SEQUENCE-STRATIGRAPHIC ANALYSIS BASED ON WELL LOGS IN TERMS OF STUDYING THE TRANSGRESSIVE-REGRESSIVE CYCLES IN PART OF CENTRAL NORTH BULGARIA

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ABSTRACT. The area of this study is located within the Central North Bulgaria (CNB). It is relatively well-studied in geological aspect, but to obtain a better understanding and to clarify some issues concerning the sedimentary environments and the evolution of sedimentary fill it is necessary to apply modern approaches, such as sequence-stratigraphic analysis. Thus formulates the main purpose of the study, which is based on well log data that provides valuable information through which one can study the transgressive-regressive cycles and the resulting sedimentary sequences, controlled by eustasy, tectonic movements and sediment supply. As a result, 5 sedimentary sequences from different order (Campanian-Maastrichtian second-order sequence, Valanginian-Aptian second-order sequence, Callovian-Valanginian first-order sequence, Bajocian-Bathonian third-order sequence, Hettangian-Lower Bajocian second-order sequence) were recognized along with their elements (system tracts) formed within transgressive-regressive cycles. Based on the analysis of the participating official lithostratigraphic units and well-log interpretation, the paleoenvironment of sedimentation is predicted for each individual sedimentary sequence. The sedimentary sequences are predominantly with carbonate composition, with interbeds of terrigenous material, typical for the late stages of the highstand system tract at a reached eustatic minimum, increasing the influence of the source of the clastics from south. The paleoenvironments of deposition mainly represent the shelf area of the basin, with individual sequences falling either in the shallow or deep zone. During the Lower Cretaceous period, the depositional environment was represented by a pelagic setting.The most significant differences in the facies appearance and sedimentation settings are found within the scope of the Callovian-Valanginian first-order sequence as a direct response to the complex geodynamic evolution of the basin during that period.The impulsive nature of importing a clastic material in the Lovech Urgonian group (Lower Cretaceous) would produce some collectors with potential for storing natural gas or CO_2 sequestration.

Key words: Sequence stratigraphic interpretation, South Moesian periplatform, Well logs

СЕКВЕНТНО-СТРАТИГРАФСКИ АНАЛИЗ ЗА ИЗУЧАВАНЕ НА ТРАНСГРЕСИВНО-РЕГРЕСИВНИТЕ ЦИКЛИ ПО СОНДАЖНО-ГЕОФИЗИЧНИ ДАННИ ЗА РАЙОН ОТ ЦЕНТРАЛНА СЕВЕРНА БЪЛГАРИЯ

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РЕЗЮМЕ. Районът на настоящето изследване е локализиран в пределите на Централна Северна България (ЦСБ). Той е относително добре изучен в геоложки аспект, но за постигане на по-добро разбиране и изясняване на някои въпроси, касаещи седиментните обстановки и запълването на част от Южномизийската периплатформена област, е необходимо прилагането на съвременни методи, какъвто е секвентно-стратиграфския анализ. Това формулира и основната цел на изследването, проведено по сондажно-геофизични данни (СГИ), които предоставят ценна информация, благодарение на която могат да се изучат трансгресивно-регресивните цикли и свързаните с тях седиментни секвенции, контролирани от еустатичните колебания, тектонските движения и седиментния приток. В резултат на проведения анализ, бяха отделени 5 седиментни секвенции от различен порядък (Кампан-Мастрихтска, Валанжин-Аптска, Калов-Валанжинска, Байос-Батска и Хетанж-Долно Байоска) и изграждащи ги системни трактове образувани в рамките на трангресивно-регресивни цикли. На база анализ на участващите официални литостратиграфски единици и интерпретация на сондажно-геофизичните изследвания е прогнозирана предполагаемата палеообстановка на седиментиране за всяка отделна седиментна секвенция. Седиментните секвенции са преимуществено с карбонатен състав с прослойки от теригенен материал, характерен за късните стадии на тракта на високо морско ниво при достигнат еустатичен минимум, засилвайки се влиянието на подхранващата суша от юг. Палеообстановките на седиментация основно характеризират шелфовата зона на басейна. Отделни секвенции попадат или в плитката или в дълбоката шелфова зона. През долнокредния период басейнът се удълбочава, част от седиментите са характерни за пелагичната зона. Най-значителни различия във фациесите и обстановката на седиментоотлагане са открити в обхвата на Калов-Валанжинската секвенция от първи порядък, характеризираща сложната геодинамична еволюция на басейна през този период. Импулсивния характер на внасяне на кластичен материал при Ловешката Ургонска група (долна креда) би било предпоставка за образуване на колектори с потенциал за съхранение на природен газ и задържане на емисии от въглероден двуокис.

