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Event Stratigraphy and Correlation of Kazanian Marine Deposits in the Stratotype Area

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Abstract—In the history of the Kazanian sea basin in the Russian plate, periods of quasi-stationary shoreline position alternated with quick phases of transgressions and regressions. The last events were responsible for appearance of facies boundaries in the Kazanian Stage sections. These "transgression–regression" boundaries are most distinct in sections of supratidal zone deposits of diverse facies composition. Boundaries of that kind are isochronous and enable the detailed correlation of marine deposits in remote sections. In this work, the lower Kazanian deposits of the Toima–Izh interfluve (lower courses of the Kama River) are correlated with their stratotype at the Sok River (Samara region). Gray deposits of the interfluve area are attributed to the Baitugan Beds separating two red-bed sequences, namely the underlying deposits of the Ufimian Stage and overlying Kamyshlov Beds. Both units of red beds are of continental origin, whereas the Baitugan Beds include the sea-bar, lagoonal, and deltaic facies tracts.

Key words: Russian plate, Kama River lower courses, Kazanian Stage, supratidal deposits, facies, transgression, regression, cyclostratigraphy, correlation.

The detailed regional stratigraphic scheme of Kazanian Stage for the Russian plate cannot be created without correlation of corresponding individual sections. The huge epicontinental Kazanian sea was of decreased salinity and had limited connections with the ocean located "to the north"[1] Faunas of that sea consisted of euryhaline forms insignificantly changeable with time and characterizing now particular rock facies, diversity of which is a distinctive feature of the Kazanian Stage. Such a situation restricts applicability of the traditional biostratigraphic method. The experience with the Kazanian Stage subdivision in the Middle Volga and Lower Kama regions, where the detailed stratigraphic schemes have been already elaborated, shows that palynological study and investigation of cyclic sedimentary units are more advantageous in this case than other stratigraphic approaches.

The well-known cyclostratigraphic scheme of wide usage in geological practice is that originally suggested by Forsh (1951, 1955) and recurrently revised in subsequent periods (Tikhvinskaya, 1967; Ignat'ev *et al.*, 1970; Ignat'ev, 1977; Solodukho and Tikhvinslaya, 1977). In the last version of the scheme (*Resheniya…*, 1990), Kazanian deposits are divided into eight cyclic units of the first rank (four in each substage), which are authorized as the Bugul'ma, Baitugan, Kamyshlov, Barbashino, Prikazanskaya, Pechishchi, Verkhnii Uslon, and Morkvashino sequences. In view of imperfect procedure used to recognize and correlate cyclic units, the above subdivisions are actually not identical in rank and inappropriate for remote correlations, which can be performed only by continuous tracing of particular beds through a series of closely spaced sections. When correlating end sections of a long profile via intermediate localities, one obtains a considerable cumulative error so that many sections (even the substage stratotypes) can be mistakenly correlated.

The palynological stratigraphic scheme was suggested by Bogov (1971) who distinguished eight complexes of palynomorphs, four in each of two Kazanian substages. Unfortunately, his scheme was published in a generalized form without indication of palynological assemblages from concrete localities. He described them as characteristic of eight units of the cyclostratigraphic scheme that was erroneous in some points, as is mentioned above. As a result, some assemblages had happened to be not of those cyclic units, to which Bogov attributed them, and his scheme is hardly suitable for further detailing. The general palynostratigraphy of the Kazanian Stage has been revised recently by Bludorova and Bogov (1996), who distinguished 19 palynomorph assemblages this time, and also by Shelekhova (1996) who described 14 assemblages.

All above schemes are of local significance, but they provide some grounds for regional correlation and can be useful by creation of regional stratigraphic scheme of the Kazanian Stage. The best way to attain the last objective is to study supratidal deposits of the Kazanian Stage. Precisely these deposits recorded the most com-

[1] The current disposition of four corners of the Earth is used here and further on. As it may be different from that of the Kazanian time, apt geographic indications are placed in inverted commas.

