Jurassic stratigraphy of the section Staro selo, Pernik District, Southwestern Bulgaria

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Ï. ×óìà÷åíêî, Ì. ßíåâà, Å. Êîëåâà-Ðåêàëîâà, Ê. Ñòîéêîâà, Ä. Èâàíîâà – Ñòðàòèãðàôèÿ þðû â ðàçðåçå îêîëî Ñòàðî ñåëî, Ïåðíèêñêèé îêðóã, Þãî-Çàïàäíàÿ Áîëãàðèÿ. Þðñêîå îñàäêîíàêîïëåíèå â ðàéîíå ã. Ïåðíèêà (Þãî-Çàïàäíàÿ Áîëãàðèÿ) íà÷àëîñü â êîíöå áàéîññêîãî âåêà îòëîæåíèåì ïåñ÷àííèêîâ Ëÿëèíñêîãî ÷ëåíà (Ãðàäåöñêàÿ ñâèòà). Îíî ïðîäîëæàëîñü â áàòñêîì âåêå îòëîæåíèåì áèîêëàñòè÷åñêèõ èçâåñòíÿêîâ Ïîëàòåíñêîé ñâèòû. Îêîëî ñ. Ñòàðî ñåëî îáíàæåí îäèí èç ñàìûõ ïîëíûõ ðàçðåçîâ þðû â Þãî-Çàïàäíîé Áîëãàðèè. Îí èññëåäîâàëñÿ ñ ëèòîôàöèàëüíîé, ñåäèìåíòîëîãè÷åñêîé, áèîñòðàòèãðàôè÷åñêîé òî÷êè çðåíèÿ, à òàêæå ñ òî÷êè çðåíèÿ ñåêâåíòíîé ñòðàòèãðàôèè. Â áàéîñ-áàòñêîì èíòåðâàëå âûäåëåíî ÷åòûðå ñåêâåíöèè 3-åãî ïîðÿäêà: Bj 5, Bat 0, Bat 1 è Bat 2. Ïîñëå ïåðåðûâà â îñàäêîíàêîïëåíèè (êýëëîâåéñêèé è îêñôîðäñêèé ÿðóñû) îòëîæèëèñü èçâåñòíÿêè Ãèíñêîé ñâèòû (íèæíèé êèììåðèäæñêèé ïîäúÿðóñ) è Äðóãàíñêîé ñâèòû (ñðåäíèé êèììåðèäæñêèé ïîäúÿðóñ). Â íèõ âûÿâëåíû òðè ñåêâåíöèè: Kim 2 - Kim 4. Â ïîðîäàõ Íåøêîâñêîé ñâèòû (âåðõíèé êèììåðèäæñêèé ïîäúÿðóñ) è â Áîáîâñêîì ÷ëåíå Êîñòåëñêîé ñâèòû (â èññëåäîâàííîì îáëàñòè îíè îõâàòûâàþò ñàìûé âåðõíèé êèììåðèäæñêèé ïîäúÿðóñ – âåðõíèé òèòîíñêèé ïîäúÿðóñ) âûäåëåíî 19 ñåêâåíöèé 3-åãî ïîðÿäêà (Kim 5-Ti 1.1-Ti 1.13, Ti 2, Ti 3.1-Ti3.2, Ti 4, Ti 5). Ñåêâåíòíî-ñòðàòèãðàôè÷åñêèå åäèíèöû âûäåëåíû ãëàâíûì îáðàçîì íà îñíîâàíèè ãåîìåòðèè è ñóïåðïîçèöèè êàðáîíàòíûõ è òåððèãåííûõ òåë. Ñåêâåíöèè Ñòàðîñåëüñêîãî ðàçðåçà ñîïîñòàâèìû ñ ñåêâåíöèÿìè çàïàäíîåâðîïåéñêîé ñõåìû Hardenbol et al. (1998). Â êàðáîíàòíîé ÷àñòè ðàçðåçà èõ ÷èñëî ñîâïàäàåò ñ ÷èñëîì ñåêâåíöèé â ýòîé ñõåìå, à â åãî òåððèãåííîé ÷àñòè èõ áîëüøå, ÷åì â íåé.

Abstract. The onset of the Jurassic sedimentation in the region of Pernik (southwestern Bulgaria) is at the end of Bajocian with deposition of sandstones (Lyalintsi Member of Gradets Fm.) and continuing during the Bathonian with bioclastic limestones (Polaten Fm.). The section Staro selo is one of the most complete Jurassic sections in Southwest Bulgaria. It is studied from several points of view: lithofacial, depositional processes, biostratigraphic and sequence stratigraphic. In Bajocian-Bathonian interval four 3rd order depositional sequences are individualized: Bj 5, Bat 0, Bat 1 and Bat 2. After a break of sedimentation (Callovian-Oxfordian), the limestones of Gintsi (Lower Kimmeridgian) and Drugan (Middle Kimmeridgian) Formation were deposited in which 3 depositional sequences were recognized (Kim 2-Kim 4). Nineteen depositional sequences of 3rd order are individualized (Kim 5-Ti 1.1-Ti 1.13, Ti 2, Ti 3.1-Ti3.2, Ti 4, Ti 5) in the sediments of Neshkovtsi Formation (Upper Kimmeridgian) and in the Bobovo Member of Kostel Formation (Uppermost Kimmeridgian – Upper Tithonian in the studied area). The recognition of the depositional sequences is based chiefly on the geometry and the superposition of the calcareous and siliciclastic sediments. The divided depositional sequences are compared to those of Western European scheme of Hardenbol et al. (1998). Within the carbonate part of the succession they are of the same number and in the siliciclastic part they are more numerous.

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Key words: Jurassic, lithostratigraphy, biostratigraphy, sequence stratigraphy, carbonate and siliciclastic sediments, Southwestern Bulgaria.

Introduction

This paper aims at making an attempt of sequence stratigraphic interpretation of the best exposed Jurassic section in southwestern Bulgaria, located near the village of Staro selo (Drugan), Pernik District (Fig. 1). The basal part of the section is outcropped in the Nikolchov Dol valley, north of the church of Staro selo. Here the sediments of Gradets (Lyalintsi Member), Polaten, Gintsi, Drugan, Neshkovtsi and the lower part of the Kostel (Bobovo Member) Formation are exposed. The higher part of the Bobovo Member of Kostel Formation crops out along the road Sofia-Athens. This part of the section is situated to the East of the village of Staro selo in the locality Izvora and continues along the old road to Staro selo. In the village of Staro selo, near the ramification, flysch sediments dipping to the North are outcropped. The uppermost part of the section is poorly exposed and thus is not described.

The term flysch is used in the paper only in sense used by Studer. According to Dzulinski & Smith (1964) "the term flysch was introduced by Studer in 1827 to describe a series of shales and muddy sandstones (Upper Cretaceous) in Siementhal area of Switzerland. Neither stratigraphic nor tectonic implications were included into original definition. The term was later extended to cover all sediments showing the same or similar features in other regions".

We have studied the flysch type rocks from several points of view: lithofacial, the depositional processes, biostratigraphic and sequence stratigraphic. For this purpose we follow the explanations of the lithofacies and the depositional processes according to Shanmugan & Moiola (1995), Shanmugan et al. (1995), etc. because they are sufficiently simple and easily usable. We attempt to combine the lithofacial / depositional processes point of view with the turbidite point of view (which is traditional for Bulgaria – Nachev, 1972, etc.). At the end of the paper we suggest a sequence stratigraphic interpretation based on the sum up of the results in all different studies.

The literature on sequence stratigraphy is very extensive and will not be reviewed here. "The sequence stratigraphy had a major influence on understanding the stacking patterns of successive depositional units. The concepts are applicable in spite of the fact that artificially forced applications may cause serious disagreements regarding their validity" (Bouma, 2000). We will not discuss here the causes for the formation of the different systems tracts, but we will try to register the difference in the lithology in different parts of the section and try to express them in terms of the sequence stratigraphy. The individual sedimentary structures generally are not sufficient diagnostic criteria, and frequently the entire suite of structures in a rock sequence can be used to recognize depositional environments, together with vertical facial sequences, rock-body geometry, grain size, etc.

Previous researches

Nachev (1970) described characteristic features and sedimentary structures in the "flysch" of the Kraishte region, considering also the Staro selo (Drugan) section. Nachev (1972) described the section Drugan. He determined Neshkovtsi Fm. as "pre-flysch" and the Bobovo Mb. of the Kostel Fm. as "flysch". In the Neshkovtsi Fm. Nachev described: marls, argillaceous marls, calcareous shales, and shales. This publication is without description of the section itself, but represents only an analysis of the building components of the rocks of the Neshkovtsi and the Kostel Fm.

The age of Gradets Fm. is Aalenian, and that of Polaten Fm. – upper Aalenian to lower Bathonian (Äîäåêîâà et al., 1984). Ñàïóíîâ et al. (1985) described the Gintsi Fm. (Lower Kimmeridgian), the Neshkovtsi Fm. (Upper Kimmeridgian, lower part – Middle Kimmeridgian) and the Bobovo Mb. of Kostel Fm. (Middle Tithonian, lower part – Upper Kimmeridgian, uppermost parts) in the section of Staro selo (Drugan). They determined the section at the village of Drugan (East of Staro selo) as complementary one for the new lithostratigraphic unit – Bobovo Member of Kostel Fortmation. Tchoumatchenco (2002) made an attempt to introduce the sequence-stratigraphic subdivision of the Jurassic in western Bulgaria without describing the lithology of the local sections. He referred the Polaten Fm. near Staro selo to the Bathonian using sequence stratigraphic arguments. He also presented the sequence stratigraphy of Middle Callovian-Berriasian 1st order sequence in the section Izvorite where the Drugan Fm. is not exposed due to the tectonic reasons. Later on, ×óìà÷åíêî et al. (2004) described the new Drugan Fm. of Middle Kimmeridgian age. Its holostratotype is a part

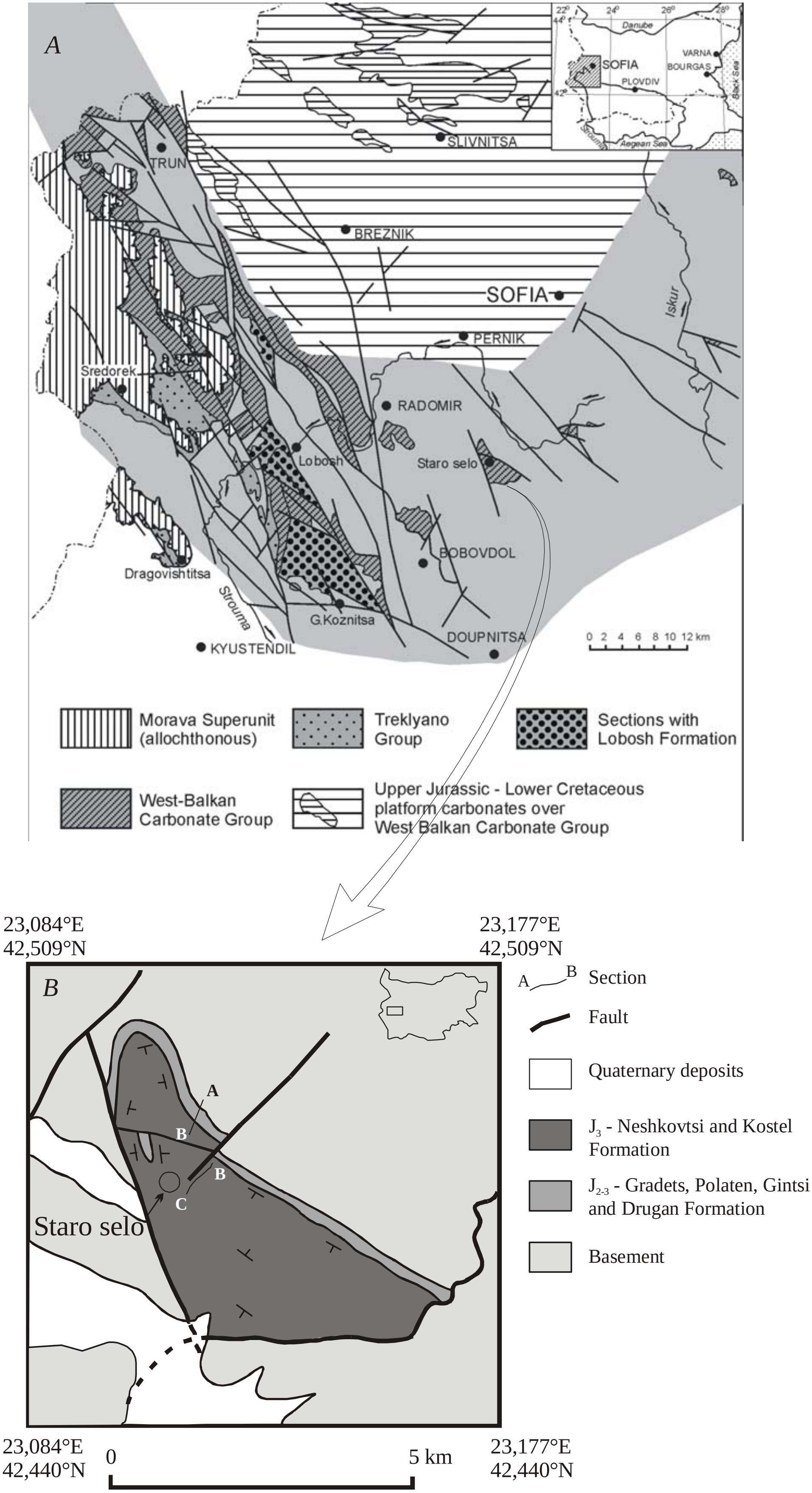

Fig. 1. *A* – geological sketch-map of the Jurassic sediments in SW Bulgaria (after Zagorchev et al., 2000); *B* – location of the studied section (after Zagorcev et al., 1991 with corrections)

