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Depositional Environments in the Eastern Paratethys during the Final Middle Miocene Transgression (Kura Basin, Eastern Georgia)

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Abstract—The mineral composition and depositional environments of the Konkian in eastern Georgia (Kura trough, eastern Paratethys) corresponding to the Kosovian (13.65–12.829 Ma) in the Central Paratethys and the final Middle Miocene marine transgression in Paratethys are considered. Jurassic and Cretaceous volcanic rocks of the Lesser Caucasus (Adzhar–Trialet and Artvin–Bolnisi zones) were identified as the main provenances for the terrigenous material. Eight lithofacies types distinguished for the studied rocks characterize depositional environments with significant wave or submarine-fluvial influence. The change of depositional environment was controlled by the phases of transgression, as well as by the progradation and lateral migration of the prodelta. The development of depositional environment corresponds to the Konkian stratigraphic beds and reflects the main stages of the final Middle Miocene transgression in the Eastern Paratethys.

Keywords: depositional environments, Konkian regional stage, Middle Miocene, Eastern Paratethys

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INTRODUCTION

Drastic changes of the depositional environment in the Eastern Paratethys took place during both its isolation from open seawater and the development of large-scale transgressions providing a revival of the connection of Paratethys basins with the Mediterranean basin and World Ocean. Comprehensive study of the transgressive stage beds is important, because it allows the interregional correlations and synchronization of stagewise sedimentation. In the Central Paratethys, the last large Middle Miocene marine transgression was represented by the late Badenian seawater input in the Kosovian (13.65–12.829 Ma) (Hohenegger et al., 2012, 2014) leading to termination of the Badenian salinity crisis. This event is represented in the Eastern Paratethys by the Konkian transgression (Hilgen et al., 2012) that promoted favorable conditions for the habitat of marine communities, which replaced the Karaganian basin environment with unstable water salinity and endemic mollusk fauna. Deposits of the Kosovian and Konkian regional stages are overlain by the Sarmatian sequences deposited in a spacious basin extending from the Alps to the Aral Sea and having only episodic connection with the open seawater.

Despite a long-term study of the Middle Miocene Konkian rocks in the Eastern Paratethys, issues related to their stratigraphic subdivision remain debatable so far. According to (Nevesskaya et al., 2004), the Konkian regional stage is subdivided into the Sartaganian and Veseljanian beds. The Sartaganian beds are characterized by a diverse assemblage of polyhaline mollusks; the overlying Veseljanian beds, by the presence of euryhaline marine fauna. According to (Merklin, 1953; Palcu et al., 2017; Popov et al., 2016), the Konkian regional stage also includes the Kartvelian beds assigned by some researchers to the Karganian (Nevesskaya et al., 2004) or identified as a separate regional stage (Il'ina, 2000; Zhgenti, 1976; Zhgenti and Maisuradze, 2016). It is believed that these beds are good markers of the main stages of the Konkian marine transgression. Other researchers, however, believe that the above-mentioned Konkian subdivisions are just lithofacies, and they lack the sequential stratigraphic position (Belokrys, 1987; Vernyhorova, 2017). Therefore, study of the facies structure of Konkian rocks and reconstruction of the depositional environment are very important for elucidating peculiarities of the Konkian transgression in the Eastern Paratethys. To solve this task, study of the Konkian shallow-marine sequences marked by the abundance of mollusk fauna and diverse depositional environment is more preferable, relative to their coeval deepwater varieties characterized by a monotonous structure and lesser amount of malacofauna.

We carried out the first detailed lithofacies analysis of shallow-marine Konkian rocks that are exposed near the Ujarma Settlement, Sagarejo district of

