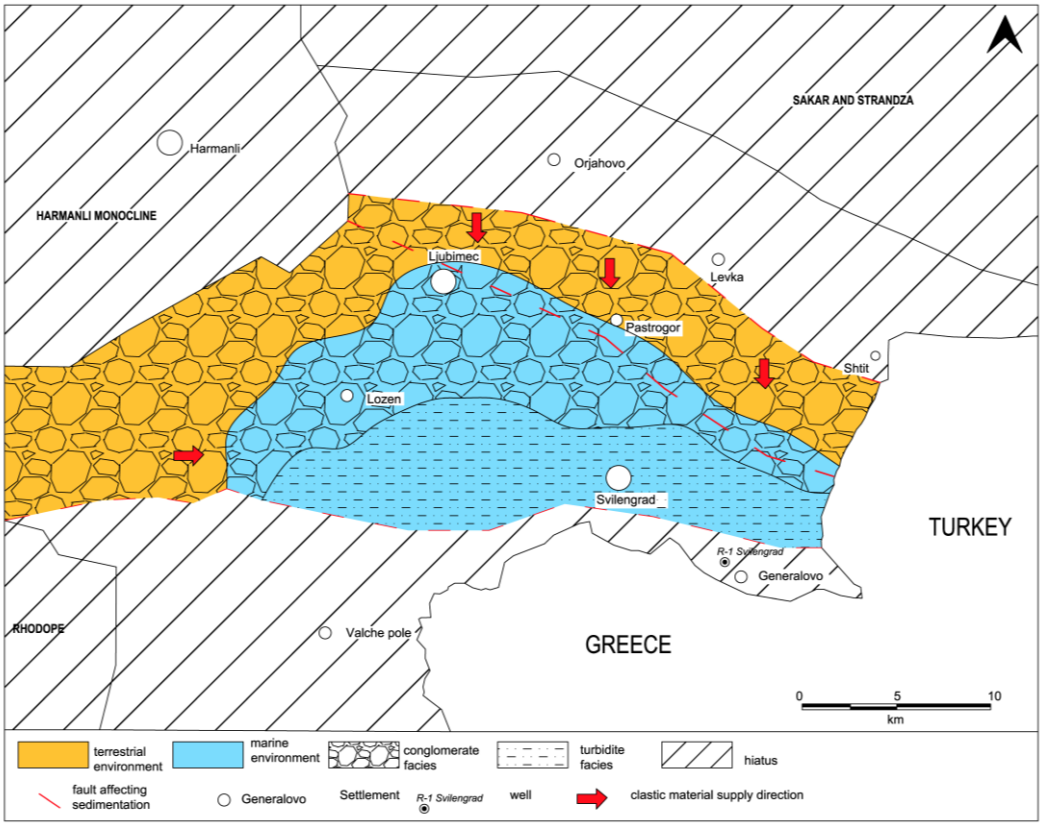

Fig. 3. Paleogeographic scheme of the study area during the Paleocene - Early-Middle Eocene Age

As a result of the analyses, the geological evolution at the beginning of the Late Eocene Age in the studied area can be interpreted as follows (Fig. 4): During the Illyrian folding phase, significant ruptures occurred and low parts of different shapes and sizes were formed, in which the waters of Late Eocene Sea invaded violently, as a result of which a thick conglomerate horizon was formed. The large-amplitude depressions along the main fault initially control diluvium, fluvial, braded river depositional environment and (talus-cone) terrestrial sedimentation, with locally revealed axis alluvial along the basin. Subsequently, after partial compensation of the accommodation space, shallow-marine shoreline sedimentation is established, and the expansion of the basin is from SE to NW. It is probable that sedimentation on the northern side of the basin started later, which is an assumption as a result of the fact that the southern side is much higher and provides an abundant flow of clastic material, while the northern side has low relief and sediments are more mature and more fine-grained. Probably, the main supply is from the south, where the thickness of Eocene sediments is thickest - about 2 km. In the area of the R-1 Svilengrad well, the thicknesses reach several hundred meters and pinch out to the north up to several meters. In the northern part of the South Sakar depression, the influence of the main high-amplitude and many low-amplitude faults with typical syn-tectonic sedimentation is observed. Probably, the initial processes of extension were followed by the activity of compression associated with the Illyrian structural Phase. They are expressed in the deposition of terrestrial sediments, up to several hundred meters thick, in the southern part of the study area. The coarse-grained terrigenous composition of these gravel to boulder and block breccia-conglomerates, the definitely clear indications for short transport, the vein saturated with iron hydroxides, all of these indicate a high rate of sedimentation in continental conditions and tectonic control. This predetermines the rapid differences in thickness in lateral direction and the change with other facies.