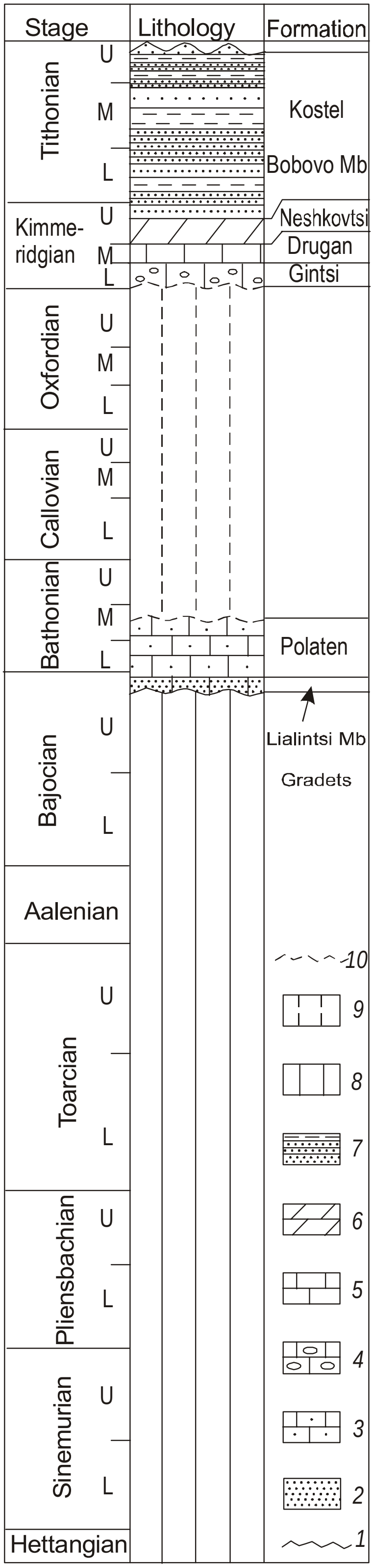

Fig. 2. Schematic stratigraphic column of the Jurassic sediments near Staro selo (Drugan Village, western Bulgaria)

1 – transgressive surface, *2* – sandstone; *3* – sandy and bioclastic limestone; *4* – lithoclastic limestone; *5* – micritic/fine grained limestones; *6* – marls, *7* – alternation – mudstone, sandstone; *8* – subaerial depositional break; *9* – submarine depositional break; *10* – hardground surface

of the section described here. The study of this new formation corrected the general sequence stratigraphic scheme and completed it.

Methods

The field study (description and revisions) has been carried out by P. Tchoumatchenco, partially assisted by E. Koleva-Rekalova, D. Ivanova and M. Yaneva. The petrographic characteristic of the sediments is accomplished by E. Koleva-Rekalova (carbonate rocks) and M. Yaneva (siliciclastic rocks); the calcareous nannofossils are determined by K. Stoykova and the foraminifers – by D. Ivanova. The sequence stratigraphic interpretation is entirely done by P. Tchoumatchenco.

Lithostratigraphy

The åxamined Jurassic section encompasses the following lithostratigraphic units from the bottom to the top (fig. 2): Gradets Fm. – Lyalintsi Member, Polaten Fm., Gintsi Fm., Drugan Fm., Neshkovtsi Fm., Kostel Formation – Bobovo Member.

1. Gradets Formation, Lyalintsi Member (1.10 m)(Fig. 3)

The base of the Lyalintsi Member of Gradets Fm. is built of grey to beige medium to fine grained sandstones with calcareous matrix and allohemes of crinoids and terrigenous components – quartz and feldspars (spec. 01). At the top these rocks turn to calcareous sandstone to sandy bioclastic limestones (packstone to rudstone) (spec. 02).

The lower boundary is transgressive – the Lyalintsi Mb. lies directly on the Upper Triassic reddish marls, intercalated by sandstones. Its upper boundary is covered by soil. The age is determined as Late Bajocian on the basis of the age of the superimposed Polaten Fm.

2. Polaten Formation (19.0 m)(Fig. 3)

The Polaten Fm. is built of gray, various bedded limestones: (a) sandy intraclastic limestones (spec. 03); (b) peloidal limestones with oncoids (packstone) (spec. 04, 05, 06, 09, 10); (c) oncoid-peloidal limestones (spec. 11, 12); (d) cortoid-peloidal limestones (spec. 07). Frequently, the limestones contain fragments or complete valves of brachiopods and/or bivalves. The lower boundary is covered by soil, but in unit Ï-1 the limestones contain many lithoclasts from micritic, bioclastic and of sandy limestones which are very characteristic for the Polaten Fm. – i.e. they are probably redeposited from the lower parts of the Polaten Fm. transported from another areas. The upper boundary is connected to a submarine break in the sedimentation (hard ground). Tchoumatchenco (1983) and Äîäåêî âà et al. (1984) regarded the Polaten Fm. as Aalenian-Middle Bathonian lithostratigraphic unit (as it is in the section of Zhablyano); but Tchoumatchenco (2002, fig. 3, column 2), on the basis of the number of the sequences below the upper boundary of the Polaten Fm. considered here the Polaten Fm. as Lower-Middle Bathonian unit. However, the occurrence of *Protopeneroplis striata* Wyenschenk, *Trocholina palastiniensis* Henson and *Patellina douvillei* Said & Barakat in the basal part of the Polaten Fm. rather suggests a Bajocian-Bathonian age.

3. Gintsi Formation (1.50 m)(Fig. 3)

The Gintsi Fm. is represented by gray limestones with calcareous debris (intraclasts), built of *Bositra*-rich wackestone to packstone. Peloidal limestones (packstone) (spec. 013) represent the base of the sequence which grades upwards into micrite limestone with filaments of *Bositra*, calcified radiolarians spicules and rare dinocyst wackestone (spec. 014). The *Bositra* valves are not oriented and are most frequently broken. In the section we didn't find any determinable fauna, but in the nearby section east of Staro selo Ñàïóíîâ et al. (1985) reported *Crussoliceras* sp. indet., ranging in the Lower Kimmeridgian *Crussoliceras divisum* ammonite Zone. Thus the Gintsi Fm. here is assigned to the Lower Kimmeridgian.

The lower boundary is marked by hard ground surface – the underlying Polaten Fm. is eroded with many "pot holes" filled by coarse-grained sandy limestones (spec. 017) or by single pebbles of quartz. This timing of the gap of sedimentation is between Middle Bathonian up to the Early Kimmeridgian. The upper boundary (with Drugan Fm.) is sharp, but parallel. The sediments of the Gintsi Fm. represent a debris flow deposits.

4. Drugan Formation (22.95 m)(Fig. 3)

The Drugan Fm. (×óìà÷åíêî et al., 2004) is built of grey to grey-greenish, clayey and micritic limestones, with rare marly interbeds. Limestones beds are 0.1-0.2 to 2.0 m thick. In the uppermost parts they contain cherty nodules. The lower and the upper boundary of the formation are sharp and conformable in the studied section. The fossil content of the Drugan Fm. – planktonic organisms as Radiolarians, Globochaetids (?), Bivalvia – *Bositra* cf. *buchi* and calcareous nannoplankton (*Ellipsagellosphaera lucasi, E. britanica, Watznaueria barnesae, W. biporta, Cyclagellosphaera margerelii)*, clearly suggests a deep-marine hemipelagic to pelagic depositional setting – periplatform ooze. The carbonates of Drugan Fm. are built of *Bositra*'s filament rich packstone (H2) in the base and of clayey radiolarian wackestones up section (spec. H4, 5, 6, 8, 10, 10a). The boundary between the *Bositra*'s and Radiolarian biofacies coincides almost completely with the boundary between the units 3 and 4. The recovered microfossils exhibit a wide stratigraphic range and thus couldn't fix precisely the age of the Drugan Fm. Its stratigraphic position between the Lower Kimmeridgian (Gintsi Fm.) and the Upper Kimmeridgian (Neshkovtsi Fm.) consequently suggests a Middle Kimmeridgian age. The inferred depositional process is suspension settling.

5. Neshkovtsi Formation (thickness 20.5 m)(Fig. 3, 4)

It is built of calcareous shales to marls, grey to dark grey; the matrix consists (98-99%) of clay minerals and micro-grained calcite (soluble components – 30.75%). Often the matrix is strongly stained by Fe-oxihydroxides, preserved into the matrix as globules with diameter under 0.063 mm. The clastic components – quartz and feldspars are in insignificant amount – about 1-2%. Their size is less than 0.063 mm. There are single muscovite flakes.

The shales to marls are interbedded by thinbedded (5-10 cm) clayey limestones, which often show ripple lamination. In the section in the locality Izvorite the calcareous shales to marls are interbedded by thin beds (5-20 cm) of fine-grained sandstones with *Chondrites furcatus*.

Nachev (1972, p. 41) interpreted these sediments as "pre-flysh" and reported the following taxa: *Subplanites* cf. *contiguus* (Catullo), *Berriasella* sp. indet. and *Punctaptychus* sp. indet., assigned to the Lower Thitonian. Ñàïóíîâ et al. (1985) found *Orthosphinctes* sp. indet. and referred the Neshkovtsi Fm. in the studied region to the Middle Kimmeridgian-lowermost parts of the Upper Kimmeridgian. Èâàíîâ (in ×óìà÷åíêî et al., 2004) reported a rich ammonite association at 0.40 cm above the base of the Neshkovtsi Fm.: *Ptychophylloceras ptychoicum* (Quenstedt), *Taramelliceras (Taramelliceras) franciscanum* (Fontannes), *T. (T.)* aff. *pugile* (Neumayr), *Orthosphinctes* cf. *subdolus* (Fontannes), *O. vandellii* (Choffat), *Virgataxioceras* cf. *setatoides* (Berckhemer), *Hybonoticeras* cf. *pressulum* Neumayr). Calcareous nannofossils recorded from the same level comprise *Ellipsagellosphaera lucasi*, *E. britanica*, *Watznaueria barnesae*, *W. biporta*, *Cyclagellosphaera margerelii*. Therefore a Late Kimmeridgian age is evidenced for the Neshkovtsi Fm.

6. Bobovo Member of the Kostel Formation (Fig. 4-6)

The Bobovo Mb. of the Kostel Fm. (Ñàïóíîâ et al., 1985) is developed in flysh facies – “a series of shales and muddy sandstones” (after Studer, 1827). Nachev (1972, p. 42-43) characterized the sediments of Drugan (Staro selo) section as “terrigenous normal flysh built up of microconglomerates (0.5%), sandstones (31.5%), siltstones (26.4%) and clayey limestones (0.3%). The palaeocurrent directions are E-NE, frequently 70°”.

The sediments of Bobovo Mb. (319 m thickness in the measured section), consist of alternation of sandstones and mudstones. The sandstones are (1a) thick bedded sandstones; here thick beds of conglomerates or breccia-conglomerate are described also; (1b) thin bedded sandstones and (1c) laminated sandstones; usually alternating with (1d) thin beds of mudstones. The lower boundary of the Member is traced by the first occurrence of thick sandstone bed above the Neshkovtsi Fm. In some other localities in SW Bulgaria the upper parts of the Bobovo Mb. encompasses the Berriasian, but they are in complicated tectonic situation and have not a direct continuity from the Tithonian beds.