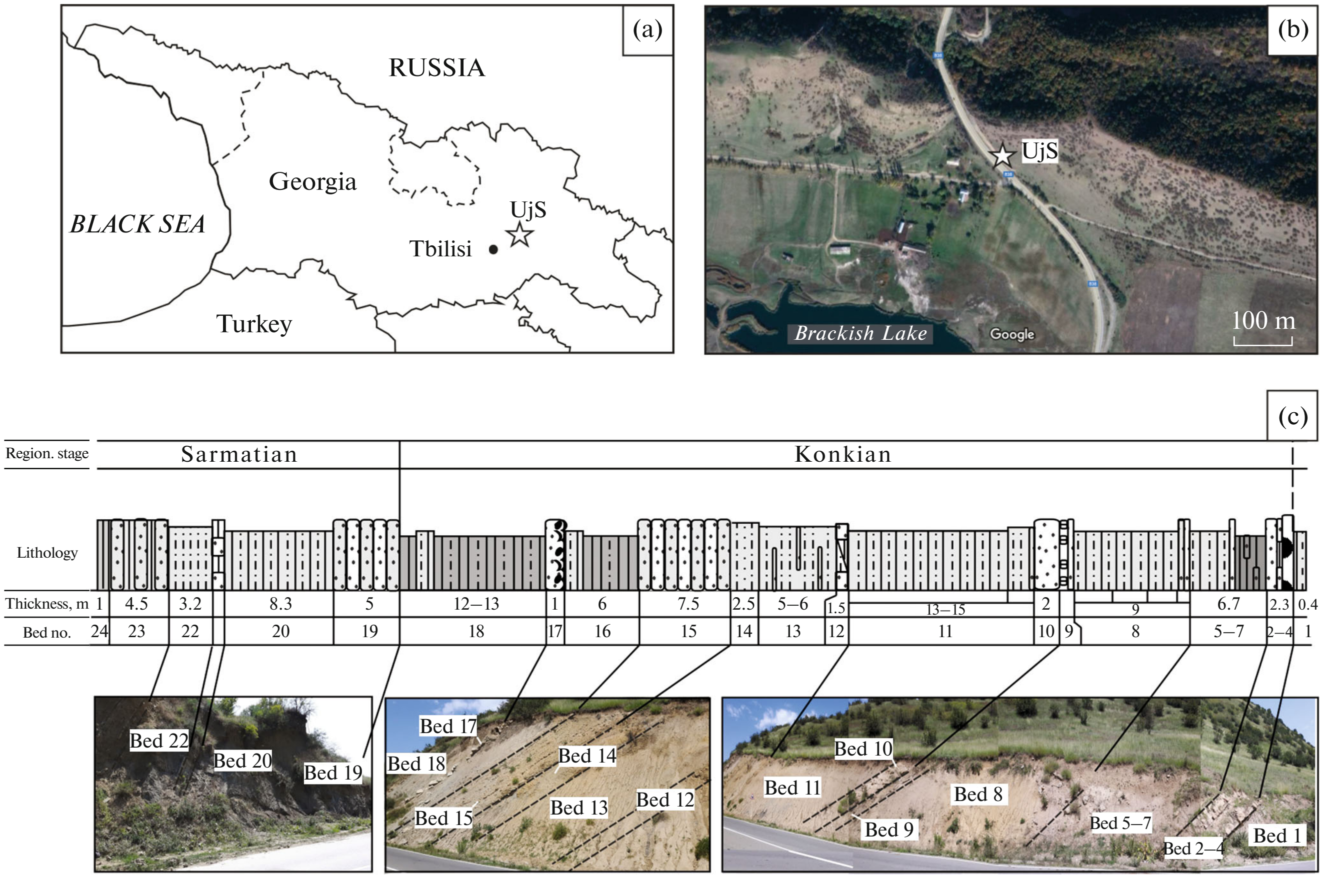

Fig. 1. Position of the studied section and layer-by-layer structure of the Konkian and Sarmatian rocks. Location of the Ujarma section (UjS) in Georgia (a) and study area (b); (c) panorama and structure of the section.

Kakheti, eastern Georgia (Kura basin) and characterized by a stratigraphic completeness of section, good exposure, and sufficient thickness. The obtained results are also essential for the subsequent comprehensive stratigraphic studies taking into consideration changes in the depositional environment (Rostovtseva et al., 2019).

OBJECT AND METHODS

The Konkian rocks exposed near the Ujarma Settlement in eastern Georgia (Kakheti), were studied by M.M. Grachevskii (1954), I.I. Janelidze (1961, 1970), V.A. Krasheninnikov (2003), E.M. Zhgenti, L.S. and Maisuradze (2016) and others. These studies yielded data on the stratigraphic subdivision of sequences, species composition of the faunal assemblages (foraminifers, mollusks, ostracods, and others), and general lithological specifics of these rocks. It was established that the sequences are represented by the Kartvelian (Folada), Sartaganian, and Veseljanian beds that are replaced upsection by the lower Sarmatian rocks (Janelidze, 1970; Krasheninnikov et al., 2003). The studied Konkian rocks contain diverse mollusk fauna: *Anadara turonica*, *Turritella atamanica*, *Mactra basteroti*, *Ervilia trigonula*, *Chlamys sartaganicus*, *Cardium* sp., and others (Janelidze, 1970).

The Konkian rocks near the Ujarma Settlement were studied at a new outcrop (41°77′62.24″ N, 45°14′95.65″ E) (Fig. 1). The section is characterized by completeness of the Konkian stratigraphic subdivisions, good exposure, sufficient thickness, and novelty. Sedimentary sequences exposed here are composed of clays containing both separate sandy interbeds and intervals with frequent alternation of the clayey and sandy rocks. The Konkian sequence base includes gritstone and fine-pebble conglomerate interbeds. Total thickness of the Konkian and lower Sarmatian sequence in the studied section is 93–97 m.

According to determinations of the foraminiferal species composition in rocks by K.P. Koiava, beds 2–6 containing *Borelis melo* (Fichtel & Moll) correspond to the Sartaganian; rocks in beds 11–18 with *Varidentella reussi sartaganica* (Krash.) and abundant representatives of the Konkian genus *Ammonia* (*Ammonia beccarii* (Linnaeus) and others), to the Veseljanian beds. Based on the presence of *Varidentella reussi reussi* (Bogd), rocks in Beds 19–24 are assigned to the lower Sarmatian.

The regional stratigraphic scale accepted in this work follows the last version for Neogene sediments in southern European part of Russia (Nevesskaya et al., 2004), in which the Konkian regional stage includes the Sartaganian and Veseljanian beds.

We accomplished a detailed lithofacies analysis of sedimentary deposits with the layer-by-layer description of section, study of the textural and structural features along with the mineral and component composition of rocks in thin sections, as well as the deciphering of genetic properties of rocks.

Clayey rocks in 28 samples taken from the section for describing rock beds were studied by the X-ray structure method in oriented preparations (fraction <0.001 mm, less commonly <0.1 mm) in the air-dry, chilled (up to 550°C), and ethylene glycol-saturated states. All samples were also analyzed in powder by the Debye method. The quantitative ratio of clay minerals in the preparations was determined by the method described in (Biscaye, 1965). The computed relative shares (in %) of components in the established association is an approximate estimate of the absolute concentration of clay minerals in the studied samples. Taking into consideration the significant number of measurements, frequency, and regularity of sampling, these data are presented in the work to reveal general trends of content variation in separate mineral varieties.

