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Documentation and correlation of transgressive-regressive cycles from three Lower-Middle Jurassic successions of the Western Balkan Mts, Bulgaria

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Е. Колева-Рекалова, Л. Методиев, Д. Иванова – Описание и корреляция трансгрессивных-регрессивных циклов в трех нижне-среднеюрских последовательностях в Западном Балкане, Болгария. Трансгрессивно-регрессивный характер и циклические параметры европейских юрских пород являются предметом продолжительного интереса и обсуждения, но в болгарской геологической литературе можно найти только незначительное число работ, посвященных секвентной стратиграфии и трансгрессивно-регрессивной цикличности юрских осадочных пород. Основная цель настощей работы – отстроить трансгрессивно-регрессивную циклическую модель трех нижне-среднеюрских разрезов, обнаженных в окрестностях сел Беледие хан и Брезе (Западные Балканы, Болгария). Проведены детальные седиментологические исследования. Выделены аммонитные зоны и получены данные о содержании фораминифер. На основании этой информации вверх по юрскому разрезу выявлено четыре трансгерссивно-регрессивных цикла третьего порядка. Установлено, что депозиционные циклы осадконакопления являются составными частями регрессивной фазы трансгрессивно-регрессивного цикла второго порядка. Эта фаза описана как фаза R6 в согласии с обозначениями, принятыми для других европейских бассейнов. Установленный циклический характер в исследованных разрезах показывает, что осадконакопление в тоарское и ранне-среднеааленское время протекало в условиях постепенной регрессии морского бассейна.

Abstract. The transgressive-regressive character and cyclic patterns of the European Jurassic rocks are topics of long-standing interest and debates. As a contrast, in Bulgarian geological literature there is a small number of publications concerning sequence stratigraphy and transgressive-regressive cyclicity of the Jurassic sediments. The main objective of the present study is to document the transgressive-regressive cyclic recurrence of three Lower-Middle Jurassic sections, exposed near the villages of Beledie Han and Breze (Western Balkan, Bulgaria). Fore third-order coarsening and shallowing upward transgressive-regressive cycles are recognized on the base of detailed sedimentlogical investigations and dated by precise ammonite zonation which is supplemented by foraminiferal data. It is evidenced that these depositional cycles build up the regressive phase (numbered R6, in accordance with other European basins) of a second order transgressive-regressive facies cycle. This investigation of cyclic character of the studied sections shows that sedimentation during the Toarcian and Early-Mid Aalenian time was formed under conditions of gradual regression of the sea basin.

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Key words: transgressive-regressive (T-R) cycles, Lower-Middle Jurassic, Western Balkan Mts, Bulgaria.

Introduction

The cyclic pattern of deposition of rocks of the Jurassic basins in Europe is topic of long-standing interest and debates (e.g. Sellwood and Jenkyns, 1975; Hallam, 1981; Vail et al., 1991; De Graciansky et al., 1998a, b; Aurell et al., 2003; Quesada et al., 2005). Most efforts have been made on sections, located in Western and Central Europe. The results that have appeared so far provided an essential framework of major sea-level changes, which are good base for further and more detailed investigations elsewhere.

Principally, the eustatic sea level variations are responsible for the formation of transgressive-regressive sedimentary sequences (Colombie and Strasser, 2005). Relative sea-level rise commonly leads to a transgressive and deepening facies trend. The regressive interval frequently consists of a series of coarsening upwards bedsets. The surface of the maximum of transgression separates the transgressive (retrogradational and aggradational) phase from the regressive (progradational) phase. The cycles are bounded by surfaces of maximum regression which represent unconformities of various character and order. Transgressive-regressive cyclicity occurs on a wide range of scales. Major cycles (with duration greater than 50 Ma) are subdivided into second-order transgressive-regressive facies cycles (average duration from 3 to 50 Ma), third-order depositional cycles (duration between 0.5 and 3 Ma) and high-frequency cycles (duration less than 0.5 Ma) (Vail et al., 1991).

