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ANALYSIS OF THE CAUSES OF CIRCULATION LOSS IN THE LOWER CRETACEOUS DEPOSITS DURING THE HORIZONTAL DRILLING UNDERCROSSING THE DANUBE RIVER (GIURGIU-RUSE SECTION)

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ABSTRACT

The geotechnical, electrometric and magnetometric investigation data, correlated with the technological data from the horizontal directional drillings made for the undercrossing of the Danube River with gas pipelines, showed that in the Giurgiu-Ruse section, under a clastic sequence of 14-19 m thickness, consisting of layers of sandy clays, sands and white-grey, alluvial gravels, are developed Cretaceous grey altered limestones, yellowish-brown lumachelle limestones and grey-pink, compact limestones. The altered, eroded, and karstified limestones seems to be the explanation of drastic circulation loss of mud in the technological process of digging through horizontal directional drillings. In the studied section, on the Giurgiu-Ruse alignment in the southern area of the Moesian Platform (Wallachian sector), there are several relevant papers occasioned by the construction of the Saint Gheorghe harbour channel related to the Giurgiu harbour, at the time of the 19th century (1888-1890), as well as the papers related to the investigations occasioned by the construction of the Giurgiu-Ruse Bridge in 1959. Older or newer papers are added, relating to the carbonate deposits of different ages of the Cretaceous in the outcrops of the Bulgarian bank of the Danube, as well as descriptions from drillings adjacent to the studied section.

Keywords: Moesian Platform, Barremian carbonate deposits, stratigraphy & tectonics, petrophysical characteristics, geological expertise

INTRODUCTION

Regarding the regional geologic and tectonic framework in the presentation of the superficial Cretaceous limestones stratigraphy, we focus on the synthetic presentation of the geologic data of the Moesian Platform (Wallachian sector) in the book “Geological structure of the Romania’s territory”, authored by Vasile Mutihac (1990) [1]. In relation to the synthesis paper previous mentioned, there are clarifications on the Barremian carbonate deposits diagnosed and detailed in the works related to the Saint Gheorghe harbour channel in the Giurgiu harbour, from the works related to the Giurgiu-Ruse Bridge, and from drillings adjacent to the studied section.

STRATIGRAPHY OF THE WALLACHIAN PLATFORM

The stratigraphy of the Wallachian Platform includes two major structural elements: (1) the basement consisting of metamorphic rocks, and (2) the cover consisting of sedimentary deposits.

In terms of lithology and age of stabilization the Wallachian Platform has a heterogeneous basement that includes: (1) retromorphosed mesometamorphites crossed by granitoids belonging to a Prebaikalian cycle (found in drilling west of Olt river in the Dioşti-Balş-Slatina area, extrapolated to the western half); (2) Central Dobrogea-type green schists formation belonging to the Baikalian cycle (found in the Bordei Verde-Tăndărei drillings and extrapolated to the northeastern part of the Wallachian Platform; (3) mesometamorphites that extrapolate in the southeast of the platform (Palazu-type basement in southern Dobrogea). [1-5]

The platform cover includes four sedimentary cycles separated by large intervals of non-deposition related to transgressions and regressions, which reflect tectonic and eustatic cyclicities:

I- The first cycle covers the Cambrian to Carboniferous-Westphalian interval, being interrupted by the emersions related to the Saalic and Pfalzic phases of the Hercynian orogeny. It includes the periods: Cambrian (blackish argillites and calcareous sandstones with trilobites like *Paradoxides paradoxisismus*, *Peronopsis fallax*=Cm_2); Ordovician (quartzite sandstones with argillite intercalations and marl/clay glauconite shales with graptolites like *Didymograptus extensus*, *Didymograptus hirundo*); Silurian (in the base, clays with *Llandoverian palynomorphs*, clays with graptolites such as *Monograptus priodon*, *Cyrtograptus murchisoni*=Wenlockian; *Monograptus uncinatus*, *Bohemograptus bohemicus*=Ludlovian with thickness variations on the horst/graben structures); Devonian (black argillites with brachiopods, conodonts, palynomorphs, in the base, gresoconglomerates=Eifelian; carbonatites and evaporites=Givetian-Fammenian, in the top with cryptocrystalline limestones, organogenic limestones, calcarenites=Givetian-Fammenian); Carboniferous (lower calcareous formation followed by a clastic formation=Westphalian, developed in depression areas and thinned until it disappears in uplifted areas such as Strehaia, Balş, Optaşi, Bordei Verde) [1-5]

II- The Upper Permian-Triassic cycle (comprising a lower red sandstone clastic suite=Permian-Eotriassic=Buntsantstein, a mixed continental marine and lagoonal carbonate-evaporitic suite=Muschelkalk, a sandstone-marly clastic suite with upper red vulcanites=Keuper. The Upper Permian-Triassic cycle is interrupted by the old Kimmeric emersion of the Alpine orogeny. [1-5]