Ключови думи: Секвентостратиграфска интерпретация, Южномизийска периплатформа, Сондажно-геофизични данни

Introduction

The area of this study (Fig.1) covers the western part of South Moesian periplatform area located within the Central Northern Bulgaria (CNB). This unit is a secondary tectonic structure within the Moesian platform. This area is limited by the South Moesian fault to the north, which joins with the Krushovitsa-Gorsko Slivovo fault to the east. The south border is presented by Brestnitsa flexure. The territory is relatively well studied in geological aspect through multiple wells and geophysical studies at the end of the last century. Due to lack of modern computing technologies for processing and interpretation of seismic data, drilling workings in large numbers were used as the main approach in studying the petroleum perspectives of Northern Bulgaria. The main petroleum play covers the rocks of the Mesozoic section. After exploring the basics fund of anticlinal structures, the focus logically shifts on the research and study of other types of stratigraphic and structural traps. This necessitated a more frequent use of seismic surveys as a particularly useful method for lateral tracking of sedimentary units including the elements of the petroleum system with a focus on the possible trapping bodies. The seismic data alone does not bring sufficient information without the required method and approach to interpretation. This requires the implementation of the sequence-stratigraphic analysis to give reasonable geological sense of seismic and drilling data. This analysis is complex and relies on the interpretation of seismic, well log and core data, as well as on field outcrops.

Comprehensive analyses of the Triassic sedimentary sequences are found in the articles of Mader, Çatalov (1992), Aydanliyski et al., (2004), Georgiev and Bakurdzhiev (2004). Tchoumatchenco (2002) separates two first-order Jurassic sequences. In the stratigraphic range of the Lower Cretaceous, within the range of the central and eastern Forebalkan area, partially within the South Moesian periplatform area, ten sequences of the third order with stratigraphic interval Berriasian-Valanginian and eight sequences in the Varremian-Aptian interval of the same order are described (Ivanov and Stoykova, 1997; Nikolov et al., 1998; Nikolov et al., 1998; Ciszak et al., 2000).

The main objectives of this article were to make a sequence stratigraphic analysis, to clarify the basin sedimentary filling and the typical depositional environments in the Mesozoic sediments based on available well data for an area falling within the South Moesian periplatform area. Four well sections within the Lukovit and Aglen areas were selected.

Regional geology

The South Moesian periplatform area represents the southern margin of the Moesian platform between the Balkan fold-thrust belt and the southern platform edge (Fig.1).

This area is defined as a transition zone (Bonchev et al., 1957) with different names – periplatform monocline (Garetskiy, 1968), pericratonic depression (Atanasov, 1973), and Targovishte-Provadiya step (Kalinko, 1976). In Monahov et al. (1981), along the Jurassic - Lower Cretaceous sediments, this area should be considered as the South Moesian periplatform area. Dabovski, Zagorchev (2009) present it as the South Moesian platform slope. It is more deeply buried and inclined to the south peripheral zone of the Bulgarian part of the Moesian platform.