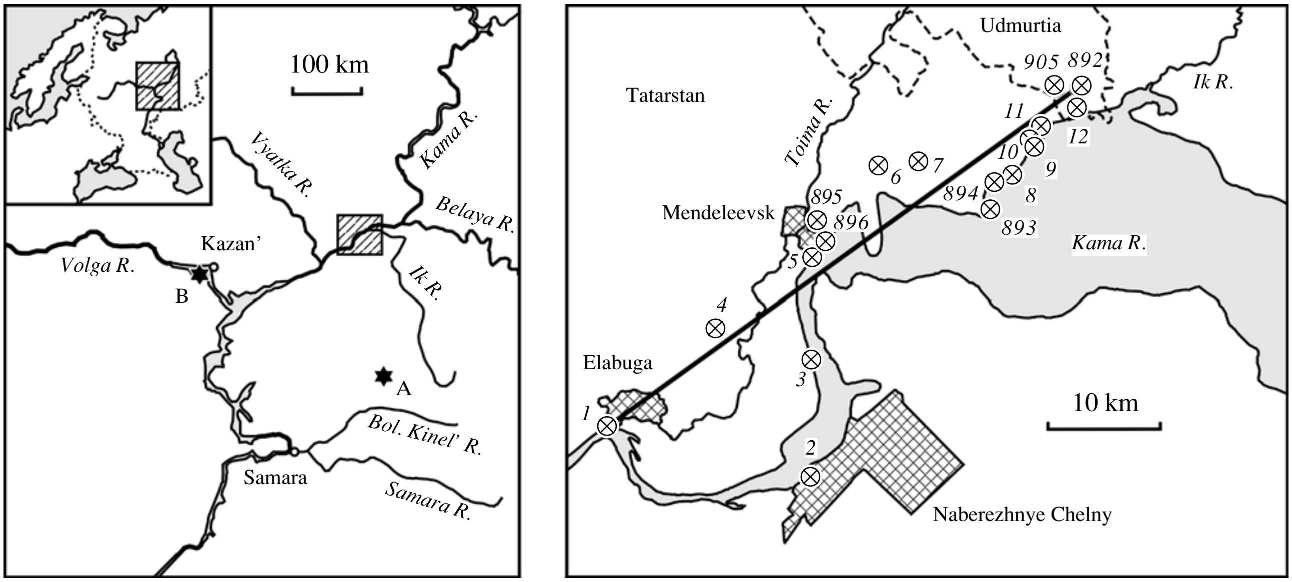

Fig. 1. Location maps showing stratotype areas of lower (A) and upper (B) Kazanian substages, and disposition of sections discussed in this work: (*1*) Elabuga; (*2*) Naberezhnye Chelny; (*3*) Bogatyi Dol Ravine; (*4*) Klyuchevka site; (*5*) Tikhie Gory Wharf; (*6*) Setyakovo village; (*7*) Bezyaki village; (*8*) right bank of the Kama River, 1.3 km upstream off the Chuman River mouth; (*9*, *10*) Izhevka village; (*11*) Rudnyi Log Ravine; (*12*) Borehole 4, Golyusherminka River; (*892*) Golyusherma section; (*893*) Ikskoe Ust'e site; (*894*) Turaevo section; (*895*) Bondyuga section; (*896*) Tikhie Gory site; (*905*) Golyusherminka River site.

plete history of the Kazanian sea. In addition, they are rich in facies favorable for accumulation of microphytofossils.

MATERIALS

Numerous outcrops in the Kama River lower riches characterize the complete succession of the Kazanian coastal-marine deposits and sedimentary strata underlying and overlying them. They are situated between the stratotype areas of the lower and upper Kazanian substages (Fig. 1). The lowermost Kazanian beds of coastal-marine origin are exposed on both sides of the Kama River upstream off the town of Elabuga, between the Toima and Izh river mouths. In 1989, 1990 and 1998, I studied these beds in the following six localities (Fig. 1): Site 892, the Pervye Prudki Ravine near the Blagodat' Village (Golyusherma); Site 893, the right side of the Kama River near the Ikskoe Ust'e Village; Site 894, quarry near the Turaevo Village, right side of the Kama River; Site 896, northern outskirts of Mendeleevsk, right side of the Kama River; Site 895, quarry near the Bondyuga Village situated northeastward of Mendeleevsk; and Site 905, a nameless ravine on the left side of the Golyusherminka River, 1 km westward of the Blagodat' Village. Rocks of the Golyusherma, Turaevo, and Bondyuga sections were sampled for palynological analysis (Fig. 2). These key sections are described below.