III- The Dogger-Cretaceous and partially Eocene cycle, interrupted by the emersion related to the Laramic phase of the Alpine orogeny. [1-6] The Lower Cretaceous deposits represent the area of interest for the technological problems during the undercrossing of the Danube River by horizontal directional drilling (fig. 1-4) in the Giurgiu-Ruse section and it will be detailed further. [7-9] After the Paleokimmerian diastrophism, in the emersion phase related to the Liassic, the stabilization of the Wallachian sector and the peneplenization of the relief were recorded, the platform acquiring the character of a rigid block of relative stability. Instead of the differential movements of some compartments generating sudden facies variations, only minor tipping episodes occurs, generating transgressions/regressions against a central-western area materialized in transitions from pelagic facies to reefal or even lagoonal facies.[6]

Fig. 1-4 Horizontal directional drilling equipment and drilling works during the undercrossing of the Danube River [7]

The Dogger begins with detrital sequences (gypsiferous and lutitic sandstones) and ends with dolomites and calcareous sandstones = upper Callovian. The clay corresponds to a marine expansion, favourable for the deposition of carbonate deposits. It begins with pelagic deposits of pseudo-oolitic limestones and reddish-brown limestones=Oxfordian, red nodular limestones=Kimmeridgian, followed in the Kimmeridgian-Tithonic by deposits related to an eastern uplift of the platform materialized in fine pelagic facies, in the central part of the platform and, respectively, reef facies of Stramberg limestone to the east and west. In the eastern extremity, the reef limestones pass to the continental lagoonal Purbeckian facies of the Tithonic (dolomites, anhydrites, clays and limestones) The Cretaceous (Fig. 5-6) maintains the sedimentation conditions of the terminal Jurassic so that, in the central part, pelagic deposits develop with transitions towards the edge to reef facies, with the mention that in the east of the platform the continental lagoonal conditions of the Purbeckian continue, as the Weald facies. The Neocomian appears in the central area as a pelagic facies with tintinnids, passing laterally to a calcareous neritic facies with trocholines and miliolides and in the eastern and western extremes to a calcareous facies with intraclasts. The Barremian marks the beginning of the retreat of the waters favouring the emergence of the western and eastern extremities of the platforms (fig. 5), with continuous sedimentation of micritic limestones only in the central part. The Aptian corresponds to the maximum retreat of the waters materialized in the deposition of calcareous sandstones with orbital lines only in the Roşiori depression, and continental deposits in the rest of the platform (Fig. 5-6). The Albian marks the beginning of a new east-west marine expansion with complete development of the suite on the eastern side of the platform. Glauconitic sands and sandstones are deposited followed by transgressive marly deposits with *Puzosia majoriana*, *Parahibolites tourtiae*, *Aucellina gryphaeoides*=Vraconian. [1-6]

Fig. 5 Lithofacies map of the Barremian and Aptian [5]

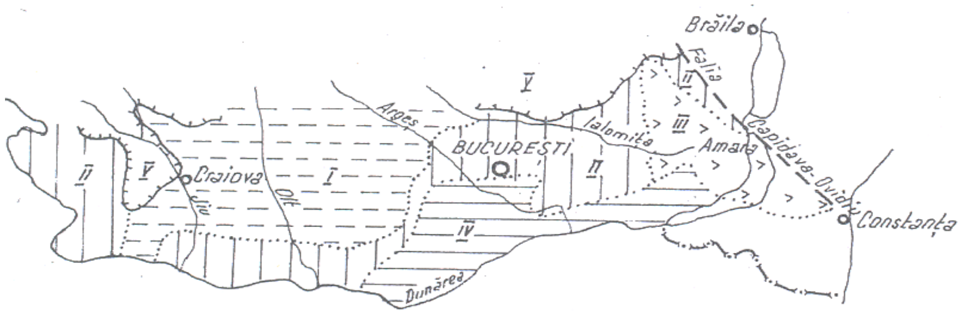

Fig. 6. Facies distribution in the Berriasian – Lower Aptian interval [3]

The Cenomanian begins with blackish compact marls with *Rotalipora monsalvensis* followed by marly limestone with *Mantelliceras mantelli*, *Schloebachia varians, Neohibolites ultimus*, *Rotalipora appenninica.* The Turonian, in continuity of sedimentation, includes in the eastern part of the platform limestone and chalky marls with *Mammites nodosoides*, *Inoceramus labiatus*, *Globotruncana crenata*, and in the Danube area, grey marls with identical fauna. The Senonian concludes the Cretaceous suite and is represented by a marly facies with *Globotruncana lapparenti*, *Globotruncana fornicate*, *Globotruncana arca*, in the western part and by a chalky calcareous facies with silex, containing *Pycnodonta brogniarti*, in the eastern part. In some sectors as well as the Giurgiu area, a large part of the Senonian deposits have been removed by erosion, or have been karstified [9], while in the sunken areas the complete suite has been identified which can reach 450 m thick. The Laramic search phase of the Alpine orogeny that manifested itself in the neighbouring labile areas also determined a general uplift of the Wallachian sector. Only limited areas (such as the Băileşti-Lom or Urziceni-Slobozia depression) remained covered by water in the Paleocene-Eocene, with deposits of marly and calcareous deposits with nummulites and foraminifera (*Globigerina bulloides*, *Globigerinoides sp.)* Further, in the Oligocene and in the Eomiocene, the Wallachian