The X-ray structural analysis was carried out at the Department of Petroleum Sedimentology and Marine Geology, Lomonosov Moscow State University, using a MiniFlex 600 diffractometer (V.L. Kosorukov, analyst).

RESULTS OF THE STUDY OF MINERAL COMPOSITION IN THE DEPOSITS

The studied deposits are dominated by clays. Clastic rocks are sufficiently widespread but subordinate. Carbonate rocks are represented by rare calcite microbial nodules only observed at one level of the section. The deposits also contain separate rock interbeds with signs of secondary carbonatization.

Clayey Rocks

Based on peculiarities of the mineral and component composition, the clayey rocks are divided into three main lithotypes: (1) carbonate clays ($CaCO_3$ 15–27%) with rare thin lenses of the sandy–silty detrital admixture; (2) clays with different degrees of carbonateness ($CaCO_3$ 0–30%) with frequent thin (millimeter-scale) lenticular sandy–silty and silty–sandy interbeds containing coalified plant remains and sapropel admixture in some places; and (3) clays with different degrees of carbonateness (silty–sandy rock with a random distribution of clastic components).

Clays of the first lithotype make up an interval about 6–7 m thick in the lower part of the studied section. Clays of the second lithotype are most widespread. Clays of the third lithotype occur episodically as separate interbeds.

Based on the X-ray structural analysis, the fine-dispersed fraction of clays includes smectite (montmorillonite), illite, chlorite, kaolinite, and mixed-layer minerals. Clay minerals are composed of the predominant smectite (54–86%, average 69%) and the subordinate illite (5–33%, average 17%), chlorite (3–15%, average 6%), and kaolinite (3–11%, average 6%) (Table 1). The mixed-layered minerals are represented by the mica–smectite varieties that occur episodically and only in two samples (4 and 8%). Clay deposits are characterized by a rather monotype composition of the major components, suggesting a monotonous pattern of the terrigenous material delivered to the basin during the studied period and uniformity of secondary processes (Fig. 2).

Clastic Rocks

Clastic rocks are represented mainly by sandy minerals. Coarse-clastic rocks occur in the lowermost part of the section. The silty material is found mainly as admixture in the clayey, sandy, and gravelly–pebbly rocks.

Coarse-clastic rocks are represented by the medium- to fine-pebble conglomerates and gritstones. Conglomerates make up two separate interbeds replaced upsection by gritstones or sandstones.

Sandstones are divided into the following main lithotypes: (1) varigrained sandstones with clasts (0.1 to 1.5 mm in size) and calcite cement; (2) fine- to medium-grained, medium- to fine-grained, fine-grained, and very fine-grained sandstones with the calcite cement; and (3) medium- to fine-grained and very fine-grained sandstones with the clayey cement. Sandstones with the fine- to medium-grained psammitic clasts and the calcite cement are developed in different parts of the section. Clastic grains are mainly angular and subrounded, testifying to the absence of their multiple redeposition and proximity to the provenance. Sandstones are marked by the medium-grained structure and good sorting. There are also sandstones with homogeneous structure, as well as wavy and cross-wavy bedding, typical for the wave-influenced and submarine-fluvial deposits. The clastic rock interbeds can include organogenic remnants that make up noticeable clusters in some places (Figs. 3a–3d, 3h).

In terms of mineralogy, sandstones correspond to feldspar and quartz–feldspar graywackes lacking significant changes in the proportion of main components along the section (Fig. 2): lithoclasts, from 36 to 64% (average 50%); feldspars, from 26 to 49% (average 36%); and quartz, from 6 to 20% (average 13%). Lithoclasts are composed mainly of volcanic rocks differently altered by secondary processes. The subordi-

Table 1. Mineral composition of the studied Konkian and Sarmatian clayey rocks

Sample no.	Content of clay and carbonate minerals, %						
	s	i	m	c	k	c + k	$CaCO_3$*
18-01	69	14	–	10	7	17	19
18-06	62	20	–	10	8	18	18
18-08	71	15	–	8	6	14	19
18-11	58	25	8	3	6	9	27
18-14	72	15	–	4	9	13	27
18-15	61	32	–	3	2	5	14
18-17	64	21	–	4	11	15	24
18-18	81	9	–	5	5	10	8
18-19	80	11	–	4	5	9	6
18-20	69	14	–	10	7	17	17
18-23	59	31	–	3	7	10	23
18-24	77	15	–	5	3	8	17
18-27	86	5	–	4	5	9	19
18-28	62	20	–	9	8	17	17
18-29	68	15	4	7	6	13	30
18-30	67	15	–	10	8	18	17
18-31	64	20	–	9	7	16	8
18-32	78	15	–	4	3	7	22
18-35	78	8	–	7	7	14	4
18-39	67	20	–	6	7	13	4
18-42	71	11	–	8	10	18	4
18-43	58	18	–	15	9	24	–
18-44	74	16	–	6	4	10	20
18-47	54	33	–	6	8	14	24
18-49	72	15	–	5	8	13	18
18-53	76	10	–	6	8	14	1
18-55	78	13	–	4	5	9	9
18-56	66	21	–	6	7	13	23

Clay minerals in the fine-dispersed fraction of clays: (s) smectite (montmorillonite), (i) illite, (m) mixed-layered minerals, (c) chlorite, (k) kaolinite, (c + k) chlorite + kaolinite; (*) $CaCO_3$ content in the bulk sample; (–) not detected.

nate lithoclasts are composed of quartzites, cherty and clayey rocks, as well as granitoids (Figs. 3e–3g).

Feldspars are represented mainly by the acid and basic plagioclases along with K-feldspar. Glauconite grains are observed in some places.