A few publications of sequence stratigraphical purpose, devoted to the transgressive-regressive cyclicity of the Jurassic sediments in Bulgaria exist (e.g. Tchoumatchenco, 2002; Koleva-Rekalova et al., 2006). They have been focused on successions mainly from Western Bulgaria. In the present study, an attempt is made to determine the amount and rate of transgressive-regressive cycles in three Lower-Middle Jurassic sections, exposed near the villages of Beledie Han and Breze (Western Balkan Mts, Sofia District, Bulgaria) (Fig. 1), using available facies evidence. Time-calibration of the cycles is accomplished on the base of a high-resolution ammonite zonal subdivision. Finally, the cycles available are compared with contemporaneous analogues identified in other European basins.

Material and methods

More than 50 thin sections were investigated in order to recognize textures, terrigenous and bioclastic amount and sizes, and mineral composition of the rocks from the sections studied. The biostratigraphic subdivision was based on numerous bed-by-bed collected ammonites. In addition, available foraminifers were determined in thin sections. Sedimentological and biostratigraphic data as well as facies method, complemented by sequence stratigraphic interpretations, were applied to define the cycles of different scales. The transgressive-regressive cycles are determined following the concept of De Graciansky et al. (1998a), assuming that facies cycles are of second order and comprise of third order depositional sequences.

Results

The section Beledie Han is situated at 26 km to the north of Sofia (Fig. 1). It is an exposure of the Ozirovo Formation which is composed mainly of Fe-ooidal limestones and rare ferruginized marls, having a total thickness of 3.25 m. A set of 9 ammonite zones of the Toarcian, from *D. (O.) tenuicostatum* to *P. aalensis* Zone, has been taken (Sapunov et al., 1974; Metodiev et al., 2005) (Fig. 1). Three third-order coarsening and shallowing upward transgressive-regressive cycles (numbered 1, 2 and 3) (Fig. 1) have been recorded earlier (Koleva-Rekalova et al., 2006). Each cycle is developed from a marlstone or micrite limestone (wackestone) to an ooidal ironstone facies (packstone and packstone to grainstone). The cycles end usually with distinct shell-beds (rudstones) where the fossil concentration is several times higher than in the rest of the beds composing the succession. An increase in grain size, ooidal and bioclastic content, and decrease in terrigenous components occur upwards within each cycle (Koleva-Rekalova et al., 2006). The cycles were determined to be of third-order, with average duration of about 3 Ma.

The sections Dobravitsa-1 and Dobravitsa-2 are located near the village of Breze, at 60 km to the north of Sofia (Fig. 1). They have been previously described by Metodiev and Koleva-Rekalova (2005a). Section Dobravitsa-1 is about 7.0 m thick. It represents an irregular alternation of marls, shales and thin limestone beds that belong to the Boukorovtsi Member of the Ozirovo Formation. The top of the section is composed of shales with siderite nodules of the Etropole Formation. The ammonites of 14 zonal associations, from *D. (O.) tenuicostatum* to *H. discites* Zone (Toarcian-Lower Bajocian) have been collected (Fig. 1). The ammonite succession gave evidence for stratigraphic condensation affected the topmost Lower Toarcian and the base of the Upper Toarcian. The bottom of the section has been proven by foraminifera and bivalves to be of Late Pliensbachian age. Studied interval of section Dobravitsa-2 consist of about 2.0 m thick sediments of the Boukorovtsi Member of Toarcian age (from *H. bifrons* Zone to *P. fallaciosum* Zone) (Fig. 1). It is composed of marls and shales which are interbedded by micritic and Fe-ooidal limestones.

The cyclic recurrence of deposition in sections Dobravitsa-1 and Dobravitsa-2 is less discernible than in section Beledie Han. It is screened probably because of homogenization. Later is due to the hemipelagic depositional environment of the sediments. So, section Beledie Han is used as a reference to define the cyclic pattern of the sediments in the other two sections. Supporting evidence for the cyclic pattern of deposition in sections Dobravitsa-1 and Do-