Platform evolved as a denudation area together with the other units of the foreland, while the sea was limited to the Carpathian Foredeep. [1-6]

IV- Badenian-Pleistocene sedimentation cycle. After the long emersion (about 50 million years) that followed the Laramic paroxysm, sedimentation resumed in the Badenian, by the advance of the waters from the Carpathian Foredeep (in a first stage covering the northern and western part of the Wallachian Platform), or from the Varna basin, achieving for the first time the connection between the central Paratethys and the eastern Paratethys (Ponto-Caspian basin). [1-5]

In the Neogene, the Wallachian Platform evolved as a sedimentation area of some molasses deposits within the Dacian Basin, with the rising Carpathian Orogen as its source area. The Upper Badenian develops in the northern half of the platform through conglomerates followed by marly deposits with intercalations of clays, sands, glauconitic sandstones, locally evaporites.

The Sarmatian marks the maximum marine expansion in the Eosarmatian when the waters covered the entire platform, which to the east (Dobrogea) was bounded by a cliff (the Ostrov-Galaţi fault). Heterogeneous sandstones are mainly deposited: gritty-sandy sequences pass towards the edge of the basin to reef facies with *Serpula*, being followed by lutitic deposits. The thicker suite from the Danube area of Islaz and Celaru allows the separation of: grezo-clayey deposits of Volhynian; marly-sandy deposits of Bessarabian, with intercalations of oolitic limestones and lumachelle limestones with *Cryptomactra pesanseris*, *Mactra fabreana;* sandy-clayey deposits with coals of Upper Bessarabian-Kersonian, with a fauna of *Mactra bulgarica*, *Mactra orbiculata*. The end of the Sarmatian has a regressive character. [1-5]

The Pliocene marks a new transgression due to the waters coming from the Carpathian Foredeep, culminating at the end of the period, when the waters exceeded the current course of the Danube.

The tectonics of the Wallachian Platform reveals a predominantly rupture tectonics arrangement in which an east-west orientated fault system and another north-south oriented fault system separate blocks whose vertically differentiated movement generated horst/graben type structures. The density of the faults, the variable age (from those contemporaneous with the consolidation of the basement to the Neogene ones), the reactivation in various periods, the vertical tilts and the presence of the cover vulcanites, argue for the unstable character of the Wallachian Platform (Fig. 5-6). [1-4]

The category of old crustal faults (fig. 7) which affect sectors of the basement includes: the Peceneaga-Camena fault (the border of the Wallachian Platform/North-Dobrogea Promontory, contemporary with the green shales of Central Dobrogea=Baikalian, reactivated in later ages, currently active, with a jump of over 10 km); Fierbinţi-Călăraşi fault (limit of mesometamorphite basement = southwest/epimetamorphic basement of green shale type and Palazu type mesometamorphic basement=northeast; outcropping with rotation tendency of the northeast block); the Palazu fault (Capidava-Ovidiu) (boundary green shale basement to the north/Palazu-type mesometamorphite basement to the south). [1-4]