(1) Sandstones

(1a) Thick-bedded sandstones. The thick-bedded sandstone (e.g. the specimen Ñ-2- unit 11 – base of the Kostel Fm., spec. Ñ-5 – unit 23, spec. C-14 – unit 84) are generally medium to coarse-grained (0.5-1.0 mm), with bed thickness from 0.5 m up to 1.4-2.0 m. Rarely their thickness varies in horizontal direction (e. g. unit 23 – from 0.40 up to 1.20 m). In thin section they represent calclithite (spec. C2, unit 11) up to lithic arenite (spec. C5, unit 23). The texture is psamitic to coarse psamitic with mineral grains and lithoclasts among matrix. Clastic components vary from 55-60% to 95%. The mineral grains are represented dominantly by monocristaline quartz, feldspars (albite-oligoclase), biotite and muscovite, and lithoclasts (siltstones to fine-grained sandstones, phyllites, acid magmatic rocks, silicites, fragments from different limestones – micritic, peloidal where the peloids are composed of microgranular calcite, recrystallized bioclasts, single bioclasts, etc.). The matrix consists of micrograined calcite, often impregnated by Fe-oxide and hydroxides (spec. C-2, 5) or of micrograined calcite and clay minerals (spec. C-14, unit No 84).

Unit 18 (thickness 0.50 m) is particular by its irregular thin bedding of fine- to medium-grained gray hybrid sandstones. In the basal part (specimen 018) the litho- and bioclasts sized 1-2 mm, rare up to 4×3 mm, and formed cc. 80% of the rock volume. The lithoclasts are predominantly of 2 types of limestones – deep and shallow water. The first group is structured by micrite with rare indeterminable bioclasts, and the last one – from peloidal limestones with many bioclasts from corals, briozoans and crinoids. The rock contain also rare (cc 1%) terrigenous component from quartz. Their determination is lithoclastic limestone (packstone or calcarenite). The specimen taken from the upper part of the bed (spec. 019) show allochem cc. 65%; they are finer then in the basal part – between 0,5-1,0 mm (coarse grained psamite) (normal upwards gradation of the clasts). The lithoclasts are also built by 2 type of limestones – deep and shallow water. Quartz, rare potassium feldspar and plagioclases, muscovite flakes represent the terrigenous grains (cc. 5%). The rock is determined as litho-bioclastic limestone (packstone or calcarenite).

The thick-bedded or massive sandstones can be determined as debrite from lithofacial point of view, deposited by sandy debris flow. From the turbidite point of view they can be determined as fluxoturbidite. In many cases the thick-bedded sandstones are capped by horizontal (parallel) laminated, followed by ripple-laminated sandstones. This phenomenon could be observed repeatedly only in sandstones (4 times in unit 70, 2 times in unit 101, etc.). Analogous case is reported by Shanmugam & Moiola (1995, p. 688-689) and interpreted as “the lower massive sandstone units as deposited of sandy debris flow and the overlying parallel- or ripple-laminated units as deposits of bottom currents”. From turbidite point of view we can have a fluxoturbidite which latter altered into distal turbidite, truncated in the base.

From sequence stratigraphic point of view these thick-bedded sandstones build the Lowstand Systems Tract developed in the flysh facies sediments.

(1a.1) Unit 17 b (0.20 m) represents a special case – a matrix supported conglomerate containing calcareous clasts. The matrix is sandy and the clasts – of grey micritic limestone with size 0.5 cm to 5-7 cm. This conglomerate lies between the Transgressive and the Highstand Systems Tract. From the lithofacial point of view it is interpreted as pebble sandstone and from depositional process point of view (Shanmugan & Moiola, 1995, p. 685) it is a sandy debris flow. From turbidite point of view this is a fluxoturbidite, and from sequence stratigraphic – we interpret it as a Maximum flooding surface.

(1a.2) The unit 96 represents a breccia-conglomerate (2.00 m thick), matrix supported built up by medium to coarse grained sandstones (with matrix of clay minerals, strongly stained by Fe-oxihydroxides), and calcareous clasts – from 1 mm up to 100 mm, rarely up to 25 cm. The calcareous pieces – pebbles to cobbles, are light grey, micritic; but there are also clasts of belemnites, ammonites and single members of crinoids. There are pebbles of sandstones with convolutions (5-15 cm) – (re-deposited from another parts of the Kostel Fm.), and intraclastic limestones with diameter cc. 5-10 cm and clasts in them smaller than 1 mm (close to Gintsi Fm. – Ñ17). Lithofacies: matrix supported sandy debrite; depositional process: sandy debris flow. From sequence stratigraphic point of view this breccia-conglomeratic unit is interpreted as Highstand Systems Tract.

(1b) Thin-bedded sandstones. The thin-bedded sandstones are similar to the thick-bedded ones, but form bed cc. 20 cm thick. They build the Ta Bouma structural interval. The turbidites of complete Bouma sequences are relatively rare in the Staro selo (Drugan) section. Complete Bouma sequences exist in units 39, 42, in the basal part of unit 81, and in the middle part of unit 102. More common are the sequences with truncated Ta, Tb intervals, which are regarded by Shanmugan & Moiola (1995) as sandy contourites. From sequence stratigraphic point of view they construct the Transgressive Systems Tract.

(1c) Laminated sandstones. The ripple and/or parallel laminated sandstones build the Tb and Tc Bouma turbidite structural intervals, and usually alternate with relatively thin beds of mudstones. (a) Ripple-laminated and/or paralel laminated sandstones (spec. C 7, C 10, C 12, C 75). They alternated with mudstone (marls to/or calcareous argillite). The laminated sandstone form beds of 0.05-0.10-0.30 m thick, or capped thick-bedded sandstones. The laminated rocks are arkose wacke (spec. C 12) to calcareous arkose wacke (spec. C 7, C 10, C 75). Their texture is psamoaleuritic to aleuropsamitic with subangular grains – coarse aleurite to fine psamite; the ratio clastic component/matrix varies between 65%-80% / 20%-30%. The microstructure is rippled or parallel and the clastic component consists predominantly of mineral grains (quartz, feldspar, biotite and muscovite), and rarely rock fragments – micritic limestones. The matrix is clayey-calcareous (micro-grained calcite).

(1d) Mudstones (spec. C 6, C 8, C 13, C 16, S 8), alternate with the horizontal or rippled laminated sandstones are grey to dark-grey thin bedded (5-6 to 10-30 cm), and represent ferriferous calcareous argillites (the soluble components are 38-39%). The matrix consists of clay minerals and micro-grained calcite, strongly stained by Fe-oxihydroxides. Rare fine-grained quartz grains and muscovite flakes are observed.

In some cases the mudstones (spec. C 6, C 8, C 13) become ferriferous calcareous argillites with clear lamination (ripple or horizontal), which can be observed only in thin sections. In these cases the matrix (clay minerals and micro-grained calcite) is cc. 50%, the clastic components (mainly quartz with silt sizes) – 30% and Fe-oxihydroxides – 20%. The lamination is outlined by the presence of laminae rich in Fe-oxihydroxide globules alternating with laminae in which the clastic components prevail. In single case the calcareous argillites are interbedded by grey to brownish compact to fine-grained, ferriferous micritic limestones (insoluble components are 16.53% – 13.53 % – clay minerals and Fe-oxihydroxides and fine-grained quartz grains and muscovite flakes – cc. 3%).

From lithofacial point of view the alternation of mudstones and thin beds of fine grained sandstones is (Shanmugan & Moiola, 1995, etc.) interpreted as pelagic/hemipelagic settling of mud in deep-water environment reworked by bottom currents, and the sands are results of reworked material, deposited in thin beds of horizontal or ripple laminated sandstone. From turbidite point of view this alternation of laminated sandstones and mudstones represents truncated or base cut out turbidites. From sequence stratigraphic point of view they structure generally the Transgressive Systems Tracts of third order depositional sequences.

(2) Thick beds of mudstones. The thick beds of mudstones are of two types: (2a) pure mudstones (without clasts) and (2b) mudstones with floating clasts.

(2a) Pure mudstones represent ferriferous marls (spec. S7, C11) to ferriferous calcareous argillites (spec. C15), grey to brown; the matrix is composed mainly of micro-grained calcite (cc. 55%) and clay minerals. The insoluble components are represented by fine muscovite flakes and prolonged Fe-oxihydroxide globules, situated parallel to the bedding surfaces. In some cases grains of quartz (with sizes under 0,063 mm), and flakes of mica, arranged parallely (spec. C15) take part in the insoluble components also and show the presence of convolutions (not visible without microscope). The mudstones build beds thick 4-11 m, some times laminated in the basal parts (fig. 5, unit 61).

(2b) Mudstones with floating clasts (spec. C4, S 5, units 17c, 71c). Mudstones represent ferriferous marls (the soluble component (spec. S5) is up to 62.86% with matrix mainly composed of micro-grained calcite and clay minerals), grey to dark-grey. They contain many floating clasts included in the matrix. The clasts are mainly from limestones and rarely from debrites redeposited from the Kostel Fm. The clasts are cobbles to boulders (size – 5-20 cm, 20-80 cm, 0.60-2.00 m up to 3 m) angular to subrounded. The limestones are: (a) grey to pink nodular (spec. H1, 025, 026), with sections of small ammonites (similar to those in the Gintsi Fm.), (b) micritic, radiolarian, similar to the Drugan Fm.- (spec. H2, H4, H5, H6, H8, H10, 10a, C3, 023, 024), (c) biodetritic, with oncolithes, similar to the Polaten Fm. (spec. 021, 022, 027, 028); (d) as clasts came single ammonites, not compressed – probably from the destructuted Gintsi Fm, prealable solidificate – allochtonous (Plate III, fig. 3; Plate IV, fig. 1). In the matrix there are also ammonites, but compressed (Plate III, fig. 4), interpreted as autochtonous (simultaneously sedimented as mudstones and diagenetically compressed) – *Virgataxioceras setatum* (Schneid) – index of the uppermost ammonite subzone of the Upper Kimmeridgian.

In unit 17 (10.50 m) there is the following superposition:

Sharp boundary

17d (0.50 m) Fine pebble calcareous conglomerate (rudstone or calcirudite), grey-greenish, contaning many pebbles of grey, micritic limestones, well rounded (0.2-1mm), matrix supported (spec. 015); in the upper part there are also fine pebble calcareous conglomerate (rudstone or calcirudite) (Plate III, fig. 5) lithified irregularly and have the aspect of blocks (cc. 0.20 m) (spec. 016), probably diagenetically formed.

Transitional boundary

17c (10 m) Marls, grey, dark-grey to grey-greenish, containing many clasts of limestones (Plate III, fig. 2).

In unit 71c-d the superposition is:

71d (3.0 m) marls without clasts

71c (6.0 m) – marls with clasts (1-3 m) predominantly of clastic limestones (closed to the Gintsi Fm.)

From lithofacial point of view the mudstone without clasts is (Shanmugan & Moiola, 1995, etc.) interpreted as pelagic/hemipelagic settling of mud in deep-water environment. The mudstone with floating clasts can be interpreted as mudy debris flow (Shanmugan & Moiola, 1995). From sequence stratigraphic point of view we report the mudstones without clasts and with floating clasts at the Highstand Systems Tracts of third order depositional sequences.

In the marls of unit 17c we found *Virgataxioceras setatum* (Schneid) (Plate III, fig. 4) – index of the uppermost ammonite subzone of the Upper Kimmeridgian which confirms the late Kimmeridgian age of the lower parts of the Bobovo Mb. proved by Ñàïóíîâ et al. (1985).

Calcareous nannofossil study of the Bobovo Mb. revealed the presence of Lower, Middle and possibly (?)Upper Tithonian. The Kimmeridgian / Tithonian boundary is traced by the first occurrence (FO) of *Conusphaera mexicana mexicana* and *Faviconus* cf. *multicolumnatus* registered in the spec. C 05. The Lower Tithonian nannofossils associations are characterized by abundant representatives of the genera *Cyclagelosphaera*, *Ellipsagellosphaera*, *Watznaueria* and *Conusphaera*. The lower part of Middle Tithonian is evidenced by the FO of *Polycostella senaria* (spec. C 12), whereas the upper part of Middle Tithonian is undoubtedly proved by the FO of the zonal index-species *Umbria granulosa minor* in the spec. C 15 (Bralower et al., 1989). The presence of the Upper Tithonian in the uppermost part of the flysch succession is supposed, but not yet proved definitely. This assumption is based on the occurrence of *Nannoconus wintereri* and *Nannoconus* sp. indet. in the spec. C 20. Thus, calcareous nannofossils offer a relatively good stratigraphic resolution for subdivision and correlation of the Upper Kimeridgian-Tithonian flysch sediments.