RESULTS OF THE FACIES ANALYSIS

Based on the genetic properties and paragenesis of lithotypes, the studied sequences are divided mainly into eight facies sediment types characterizing the depositional environment with the wave-influenced or submarine-fluvial depositional environment (Table 2). In the wave-influenced environment, sediments were accumulated in shallow-water coastal sectors with different water mobility depending on the transgression development stage (facies OF_2, OF_1, IB, BR, and BC). During the progradation of submarine discharges, some sectors of the basin were favorable for the deposition of sediments at margins of the prodelta (facies PR_1, PR_2, and DF).

Deposits in the Coastal Shallow-Water Wave-Dominated Depositional Environment

Sediments in the coastal shallow-water zone with low water mobility (OF_2) are represented by the subcalcareous and calcareous ($CaCO_3$ up to 27%) laminated clays with lenticular (millimeter-scale) clusters of the silty detrital admixture. The clays contain separate thin (4–12 cm) lenticular interbeds of very fine-grained sandstones with the calcite cement. The sandstones include large foraminiferal tests (*Borelis melo* (Fichtel & Moll) and others), gastropods, as well as fragments of shells and red algae.

Deposits of this facies occur in the lower part of the section and make up interval about 5–7 m thick (Beds 5–7).

Sediments in the coastal shallow-water zone with medium water mobility (OF_1) are composed of the subcalcareous ($CaCO_3$ up to 19%) laminated clays with the millimeter-scale interbeds and lenticular clusters of the sandy–silty admixture (clasts size up to 0.1 mm) along with single shells of bivalve mollusks and ferrugination in some places.

Sediments of this type are recorded as a minor portion at the section base (Bed 1).

Sediments in the coastal shallow-water zone with medium and high water mobility and at margins of sand sheets (IB) are represented by the subcalcareous and calcareous clays ($CaCO_3$ up to 24%). Their lower part is sandy (0.6 m), whereas the upper part is laminated, with frequent millimeter-scale interbeds and lenticular clusters of the silty and sandy material (clast size up to 0.25 mm), small fragments of fish bone, isolated small foraminiferal tests, as well as intervals of intense ferrugination. The upper part of these clays contain lenticular interbeds (up to 18 cm) of the medium- to fine-grained (clast size 0.1–0.4 mm, mainly 0.1–0.25 mm) sandstones with medium sorting and calcite cement. In addition to sandstones, the deposits contain intervals with the calcareous microbial nodules up to 5–8 cm across (Bed 9).

Sediments of this facies make up the lower part of the studied sequence and occur in the section interval about 10–11 m thick (Beds 8–9).

Sediments in the coastal shallow-water zone with high water mobility and in central parts of sand sheets (BR) are composed of the fine- to medium-grained and

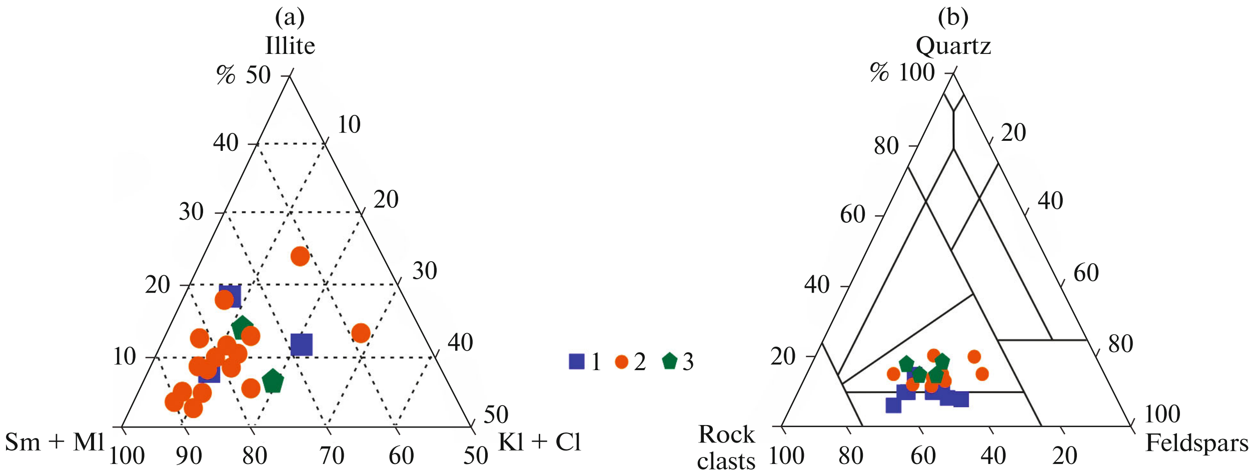

Fig. 2. Mineral composition of the Konkian and Sarmatian rocks: (a) clays, (b) sandstones—classification according to (Shutov, 1967). (1) Samples from Beds 1–7; (2) samples from Beds 8–18; (3) samples from Beds 19–24. (Sm + Ml) smectite (montmorillonite) + mixed-layer minerals, (Kl + Cl) kaolinite + chlorite.

fine-grained, sorted sandstones with the calcite cement and abundant diverse organogenic remnants (gastropods, bivalve mollusks, small foraminiferal tests, and bioclasts) in some places.

Such sediments make up interbeds (up to 1.2–1.5 m thick) identified as 'enveloping' intervals (Beds 10 and 17) in the lower and upper parts of the studied sequence.