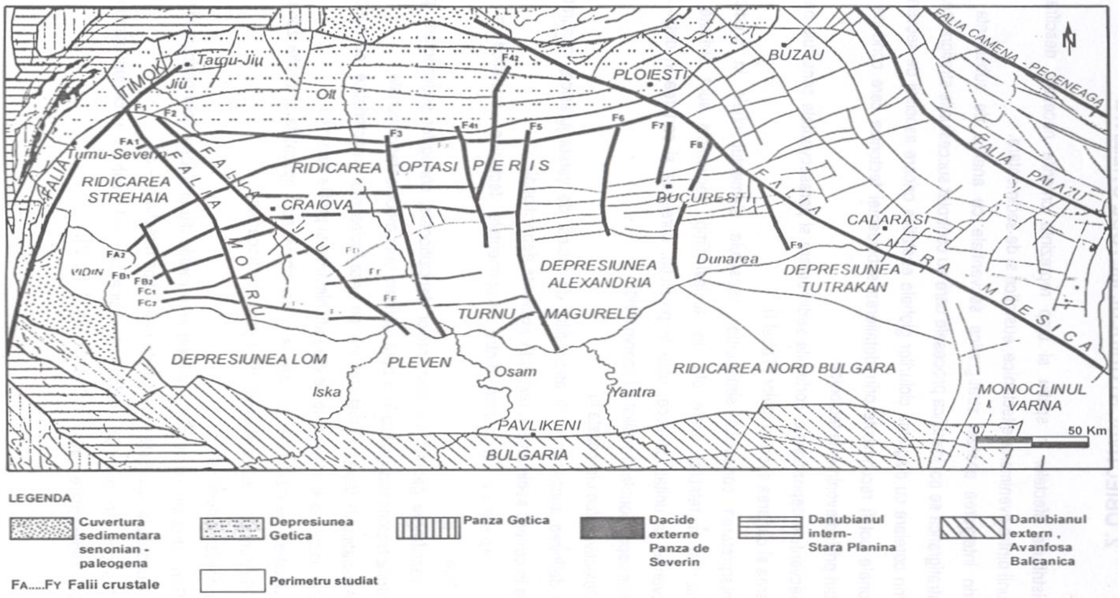

Fig. 7. Tectonic sketch detailing the fault systems in the Moesian Platform [10]

The category of younger faults (fig. 7) that separate uplifted blocks from depression areas includes: (1) in the western part of the Moesian (Wallachian) Platform area, the faults that delimit the Strehaia-Vidin uplift: the fault to the west of Drobeta Turnu Severin and respectively the fault to the east of Dârvari; (2) to the east of Craiova the faults that delimit the Balş-Optaşi uplift with continuation in the Corabia uplift; (3) between the Strehaia-Vidin and Balş-Optaşi uplifts is the Lom-Băileşti depression (with Triassic at approx. 4000m); (4) to the southeast of the Balş-Optaşi uplift, the Roşiori-Alexandria depression it develop (with Triassic at 5200m); (5) towards the east, the Roşiori-Alexandria depression is delimited by the Bucureşti-Giurgiu fault which separates it from the extension to the north of the Danube of the North-Bulgaria uplift; (6) to the east of the Fierbinţi fault, a depression is delimited, in turn delimited to the east by the bordering uplift of the Danube (Ostrov-Galaţi): there is Amara descended block, flanked by two uplifts Bordei Verde-Însurăței and Brădeanu, respectively; (7) the eastern limit of the Wallachian Platform is given by the Ostrov-Galaţi fault that follows the meridian course of the Danube. It is a Neogene fault concretizing the Dobrogea cliff from the Sarmatian and having active behaviour in the Pliocene. [1-4]

The category of east-west oriented faults generates parallel and increasingly descended steps compared to the Carpathian Orogen. Most are Neogene or older faults reactivated in the Neogene. The southern limit of the platform is given by the route of the Danube fault; the northern limit is given by the Pericarpathian Fault (the Volhynian limit of the platform is crossed by the Bessarabian from Carpathian Foredeep). [1-4]

In a detailed analysis of the Cretaceous-Urgonian calcareous deposits from Giurgiu (occasioned by the reinterpretation of material collected from the area since 1888-1890 by Gregoriu Ştefănescu), Eugen Grădinaru (University of Bucharest) makes a history of the descriptions of these deposits from which argues and establishes the lithology and age of these deposits as belonging to the Barremian age. [11] Citations are made about the existence of Urgonian reef calcareous deposits from Giurgiu: Murgoci (1907), Liteanu (1953), Paucă & Patrulius (1960), Patrulius et al. (1966). [12-14]. The Urgonian limestones were initially highlighted by digging the Sf. Gheorghe harbour channel during the construction of Giurgiu harbour. Later, the same Urgonian limestones were intercepted by the excavation works executed for the construction of the Giurgiu-Ruse Bridge over the Danube, establishing the following stratigraphic sequence [13]: (1) grey marls; (2) glauconitic sandstones; (3) basal level of breccias with reefal limestone elements; (4) white-yellow reef limestones with *pachyodonts* (*Requienia*). From lithological entities 1 and 2, Neagu (1959) [15], Paucă & Patrulius (1960) [13] described a rich microfauna and macrofauna on the basis of which the presence of the terminal part of the lower Albian and the lower and middle part of the middle Albian was established. From complex 3 of the reef limestones, only the presence of the genus *Requienia* is mentioned [13-14] without citing a more comprehensive faunal association. The mentioned deposits were, in turn, attributed to: the Cretaceous (Murgoci, 1907; Liteanu, 1953); Aptian and probably Barremian (Paucă & Patrulius 1960); and more recently, the Barremian (Patrulius et al., 1966). [12-14]

Based on the research of a material taken by Gregoriu Ştefãnescu in the years 1888-1890 on the occasion of the excavation of the Sf. Gheorghe harbour channel of the Giurgiu harbour, the author (E. Grădinaru, 1973) [11] presents some considerations with implications in specifying the stratigraphy of the Cretaceous deposits from Giurgiu, as well as the relationships with the deposits Cretaceous outcrops in the Ruse area (Bulgaria) or with the deposits intercepted in the adjacent drillings in the Romanian Plain. White-yellow organic limestone samples, some strongly diagenized, with internal casts of *Requienia ammonia* (Goldfuss), *Requienia renewieri Paquier*, *Matheroni grypheoides (Matheron)*, *Monopleura sp.*, *Pterocardia besarbovense (Toula*) are described, to which chaetetids are associated, hydrozoa, polypira, echinids, gastropods.