On the Turkish territory, in the central part of the basin, terrigenous sediments pass, laterally or vertically, in the stratigraphic range of the Sogucak Formation, which consists of thickly bedded to massive shallow-marine reefal limestones with algae, corals, foraminifera. The carbonate rocks overlay with conformity the rocks of the Koyunbaba and the Akalan Formations, respectively in the Central Thrace High and in the northern parts of the basin (shallow-marine environment), and the rocks of the Hamitabat formation (deep-marine environment). This suggests that they are formed in reef, pre-reef and deep-marine depositional environment from the Priabonian to the Late Oligocene Age (Varol et al., 2009).

On the Bulgarian territory such a limestone level exists, which is assigned, probably due to the complex lateral relations, to the uppermost part of Terrigenous-limestone-marl formation. But these solid limestones with reefal origin, containing numerous remains of bivalves, corals, algae, foraminifera, are clearly traceable, and should therefore be dissociated as a

separate lithological unit, well correlated with the Sogucak formation. They are traced along the entire northern board of the basin and are revealed at the quarry near the village of Shtit, where the south-sloping layers and the progradation in this direction are clearly visible. On the seismic sections, in the northern part near the basement, distinctive chaotic reflections are observed, typical for reefal structures, which have a distinct hummocky shape and typical drape of the overlying clear seismic reflections (Fig. 2, horizon in light blue).

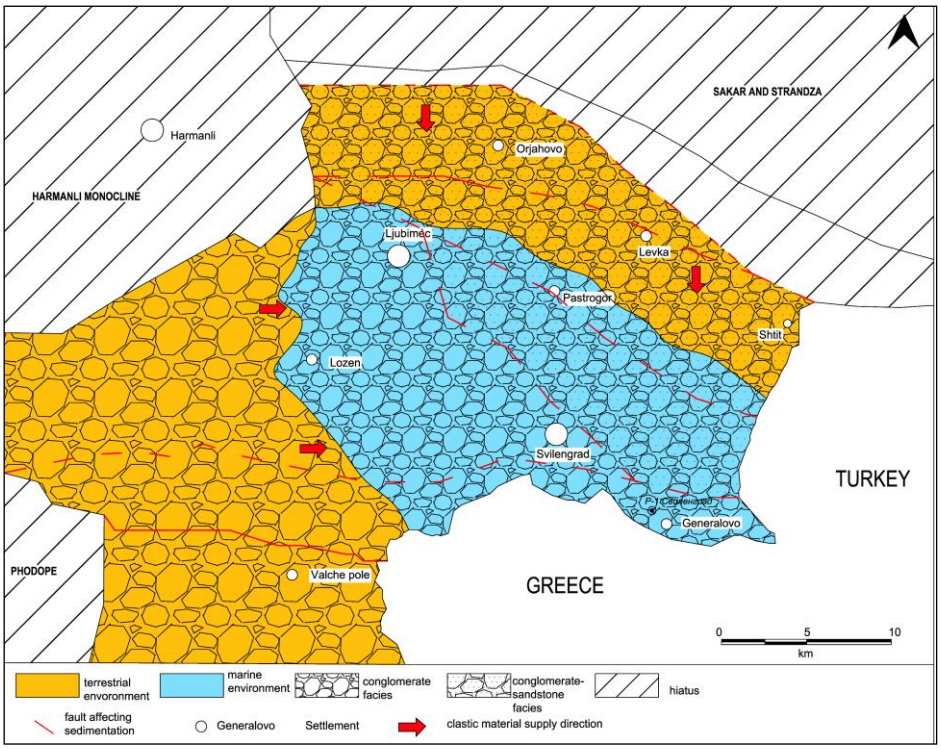

Fig. 4. Paleo-geographic scheme for the beginning of the Late Eocene Age

During the Late Eocene Age, while the limestones of the Sogucak Formation were deposited in the northern parts of the basin, in the central part of the basin in Turkey the processes are associated with the deposition of a sequence of fine-grained sandstones, siltstones, shales, marls, argillite limestones and tuffs of the Ceylan Formation (Elmas, 2012). These data, as well as the presence of foraminifera and nanoplankton, confirm the deepening of the basin in the Priabonian Age. Turkish researchers correlate the successions with the Kesan formation in the southern part of the basin, in which stratums of conglomerates with shale beddings and tuffs are often observed among the turbidite layers.