Sediments of transgressive erosion beds (EC) are represented by the sand–gravel–pebble and gravel–sand deposits. The sand–gravel–pebble deposits include two interbeds (thickness 0.1 and 0.3 m, respectively) of the medium- to fine-pebble (pebbles up to 15 cm or less) conglomerates including flattened clasts that are oriented along or slightly inclined to the bedding plane. The conglomerate interbeds are characterized by a lower eroded boundary and sole marks. They are overlain by thin (0.2 m) gritstone or sandstone beds. The gravel–sand deposits make up the fine- to medium-grained (clast size from 0.1 to 0.5 mm, mainly 0.2–0.4 mm) sandstone interbed (0.9 m) marked by medium sorting along with clay pellets and gravel inclusions at the base. These rocks (conglomerates, gritstones, and sandstones) are cemented with calcite. They contain large foraminiferal tests, gastropods, various bioclasts, and biocenotic nodules composed of remnants of red algae and foraminifers.

Sediments of this type (total thickness about 2.4 m) are developed in the lower part of the section (Beds 2 and 4).

Sediments in the Coastal Shallow-Water Zone Dominated by the Submarine-Fluvial Depositional Environment

Sediments in lower parts of the prodelta (PR_2) are composed of laminated clays with different degrees of

Table 2. Facies types of sediments in the studied Konkian and Sarmatian rocks

<table>
<tr><th colspan="2">Sediment facies/types</th><th>Index</th></tr>
<tr><td colspan="3">Coastal shallow-water zone with wave-influenced depositional environment</td></tr>
<tr><td colspan="2">Environmental setting with low mobility of water/silty–clayey and sandy sediments</td><td>OF_2</td></tr>
<tr><td colspan="2">Environmental setting with medium mobility of water/sandy–silty–clayey sediments</td><td>OF_1</td></tr>
<tr><td rowspan="3">Environmental setting with medium and high mobility of water</td><td>Marginal parts of sand sheets/silty–sandy–clayey sediments</td><td>IB</td></tr>
<tr><td>Central parts of sand sheets/sandy sediments</td><td>BR</td></tr>
<tr><td>Transgressive erosion beds/sandy–gravelly–pebbly sediments</td><td>EC</td></tr>
<tr><td colspan="3">Coastal shallow-water zone with submarine-fluvial depositional environment (prodelta)</td></tr>
<tr><td colspan="2">Lower part of prodelta/silty–sandy–clayey sediments</td><td>PR_2</td></tr>
<tr><td colspan="2">Upper part of prodelta/silty–sandy–clayey and sandy sediments</td><td>PR_1</td></tr>
<tr><td colspan="2">Margin of delta front/clayey–sandy sediments</td><td>DF</td></tr>
</table>