The South Moesian periplatform area has a complex structural feature in which is dominated by the monoclinal south subsiding. Its formation starts from the beginning of Jurassic where the contemporary morphological image is shaped at the end of the Upper Jurassic and the Early Cretaceous periods. The geodynamic evolution of the area is marked by rift cycles in the Late Permian – Early Triassic, Late Triassic, Early Jurassic and Late Cretaceous periods that were repeatedly interrupted and followed by compression events (Georgiev et al., 2001). The major tectonic events and the deposition of a thicker diversion in the sediments were mainly

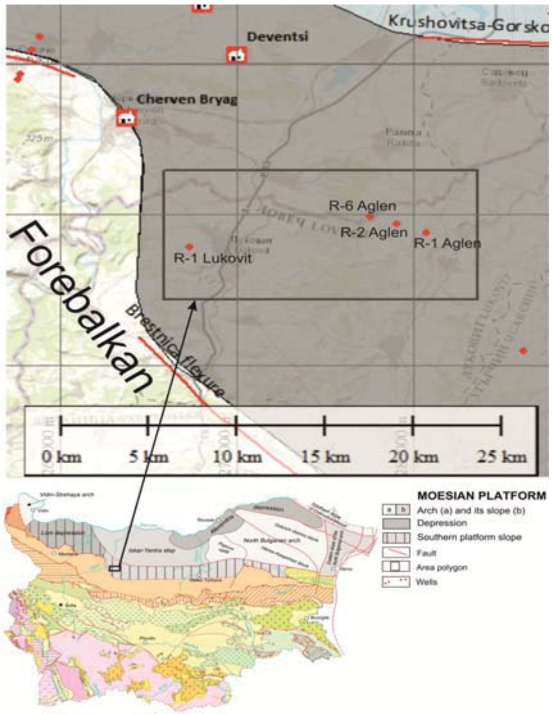

Fig. 1. Generalized tectonic map of Central North Bulgaria (Dabovski, Zagorchev, 2009) and Scheme of the studied area (Bokov and Atanasov, 1983).

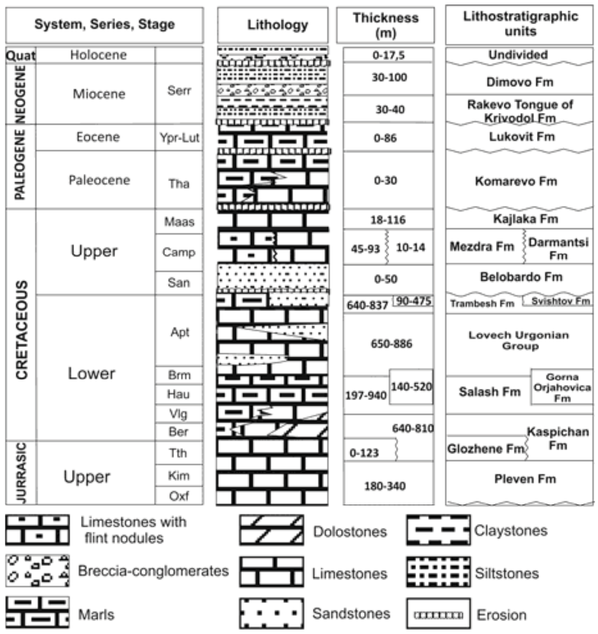

Fig. 2. Generalized lithostratigraphical scheme of sediments from the western part of the South Moesian platform slope (Bokov, 1983, with additions from the geological descriptions of R-1 Lukovit, R-1, 2, 6 Aglen).

through the Triassic, Lower-Middle Jurassic, Tithonian-Valanginian and to a lesser extent Late Cretaceous-Tertiary time (Botusharov, 2005). The sedimentary fill consists of Mesozoic rocks with a thickness of 4-6 km (Fig. 2) lying discordantly on a slightly deformed Paleozoic basement. They are covered by Paleogene, Neogene and Quaternary sediments and locally with Quaternary. The section has primarily a carbonate composition – limestones, clayey limestones, marls, and dolostones interbedded with relatively not so thick terrigenous deposits.