Sequence stratigraphic interpretation

The sequence stratigraphic analysis is introduced by Sloss (1963), but has been developed by the research of EXXON group. The hierarchy of the sequences is according to their order – I^{-st}, II^{-nd}, III^{-rd}, IV^{-th}, etc. For the nomination of the I^{-st} order sequences the names of North American Indian tribes as Absaroka, Zuni, etc. are used. Their further subdivision includes the terms "Lower" and "Upper", for example Upper Absaroka, etc. followed by number – 1, 1.3, etc. (Haq et al., 1988). By this way the hierarchy of the order of sequences is clear. Hardenbol et al. (1998) used another system – they gave to the sequence the index of the stage, where the lower sequence boundary is situated – Toa 1, Toa 2, etc. for the Toarcian sequences. Unfortunately, these authors didn't designate the sequences of highest order – 1^{st}, 2^{nd} etc. order.

We accept the designation of the lower order sequences used by Hardenbol et al. (1998) for correlation of the Bulgarian sequences with the West European ones. Different volume of years for the definition of the order of one sequence are proposed in the literature – e.g. for the sequences of III^{rd} order – Vail et al. (1977) used 1-10 Ma, Vail et al. (1991) – 0.5-3 Ma, Mitchum, Van Wagoner (1991) – 1-2 Ma. We use another criterion for the determination of the order of the sequences – lowermost sequences enter in the framework of the higher order sequences. For example – the IV^{-th} order sequences are part of the III^{-rd} order sequences, which are individualized on the background of the II^{-nd} order sequences, and these of II^{-nd} order – are part of the I^{-st} order sequence.

The Bulgarian Lower and Middle Jurassic fauna, especially ammonites (Sapunov, 1976a, b, 1977 a, b), etc. possesses the links to the Northwestern European (Boreal/Subboreal) bioprovince and the Upper Jurassic – with the Southwestern European (Tethyan/Submediterranean) bioprovince. Thus we correlate the two parts of the Bulgarian Jurassic sequence stratigraphic scheme with the corresponding Western European sequence stratigraphic standards of Hardenbol et al. (1998).

The Jurassic sediments of Western Bulgaria are divided by Tchoumatchenco, Lakova (1994) into two 1^{st} order sequences. The lower one is Hettangian-Lower Callovian (Tchoumatchenco, 2002) and the upper one – Middle Callovian-Berriasian. The Hettangian-Lower Callovian Sequence is subdivided into two 2^{nd} order sequences – Hettangian-Lower Toarcian and Upper Toarcian-Lower Callovian. The Middle Callovian-Berriasian sequence is subdivided as well into two 2^{nd} order sequences: Middle Callovian-Oxfordian and Lower Kimmeridgian-Berriasian.

In the studied section of the 1^{st} order Hettangian-Lower Callovian sequence only part of the upper 2^{nd} order – Upper Toarcian – Lower Callovian sequence is present; Middle Callovian-Berriasian sequence is represented also by parts of the upper 2^{nd} order sequence. In both cases the two lower 2^{nd} order sequences are not deposited.

Usually, as noted Jan du Chene et al. (1993) "besides facies type, it is to a large part the geometry of the carbonates and the marlstones beds as well as the vertical changes in their relative thicknesses that allow the proposal sequential subdivision of the studied section". In our practice we used this criterion for the delimitation of the depositional sequences between them.

We have divided the systems tracts in the carbonate rocks following the criterion: the Lowstand Systems Tract is characterized by the predominance of thick bedded limestones; the Transgressive Systems Tract is individualized on the base of dominance of thin-bedded limestones in alternation with marls or marly limestones; in the Highstand Systems Tract the clayey limestones dominated in relatively thick, but not well individualized, beds.

The criterion followed for the individualization of the system tracts in one depositional sequence in the flysch sediments is: the Lowstand Systems Tract is individualized by the predominance of the thick beds of sandstones; the Transgressive Systems Tract is individualized according to the predominance of alternation of marls and thin beds of sandstones; the Highstand Systems Tract is individualized according to the dominance of marls/calcareous argillites.

We use the following manner of the numbering of the 3rd order depositional sequences: Index StS (Staro selo), followed by the respective number (No 1-27), and in the brackets – index of the relevant West European sequence (Hardenbol et al., 1998).

Description of the depositional sequences

Hettangian-Lower Callovian 1^{st} order depositional sequence

Hettangian-Lower Toarcian 2^{nd} order depositional sequence – not deposited in the studied area.

PLATE I

1. Gradets Fm., Unit Ï-0, Nikolchov Dol Valley, Staro selo Village, StS 1 (Bj 5)
2. Unit Ï-1 – Polaten Fm.; Nikolchov Dol Valley, Staro selo Village; tick bedded limestones, LST of StS 2 (Bat 0)
3. Polaten Fm., Unit Ï-2, relatively thin bedded limestones – TST of StS 2(Bat 0)
4. Polaten Fm., Unit Ï-3, HST of StS 2 (Bat 0)
5. Polaten Fm., Unit Ï-3, HST of StS 2 (Bat 0) – detail with the brachiopods *Druganirhynchia nevelinae*
6. Polaten Fm., Unit Ï-3, detail with oolithic limestones, HST, StS 2 (Bat 0)
7. Unit Ï-4, relatively thick bedded limestones; LST of StS 3 (Bat 1)
8. Polaten Fm., Unit Ï-5 – thin bedded limestones, TST of StS 3 (Bat 1) and clayey limestones. Unit "Ï-6" – HST of StS 3 (Bat 1)

PLATE II

1. Polaten Fm., Unit Ï-7 – relatively thick bedded limestones, with pot holes and LST of StS 4 (Bat 2), and the boundary (with the unrolled meter) with the Gintsi Fm. (Unit 1), Lower Kimmeridgian, LST of StS 5 (Kim 2)
2. Upper surface of the Polaten Fm., with pot holes with boulder of quartz in them and ichnofossils igen. & sp. indet. – SB of StS 5 (Kim 2)
3. Gintsi Fm., LST of StS 5 (Kim 2)
4. Gintsi Fm. (Unit 1, LST of StS 5 and the boundary with Unit 2 – Drugan Fm. – TS and TST of StS 5 (Kim 2)
5. Unit 4, Drugan Fm., LST of StS 6 (Kim 3)
6. Unit 11, Drugan Fm., TST of StS 7 (Kim 4)
7. Unit 13, Drugan Fm., MFS of StS 7 (Kim 4) and the boundary with Unit 14, Neshkovtsi Fm.
8. Unit 16, Bobovo Mb. of Kostel Fm. – thick bedded sandstones, LST of StS 8 (Kim 5)

PLATE III

1. Unit 17a, Bobovo Mb. of Kostel Fm., thin bedded sandstones and mudstones, TST of StS 8 (Kim 5)
2. Unit 17c, Bobovo Mb. of Kostel Fm., thick bedded mudstones with floating boulders, HST of StS 8 (Kim 5)
3. Allochthonous boulder of the Late Oxfordian ammonite *Sowerbyceras* cf. *tortisulcatum* (d'Orbigny) in Unit 17c
4. *Virgataxioceras setatum* (Schneid), Upper Kimmeridgian, *Virgataxioceras setatum* Subzone, *Hybonoticeras beckeri* Zone, Upper Kimmeridgian, Unit 17c, autochthonous
5. Unit 17d (sample 015), Bobovo Mb. of Kostel Fm., with out cement – HST of StS 8 (Kim 5)
6. Unit 17d (sample 016), Bobovo Mb. of Kostel Fm. – with rich cement – HST of StS 8 (Kim 5)
7. Unit 19, Bobovo Mb. of Kostel Fm. – alternation of thin bedded laminated and rippled sandstones and mudstones, Nikolchov Dol Valley, TST of StS 9 (Ti1.1)
8. Unit 19, Bobovo Mb. of Kostel Fm. – detail of fig. 7, showing rippled laminated sandstones and mudstones

PLATE IV

1. Allochthonous boulder of *Taramelliceras (Taramelliceras) pugile* (Neumayr), Middle and Upper Kimmeridgian in Unit 17c .
2. Unit 26, Bobovo Mb. of Kostel Fm., laminated mudstones, lower part of TST of StS 11 (Ti 1. 3)
3. Unit 38, Bobovo Mb. of Kostel Fm., thick bedded sandstones – LST and Unit 39 – thin bedded sandstones and mudstones – TST of StS 12 (Ti 1.4)
4. Unit 33, Bobovo Mb. of Kostel Fm. – thin bedded sandstones and mudstones – StS 11 (Ti 1.3) and Units 34 and 35 – dominantly thick bedded sandstones – LST of StS 12 (Ti 1.4)
5. Unit 33, Bobovo Mb. of Kostel Fm. – rippled laminated sandstones, TST of StS 11 (Ti 1.3)
6. Units 39, 40, 41, 42, Bobovo Mb. of Kostel Fm. – relatively thin bedded sandstones and mudstones – TST of StS 12 (Ti 1. 4)
7. Unit 48, Bobovo Mb. of Kostel Fm. – relatively thick bedded sandstones and mudstones – LST of StS 13 (Ti 1. 5)
8. Units 50, 51, 52a, b, Bobovo Mb. of Kostel Fm. – dominantly relatively thick bedded sandstones, interbedded by thin beds of mudstones and/or thin beds of sandstones – TST of StS 13 (Ti 1.5)

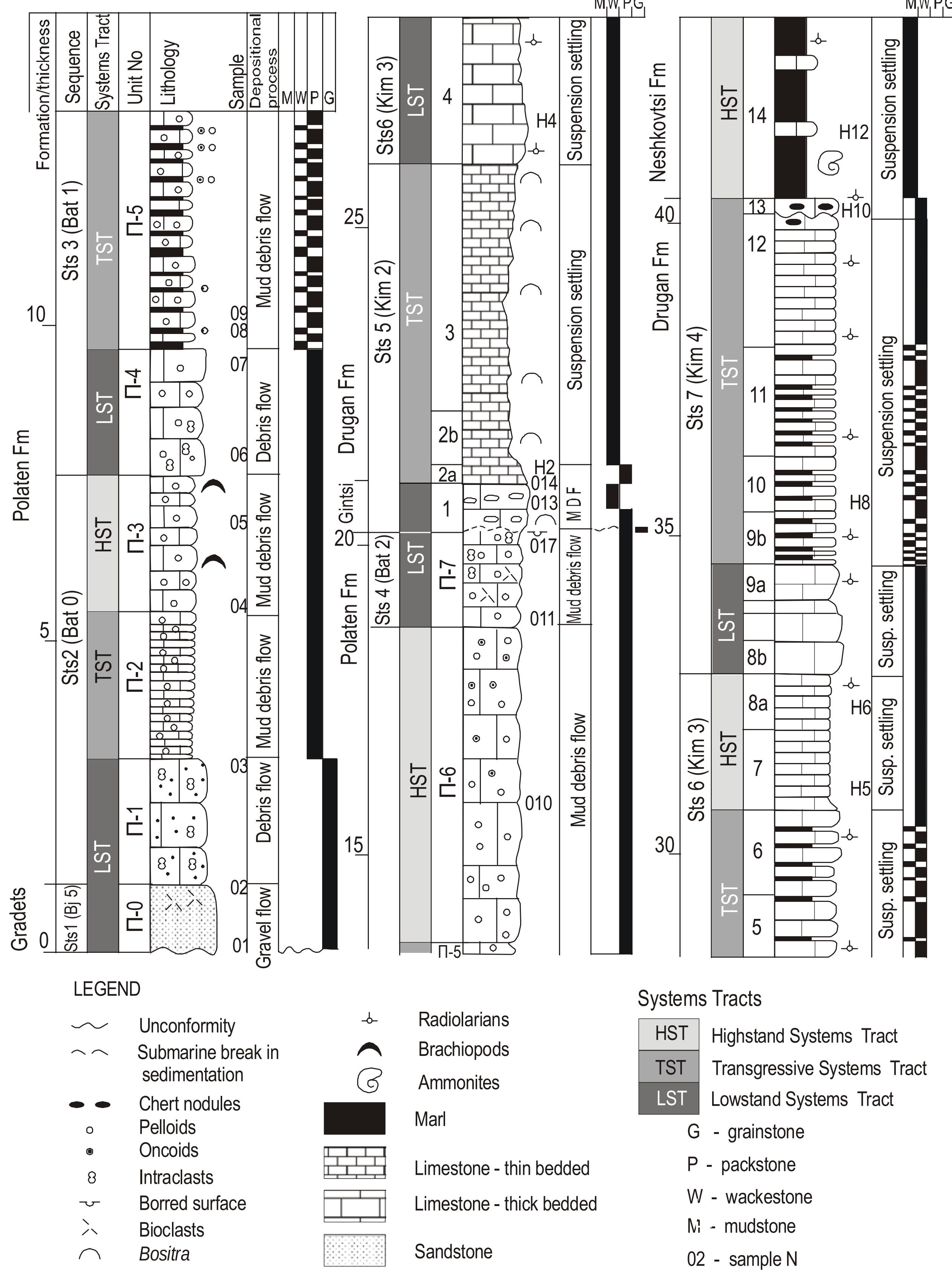

Fig. 3. Sedimentological log of the Jurassic section exposed in Nikolchov Dol Valley

Upper Toarcian-Lower Callovian 2nd order depositional sequence.