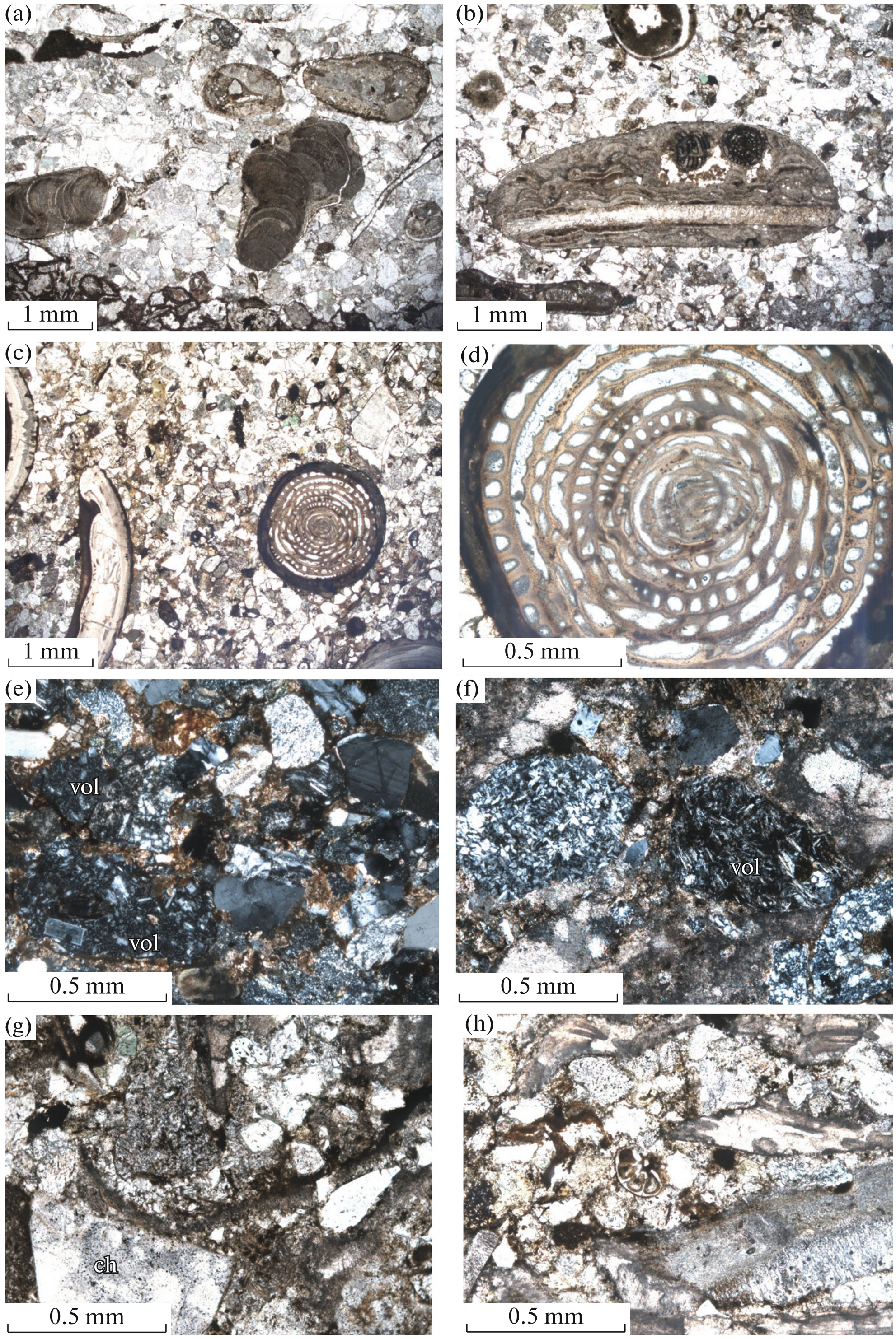

Fig. 3. Photomicrographs of Konkian rocks. (a) Micronodules of red algae (Bed 2); (b) micronodules of red algae and foraminifers (Bed 4); (c, d) test of foraminifers *Borelis melo* (Fichtel & Moll) in sandstone (Bed 6); (e, f) volcanic rock clasts in the sandstone (Beds 2 and 17, respectively); (g) cherty rock clast with relicts of radiolarian remnants (Bed 17); (h) foraminiferal test in the sandstone (Bed 17). (a–d, g, h) parallel nicols; (e, f) crossed nicols.

carbonateness ($CaCO_3$ up to 30%, usually less than 25%), thin (millimeter-scale) interbeds, and lenticular silty–sandy clusters scattered or disseminated as nepheloid suspension in the clayey matrix. The clays contain filamentous fragments of the organic (often pyritized) material, as well as single small foraminiferal tests.

These sediments are widespread in the studied sequences as intervals with thickness ranging from 6 to 15 m (Beds 11, 16, 20, 24).

Sediments in upper parts of the prodelta (PR_1) are represented by the dark gray sandy–silty clays. Their clasts are scattered in the clayey matrix or concentrated as millimeter-scale interbeds. The clays are characterized by the abundance of coalified plant remains concentrated on bedding planes and the presence of thin (1–2 cm) fine-grained sandstones interbeds recurring in the section after 0.3–0.9 m. There are also separate intervals (thickness 1.5–2.5 m) with more frequent recurrence of the thin sandy–silty and sandy interbeds in the section. The deposits are marked by syngenetic deformation structures as traces of "loading" and slumping of thin laminas detected during the microscopic observation.

These sediments make up intervals 7 to 10 m thick in the section (Beds 12–14, 22–23) and show close spatial correlation with other facies types of prodelta deposits

Sediments at margins of the delta front (DF) are composed of a rhythmic alternation of the fine-grained sandstone beds and intervals with intercalations of the sandy and clayey material. The sandstones are grayish green (or brownish due to the secondary ferrugination) fine-grained (with clasts 0.1–0.15 mm across) rocks with cross-wavy bedding, good sorting, and calcite cement. The sandstone beds are commonly lenticular (undulated) and up to 0.2 m thick. Intercalation intervals (up to 0.1–0.15 m thick) are composed of the medium- to very fine-grained (clast size 0.05–0.25 mm) sandstones with the clayey filler. The rocks are "layered" due to the presence of numerous thin, appreciably more clayey laminas. One can also see separate sandstone interbeds with a gently converging fine bedding and southwestward dip of oblique series.

These sediments are identified in the middle and upper parts of the section as intervals 7.5 and 5 m thick (Beds 15, 19).

DISCUSSION

The development of large marine transgression in the initial Konkian (Sartaganian beds) promoted the formation of several intraformation coarse-clastic beds in the studied sector of the basin, testifying to a rapid inflow of open water into the Eastern Paratethys at this time (facies EC, Figs. 4a, 4b). Diversity and species composition of the faunal remnants in rocks from the lower part of the section suggest the revival of normal marine salinity in water (up to 30–32‰), according to (Merklin, 1953). Inclination of the flattened pebbles in conglomerates and orientation of the sole marks indicate that water entered the basin from the northwestern side. Owing to marine transgression in this part of the basin, the coastal shallow-water environment with medium water mobility (facies OF_1) gave way to the shallow-water environment with a calmer hydrodynamic setting. This period was marked by the deposition of mainly clayey rocks, with episodic formation of small- and very fine-grained sandy ridges containing abundant remnants of marine organisms, such as foraminifers, red algae, and others (facies OF_2). Sediments were deposited below the FWWB but in the MSWB zone at a depth down to 40–50 m. Subsequently, the deposition of such rocks gave way to the formation of wave-influenced deposits (sand sheets), testifying to the onset of basin shoaling (facies IB and BR, Fig. 4). The central parts of sand sheets formed with the active involvement of agitation at average depth down to 20–30 m. At sand sheet margins, the microbial carbonate minerals usually recording changes in the sedimentation setting are developed, while remnants of red algae are absent—this fact suggests an unstable water salinity or its decrease during this period. Sand sheets could form due to the redeposition of sediments from the distal areas of the submarine discharge. The sequential development of sediments in the lower and upper parts of the prodelta followed by the accumulation of sediments at the delta front periphery in the middle part of the section testify to the prodelta progradation and the predominant influence of submarine-fluvial processes in the studied sector of the basin at this time (facies PR_2, PR_1, and DF; Figs. 4c, 4d, 4g, and 4h). Sediments of the delta front periphery were deposited within the MSWB zone, resulting in the formation of rewashed sandy sediment interbeds among the less sorted sandy deposits with the clayey filler. Orientation of the oblique series in sandstone interbeds suggests that the terrigenous material was delivered to the basin by submarine currents from the southwestern side. Under the attenuation of submarine-fluvial processes and the lateral migration of river discharges or water influx during the short-term transgression phases, conditions became favorable for the wave reworking and redeposition of prodelta sediments as sand deposits (sheets) shown as facies BR (Figs. 4e, 4f, $5a_1$). The development of marginal submarine-deltaic deposits also continued in the earliest Sarmatian during the onset of general deepening and expansion of the basin (Koiava et al., 2012) (Fig. 5b).