Methodology

To perform this analysis, well log data were used which include the curves of spontaneous potentials, deep laterolog resistivity, and gamma ray. They were processed by the Neuralog software, and were then imported in the Petrel software for further interpretation. The methodology of interpretation is entirely based on the concepts of the sequence-stratigraphic analysis (Mitchum and Van Wagoner. 1991; Posamentier et al. 1988a, 1988b). The presented well log sections are typical with their incomplete information, but are described in details according to the core and well cuttings.

Results

Based on studying the lithological descriptions and well log data, 5 sedimentary sequences (Fig. 3) formed within the transgressive-regressive cycles were separated.

Campanian-Maastrichtian second-order sequence

A sequence of the second order is separated. It covers the Campanian and Maastrichtian stages of the Upper Cretaceous. Its thickness reaches 187 m at the R-6 Aglen. The lower and upper sequence boundaries are erosive. It is composed of a highstand system tract, including the micritic limestones with flint concretions of the Mezdra formation (Fm) and the organogenic limestones of the Kaylaka Fm. The predominant part of the fossil remains in the Mezdra Fm is from organisms typical for the deep shelf environment (100-200m water column). While at the Kaylaka Fm - for shallow marine areas of the shelf, most likely as a result of the decrease of seawater towards the end of this system tract - the sequence is tracked at the four well sections.

Valanginian-Aptian second-order sequence

A Lower Cretaceous sequence of a second order is separated and comprises the stages from the Valanginian to the Aaptian. Its thickness reaches 2858 m at the R-1 Aglen. Only a highstand system track is outlined. The sequence begins with an erosion at the top of the Kaspichan Fm (at the R-1, 2, 6 Aglen), the Slivnitsa Fm (R-1 Lukovit), and ends again with erosion at the border of the Aptian-Upper Cretaceous. Within the scope of the sequence are the Salash Fm, the Gornooryahovo Fm, the Lovech Urgonian group, the Tramsbesh and the Svishtov Fm. Generally, the depositional environment is pelagic in the sediments of the Salash and the Gornooryahovo Fm, the latter being considered as a transitional shelf-deepwater setting because of the content of neritic fossil remains. The tendency of lowering the sea level can also be presumed with the deposition of a bed of clayey limestone in the upper parts of the Salash Fm (Fig. 3). The forming of the sediments of the Lovech Urgonian group (the Krushevo Fm, the Balgarene Fm, the Emen Fm, the Byala reka Fm, the Stratesh Fm, the Smochan Fm) is a direct reflection of the regressive development of the sedimentation basin towards the end of the Lower Cretaceous period when the subsiding rate was noticeably reduced and the adjacent elevated land on the south became the source of tremendous masses of diverse clastic and clay material. The sedimentation itself is with impulsive nature (Hrischev 1969, 1972). The sediments of the Trambesh Fm are formed in the shelf zone under a general regressive trend of the sea waters. Upward in the sedimentary section, the deposition of a bed of sandy sediments (presuming it is a wedge from the Roman Fm), subsequently the deposition of the Svishtov Fm inferring the reached eustatic minimum of the marine waters, increasing the influence of the alluvial systems from the south.

Callovian-Valanginian first-order sequence

Below the previous sequence, a sequence separated by Tchoumatchenco (2002) is observed with stratigraphic age Callovian-Valanginian. Based on the used well data, it is seen that its two boundaries are erosive. The thickness reaches 1453 m. It comprises a highstand system tract. Its sedimentary rocks have a carbonate composition (the Kaspichan Fm in the east, the Slivnitsa Fm and the Glozhene Fm in the west, the Pleven Fm in the east, the Yavorets Fm in the west). Tchoumatchenco (2002) relates the sediments of the Javorets Fm to the lowstand system tract, subsequently it is specified that they represent post-transgressive sediments typical for the highstand system tracts. The deposits of the Kaspichan Fm (at R-1, 2, 6 Aglen) are platform sediments deposited in a neritic environment. On the other hand, the limestones of the Slivnitsa Fm (at R-1 Lukovit) suggest the formation of submarine shallows in the pelagic parts of the basin.