2nd order Highstand Systems Tract (Lowstand and the Transgressive Systems Tracts are not deposited).

3rd order depositional sequences

Gradets Formation

Depositional sequence StS 1 (=Bj 5)

The SB represents the transgressive contact of the Gradets Fm. over the Upper Triassic sediments.

LST (1.0 m)(Ï-0 – fig. 3)(Plate I, fig. 1)

Represented by a bed (1 m) of medium to fine-grained sandstone (spec.01) in the base, which grade to sandy bioclastic limestone (packstone to rudstone) in the upper part (spec.02). These sediments represent a calcareous sandy debrite. The upper boundary of the bed is not exposed.

The TST and HST are eroded (?).

Polaten Formation

Depositional sequence StS 2 (=Bat 0)

SB

The SB is not exposed. We deduce the presence of SB by the presence of lithoclasts in the beds of the LST.

LST (2.0 m)(Ï-1 – fig. 3) (Plate I, fig. 2)

It is built of relatively thick bedded (0.70-0.80 cm) gray, sandy intraclastic limestones (grainstones) (spec.03) (SMF 18), thick cc. 2.00 m. They contain well rounded allochems (cc. 2.0 mm), predominantly composed of intraclasts, built of: (a) micritic limestones with grains of quartz and/or small gastropods – probably the micrite is with bacterial-algal genesis; (b) peloidal limestones with rare oncoids with nucleus of grains of quartz or bioclast and concentric laminae; (c) rare bioclasts of corals and *Tubiphytes*. The terrigeneous component is of rounded or sub rounded quartz – 1.0-2.0 mm – coarse psamite. Here *Protopeneroplis striata* Wyenschenk is found (range Bajocian-Tithonian).

We interpret the lithoclasts as coming from eroded parts of the Polaten Fm.

TS

The Transgressive Surface is expressed by the change of the character of the sediments.

TST (2.20 m)(Ï-2 – Plate I, fig. 3)

Built of discontinous-bedded (channelized?) grey limestones (packstones), and thin-bedded limestones with small biodetritus.

MFS

It is expressed by the change of the sediments.

HST (2.50 m)(Ï-3 – fig. 3)(Plate I, figs. 4, 5, 6)

Limestones, grey, thick-bedded, biodetritic – from bivalves and brachiopods. The biodetritus construct irregular forms. In the basal parts (spec.03) the limestones are peloidal with rare oncoids (packstones) and in the central parts (spec.05) peloidal-oncoidal limestones (packstone to rudstone) (SMF 16). *Druganirhynchia nevelinae* Tchoumatchenco and *Trocholina palastiniensis* Henson (range Bathonian) were found there.

Depositional sequence StS 3 (=Bat 1)

SB

It is expressed by the change of the sediments and the presence of intraclasts in the sediments of the LST.

LST (2.0 m)(Ï-4 – fig. 3)(Plate I, fig. 7)

Limestones, peloidal (packstones) grey, thick-bedded. At the base (spec.06) they are peloidal with rare bioclasts and oncoids, and intraclasts with bioclasts (redeposited bioclastic limestones (SMF 18). In the upper parts (spec.07) they become cortoid-peloidal limestones (SMF 18). In spec. 06 – *Patellina douvillei* Said & Barakat (range Bathonian).

TS

It is expressed by the change in the sediments.

TST (4.0 m)(Ï-5 – fig. 3) (Plate I, fig. 8)

Built of an alternation between marly (to marls) peloid-oncoidal dark gray limestones (packstone to rudstone) (spec. 09) and micrite limestones with peloids and rare bioclasts and oncoids (wackstones) (spec. 08); they are discontinuous – bedded (channelized?).(SMF 18).

MFS

It is expressed by the change of the sediments.

HST (5.0 m) (Ï5 – fig. 3) (Plate I, fig. 8)

The systems tract is built of unclear thick-bedded oncoid-peloidal limestones with bioclasts and oncoids (packstones) (spec. 010) (SMF 18)

Depositional sequence StS 4 (=Bat 2)

LST (1.5 m)(Ï-7 – fig. 3) (Plate II, figs. 1, 2)

Peloidal limestone with rare bioclasts and oncoids (packstone) (spec. 011), and some intraclasts from brown micrite, some times containing small and undistinct bioclasts (SMF 18).

TST and HST – eroded

The upper boundary of the Polaten Fm. represents a hardground with many ichnofossils and erosional pots with pebbles of quartz (4×6 cm) in them and fulfilled with coarse-grained sandy limestones – packstone to grainestone (spec.017)(fig. 3)(Plate II, fig. 2).

Middle Callovian-Berriasian 1st order depositional sequence

Middle Callovian-Oxfordian 2nd order depositional sequence – not deposited in the studied section

3rd order depositional sequences

Gintsi Formation

Depositional sequence StS 5 (=Kim 2)

SB

It is represented by the surface of hard ground and the submarine break in the sedimentation between the Polaten Fm. (Middle Bathonian) and the Gintsi Fm. (Lower Kimmeridgian)

LST (0.80 m) (nº 1, fig. 3) (Plate II, figs. 3, 4)

Grey to pinkish nodular limestone to calcareous conglomerate built of lithoclasts and/or bioclasts – ammonites, belemnites. The lithoclasts represent filament-rich wackstones to packstones – micritic matrix – 40-50% and allochemes – 50-60% predominantly by filaments of *Bositra* and rare spicules of calcified radiolarians (spec.013, 014). Foraminifers: *Cornuspira orbicular*, *Ophthalmidium* sp. indet., *Lenticulina* sp. indet., *Lingulina* sp. indet., *Epistomina* sp. indet.

TS (Plate II, fig. 4)

It is expressed by the change in the sediments.

Drugan Formation

TST (5.20 m)(nº 2a,b, 3 – fig. 3), (Plate II, fig. 4)

In the base – limestones enriched in filaments of *Bositra* (packstone), grey, thin-bedded (cc. 2-6 cm) in alternation with calcareous marls (cc. 2-4 cm) (spec. H 2), and in the upper part – thin bedded micritic limestones (filament rich packstone). Nannofossils: *Ellipsagellosphaera lucasi, E. britanica, Watznaueria barnesae, W. biporta, Cyclagellosphaera margerelli, C. deflandrei.*

MFS and HST – are not preserved

Depositional sequence StS 6 (=Kim 3)

SB. It is expressed by the change of the limestones' thickness.

LST (2.3 m) (nº 4 – fig. 3) (Plate II, fig. 5)

Grey clayey limestones with calcified radiolarians (clayey radiolarian wackestones) in beds of 30-40 cm (spec. H 4).

TS

It is expressed by the change of the sediments.

TST (2.3 m) (nº 5, 6, fig. 3).

Limestones, fine-grained, 0.4 – 0.5 m thick at the base, interbedded by thin beds (3-4 cm) of marls, and in the upper part – thick 20-30 cm interbedded also by thin beds (2-5 cm) of marls (mudstone and wackstone). They are rich in nannofossils. Nannofossils: *C. deflandrei, W. biporta, W. barnesae, E. britanica, E. lucasi.*

MFS

It is expressed by slight change in the sediments.

HST (2.20 m) (nº 7 and 8a)

Limestones, clayey, grey, thin-bedded (10-15 cm) with calcified radiolarians (clayey radiolarian wackstone – spec. H 5, 6). Nannofossils: *C. deflandrei, C. margerelii, W. barnease, E. britanica.*

Depositional sequence StS 7 (=Kim 4)

LST (1.70 m) (nº 8b, c, 9a, fig. 3)

Limestones, grey, relatively thick-bedded (nº 8b and 9a) intercalated by relatively thinner beds (nº 8c). Nannofossils: *C. deflandrei, W. biporta, W. barnease, E. britanica, E. lucasi.*

TST (5.60 m) (nº 9b, 10, 11, 12) (Plate II, fig. 6, bed 11)

Alternation of thin-bedded (5-10 cm) grey clayey limestones, containing many calcified radiolarians (clayey radiolarian wackstones) and calcareous marls (2-3 cm) (beds 9b, 10, 11) (spec. H 8); and in the upper part (bed 12) they become thin bedded (10 cm) clayey limestones-with chert concretions (3-4 × 2 cm): *C. margerelii, C. deflandrei, E. britanica, E. lucasi.*

MFS (0.25-0,30 m) (nº 13) (Plate II, fig. 7)

Bed 13 is interpreted as MFS the (0.25-0.30 m) – clayey limestones (clayey radiolarian wackstone) (spec. H 10). Its lower boundary is irregular; and upwards limestone turns into cross-bedded laminated limestone. The bed 13 contains interrupted lenses of grey-blackish chert – 20-30 cm long and 2-3 cm thick. The upper boundary of bed 13 is horizontal and concordant (Plate II, fig. 7).

Neshkovtsi Formation

HST (12.8 m) (nº 14)

Marls grey-greenish, irregularly thin-bedded, with rare thin beds (2-3 cm) of calcareous marls, some with cross stratification (depositional process – suspension settling reworked by bottom currents or by distal turbidites. At 0.40 m above the lower boundary of bed 14 crops out a bed rich in ammonites (Èâàíîâ in ×óìà÷åíêî et al., 2004): *Ptychophylloceras ptychoicum* (Quenstedt), *Taramelliceras (Taramelliceras) franciscanum* (Fontannes), *Taramelliceras (T.)* aff. *pugile* (Neumayr), *Orthosphinctes* cf. *subdolus* (Fontannes), *O. vandellii* (Choffat), *Virgataxioceras* cf. *setatoides* (Berckhemer), *Hybonoticeras* cf. *pressulum* (Neumayr), as well as rich nannofossil association: *Ellipsagellosphaera lucasi, E. britanica, Watznaueria barnesae, W. biporta, W. manivitae, Cyclagellosphaera margerelli, C. deflandrei, Cyclagelosphaera* sp.

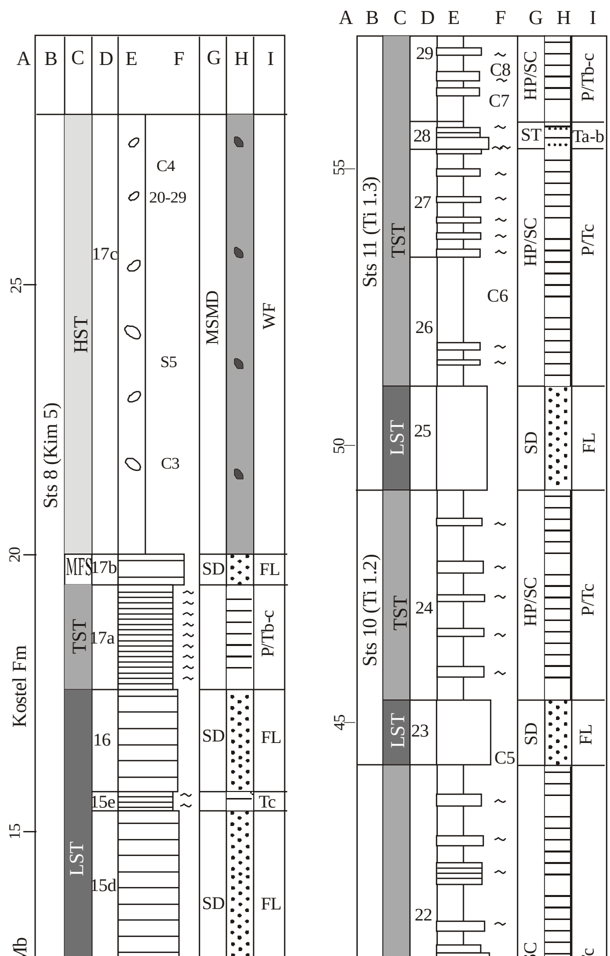
A B C D E F G H I
Kostel Fm
Sts 8 (Kim 5)
HST
MFS
TST
LST
17c
17b
17a
16
15e
15d
C4
20-29
S5
C3
MSMD
SD
WF
FL
P/Tb-c
Tc
25
20
15
Sts 11 (Ti 1.3)
Sts 10 (Ti 1.2)
29
28
27
26
25
24
23
22
C8
C7
C6
C5
HP/SC
ST
Ta-b
P/Tc
55
50
45

Fig. 4

In the Izvorite section, east from the village of Staro selo, the intercalations are of fine-grained sandstone.