Within eastern Georgia, the Konkian basin extended as a narrow band limited by land on the southwest and northeast (Popov et al., 2004) (Fig. 5c). Its axial sector accumulated deeper-water sediments that gave way to the shallow-water varieties at margins. Land existed within the Lesser Caucasus and Greater Caucasus orogenic systems, respectively, on the southwestern and northeastern sides. Based on position of the studied section relative to axial part of the basin, the direction of terrigenous material transport from southwest, and the mineral composition of clastic rocks, rock complexes in eastern parts of the

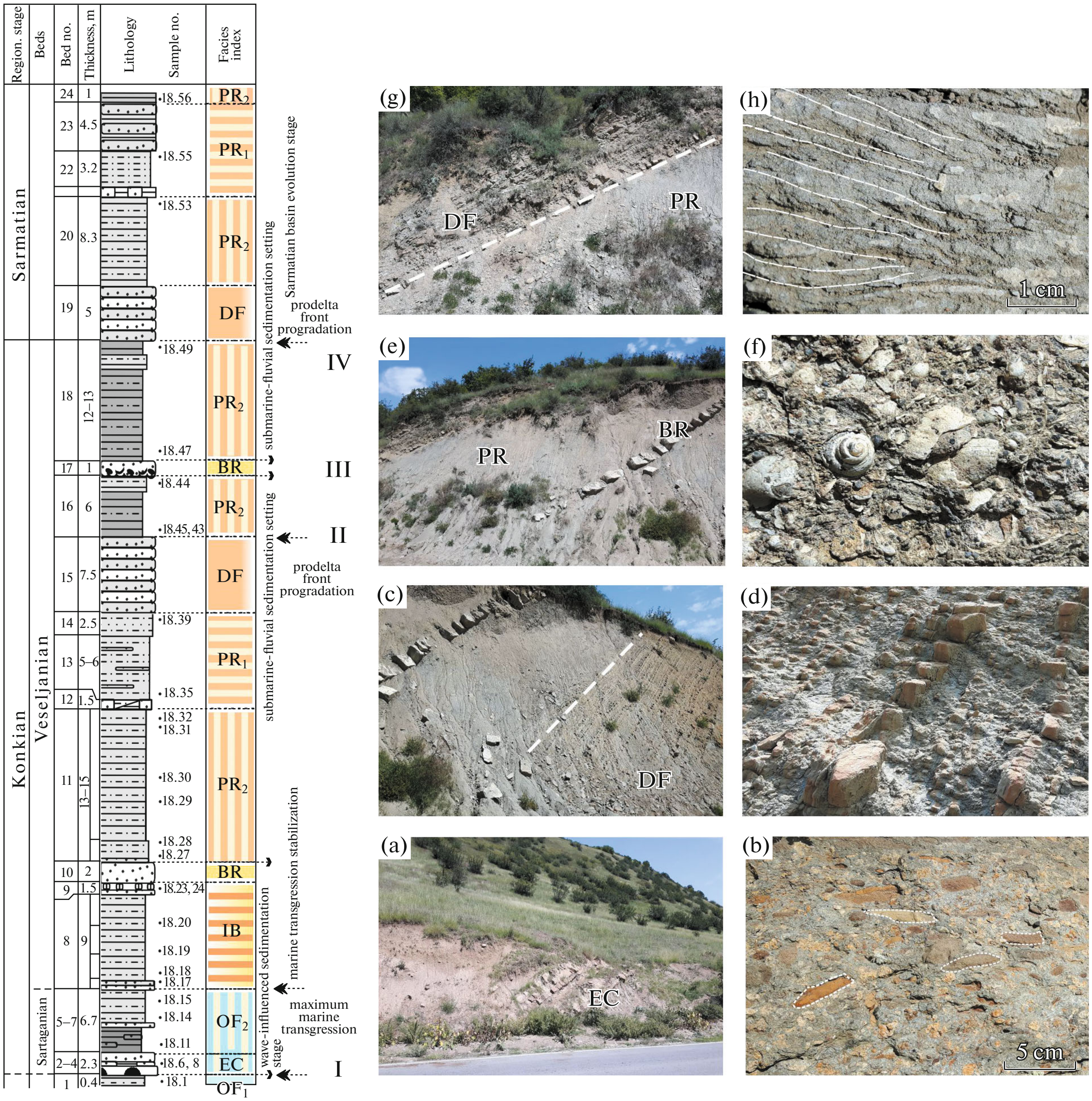

Fig. 4. Facies structure of the studied Konkian and Sarmatian rocks. (I) Sediments in transgressive erosion beds (Bed 2): general view (a) and pebble location in conglomerates (b); (II) sediments at the delta front margin (Bed 15): general view (c) and rock alternation pattern (d); (III) sediments in the central part of sand sheets (Bed 17): general view (e) and organogenic remnant clusters (f); (IV) sediments at the delta front margin (Bed 19): general view (g) and typical gentle cross-bedding in separate sandstone interlayers (h). Lines show the boundaries of series. Designation of facies indexes is given in Table 2.