The layers of sandstones, siltstones and marls of the Terrigenous-limestone-marl formation, with numerous foraminifera in them, located on the Bulgarian territory, gradually pass upward the rocks of the Breccia-conglomerate formation in the horst, where the R-1 Svilengrad well is drilled and northward. This formation gradually passes vertically and laterally westward and south-westward into the Pyroclastic-marl-limestone formation, which consists of marls, sandstones and tuffs. A clearly visible boundary in the seismic sections is not observed, so it is interpreted as part of the Priabonian sequence (Fig. 2, horizon in orange colour). This gives reasons to consider the rocks of these formations as an analogue to the Ceylan Formation from the Turkish territory. The upper boundary of the Ceylan Formation or the Terrigenous-limestone-marl formation is difficult to trace in seismic sections where changes in facies type, formation conditions, and thickness vary widely. What is typical of the northern board of the basin (the section of the South Sakar Depression) is a very rapid change from shoreline to relatively deep-marine sediments, which marks the tectonic control of sedimentation and significant tectonic subsidence of the depocenter.

In the southwestern part of the study area, the rocks of a Coal-sandy formation, which consist of fine-grained sandstones with regularly alternating brakestone to gravelly sandstones (high-density sandy turbidites to matrix-supported debris frow), siltstones, marls in the upper parts, are an indication of deepening of the basin. The presence of olistostromes and olistoliths indicates the activity of intra-basin faults, expanding the accommodation space, imposing an initially brackish and subsequently marine regime and to some extent representing barriers for correlation of the facial zones. However, on the basis of the analyses made, the existence of lateral relations to the south-southeast with the Kesan Formation from the southern part of the Thrace basin in Turkey can be assumed.

Observations and analyses show that in general at the end of the Priabonian Age, the transgression continued until the sea reached the northern parts of the Thrace basin, after that the waters became calmer and the deposition of marls and sandstones began (Fig. 5). At the end of the Late Eocene Age, as a result of the shallowing of the sea waters, regressive marine deposits accumulated - reefal limestones, clay limestones, and calcareous marls. This succession definitely marks a marine environment and a fairly rapid tectonic subsidence with increasing deposition distance. There is mainly a basin nature of the conditions of deposition and separation of lithofacies due to the lateral change of the sedimentation rate, the different

direction of sediment supply, the difference in the degree of subsidence, the volume of accommodation space, and the relative change of sea level. This lateral inhomogeneous sedimentation is increased by the unstable nature of the paleogeography of the basin, which is mainly controlled by tectonic activity.