Kostel Formation, Bobovo Member

Depositional sequence StS 8 (=Kim 5)

SB

Sharp boundary between the marls of the Neshkovtsi Fm. and the first sandstone bed of the Bobovo Mb.

LST (7.60 m) (nº 15a-e, 16; fig. 4) (Plate II, fig. 8 – bed 16)

Sandstones, thick-bedded (nº 15a, 15c, d, 16) and thin-bedded (nº 15b) or rippled (nº 15e). The LST begins by a bed of calclithite with very fine to fine-grained (psamitic) texture (spec. C 2). The rock is composed of 40-45% matrix – micro-grained calcite and 55-60% clastic component – mineral grains (monocrystalline quartz, feldspars (predominantly albite), biotite and muscovite, etc) and rock fragmens (micritic limestones): *Orthosphinctes* sp. indet.; *W. barnesae, W. biporta, Cyclagelosphaera* sp. 1, *Cy. deflandrei, Ell. britannica.*

TST (2.0 m) (nº 17a)(Plate III, fig. 1)

Marls to calcareous argillites intercalated by thin bedded very fine-grained sandstones with horizontal or rippled lamination.

MFS (0.60 m) (nº 17b)

As MFS are individualized sandstone, which in the upper part becomes matrix supported sandy debrite with rounded calcareous clasts (pebbles)

HST (11.1 m) (nº 17c, d; fig. 4) (Plate III, figs. 2, 3, 4, 5, 6)

HST-1 (10.30 m) (n 17c; fig. 4) (Plate III, figs. 2, 3, 4; Plate IV, fig. 1)

Marls, grey to dark-grey. They contain many blocks of limestones with dimensions – 5 × 20 cm, 20 × 80 cm, 0,60 × 2,00 m; some of them are nodular (spec. Í-1, 025, 026), with sections of small ammonites (similar to those from the Gintsi Fm.), other are micritic radiolarian (similar to those from Drugan Fm. – (spec. Í-2, 4, 5, 6, 8, 10, 10à, Ñ- 3, 023, 024), or biodetritic with oncolithes (similar to those from Polaten Fm. (spec. 021, 022, 027, 028). As small blocks came single ammonites, redeposited probably from the Gintsi Fm (allohtonous): *Sowerbiceras* cf. *tortisulcatum* (d'Orbigny)(Plate III, fig. 3), *Taramelliceras (Taramelliceras) pugile* (Neumayr)(Plate IV, fig. 1) etc. These blocks are clearly included in the matrix, which consists of ferriferous marls (soluble components are up to 63%) (spec. Ñ 4). In the marls there are also ammonites, compressed (simultaneous with the sedimentation – autochthonous) – *Virgataxioceras setatum* (Schneid) (Plate III, fig. 4). Nannofossils: *Cy. margerellii, W. barnesae, W. biporta* (many*), Ell. britannica, Cyclagellosphaera deflandrei* (many) (spec. Ñ 4).

HST-2 (0.80 m)(nº 17d; fig. 4) (Plate III, figs. 5, 6)

Fine pebble calcareous conglomerate (rudstone or calcirudite), grey-greenish, containing many pebbles of grey, micritic limestones, well rounded (0.2-1mm), matrix supported (spec. 015). In the upper part they are also fine pebble calcareous conglomerate (rudstone or calcirudite) solidificated irregularly and with blocky aspect (cc. 0,20m) (spec. 016), probably diagenetically formed.

Depositional sequence StS 9 (=Ti 1.1)

SB-sharp, irregular boundary.

LST (0.80 m)(nº 18, fig. 4)

Lithoclastic limestone (packstone or calcarenite – the particle size is 1-2 mm but single are up to 4 mm), grey-greenish, rich in muscovite, containing also calcareous pebbles (spec. 018). In the upper part they are litho-bioclastic limestones (packstone or calcarenite) – the clasts are between 0.5-1.0 mm, in rare cases up to 1,5mm (spec. 019). The rock is normal grading upwards.

TS – sharp boundary.

TST (12,65 m)

TST-1 (1.60 m)(nº 19, fig. 4) (Plate III, figs. 7, 8)

Marls, grey to dark grey, laminated, intercalated by thin beds of very fine-grained sandstone with rippled lamination.

←

Fig. 4. Sedimentological log of the Jurassic exposed in Staro selo village, along the escarp of the road Sofia-Dupnitsa **A**. Formation (Member) and thickness; **B**. Depositional Sequences; **C**. Systems Tracts: LST – Lowstand Systems Tract; TST – Transgressive Systems Tract; HST – High Stand Systems Tract; MFS – Maximum Flooding Surface; **D** – Units Number; **E** & **F** – Lithology, and location of Samples: C 1-C 11, S 1 – S 8, 20 – 29; **G**: Lithofacies: HP – pelagite/hemipelagite, SD – sandy debrite, MSD – matrix supported sandy debrite (with calcareous clasts), MD – -muddy debrite, MSMD – matrix supported muddy debrite (with floating dominantly calcareous clasts), ST-siliciclastic turbidite, SC – sandy contourite; **H.** 1. sandy debris flow, 2. muddy debris flow, 3. suspension settling reworked by bottom currents, 4. siliciclastic turbidity flow, 5. suspension settling; **I.** Turbidite Structural Interval: FL – fluxoturbidite, Ta-c – complete Bouma turbidite, Tb – horizontal laminated Bouma interval, Tc – rippled laminated Bouma interval, Tb-c – horizontal and rippled Bouma intervals, P/HP – pelagite/hemipelagite, P/Tb – pelagite/hemipelagite/crossed by Tb turbidite interval, P/Tc – pelagite/hemipelagite, crossed by Tc turbidite interval, P/Tb-c – pelagite/hemipelagite, crossed by Tb-c turbidite intervals, WF – wild flysch (mudstone /pelagite, with floating clasts)

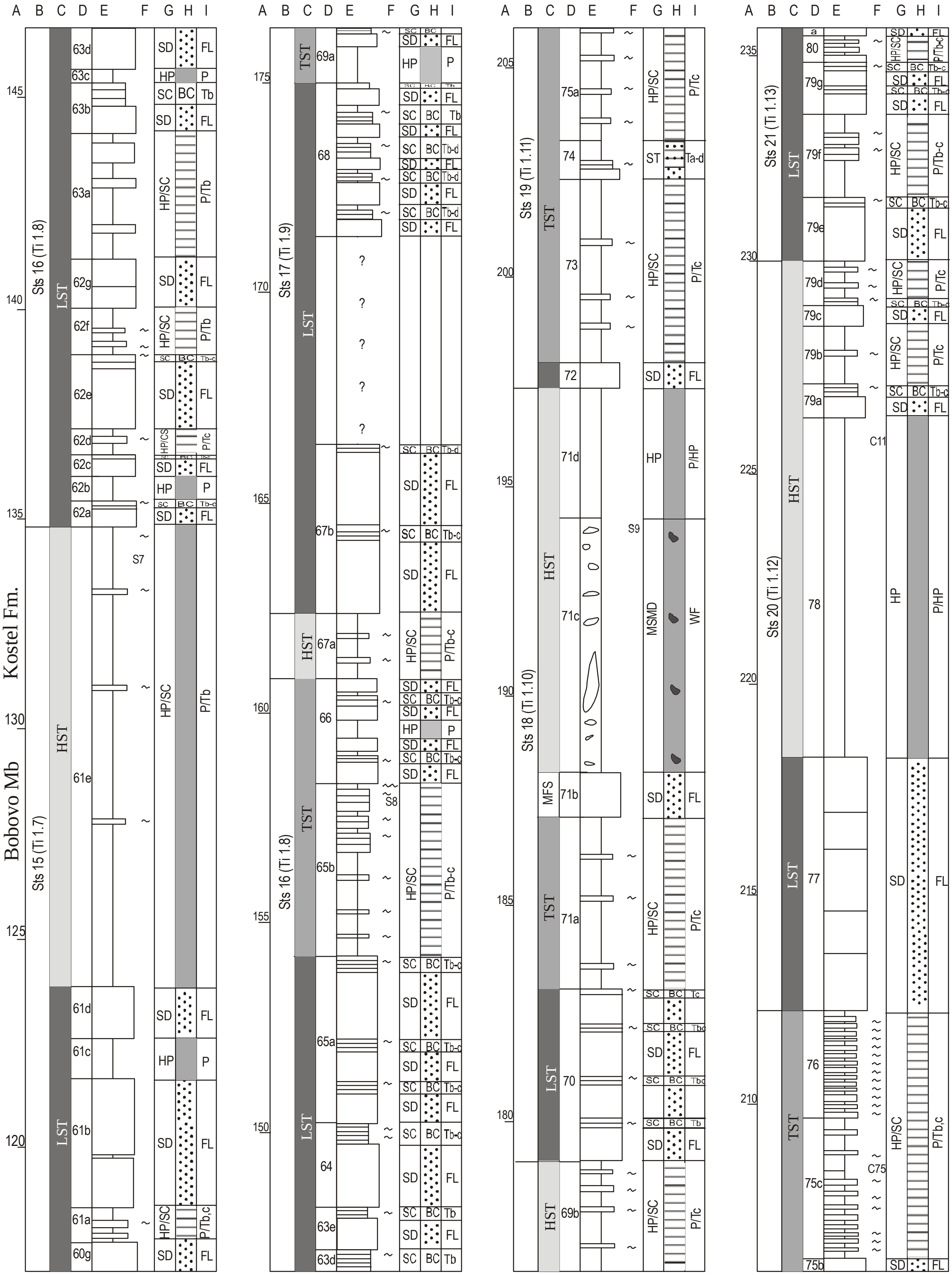

Fig. 5. Sedimentological log showing middle part (117-245.7 m) of Staro selo section – Bobovo Mb. (Kostel Formation, Lower Tithonian) in the road cutting along the road Sofia-Dupnitsa
Explanations – as for fig. 4

TST – 2 (3.20 m)(nº 20, fig. 4)
Three Bouma siliciclastic sequences.
TST – 3 (2.40 m)(nº 21,fig. 4)
Argillites to marls (0,80-1,0 m), laminated and intercalated by thin beds (3-4 to 10 cm) of very fine-grained, horizontal or rippled laminated (cc. 6 mm) sandstones
TST – 4 (5.45 m) (nº 22, fig. 4)
Alternations of silty argillites, slightly calcareous, and very fine to medium-grained sandstones, often with horizontal or rippled lamination.
HST – not represented.

Depositional sequence StS 10 (=Ti 1.2)
SB – sharp boundary.
LST – (1.20 m)(nº 23, fig. 4)
Sandstones, limy, (spec. Ñ5) coarse to very coarse-grained, consisting of quartz (the predominant component), feldspars and femic minerals and rock fragments from siliciclastic rocks, peloid limestones and bioclasts probably of recrystalized crinoids and *Tubiphytes*. The matrix is clayey, in insignificant amount (cc. 20%). The thickness changes in horizontal direction. The recovered nannofossils are *Conusphaera mexicana mexicana*, *Conusphaera mexicana minor*, *Cy. margerelli*, *Cy. deflandrei*, *Watznaueria barnesae*, *W. biporta*, *Ell. britannica*, *Faviconus* cf. *multicolumnatus* (spec. C 5).

TS-sharp boundary.
TST (4.0 m) (nº 24, fig. 4)
Alternation between argillites (50-60 cm) and fine-grained sandstones (3-4 cm), often with rippled lamination.
HST – not represented.