The lithofacies and biofacies characters indicate the presence of the Urgonian facies known as developed in classical regions in the Barremian-Aptian interval. According to data from the literature [12], in the Giurgiu-Harbour area, these deposits are very close to the surface, about 25 meters deep, which allowed their interception during the excavation works. These deposits are found in outcrop on the right (southern) bank of the Danube at Ruse (Bulgaria), being cited in different paleontological and stratigraphic studies: Toula (1892-1896) describes them as *Requienien kalke*, and Paquier (1903) contributes to the knowledge of the fauna by description of new species. All the species described and determined in the material from Giurgiu appear in the faunal association of the Ruse limestones. Regarding the stratigraphic position of the Urgonian deposits from Ruse, a diversity of opinions is cited: Paquier, Zlatarski (1901) and Paquier (1903) attribute them to the upper Barremian; Boncev (1955), Boncev, Cesitev, Karagjuleva (1956) attribute them to Aptian, opinion also found in Tzankov (1960); and based on the stratigraphic relationships with the adjacent deposits, Dimitrova (1967) places the Urgonian deposits from Ruse to Barremian. [11]

At north of the Danube, bordering the Giurgiu area, these Urgonian deposits were intercepted in some drillings in the Wallachian Platform. Thus, several papers [12, 14, 16] makes detailed research on the Barremian-Aptian deposits intercepted in the drilling at Cernetu (Atârnaţi), deposits partially correlative with those in the Giurgiu-Ruse area. The stratigraphic position of the Urgonian deposits from Cernetu-Giurgiu-Ruse, is deduced after the analysis of the stratigraphic relationships with the adjacent deposits: (1) in Ruse, the Urgonian deposits are covered transgressively by Middle Albian deposits with glauconitic sandstones, marls and marlstones with species of the genus *Hoplites* and *Douvilleiceras* (Dimitrova, 1952, 1967); (2) at Giurgiu, the excavation works for the construction of the Sf. Gheorghe harbour channel and the bridge over the Danube showed the same sequence.[11] In the material taken by Gregoriu Ştefãnescu, next to the limestones with the mentioned pachyodonts, samples of coarse glauconitic sandstone appear glued together. It is suggested that the Albian, through the glauconitic sandstone complex, lies transgressively over the Urgonian deposits. In the area of the bridge, the excavation works have the relevance that above the Urgonian deposits there is a level of breccias with elements of white reef limestone and then a complex consisting mainly of glauconitic sandstones that pass to grey, fossiliferous marl and marlstone, belonging to the terminal part of the lower Albian (the zone with *Douvilleceras mammilare*) and the lower part (zone with *Hoplites dentatus*) and middle (zone with *Anahoplites intermedius)* of the Middle Albian [13-15]; (3) a similar succession of Cretaceous deposits is described in the Cernetu (Atârnaţi) drilling [16].

Based on the mentioned stratigraphic successions developed near the studied section in the Wallachian Platform, it is concluded that the Urgonian deposits from Giurgiu and the adjacent areas belong to the Barremian interval, which is in accordance with other authors (Paquier, Zlatarski, 1901; Paquier, 1903; Patrulius et al., 1966; Dimitrova, 1967).[11]. With regard to the studied section related to the Cretaceous limestones that favour massive fluid circulation loss, Oncescu's paper provides information on the stratigraphic position and the depth in the drillings for Giurgiu and some neighbouring locations. Interesting considerations are also made regarding the problem of the Danube fault.[17]

STRATIGRAPHIC POSITION AND DEPTH IN DRILLING

1) In Giurgiu, when digging the St. Gheorghe harbour channel, they found on the left bank of the Danube, very close to the water level, Barremian limestones similar to those on the right bank, which are exposed today, close to Ruse; 2) Near Giurgiu, a drilling it passed from the Pliocene to the Cretaceous, at 51 meters depth; 3) At Daia, a locality located about 12 km north of Giurgiu, the Middle Cretaceous was found below the Quaternary at 17 meters depth; 4) At Stăneşti-Hodivoaia, Giurgiu district, located 17 km north of the Danube bank, the Cretaceous was encountered at 70 meters depth; 5) At Călugăreni, in the Neajlov valley, about 25 km north of Giurgiu, a well placed in the Quaternary, at 65 meters altitude, passed from the Pliocene to the Cretaceous at 230 meters depth; 6) At Alexandria, on Vedea, a drilling encountered the limits Quaternary/ Romanian at 5 meters depth; Romanian/Dacian at 114 meters; Dacian/Cretaceous above 180 meters. The bottom of the well remained in the Upper Cretaceous.