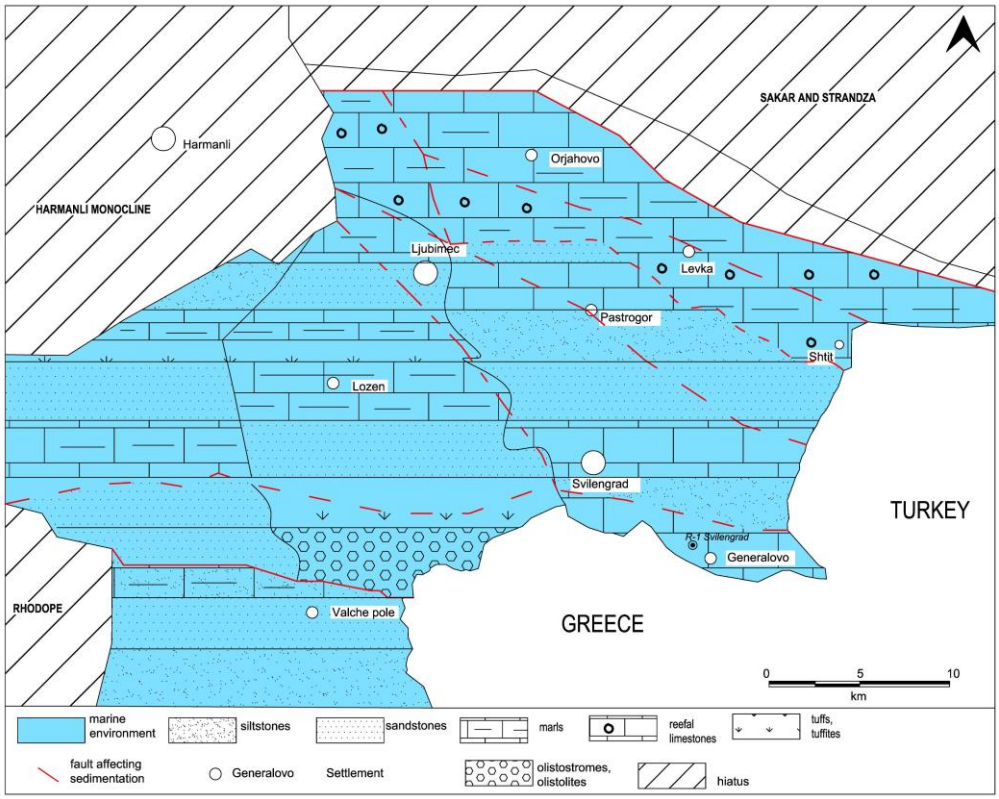

Fig. 5. Paleogeographic scheme for the end of the Late Eocene Age

The Oligocene

In the Turkish part of the basin, above the sediments of the Ceylan Formation, are the marginal-marine and terrestrial sediments of the Yenimuhacir group, which pass gradually upwards and are represented by alternating sandstones and shales with well-developed lamination, lignite horizons, and layers with shallow-water fossils – gastropods, ostracods, fish and plant remains. The first formation of the group – Mezardere, composed of interbedded greenish grey to green shales, siltstones, marls and sandstones with sporadic tuffite intercalations, is interpreted as part of the prodelta. This is evidenced by the dominance of shales deposited in shallow to medium-deep marine environment, and the sandstone layers among the shales are interpreted as offshore bar (Sünnetçioğlu, 2008). The rocks of this formation, with a gradual transition, pass into the sediments of the Osmancik Formation, represented by irregularly alternating layers of sandstones, shales, mudstones, siltstones. This formation illustrates the evolution of various facies - from terrestrial channel system, fluvial-deltaic, to delta-front. The upper sediments of the group section, included in the Danismen Formation, are represented by shales, argillites, siltstones, clayey sandstones, and coal seams, which are the product of lagoon, swamp, alluvial, and fluvial depositional conditions.

The described regressive stage of evolution of the Thrace basin during the Oligocene - Lower Miocene Age is also observed on the territory of our country. Although the Oligocene part of the section is very contradictory, both in age and in lithology and distribution, an assumption can be made here about the conditions of sedimentation during this period. In general, the Oligocene section in the Madzharovo depression is characterised by different lithological sediments, incontinence in the lateral and vertical direction, in places with magmatism, which makes this part of the sedimentary filling difficult to correlate.

In the southern and western parts of the study area (the Lozen-Imbredjek zone and the Bryagovo depression) the Oligocene is represented by tuffs, tuffites, sandy and shaly volcaniclastic turbidites, marls, and reefal limestones. In these sequences composed of debris flows and turbidite successions, tectonic control of sedimentation and proximity of the source of sediment supply is clearly observed. The rocks indicate a shallow-marine sedimentation environment, with syn-sedimentary volcanism behaviour (Fig. 6, left).

The north-eastern part of the study area is characterised by a complete absence of volcanism and completely different sedimentation conditions. In the area around the R-1 Svilengrad well, the Oligocene is composed of irregularly alternating shales, calcareous shales, siltstones, and sandstones (Fig. 6, centre). The upper half of the Oligocene section consists of fine shales, with beddings of siltstones and sandstones resembling turbidites, but in a limnic-brackish environment, marls, shaly limestones, also called "freshwater Oligocene".

In the north-eastern part of the study area, the rocks of a Shale-marl formation are outcropping on the surface, which are represented by marls, marl limestones, shales, sandy turbidites, typical for the shelf or the upper part of the slope (Fig. 6, top right).