Adzhar–Trialet and Artvin–Bolnisi tectonic zones could likely serve as the main provenances. Diversity of volcanic rock clasts prevailing in sandstones suggest an intense washout of Jurassic and Cretaceous volcanic rocks exposed as extended sections, for example, in the Bolnisi subzone (*Geologiya SSSR*, 1964; Gamkrelidze, 2000).

The studied Ujarma section shows a successive replacement of depositional environment corresponding to the Konkian stratigraphic subdivisions and reflecting the successive development of marine transgression (Sartaganian beds) and tectonic stabilization (Veseljanian beds).

CONCLUSIONS

The detailed layer-by-layer description of rocks exposed in the Ujarma section made it possible to unravel lithological features of the Middle Miocene Konkian rocks in eastern Georgia (Kura basin). Based

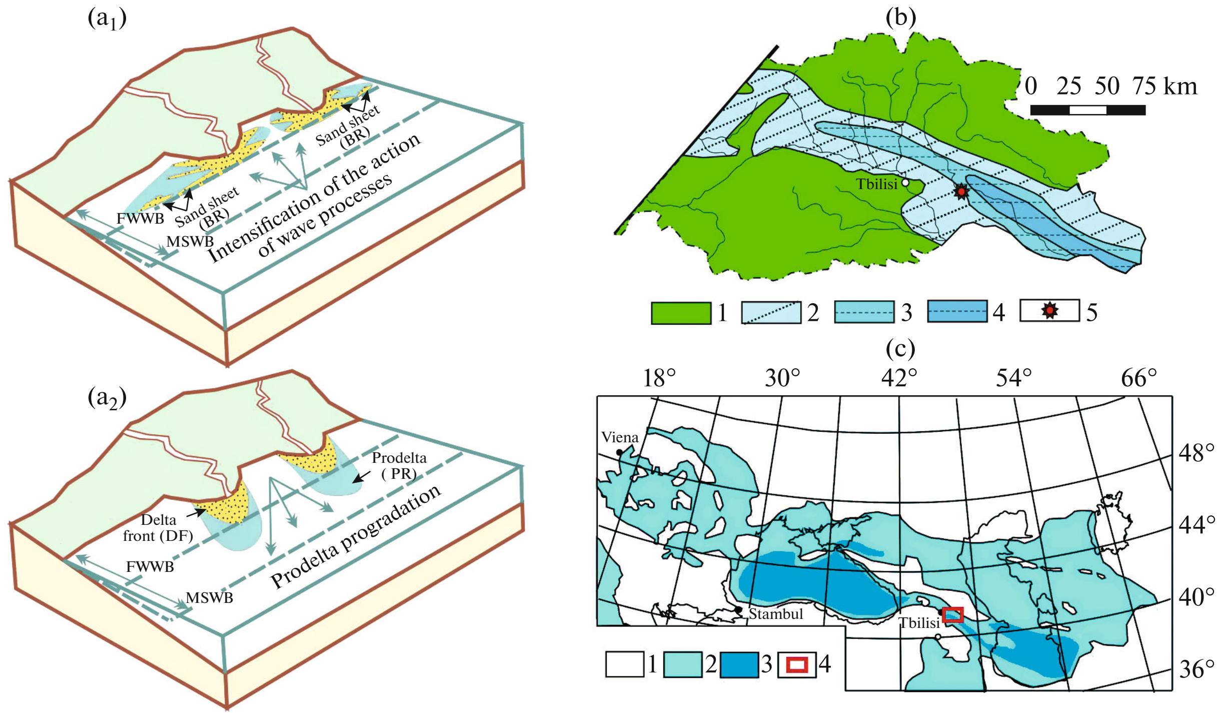

Fig. 5. Depositional environment of the studied Konkian and Sarmatian rocks. (a) Models of the shallow-marine depositional environment of the Konkian rocks: (a_1) at intensification of the influence of wave processes (Beds 8–10, 17); (a_2) at predominance of the submarine-fluvial processes (Beds 11–16, 18–24), (FWWB) fair weather wave base (still), (MSWB) maximum storm wave base; (b) depositional environment at the initial Sarmatian in the Kura intermontane trough, modified after (Koiava et al., 2012): land zones (1), shallow-water (2), transitional (3), relatively deep-water (4), location of the studied section (5); (c) Paratethys during the last large marine transgression in the Middle Miocene, modified after (Studencka et al., 1998): land zones (1), shallow-water (2), deep-water (3), location of the study area (4).

on the macro- and microscopic characteristics of rocks, we identified the major lithotypes represented mainly by varieties of clays and clastic rocks.

The X-ray structural analysis revealed that the clayey rocks include smectite (montmorillonite), illite, chlorite, and kaolinite. The mixed-layer minerals are present in some places. The study of rocks in thin sections showed that the sandstones correspond in terms of mineralogy to the feldspar and quartz–feldspar graywackes with lithoclasts dominated by different volcanic rock varieties. Based on genetic properties of deposits and the paragenetic association of the main lithotypes, the studied sequences are divided into eight main facies types that are typical of the wave-influenced and submarine-fluvial depositional environments. At first, the sediments were deposited in the course of water level rise in the basin and marine transgression (Sartaganian beds) in the shallow-water environment characterized by weak water mobility. During the subsequent formation of sand sheets and the development of peripheral sectors of the prodelta deposits, the sediments were deposited due to the terrigenous material input mainly from southwest (Veseljanian beds). Volcanic complexes in the eastern parts of the Adzhar–Trialet and Artvin–Bolnisi tectonic zones could serve as the main provenances of the terrigenous material.

In the studied Ujarma section, the Konkian stratigraphic succession corresponds to replacement of the sedimentation setting reflecting the main stages of marine transgression.

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