Plotting the facies profile, I also used the published description of sections studied in the following localities (Figs. 1, 5): (*1*) Kama River right side near Elabuga (Egorov, 1932; Chernomorski, 1932; Silant'ev *et al.*, 1998); (*2*) Kama River left side near the Naberezhnye Chelny (Zaitsev, 1878); (*3*) Bogatyi Dol Ravine, the right side of that river 9 km downstream off the Tikhie Gory wharf (Egorov, 1932); (*4*) Klyuchevka Ravincavine at the left side of the Korinka River (Egorov, 1932); (*5*) right side of the Kama River 1.5 km downstream off the Tikhie Gory wharf (Egorov, 1932); (*6*) nameless ravine near Setyakovo (Egorov, 1932); (*7*) Bezyak Creek 3 km upstream off the Bezyaki Village (Egorov, 1932); (*8*) right side of the Kama River 1.3 km upstream off the Chuman River mouth (Egorov, 1932); (*9*, *10*) Izhovka Village (Zaitsev, 1878; Noinskii, 1924); (*11*) head area of the Rudnyi Log Ravine 1 km northward off the Izhovka Village (Bludorov, 1938); Borehole 4 near the Golyusherminka River mouth (Bludorov, 1938).

Golyusherma Section (Site 892)

Udmurtia, Alnash district, Blagodat' Village, Pervye Prudki Ravine, the left branch of the Takhtashur (Shakhterskii) Ravine at the right side of the Golyusherminka River, the right tributary of the Izh River (Fig. 1): the site is known as the Golyusherma locality of Permian tetrapods (Efremov and V'yushkov, 1955; Golubev, 1992), but the toponym is now spelled as Golyushurma, and I use here both names in their proper meaning.

Opposite the Blagodat' village, the following bed succession has been distinguished in the thalweg of the Pervye Prudki Ravine about 50 m upstream of its mouth (Figs. 2, 3):