Bajocian-Bathonian third-order sequence

It is tracked in the well sections of R-1, 2, 6 Aglen. It has the smallest thickness – 156 m and covers 2 stages - Bajocian and Bathonian from the Middle Jurassic. This circumstance implies the order of the sequence - third. It comprises two system tracts - a transgressive (TST) and a highstand (HST). The TST is composed of the sandy marls of the Bov Fm. The last 20 meters (4150-4170m at the R-1 Aglen) of this formation are characterized by increased values of the gamma ray log (GR). Generally, such anomaly could also be induced by micaceous sandstones and/or siltstones, but the other well logs (spontaneous potential and resistivity) do not confirm this.

Therefore, these anomalous values could be interpreted as an organic-rich sedimentary layer typical of the condensed section at TST. The radioactive elements that cause positive anomalies normally are sequestered by the organic matter (often cyanobacteria and phytoplankton). The top of this layer corresponds to the maximum flooding surface (Fig.3 - the green line). The transition to HST is marked by the deposition of clayey limestones of the Polaten Fm. The sediments are deposited in the shelf area of the basin.

Hettangian-Lower Bajocian second-order sequence

The sequence is totally transected by R-1, 2, 6 Aglen. It reaches up to 685 m thick at the R-6 Aglen. There is a stratigraphic range of Hettangian-Lower Bajocian and is of second order. Its boundaries are associated with erosion. Two system tracts (TST and HST) are distinguished. The transgressive system tract is represented by a condensed section - siltstones with glauconite and fossil remains-appertaining to the Bachiishte Fm. The latter is the thickest at R-1 Aglen - 15 m (4835-4850 m). GR values are high, reflecting the enrichment of glauconite and organic matter in this interval. The maximum flooding surface could be marked at the summit of the Bachiishte Fm. The highstand system tract comprises the sediments of the Ozirovo Fm and the Etropole Fm. Late sandstone intervals in the Etropole Fm could be