Depositional sequence StS 11 (= Ti 1.3)
SB – sharp lithological boundary.
LST (2.00 m)(nº 25, fig. 4)
Sandstones, coarse-grained (0.5-1 mm), monolith (thickness 0.40-0.80 m).
TST – (11 m)(nº 26-33, fig. 4)
TST – 1 (2.40 m) (nº 26, fig. 4)(Plate IV, fig. 2)
Argillite, dark-grey, thin laminated, ferriferous, limy, with rare fine-grained quartz grains and muscovite flakes (spec. Ñ 6), intercalated by thin beds of rippled laminated fine-grained sandstones: *Cyclagellosphaera margerelli*, *Cy. deflandrei*, *W. barnesae*, *W. biporta*, *Ell. britanica*.
TST-2 (8.60 m) (nº 27-33, fig. 4)
Alternation between calcareous marls (spec. C 8) and sandstones, fine-grained, often with rippled lamination (thickness 5-25 cm) (spec. C 7); some of the sandstone beds are thick up to 0.45 m.
HST – not represented.

Depositional sequence StS 12 (=Ti 1.4)
LST – 1 (1.40 m)(nº 34, fig. 4)
Sandstones, fine to medium-grained, monolithic.
LST-2 (0.75 m)(nº 35, fig. 4)
Alternation between fine-grained, horizontally and rippled laminated sandstones (0.04-0.11 m) and blackish marls.
LST-3 (0.80 m) (nº 36, fig. 4)
Sandstones: (a) 0.55 m – fine-grained, massive; (b) 0.15 m – horizontally laminated (c) 0.10 m – rippled laminated.
LST-4 (0.80 m)(nº 37, fig. 4)
Marls, to limy argillites, grey-blackish, thin laminated.
LST-5 (1.35 m)(nº 38, fig. 4) (Plate IV, fig. 3)
Sandstones, 3 beds fine-grained (0.25 m, 0.50 m, 0.40 m), with flute casts on the soles, separated by marls (8-10 cm) grey-blackish, laminated.
TST (8.20 m)(nº 39-45, fig. 4) (Plate IV, fig. 3)
TST – 1(1.40 m) (nº 39, fig. 4)(Plate IV, fig. 6)
Marls, laminated, grey-blackish (0.05-0.20 m) intercalated by sandstone, very fine-grained, with horizontal and/or rippled lamination (0.06-0.40 m)
TST-2 (0.55 m) (nº 40, fig. 4) (Plate IV, fig. 6)
Sandstones: (a) 0.30 m – medium grained, massive; (b) 0.08 m – laminated; (c) 0.07 m – rippled laminated.
TST-3 (3.20 m)(nº 41, 42, fig. 4)
Five Bouma siciclastic sequences – alternation between sandstones and marls
0.10 m – marls
0.15 m – rippled laminated
0.05 m – horizontally laminated
0.25 m – monolithic.
TST-4 (0.80 m) (nº 43, fig. 4)
Marls intercalated by thin beds of fine-grained sandstones with rippled lamination.
TST-5 (0.60 m) (nº 44a, fig. 4)
0.30 m – middle grained sandstone, capped by 0.30 m horizontally and rippled laminated very fine grained sandstones.
TST-6 (1.50 m)(nº 44b, 45, fig. 4)
Marls intercalated by thin beds of very fine-grained sandstones with rippled lamination (spec. C 10)
MFS (0.50 m)(nº 46, fig. 4)
Sandstones, fine to medium grained, with irregular lower surface
0.04 m – fine horizontally and rippled laminated.
0.46 m – massive.
HST (2.50 m) (nº 47, fig. 4)
Marls, intercalated by thin rippled laminated sandstones (0.05 m).

Depositional sequence StS 13 (=Ti 1.5)
SB-sharp change in the sedimentation.
LST (3.45 m) (nº 48, fig. 4)(Plate IV, fig. 7)
Five beds of massive, medium-grained sandstones (0.50-0.60m), covered by fine laminated – horizontal and rippled sandstones (0.05 m) and marls (0.07-0.30 m).
TST (4.43 m)(nº 49a,b,c, fig. 4)
TST-1(0.70 m)(nº 49a, fig. 4)
Marls, intercalated by thin beds (2-10 cm) of fine-grained sandstones with convolutions.
TST-2 (0.80 m) (nº 49b, fig. 4)
Two beds of sandstones, medium-grained (0.35 m), intercalated by grey marls (0.10 m)
TST-3 (3.20 m) (nº 49c, fig. 4)
Marls (in beds 0.60-0.70 m) intercalated by few beds of fine-grained sandstones (2-5 – 20 cm)
TST-4 (3.90 m)(nº 50-52, fig. 4) (Plate IV, fig. 8 – unit 51)
Marls, intercalated by 4 beds of thicker (0,40-0,70 m) medium-grained sandstones, covered by thin beds (0,05-0,20 m) of horizontal and rippled laminated fine sandstones, and few thin (0,05-0,15 m) beds of laminated sandstones.
HST (2.90 m)(nº 53, fig. 4)
3.00 m – marls, with 5 intercalations of fine-grained sandstones (cc. 0.20 m) with horizontal and rippled lamination. In the upper part – intercalated by a limestone bed (5-7 cm), compact, fine-grained to micritic, grey to brown, ferriferous with irregular upper surface (spec. S-06)

Depositional sequence StS 14 (=Ti 1.6)
SB – expressed by a sharp change in the sedimentation.
LST (2.60 m)(nº 54-55, fig. 4)
3 beds of thick (0.60-0.90 m) limy sandstones covered by 0,20-0,30 m fine-grained and laminated (horizontal and rippled) sandstone and marls (0,15-0,20 m)
TST (3.25 m) (nº 56, fig. 4)
Marls with intercalations of fine-grained laminated (horizontally and/or rippled) sandstones (cc. 7-8 cm).
HST – not presented.

Depositional sequence StS 15 (=Ti 1.7)
LST (24,20 m)(nº 57-61d, fig. 4, 5)
13 beds of thick (0.70-3.00 m) fine-to medium-grained sandstones, which in the upper part become laminated – horizontally or rippled, separated by marls to limy argillites (up to 0.80 m), interbedded by fine-grained laminated (predominantly rippled) sandstones (5-20 cm).
TST – not presented (?)
HST (17.0 m) (nº 61e, fig. 5)
Marls, ferriferous, dark-grey, in the basal part – laminated (S7), intercalated by rare and thin beds of laminated, fine-grained sandstone.

Depositional sequence StS 16 (=Ti 1.8)
SB – expressed by a sharp change in the sedimentation.
LST (19.7 m) (nº 62-65a, fig. 5)
LST 1(6.50 m) (nº 62a-g, fig. 5)
Sandstones, thick bedded (0.60 -1.80 m), medium-grained, in the upper part covered by fine-grained sandstones with horizontal bedding, followed – by rippled lamination (0.05 m), interbedded by marls (0.40-1.00 m) with thin beds of laminated sandstones with rippled lamination.
LST 2 (3.00 m) (nº 63a, fig. 5)
Marls, interbedded by sandstones (0.3-0.5 m)
LST 3 (1.05 m) (nº 63b, fig. 5)
Sandstones, fine-grained (0.50 m), covered by horizontal (0.30 m) and rippled (0.20 m) fine-grained sandstones, and marls (0.30 m).
LST 4 (nº 63d-65a, fig. 5)
6 beds of massive sandstones, in the upper part – with horizontal and rippled lamination.
TS-expressed by the change of sedimentation.
TST (8.20 m) (nº 65b-66, fig. 5)
TST 1(4.10 m) (65b)
Marls with thin intercalations of fine-grained sandstones with convolutions (4-6 cm); in the upper part the sandstones predominate (spec. S8).
TST 2 (2.50 m) (nº 66, fig. 5)
4 beds of sandstones (0.20-0.80 m thick), massive in the lower part and laminated – in the upper part, separated by marl beds (0.10-0.40 m)
HST (1.60 m)(nº 67a, fig. 5)
Marls with rare intercalations of thin laminated fine sandstone.

Depositional sequence StS 17 (=Ti 1.9)
SB – expressed by sharp change in the sedimentation.
LST (12.70 m)(nº 67b, 68, fig. 5)
LST-1 (4.0 m) (nº 67b, fig. 5)
2 beds of massive sandstones (1.70 m) in the upper part – fine laminated.
LST-2 (5.00 m)
No exposure.
LST-3 (3.20 m)(nº 68, fig. 5)
5 beds of medium-grained, thick-bedded (0,30-0,50 m) sandstones covered by thin-bedded laminated (horizontally and rippled) sandstones, followed by marls (0,10-0,15 m).
TST (3.50 m)(nº 69a,b, fig. 5)
Marls, intercalated by thin beds of sandstones, often with rippled lamination.

Depositional sequence StS 18 (=Ti 1.10)
SB – expressed by sharp change in the sedimentation.

Transgressive Systems Tract

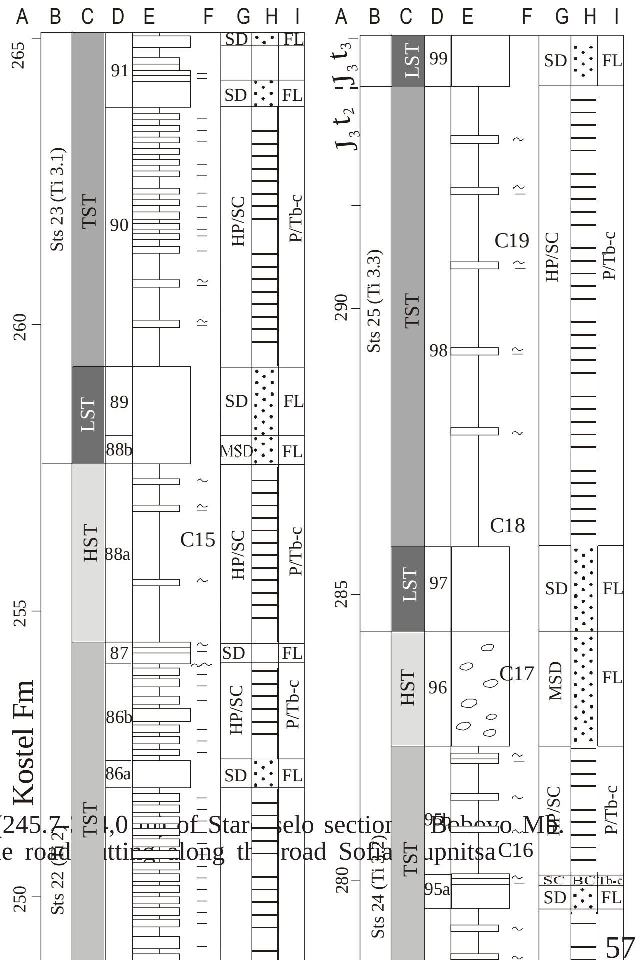

Fig. 6. Sedimentological log showing upper part (245.7–[illegible],0 m) of Star[illegible] selo section [illegible] Bebovo Mb. (Kostel Formation, Lower-MiddleTithonian) in the road [illegible] along th[illegible] road Sofia–[illegible]upnitsa
Explanations – as for fig. 4

LST (4.10 m)(nº 70, fig. 5)
4 beds of thick (1.00-1.50 m) sandstones, predominantly fine-grained, in the upper parts with fine parallel and rippled lamination.
TST (4.10 m)(nº 71a, fig. 5)
Marls, grey to dark grey, interbedded by rare beds of fine grained and ripple laminated sandstones.
MFS (1.20 m)(nº 71b, fig. 5)
Thick-bedded sandstone.
HST (9.10 m) (nº 71c, d, fig. 5)
Marls to calcareous argillites with pebbles of limestones (S 09) – (1.5-20 cm), floating in the mudstone (matrix). Along these clasts sandy fragments exist too. Upwards – marls with boulders with zonal structure (thickness 5.0 m) and above – marls (thick 1 m) containing well rounded pebbly and cobbly clasts (predominantly bright grey) of fine-grained sandstones (probably resedimented from the turbidites). In the central part – marls with blocks of lithoclastic limestones (the clasts are angular to slightly rounded), predominantly bright-grey, micritic and fine-grained sandstones (probably residimented from the flysch). The dimensions of the boulders are 1-3 m. The lithoclastic limestones are similar to those of the Polaten Formation, but also differ from them (something unknown in the Jurassic of Bulgaria). The elongation of the block is more or less parallel to the bedding of the flysch of Kostel Formation.