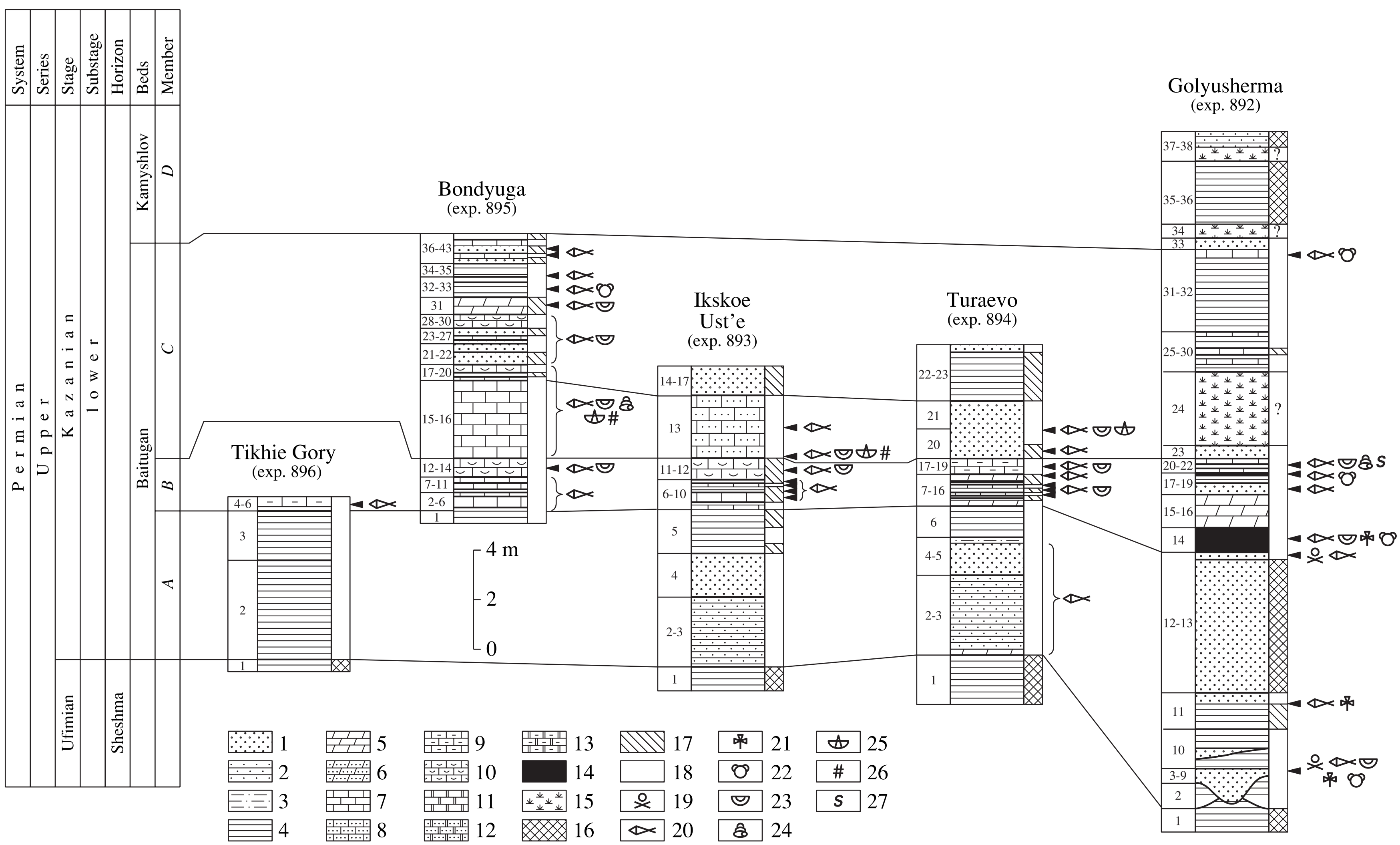

Fig. 2. Correlated sections of Upper Permian deposits in the Toima–Izh interfluve area: (1) sandstone; (2) alternating clay, siltstone, and sandstone beds; (3) siltstone; (4) clay; (5) marl; (6) sandy marl; (7) limestone; (8) sandy limestone; (9) clayey limestone; (10) limestone with abundant invertebrate shells; (11) dolomite; (12) sandy dolomite; (13) clayey dolomite; (14) coal; (15) talus; (16) red beds; (17) yellow to brown beds; (18) gray beds; (19) bones of terrestrial vertebrates; (20) fish remains; (21) macrophytofossils; (22) microphytofossils; (23) bivalves; (24) gastropods; (25) brachiopods; (26) bryozoans; (27) serpulids (figures on right indicate bed nos.).

Ufimian Stage

(1) Vinous clay; rock is massive, bearing abundant nodules of brown marl and detritus of carbonized wood. Apparent thickness is 1.5 m.

Kazanian Stage, Baitugan Beds, Member "A"

(2) Yellow to grayish green clay; rock is horizontally bedded, bearing green marly nodules (up to 5 cm across). Its boundary with Bed 1 is sharp, uneven, having pocket-like concavities. The bed is 1.5 m thick.

(3) Lilac-gray sandstone; rock is fine-grained, massive, corresponding to rhisosphere in the upper part of the bed, where carbonized root remains are concentrated (Fig. 4). The bed yields microphytofossils of the *Vittatina vittifera* f. *minor–V. subsaccata* palynological assemblage (PA II after Shelekhova and Golubev, 1993a, 1993b; PA I after Shelekhova, 1996). This lenticular bed is over 2 m long and up to 0.6 m thick.

(4) Gray clay; rock is massive, rich in carbonized plant detritus. The lentil is more than 4 m long and up to 0.25 m thick.

(5) Brown clay with grayish or yellowish tint; clay is fine-laminated, silty, enclosing remains of fish scale. The lower boundary of the bed is uneven, showing deep (10 cm) pocket-like concavities. The bed yields microphytofossils of the *Cyclogranisporites polypyrenus–Lycospora* palynological assemblage (PA III after Shelekhova and Golubev, 1993a, 1993b; PA II after Shelekhova, 1996). The lentil is over 0.5 m long and up to 0.15 m thick.