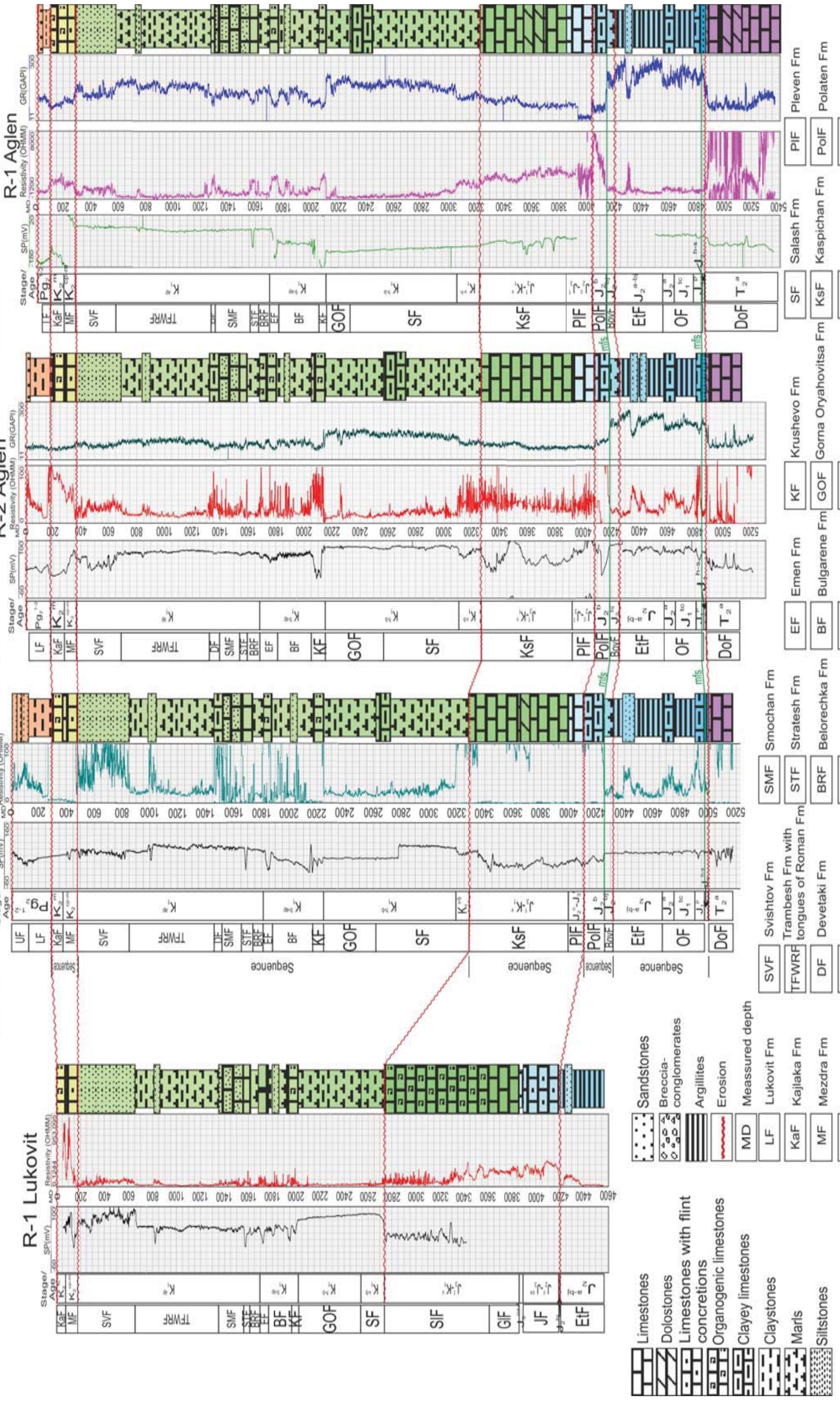

Fig. 3. Sedimentary sequences within the Mesozoic period interpreted on well log data (R-1 Lukovit; R-1, 2, 6 Aglen).

interpreted as a result of the reached eustatic minimum of the sea level and increasing the influence of the alluvial systems from the south. The sediments are deposited in the shelf area of the basin.

Conclusions

Based on the conducted study and the results in the Mesozoic section of the surveyed area, five sedimentary sequences from different orders (Campanian-Maastrichtian second-order sequence, Valanginian-Aptian second-order sequence, Callovian-Valanginian first-order sequence, Bajocian-Bathonian third-order sequence, Hettangian-Lower Bajocian second-order sequence) were distinguished along with their elements (system tracts) formed within transgressive-regressive cycles. Based on the analysis of the participating official lithostratigraphic units and well-log interpretation, the paleoenvironment of sedimentation is predicted for each individual sedimentary sequence.

The sedimentary sequences are predominantly with carbonate composition, with interbeds of terrigenous material, typical for the late stages of the highstand system tract at a reached eustatic minimum, increasing the influence of the source of the clastics from the south.

The paleoenvironments of deposition mainly represent the shelf area of the basin, with individual sequences falling either in the shallow or in the deep zone. During the Lower Cretaceous period, the depositional environment is represented by pelagic setting. The most significant differences in the facial appearance and sedimentation settings are found within the scope of the Callovian-Valanginian first-order sequence as a direct response to the complex geodynamic evolution of the basin during that period.The impulsive nature of importing a clastic material in the Lovech Urgonian group (Lower Cretaceous) would produce some collectors with the potential for storing natural gas or CO_2 sequestration.

It is difficult to pinpoint favorable reservoir bodies, especially when they have to be predicted within the HST. In this case, it is necessary to combine with seismic profiles in order to achieve a complete sequence-stratigraphic interpretation with emphasis on the petroleum system approach.

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