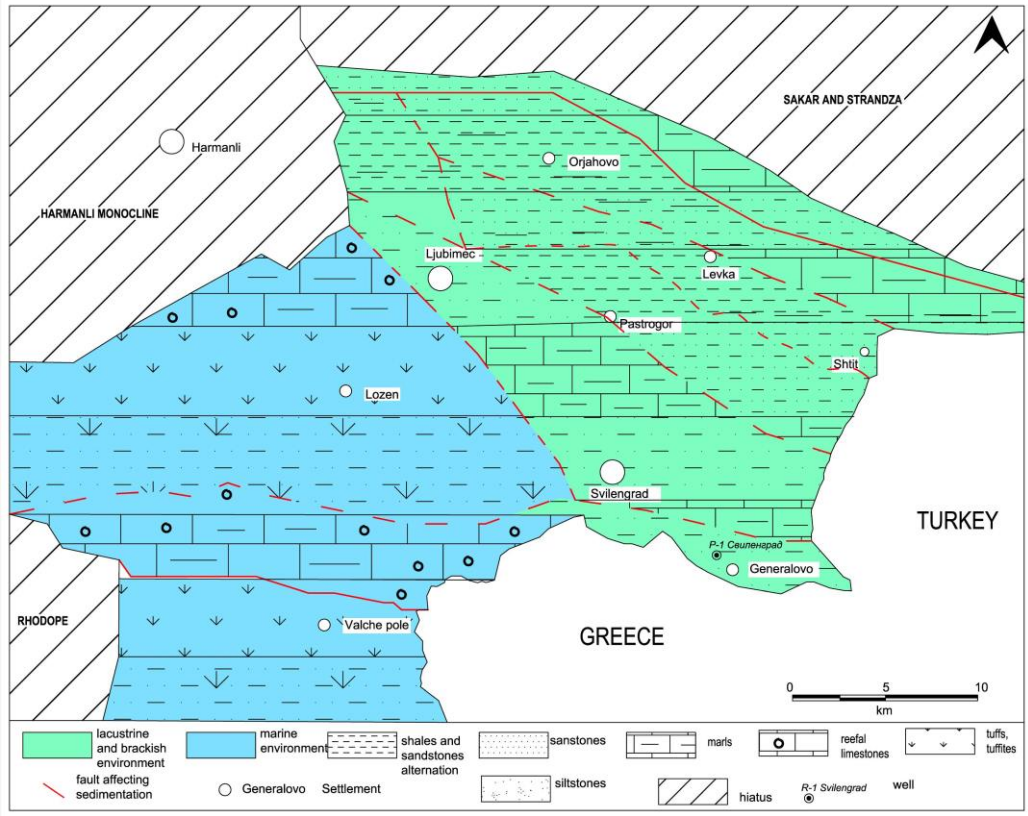

Fig. 6. Paleogeographic scheme of the Oligocene Age

Based on the analysis of the data, it can be assumed that in general at the end of the Oligocene Epoch, in the south-southwestern part of the studied area, sedimentary-volcanogenic processes took place in a shallow-marine environment. The conditions of deposition of the sedimentary complexes in the area of the R-1 Svilengrad well are also in a shallow-marine environment, with the distinctive facies of basin shallowing, but in the complete absence of volcanism. Probably there was a bay or the estuary of a paleo-river and the source of supply was mainly from fluvial sediments. The northernmost part of the area coincides with the northernmost shores of an existing freshwater basin during this time phase.

Conclusions

The characteristics and the analysis of the basin space of the studied area and the analysis of the data in the Turkish part of the Thrace basin are the basis for the created 2D paleo-reconstruction models of the Tertiary succession. This allows to trace the stages of formation of the basin system, as well as to determine a mutual geological evolution of the sedimentary succession on the Bulgarian and the Turkish territory.

The Palaeocene - Early-Middle Eocene (?) Syn-rift Phase is associated with the deposition of the first sedimentary succession in some parts of the basin, including in some part of the study area. The tectonic processes and morphology of the basin strongly affect the deposition of a typical turbidite system in separate depocentres with their own sources and sedimentation paths, distribution area and nature of the filling sediments. These are the sediments that are considered to be the analogue to the oil and gas bearing Hamitabat Formation from the Turkish part.

The next syn-rift phase in the Priabonian Age is associated with the formation of depressions in different shapes, in which a thick conglomerate-sandy succession was deposited, whose rocks can be considered as analogous to the Koyunbaba Formation. Initially, tectonically controlled diluvial-fluvial and talus-cone terrestrial sedimentation took place, and subsequently, shoreline and shallow-marine sedimentation was established.

The paleogeographic reconstruction of the end of the Priabonian Age illustrates the widespread establishment of marine environment and the deposition of marls and sandstones (Terrigenous-limestone-marl and Pyroclastic-marl-limestone formations, analogous to the Ceylan Formation), and in the end part of the basin – reefal and skeleton limestones (analogue of the Sogucak Formation).

For the Oligocene Epoch, a complex paleo-environment is assumed: in the south-western part, sedimentary-volcanic processes took place in a marine environment, in the area of the horst, in which the R-1 Svilengrad well is located, probably there was a bay or the estuary of a paleo-river, and it is assumed that the shoreline of an existing freshwater basin was located to the north. All these sediments compose a Shale-marl formation, which can be considered the analogue to the Mezardere, the Osmancik, and the Danismen Formations.

By means of the analysis of the basin space and the created paleo-reconstruction models, it is possible to identify the main depocentres in the NW part of the Thrace basin. This makes it possible to identify areas with a suitable formation of reservoir and seal rocks with different lithological composition, as well as potential source rocks. The most important advantage of the

created paleo-reconstruction models is that in this way, a modern assessment of the studied area can be made both in reference to its oil and gas potential, and the sustainable extraction of ore and fuel raw materials in it.

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