THE PROBLEM OF THE DANUBE FAULT

It is noticed the observation that along of the Danube, the Bulgarian (right) bank is higher than the Romanian (left) bank by 50-200 m, correlated with the presence of outcrops and cliffs on the Bulgarian bank in total relief contrast with the Romanian bank loses in a smooth slope in the Danube waters. The level difference between the two Danube banks (fig. 8) perfectly marks the morphological limit of the Wallachian Platform north of the Danube from the Prebalkan Platform in the south. As on the southern bank (Bulgarian) Pliocene and especially Cretaceous formations appear, and on the northern bank (Romanian) Quaternary alluvial formations are found on the surface, some authors attributed this level difference to a fault relief, after which, the left bank (Romanian) would be lower than the right one (Bulgarian).

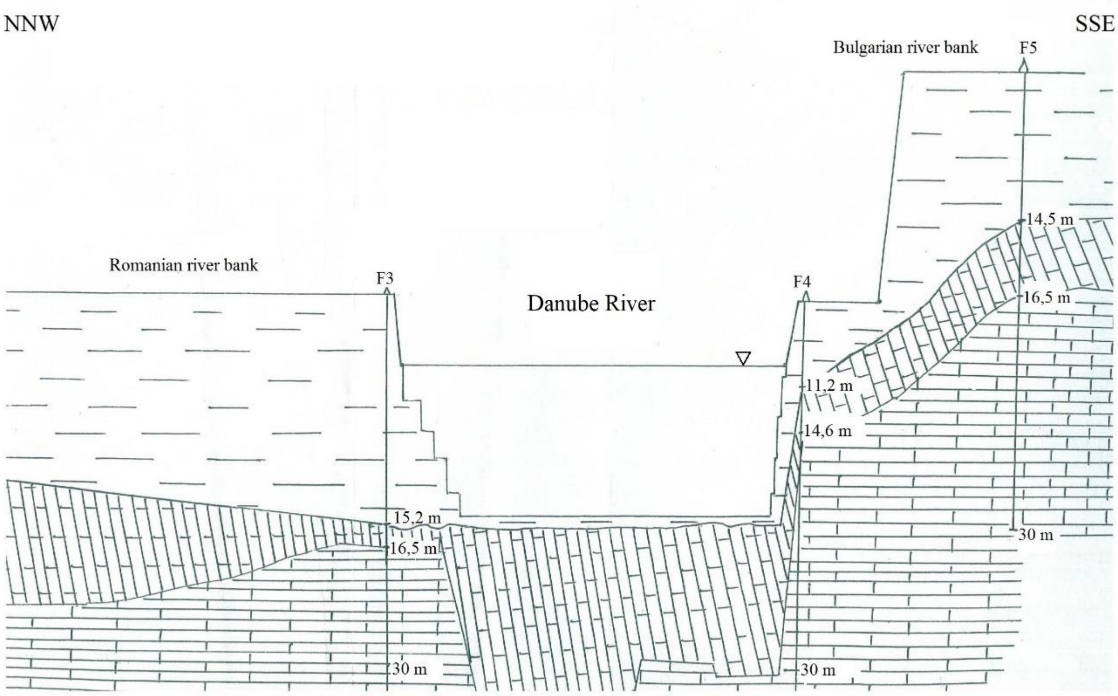

Fig. 8. Geological cross section between Comasca (Romania) and Marten (Bulgaria) [18]

Gheorghe Munteanu-Murgoci emphasizes the presence of the Lower Cretaceous at the water surface, in the excavations made for the construction of the St. Gheorghe harbour channel in Giurgiu. The reduced depth of the Cretaceous is confirmed in the excavations and drillings at the Giurgiu-Ruse Bridge or in the Călăraşi, Daia, Stăneşti-Hodovoaia drillings. As such, G.M. Murgoci and others, including D.M. Preda supports the continuity of the deposits on the Romanian shore with those developed on the Bulgarian shore, the difference being only in a difference in inclination of 1-2 degrees to the north. The fault relief is contested and the existing morphological difference is attributed to an erosion effect against the background of a southward erosion trend of the river, correlated with major alluvial accumulation on the northern bank.