(6) Gray sand, medium-grained and cross-bedded, bearing abundant carbonized detritus; the bed is lenticular, over 4 m long and up to 0.2 m thick.

(7) Gray sandstone; rock is medium-grained, massive, enclosing intraformational pebbles and gravel (light gray, highly calcareous clay), and yielding shells of *Palaeomutela* sp. Abundant fish scale is that of *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Kasanichthys golyushermensis* Esin, *Palaeostrugia rhombifera* (Eichwald), *Watsonichthys* sp., *Grygorichthys* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Acrolepis* cf. *sedgwicki* Agassis, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, *Amblypterina* sp., *Paramblypterus* sp., *Boreolepis jenseni* Aldinger, *Plegmolepis* sp., *?Pygopterus* sp., *Platysomus* cf. *striatus* Agassis, *Koinichthys ivachenkoi* Esin, *Eurysomus* sp., *?Kargalichthys* sp., and *Wardichthys inobilis* Esin. Associated fossils are tooth remains of Hybodontoidea sharks (fam. indet.) and bones of tetrapods *Melosaurus compliatus* Golubev, *Microsyodon orlovi* Ivachnenko, Leptorophidae gen. indet., and *Platyoposaurus* sp.[2] The bed also yields microphytofossils of the *Striatohaplopinites perfectus–Limitisporites* palynological assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996). The bed of lenticular shape is over 1.6 m long and up to 0.1 m thick.

(8) Gray sandstone; rock is medium-grained, locally carbonized and bearing bivalve shells, fish scale, and carbonized plant remains. *Cordiacarpus* sp. and some other forms were identified among the latter. The bed is 0.05–0.3 m thick.

(9) Gray fine-grained cross-bedded sand; the bed is 0.05–0.2 m thick.

(10) Dark gray clay; clay is horizontally laminated, enclosing carbonized plant detritus and sandstone lentils or interbeds (up to 0.5 m) in the lower part of the bed. Sandstone with carbonized detritus is gray, fine-grained, showing fine lamination. The bed is 1.6 m thick.

(11) Brown clay grading upward into intercalated lentils of gray marl and sandstone; clay is horizontally laminated, sandy, bearing abundant small-sized detritus of carbonized plant remains. The upper part of the bed yields fish scale and abundant plant fossils: *Compsopteris* sp. (aff. *adzvensis* Zal.), *Cordaites* vel *Rufloria* sp., *Cordiacarpus* sp., *Cordiacarpus* cf. *chalmerjanus* Dombr., *Lepidophyta* indet. (preservation type *Aspidiaria*), *Nucicarpus* sp., "*Odontopteris*" *rossica* Zal., *Paracalamites* aff. *striatus* (Schmalhausen), and *Pecopteris* sp., cf. *Prynadaeopteris* (?) *minuta* Vlad. The lover boundary of the bed is uneven, with pocket-like concavities. The bed is 1.5 m thick.

(12) Rust-brown sandstone; rock is massive to cross-bedded. The bed is 5–6 m thick.

(13) Greenish gray sandstone; rock is fine-grained, with marcasite cement. Intercalated lentils with gray marl gravel yield tetrapods and fish remains. The bed is 0.5 m thick.

Member "B"

(14) Coal seam with intercalations of dark gray clay coaliferous to a variable extent; abundance of clay admixture decreases upward. In addition to bivalves, the bed yielded remains of fishes *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, and plant fossils *Paracalamites* sp. Microphytofossils from the bed represent the *Striatohaplopinites perfectus–Limitisporites* palynological assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996). The seam is 1.0 m thick.

(15) Yellowish gray marl; rock is fine-laminated to foliated. The bed is 0.9–1.0 m thick.

(16) Bluish gray massive and dense bituminous marl; the bed is 0.3 m thick.

(17) Yellowish gray sandstone; rock is fine-grained, yielding scarce scale of fishes *Acentrophorus* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanich-*

[2] Throughout the paper, *Palaeoniscum* species are cited from works by Esin (Esin, 1995; Esin and Mashin, 1996); plant remains are identified by S.V. Naugol'nykh (GIN RAS), and bivalves by V.V. Silant'ev (MSU).