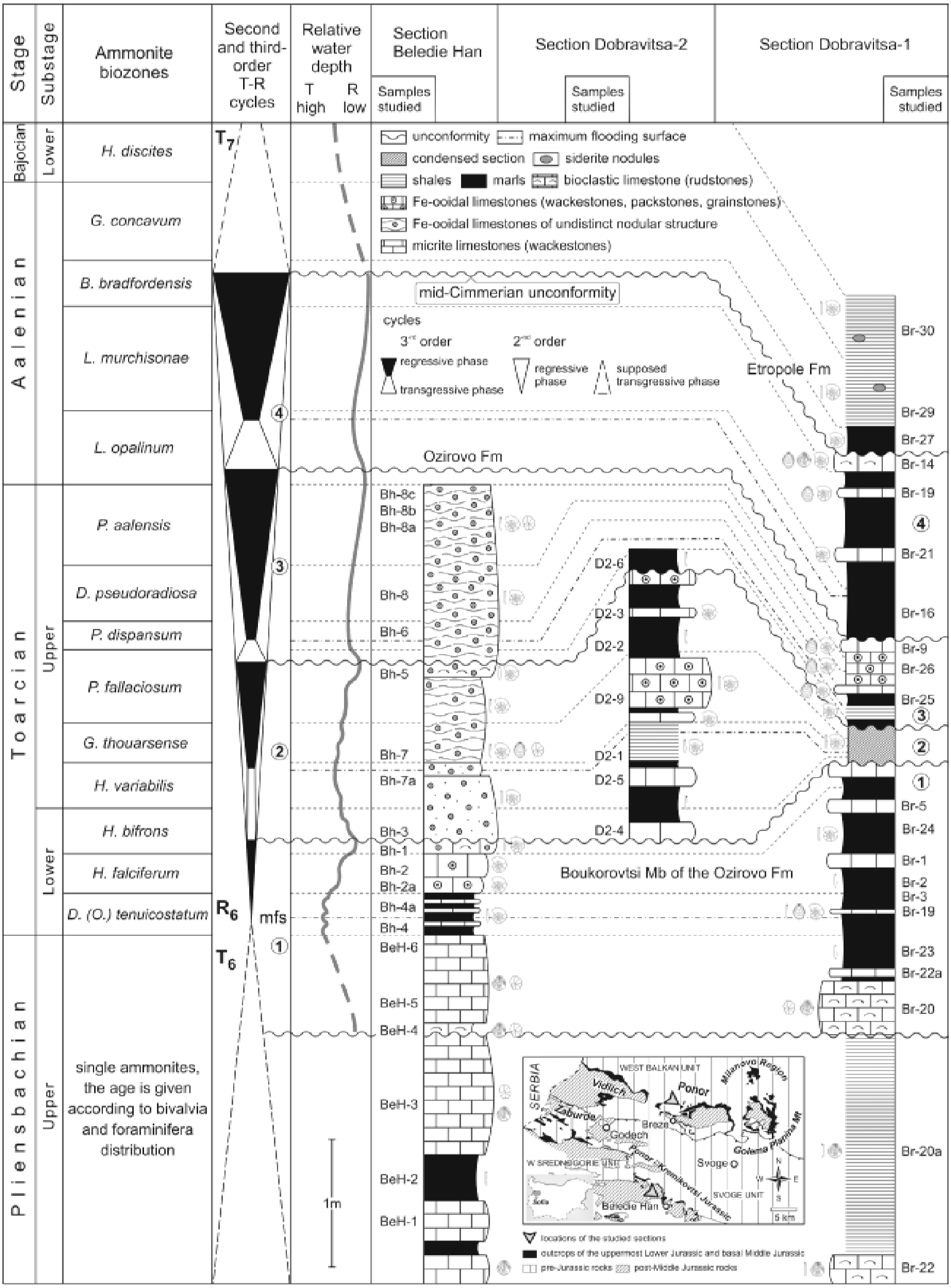

Fig. 1. Second and third-order transgressive-regressive (T-R) cycles and relative water depth curve, plotted against lithological columns and ammonite zonal subdivision of sections Beledie Han, Dobravitsa-1 and Dobravitsa-2. The right lower corner represents geographical location of the sections

bravitsa-2 has been received after the approximate estimation of the amount and the rate of the fossils preserved into the rocks.