In the stratigraphic succession chapter the sedimentary cycles of the cover are mentioned, subject of interest for the issue of circulation loss in subsurface Cretaceous limestones, being some details describing the third sedimentation cycle: Upper Liassic-Senonian. It should be remembered that the Malm-Lower Cretaceous subcycle is characterized by 1600 m of carbonate deposits arranged transgressively on various terms and showing continuity only in the central part of the Moesian Platform. The stratigraphic detailing of the Upper Kimmeridgian-Lower Barremian interval reveals the presentation under three facies: (1) pelagic (as basinal sedimentation domain in the central part of the platform),

(2) reefal (as accumulation in submerged platform areas, adjacent to the central Moesian basin between Jiu and Teleorman), (3) lagoonal (centered in the east of the platform, roughly in the area of the lower course of the Ialomiţa).[5] The pelagic facies (1) corresponds to carbonate deposits of chemical-biochemical precipitation from the open sea. The reef facies (2) accumulates on the background of some tilting of the bottom of the basin which initially involves an alternation of pelagic and reef deposits followed by a reef facies: coralline and algal, associated with pre-reef deposits with extension over the entire submerged platform area. In the west of the platform, the reef facies takes on the appearance of massive Neo-Jurassic limestones of the Stramberg type; in the east of the platform, fringing reefs were identified in the eastern and northern extremities and barrier reefs along the Ungureni-Brâncoveanu-Cartojani-Talpa-Frăsinet-Alexandria-Bogdana-Vişina-Potelu structural alignment (that separates the basin area from the platform area submerged). The lagoonal facies (3) Tithonic-Lower Cretaceous corresponds to dolomite and anhydrite deposits that pass upwards to grey-whitish clays and limestones. The stratigraphic detailing of the upper Barremian-Aptian interval (Fig. 5-6) reveals the continuous reduction of the sedimentation area starting from the Hauterivian. The western and eastern extremities of the former sedimentation area become emerged, the submerged platform area, being reduced only to the area south of Bucharest. [5]

On the entire Kimmeridgian-Aptian interval, the pelagic facies is represented by microcrystalline limestones, pseudo-oolitic limestones, calcarenites, marlstones; the reef facies is represented by biostromal limestones, pseudooolitic limestones, microcrystalline limestones affected by recrystallization and dolomitization, dolomitic limestones of the type of algal or coralligenous biostromes, gritty limestones, marl intercalations, sandstones, sands. The assemblage of the interval is well argued paleontologically (Muţiu, 1963, 1966, 1967, 1969; Muţiu, Bădăluţă, 1970; Patrulius, 1964). The Albian-Senonian sedimentation subcycle develops, outside the area of interest, respectively to the east and west of the platform. Related to the post-Cretaceous denudation, the Senonian and older deposits reveal an uneven development with complete succession in low sectors and being completely eroded in high sectors. At the end of the Cretaceous, the Laramic diastrophism has a major echo in the Carpathian Foreland causing the flooding of the Moesian platform, a situation that lasts until the Upper Miocene (Badenian). [5]

STRUCTURAL CONSIDERATIONS

The rupture tectonic style of the platform is marked by a network of faults arranged in two dominant directions: one east-west, related to the important, regional faults that affect the entire sedimentary stack up to the Pliocene; the second somewhat perpendicular related to minor faults; on the same northeast-southwest direction, structures with the aspect of promontories or "structural noses" separated by lowered areas are added. Often, the mentioned promontories represent buried paleo-reliefs, molded by the sedimentary cover. Most of these ridges were active during the evolution of the platform, causing lithofacial variations, among which, in the Upper Jurassic-Upper Cretaceous interval, favouring the development of reefs. Some of the paleo-reliefs have tectonic causes, the age of some promontories can be pushed to the Laramic diastrophism or earlier.

CONSIDERATIONS OF GEOLOGICAL EVOLUTION OF THE PLATFORM

The detailing of the Malm-Cretaceous interval reveals the accumulation of pelagic deposits by general submergence of the platform starting from Malm. Progressively and rhythmically, the eastern and western extremities were uplifted, a fact reflected by the alternation of pelagic and reef limestones, and then only by reef and pre-reef limestones accumulated on submerged platforms. In the central sector (Jiu-Teleorman) the accumulation of pelagic deposits continued until Aptian. The eastern extremity was uplifted, favouring the carbonate-evaporitic facies of the Purbeckian and, respectively, the Lower Cretaceous (Wealdean). While the central basin was favourable for the accumulation of hydrocarbon source rocks, the carbonate reef platforms showed favourable reservoir rock characters.[5, 19]

The Moesian Platform evolves as dry land during the Paleogene and lower Miocene. Controlled by the different intensity of the positive movements, by the predominantly calcareous nature of the rocks in the western half and respectively by the varied range of rocks in the eastern half, the denudation generated energic reliefs with diversity of forms: starting with typical erosion reliefs, continuing with karst structures and ending with abrasion surfaces. The forms of erosion generated paleovalleys, tribute to the basin of the Foredeep that seemed to drain the entire land between the Carpathians and the Balkans. The flow direction of the hydrographic network seemed to be from south to north during the Oligocene and lower Miocene. The increase in the slope gradients in the paleovalleys deduced from their progressive deepening suggests the beginning of the tilting of the platform from the south to the north. The pronounced deepening of the paleovalleys related to the Savic diastrophism allowed the Miocene paleovalleys to section the Mesozoic stack sometimes up to the Palaeozoic level. The subsidence that began in the Savic phase is accentuated towards the end of the Miocene, delimiting the actual foreshore platform in a broad sense. [5]