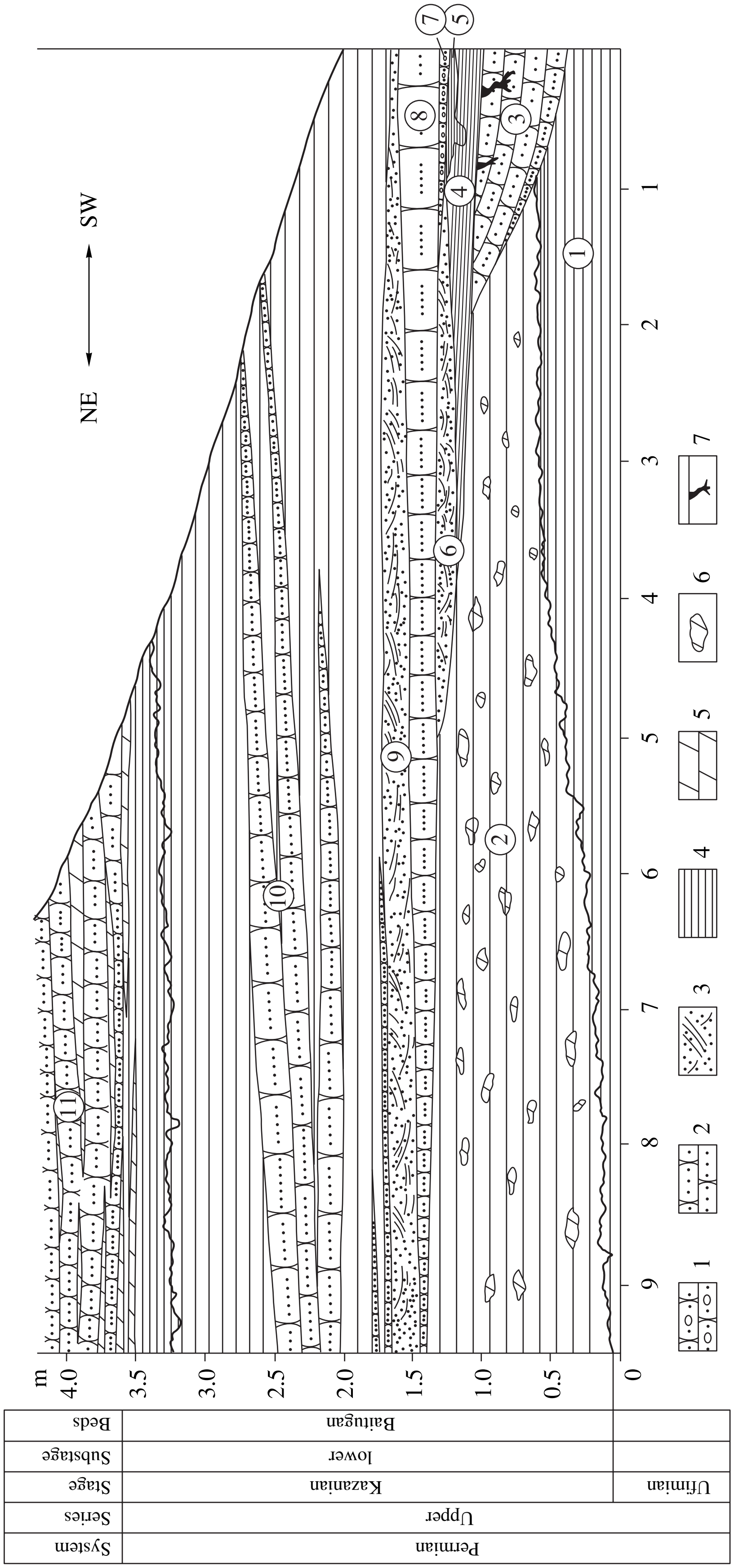

Fig. 3. Lower Baitugan Beds of the Kazanian Stage, Golyusherma section: (1) sandstone with marl gravel; (2) sandstone; (3) cross-bedded sand; (4) clay; (5) marl; (6) marl nodules; (7) carbonized plant roots (bed numbers are encircled).

thys golyushermensis Esin, and *Acropholis kamensis* Esin. The bed is 0.5 m thick.

(18) Dark gray clay; the bed is 0.3 m thick.