Discussion

Recently, it was found that the third-order transgressive-regressive depositional cycles determined in section Beledie Han were superimposed on a large trend of the regressive part (numbered R6 by De Graciansky et al., 1998a), of a second-order T-R facies cycle (Koleva-Rekalova et al., 2006). The marls at the base of the first third-order cycle represent offshore shelf deposits which are similar to some marls from section Dobravitsa-1. They were formed during the global early Toarcian transgression that was recorded in many sites in Europe (Jenkyns et al., 2002). In fact, the maximum peak of transgression was located in these marls (Metodiev and Koleva-Rekalova, 2005b). It was registered in sections Beledie Han and Dobravitsa-1 by isotopic data ($\delta^{13}C$ and $\delta^{18}O$) obtained from belemnite rostra, close to the Pliensbachian-Toarcian boundary – the base of *D. (O.) tenuicostatum* Zone. This peak represents maximum flooding surface of the second-order transgressive-regressive facies cycle (Fig. 1). Jenkyns et al. (2002) assumed that for the most European Jurassic basins this transgressive peak happened during the time span of the Lower Toarcian *H. falciferum* Zone. Aurell et al. (2003) considered the time of the Lower Toarcian *H. bifrons* Zone as maximum of transgression in Northeast Iberia. The same authors discussed that the different age of the maximum of transgression from one basin to another could be explained by different subsidence evolution caused by tectonic events of local or regional scale. It is noteworthy that the maximum peak of transgression both in section Beledie Han and section Dobravitsa-1 coincides with the first appearance in abundance of ammonites. That concurrence is enhanced by the rapid increase of the fossil contents of the rocks, the presence of real belemnite battlefields, as well as by the circumstance that only single ammonites have been found below and the fossil record of the Upper Pliensbachian is exclusively represented by scattered benthic fossils such as bivalves and foraminifers.

Even more unclear, the threefold cyclic model of sedimentary development has been found working for the Toarcian part of section Dobravitsa-1 as well (Fig. 1). In general, each cycle starts from marls and ends with a limestone bed. The first cycle is framed by the ammonite-bearing marls of the Lower Toarcian which are preceded by a shell-bed containing bivalves and abundant foraminifers. The maximum of the sea-level rise agrees on a peak of fossil abundance at the base of *D. (O.) tenuicostatum* Zone. The condensed section, spanning from upper part of the Lower Toarcian *H. bifrons* Zone to lower part of the Upper Toarcian *P. fallaciosum* Zone which follows upwards, entirely falls into the second cycle. This interval is coeval to section Dobravitsa-2 which has a normal pattern of sedimentation (Fig. 1). The third cycle is defined from the marls of the top of *P. fallaciosum* Zone to the Fe-ooidal limestones with ammonites that indicate the Upper Toarcian *P. dispansum*, *D. pseudoradiosa* and *P. aalensis* Zones. It terminates with a bed of micrite limestone (wackestone) whose lower surface the boundary between the Toarcian and the Aalenian has been traced on. Additionally, another third-order T-R cycle (4) which is lengthened from the lowermost part of *L. opalinum* Zone to the middle part of *B. bradfordensis* Zone seems to be manifested upwards into the Aalenian. Its character is the same as the rest of three cycles. This cycle ends with bioclastic limestone (rudstone), situated just below the limit between *B. bradfordensis* and *G. concavum* Zones. It is likely that this bed was formed under condition of a global maximum regression. The upper surface of this bed appears to be a correlative to the mid-Cimmerian unconformity distinguished by De Graciansky et al. (1998b).

The above described third-order T-R cycles display an asymmetric pattern. The asymmetry of a transgressive-regressive sequence is obvious in sedimentary columns where the relative water depth can be inferred using sedimentological and palaeontological data (Einsele and Bayer, 1991). As a result water-depth curves are drawn (Fig. 1). They show that second, third and forth cycles are asymmetric, reflecting a relatively rapid rise and an apparently slow fall of the sea level. The transgressive surfaces of third-order are defined by the deepest and finest sediments (marls and wackestones of section Beledie Han, as well as shales and marls of sections Dobravitsa-1 and Dobravitsa-2). Conversely, the regressive peaks associate with the most shallow-water and the coarsest deposits (mainly rudstones).