Petroleum geology considerations that may suggest petrophysical characteristics of the rocks in the studied section. The carbonate deposits of the NeoJurassic-Lower Cretaceous, which can be classified as porous and fissured mixed type reservoirs, show for the predominantly fissured ones as in the eastern area with partially cavernous submerged platform reef limestones, porosities that vary from deposit to deposit between 13% and 25% with permeabilities that often exceed 200 mD. Sometimes, contradictory flow rates (between 2 and 35 m^3/day of oil) are quoted in reservoirs of fissured reef limestone from the top of the Lower Cretaceous. The contradictory flows are attributed to the major variation in the degree of fracturing and alteration of the reservoirs under the Meso-Cretaceous unconformity.[5, 10, 19]

CONCLUSIONS

In the Danube undercrossing section by horizontal directional drilling in the Giurgiu-Ruse area, the investigation of the geotechnical, electrometric and magnetometric data reveals the presence of a shallow alluvial formation consisting of gravel, clay and sand, lying on the white-grey and grey limestones, yellowish-brown lumachelle limestones and grey-pink, compact limestones. These limestones are altered, eroded and karstified and seems to be the cause of the fluid loss during the drilling process. Based on references, we tried to diagnose the stratigraphic, tectonic and petrophysical properties in the Giurgiu-Ruse undercrossing section. The above-mentioned limestones found at depths of 14-19 meters during the geotechnical investigations are also mentioned for comparable depths (below 50 meters) in citing references in the studied section or in the adjacent area.

The limestones encountered during the drilling process are Urgonian reef limestones belonging to the Barremian age and belongs to the third cycle of the sedimentary cover of the Wallachian Platform, i.e. the Dogger-Cretaceous cycle respectively, which, after deposition, was followed by an uplift process of 55 million years, covering the interval from the Cretaceous to the Badenian stage which began with the Laramic phase of the Alpine orogenesis.

The presence of white-yellowish, diagenized organogenic limestones is cited in the Giurgiu-Ruse area on the basis of the data collected during the digging process of the St. Gheorghe harbour channel in the Giurgiu harbour, and correlated with the data related to the excavations for the Giurgiu-Ruse Bridge over the Danube, with the description of the outcrops in the Ruse area and with the information obtained from the drillings executed in the northern part of the Danube in the neighbouring area to the Giurgiu-Ruse section. The lithofacial and biofacial features of these limestones suggest that they belong to the Urgonian reef facies. The detailed examination of the sequence reveals the transition from marl and glauconitic sandstones to a basal level of breccias with elements of reef limestones and white-yellowish limestones with pachyodonta, offering solid premises for porosity and intense fissuring.

The stratigraphic details of the Barremian reefal limestones, integrated with some considerations about the geological evolution of the Moesian Platform and mentioned in important studies on petroleum geology, reveal the major effect of the long period of emersion and denudation that began immediately after the Barremian deposition, acting intermittently during the Upper Cretaceous and continuously during the entire period of 55 million years between the Cretaceous and the Upper Miocene (Badenian). Energic forms of relief erosion associated with karst phenomena and abrasion surfaces have been cited. The denudation that continued during the Miocene in the Savic phase led to the emergence of paleovalleys, sometimes cutting the entire Mesozoic sequence even up to the Palaeozoic level.

There are also references to enormous variations in the petrophysical properties of some reservoir rocks occurring in deposits similar to the Barremian ones in the studied section: fissures and porosities that exceed 25%, permeabilities exceeding 200 mD or contradictory flow rates in neighbouring areas (between 2 and 35 m^3/day of oil) attributed to the major variation in the degree of fissuring and alteration of the reservoirs situated under the Meso-Cretaceous stratigraphic discordance.

The information on the structure of the Moesian Platform highlights a characteristic rupture tectonics determined by an enormous network of fractures, where deep alignments oriented east-west, as well as alignments oriented north-south or north-east and south-west, can be noticed. They are associated with slightly fractured structures of the promontory type or structural nose composed of compartments alternately high and low, leading to variations from reefal to pelagic in the facies, in neighbouring areas. The Bucharest-Giurgiu fault is cited among the transversal faults, but in fact it belongs to a wider fracture zone.

Although the major level difference between the southern Bulgarian bank and the northern Romanian bank would argue for a fault relief, the analysis of the level of the similar Barremian deposits on the two banks reveals continuity, which contradicts the occurrence of the fault jump.

The escarpments and cliffs of the Bulgarian bank indicate to a greater extent that they are effects related to the tilting movement of the base of the Dacian basin, generating erosion tendencies towards the south and massive sedimentary accumulation tendencies towards the north.

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