Depositional sequence StS 19 (=Ti 1.11)
SB – expressed by sharp change in the sedimentation.
LST (0.60 m)(nº 72, fig. 5)
Sandstone, massive, grey-greenish, fine-grained, with mica.
TST (14.20 m)(nº 73-76, fig. 5)(photograph VI/ 6 – unit 75 c)
Marls intercalated by fine-grained sandstones predominantly with rippled lamination (5 to 12 cm). The intercalations are irregularly distributed in the units (dense in nº 75c, 76 and rare in nº 73-75a). Normal gradation is observed upward (spec. C 75 in unit 75).
HST – is not presents.

Depositional sequence StS 20 (=Ti 1.12)
SB – expressed by sharp change in the sedimentation.
LST (6.00 m)(nº 77, fig. 5)
Sandstones, thick-bedded (cc.1.50 m), very fine-grained, with fine lamination – alternation between more fine-grained and coarser grained laminae (up to 1-3 mm), sometimes with rippled lamination. Lower boundary – sharp, upper boundary – transitional.
TST – is not present.
HST (11.90 m)(nº 78-79a-d, fig. 5)
HST-1 (8.10 m)(nº 78, fig. 5)
Marls to limy shales, ferriferous, thick-bedded – cc. 2 m, dark grey to brown, in the base showing fine lamination – in 5 cm there are cc. 25 couplets (with 30% of globules of Fe-oxihydroxides) and massive in the upper part (Ñ 11): *Conusphaera mexicana minor*, *Watznaueria barnesae*, *Watznaueria* sp. (many small-sized specimens), *Cy. deflandrei*, *Cy. margerelli*, *Cyclagelosphaera* sp. 1, *Ellipsagellosphaera britannica.*
HST-2 (3.80 m)(nº 79a-d, fig. 5)
Marls with intercalations of very fine-grained sandstones with rippled lamination; some of the intercalations (units 79a, 79,c) represent fine-grained sandstones (0.50 m) covered by horizontal (0.20 m) and rippled lamination (0.10 m).

Depositional sequence StS 21 (=Ti 1.13)
SB – expressed by sharp change in the sedimentation.
LST (8.20 m) (nº79e-80a, fig. 5, 81a-81e, fig. 6)
LST-1(1.50 m)(nº 79e, fig. 5)
Sandstones, massive (1.40 m) covered by 0.10 m horizontal and rippled laminated very fine-grained sandstone.
LST-2(2.0 m)(nº 79f, fig. 5)
Marls interbedded by 2 beds horizontal and ripple laminated very fine-grained sandstones horizontal and rippled.
LST-3 (1.20 m)(nº 79g, 80, fig. 5, n 81a-e, fig. 6))
5 beds of massive sandstones in the upper part horizontal and rippled laminated, intercalated by thin beds of marls and thin beds of very fine-grained sandstones – horizontally and/or rippled laminated.
TST (4.90 m) (nº 82, 83a-d, fig. 6)
Marls with many intercalations of thin-bedded sandstones, predominantly rippled (C 12): *Polycostella beckmanni*, *Conusphaera mexicana minor*, *Conusphaera mexicana mexicana*, *W. barnesae*, *Cy. deflandrei*, *Cy. margerelli*, *Ellipsagellosphaera britannica* and rarely horizontally laminated (2 of the intercalations are thicker – 0.40-0.50 m (n 83a, 83c), and are covered by laminated sandstones). In the uppermost part of the packet 1 bed of micritic carbonate, conchoidal, grey-brown – siderite crops out (Ñ 13): *Cyclagelosphaera deflandrei*, *Cy. margerelii*, *Watznaueria barnesae*, *Polycostella senaria*, *Ellipsagellosphaera britannica*, *Conusphaera mexicana mexicana*, *Conusphaera mexicana minor*.

Depositional sequence StS 22 (=Ti 2)
SB – expressed by sharp change in the sedimentation.

LST (1.20 m)(nº 84, fig. 6)
Sandstones, limy, fine-to medium-grained (1.00 m; and 0.20m fine-grained and horizontal)
TST (10.30 m)(nº 85, 86 a, b, 87, fig. 6)
Couplets of marls and fine grained sandstones (4-6 cm) and marls (2-10 cm.), crowned by sandstone, fine-grained (25 cm) and laminated – horizontally and rippled (10 cm) (N.B. The turbidite, with which ends the systems tract may be assigned to MFS?)
HST (3.20 m) (nº 88a, fig. 6)
HST-1 (2.00 m)
Marls – fine laminated in the base and undistinctly laminated upward, with 1 intercalation of fine-grained sandstones with rippled lamination.
HST-2 (1.20 m)

Argillites ferriferous and limy with convolute lamination (Ñ 15) with 2 interbeds of fine-grained sandstones (0.05 and 0.10 m): *Umbria granulosa minor, Cyclagelosphaera margerelli, Cy. deflandrei, Conusphaera mexicana mexicana, Ellipsagellosphaera britannica.*

Depositional sequence StS 23 (=Ti 3.1)
SB – expressed by sharp change in the sedimentation.
LST (1.60 m) (nº 88b, 89, fig. 6)
(a) At the base – fine-grained sandstones with pebbles of sandstones – 1-3 cm, rarely more, subrounded (0.50 m). (b) Sandstones, medium-grained, normal graded up ward (1,10 m)
TST (14.10 m)(nº 90-92a, fig. 6)
Couplets of fine-grained and fine laminated sandstones (0.10-0.15 m) and marls (0.10-0.70 m).
HST (1.20 m) (nº 92b, fig. 6)
Marls with two intercalations of fine-grained sandstones with horizontal and rippled lamination.

Depositional sequence StS 24 (=Ti 3.2)
SB – expressed by sharp change in the sedimentation.
LST (1.20 m)(nº 93, fig. 6)
Sandstones, thick bedded (1.00 m), in the upper part – laminated (0.20 m).
TST (7.80 m)(nº 94, 95a,b, fig. 6)
Argillites, limy to marls, ferriferous, dark brown (2.00 m) (Ñ 16) intercalated by beds of fine-grained horizontally and rippled laminated sandstones (10-15 cm). At 5 m above the base of unit 94 the marls are interbedded by 0.55 m of sandstones (a) medium-grained (0.35 m), (b) 0.05 m – thin-bedded, laminated, (c) 0.10 m – rippled bedded (unit 95a): *Conusphaera mexicana mexicana*, *Watznaueria biporta, W. barnesae, Ellipsagellosphaera britannica*, *Cyclagelosphaera margerelli.*

HST (2.00 m)(nº 96, fig. 6)
Breccio-conglomerate, matrix supported, built of medium to coarse grained sandstones (with matrix of clay minerals, strongly stained by Fe-oxihydroxides), and calcareous clasts – cc. 1mm up to 100 mm, rarely up to 25 cm. Nannofossils: *Polycostella beckmanni, Ellipsagellosphaera britannica, Parhadolithus embergeri, Cy. margerelli, Watznaueria barnesae, W. biporta.* The calcareous pieces – pebbles to cobbles, are bright grey, micritic; there are also as clasts fragments of belemnites, ammonites and single members of crinoids. There are also pebbles of sandstones with ripple lamination (5-15 cm) – from the Kostel Fm., and intraclastics limestones with diameter cc. 5-10 cm and clasts in them below 1 mm (Gintsi Fm) (spec. Ñ 17).

Depositional sequence StS 25 (=Ti 3.3)
SB – expressed by sharp change in the sedimentation.
LST (1.60 m)(nº 97, fig. 6)
Sandstones, thick-bedded, very fine-grained.
TST (8.0 m)(nº 98, fig. 6)
Marls (poorly exposed) with rare thin beds of very fine-grained sandstones. In the base of the packet (C 18) rich calcareous nannofossils association is recorded, comprising *Polycostella senaria, Conusphaera mexicana mexicana, C. mexicana minor, Watznaueria barnesae, W. biporta, Cyclagellosphaera margerelii, C. deflandrei, Ellipsagellosphaera britannica.* The same association, complemented by *Faviconus multicolumnatus*, is documented 5 meters higher (C 19).
HST – not presented.

Depositional sequence StS 26 (=Ti 4)
SB – expressed by sharp change in the sedimentation.
LST (3.90 m)(nº 99, fig. 6)
Sandstones: 3.60 m- beds of medium-grained, thick-bedded sandstones (0.50-1.0 m) covered by 0.20 m sandstones with horizontal lamination and 0.10 m – with rippled lamination.
TST (4.90 m)(nº 100, fig. 6)
Marls to calcareous argillites with rare intercalations of horizontal and/or rippled laminated sandstones (0.05-0.20 m). The nannofossil association includes (C 20): *Nannoconus wintereri*, *Nannoconus* spp., (indicating Upper Tithonian), *Polycostella senaria*, *Conusphaera mexicana minor, Watznaueria barnesae, W. biporta*, *Cyclagellosphaera margerelii*. The samples, collected at 1.5 m (C 21) and at 3.50 m (C 22) above the spec. C 20, contained *Cyclagellosphaera margerelii*, *Conusphaera mexicana mexicana*, *Watznaueria barnesae*, *W.*

biporta, Ellipsagellosphaera britannica, Cyclagelosphaera sp.-1, *C. deflandrei.*
HST – not presented.

Depositional sequence StS 27 (=Ti 5)
SB – expressed by sharp change in the sedimentation.
LST (2.20 m)(n° 101, fig. 6)
2 beds of massive sandstones (0.75 and 0.25 m) covered by laminated – horizontal (0.05-0.15 m) and rippled (0.10-0.15 m) fine-grained sandstones.
TST (5.20 m)(n° 102a-g, fig. 6)
Marls to calcareous argillites, intercalated by 3 tick beds (0,60-0,90 m) of sandstones, composed by Bouma turbidite (n° 102d) or by a thick bed, covered by horizontal and rippled laminated very fine-grained sandstones (n° 102b, f), or by thin beds of laminated sandstones.
HST is not presented.
N.B.
The upper part of the section is poorly exposed and is impossible to be measured.

Conclusions

The following principal results are obtained during the present study:

1. Jurassic sedimentation in the region started at the end of Bajocian and continued during the Early and Middle Bathonian. This conclusion is revealed by the study of foraminifers. It confirms the suggestion of Tchoumatchenco (2002, fig. 3), obtained by the analysis of the depositional sequences, and disproves the preexisting notions of Tchoumatchenco (1983) and Sapunov et al. (1985) that the sedimentation started in the Aalenian.
2. The Middle Jurassic rocks in the section are separated into 4 sequences – StS 1-4, corresponding to the western European ones (Hardenbol et al., 1998) – Bj 5, Bat 0 – Bat 2.
3. Four depositional sequences are separated in the Kimmeridgian (after a break of sedimentation between the Middle Bathonian and the Lower Kimmeridgian). The sequences StS 5-7 (Kim 2-Kim 4) are individualized in the carbonate succession of the Gintsi and Drugan Fm. and in the mudstone of Neshkovtsi Fm. The last sequence StS 8 (Kim 5) is divided in the alternation of sandstones and marls of the Kostel Fm. (Bobovo Member).
4. In the Tithonian, 19 depositional sequences are recognized (StS 9-27). They comprise 13 sequences in the Lower Tithonian (StS 9-21), 4 sequences in the Middle Tithonian (StS 22-25 = Ti2, Ti 3.1, 3.2, 3.3), and 2 sequences (StS 26-27 = Ti 4 and Ti 5) in the Upper Tithonian. The sequences StS 12, 13, 18, 22, 24 are complete – composed of LST, TST and HST. In the sequences StS 9, 10, 11, 14, 16, 17, 19, 21, 23, 25, 26, 27 only the LST and TST are presented, whereas in StS 15, 20 only the LST and HST are divided.
5. The sequences in the carbonate rocks (Polaten Fm., Gintsi Fm., Drugan Fm., and Neshkovtsi Fm.) are based principally on the geometry and the superposition of the calcareous beds – the LST is structured by thick beds of limestones, the TST – by alternation of thinner beds of limestons and clayey limestones to marls, and the HST – by thick beds of clayey limestones.
6. The subdivision of the sequences in the flysh type of rocks (Bobovo Mb. of Kostel Fm.) is based on the lithology and the geometry of the rocks – predominance of thick-bedded sandstones – LST, alternation of mudstones and thin-bedded sandstones – TST and of the predominance of mudstones – HST.
7. Each unit from the Bobovo Mb. of Kostel Fm. (fig. 4, 5, 6) was referred to a specific depositional process and lithofacial type considering Bouma (2000) and Shanmugam et al. (1995).

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