The shales with siderite nodules of the Etropole Formation cover the forth cycle form the transgressive part (numbered T7) of the following second-order T-R cycle (Fig. 1). In the same way, the shales, marls and limestones from the Upper Pliensbachian of sections Beledie Han and Dobravitsa-1 represent a part of the transgressive interval (numbered T6) of studied second-order T-R cycle. They are arranged in a deepening upward manner. In a general view this second-order facies cycle belongs to the first-order Ligurian cycle as defined in other European basins (De Graciansky et al., 1998b). It extends from the Late Triassic to the end-Aalenian time, being bounded by the early Cimmerian (latest Norian) and mid-Cimmerian (end-Aalenian) unconformities (De Graciansky et al., 1998b).

Conclusion

The present study documents the cyclic pattern of sedimentation of three Lower-Middle Jurassic successions, located in the Western Balkan Mountains

(Bulgaria). Four third-order coarsening and shallowing upwards T-R cycles are recognized in the sediments of the Toarcian and Aalenian. It is evidenced that these depositional cycles build up the regressive phase of a second order transgressive-regressive facies cycle that belongs to the Ligurian major transgressive-regressive cycle. Lithological record of the sections studied talks about deposition under conditions of a gradual regression of the sea basin during the Toarcian and the early Aalenian time.

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Резюме. Е. Колева-Рекалова, Л. Методиев, Д. Иванова – Описание и корелация на трансгресивно-регресивните цикли в три долно-средноюрски разреза от Западния Балкан, България. Трансгресивно-регресивният цикличен характер на седиментацията в юрските басейни в Западна и Централна Европа е обект на усилено изследване и дискусии през последните 30–40 години. В България този вид проучвания са все още спорадични и твърде недостатъчни. Целта на настоящата работа е документирането на трансгресивно-регресивните цикли от различен порядък в долно-средноюрски скали, които изграждат три разреза, разположени в Западна Стара планина. Направен е и опит за корелиране на отделените цикли с едновъзрастови аналози, описани в чуждестранната геоложка литература. Цикличността на седиментите е установена въз основа на детайлни макро- и микроскопски седиментоложки изследвания, съпътствани с прецизна амонитна зонална подялба и фораминиферни определения. Порядъкът и продължителността на отделените трансгресивно-регресивни цикли са съобразени със скалата на Vail et al. (1991). За определяне и илюстриране характера на циклите е използвана концепцията на De Graciansky et al. (1998a).

Първият от изследваните разрези се разкрива в околностите на с. Беледие хан (Софийско), на 26 km северно от гр. София. Той е изграден от варовици, съдържащи в различно количество Fe-ооиди, които принадлежат на тоарския етаж. В основата му присъстват и мергели. Като подложка се разкриват седименти от най-горната част на горния плийнсбахски подетаж. В едно предходно изследване на разреза бяха установени три трансгресивно-регресивни цикъла от трети порядък през тоарския век, със средна продължителност около 3 Ma. Всеки цикъл започва с по-дълбоководни и по-финозърнести седименти, които нагоре стават по-плитководни и по-едроразмерни. В допълнение към този профил са изследвани още два разреза, които се разкриват в района на с. Брезе (Софийско), на 60 km северно от гр. София: Добравица-1 (горен плийнсбахски подетаж-долен байоски подетаж) и Добравица-2 (долен тоарски подетаж, горна част-горен тоарски подетаж, долна част). Те са представени от незакономерна алтернация на аргилити, мергели и варовици. В разрез Добравица-1 също са разграничени три трансгресивно-регресивни цикъла от трети порядък през тоарския век и един цикъл от този порядък през ааленския век. Отделените четири цикъла съставят регресивната фаза на един трансгресивно-регресивен цикъл от втори порядък, описан от De Graciansky et al. (1998a), което е доказателство за седиментация в условията на постъпателна регресия на морския басейн през тоарския век и по-голямата част от ааленския век, в района на изследваните профили.