(19) Clayey slaty coal yielding plant fossils and fish scale of *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, and *Palaeoniscum kasanense* Geinitz et Vetter; microphytofossils of the *Striatohaplopinites perfectus–Limitisporites* assemblage (PA IV after Shelekhova and Golubev, 1993a, 1993b; PA III after Shelekhova, 1996) are detected as well. The seam is 0.1 m thick.

(20–22) Dark gray massive limestone beds with intercalations of gray clay; rocks yield polychaetes *Spirorbis* cf. *permianus* King, gastropods *Goniasma* sp., *G.* (?) *biarmica* (Kutorga), *Naticopsis* sp., and bivalves *Pseudomonotis garforthensis* King, *Ps. speluncaria* (Schloth.) in association with fish remains *Acentrophorus* sp., *Palaeoniscum kasanense* Geinitz et Vetter, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Platysomus* sp., and *Acrolepis* sp. The beds are 0.6 m thick in total.

Member "C"

(23) Yellowish gray sandstone; rock is fine-grained, cross-laminated and weakly cemented. The apparent thickness of the bed is 0.5 m.

(24) Talus; the unexposed interval is about 3 m.

(25) Brownish gray clay with intercalations of brownish gray massive and hard limestone; the bed is 0.25 m thick.

(26) Mottled, dark gray to light brown limestone; rock is massive, dense and hard. At the base, it is gray-yellow and sandy, resting on fine-laminated fragile marl. The bed is 0.25 m thick.

(27) Gray, slightly bluish, dense and lumpy clay; rock is intercalated with interlayer (4 cm) of yellowish gray flaggy marl. The bed is 0.15 m thick.

(28) Gary-brown massive hard limestone; scarce carbonized detritus is dispersed in rock. The bed is 0.25 m thick.

(29) Clay as in Bed 27; the bed is 0.5 m thick.

(30) Mottled, pinkish gray to cream-gray limestone; rock is very hard, vaguely bedded and very clayey, approaching marl in composition; carbonized plant detritus is scarce. The bed is 0.1–0.15 m thick.

(31) Gray, slightly bluish clay; rock is dense and lumpy, intercalated with marl and yellow clay interlayers. Near the top, there is a coaly interlayer (7 cm), above which the clay is gray-yellow. The bed is 3.0 m thick.

(32) Gray massive limestone with carbonized plant detritus and thin interlayers of gray clay; the bed yields abundant fish scale of *Acentrophorus varians* (Kirkby), *Palaeostrugia rhombifera* (Eichwald), *Acrolepis* cf. *sedgwicki* Agassis, *Acropholis* sp., *Kasanichthys golyushermensis* Esin, *Palaeoniscum kasanense* Geinitz et Vetter, *Platysomus* cf. *striatus* Agassis, and *Watsonichthys* sp. Microphytofossils from the bed are typical of the *Striatohaplopinites perfectus–Schizosporis permianus* palynological assemblage (PA V after Shelekhova and Golubev, 1993a, 1993b; PA IV after Shelekhova, 1996). The bed is 0.35 m thick.

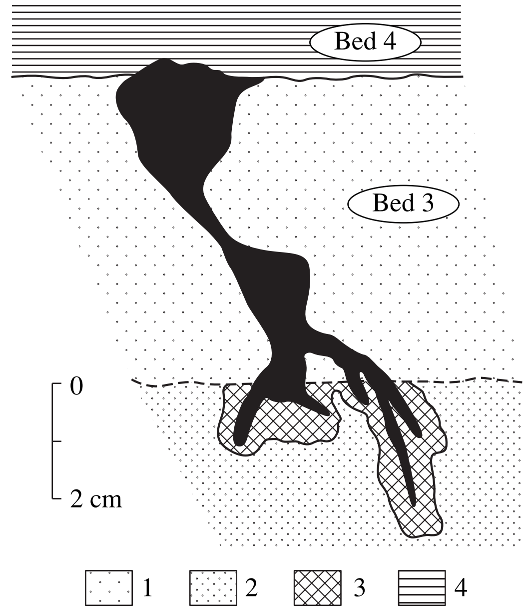

Fig. 4. Carbonized plant root in deltaic deposits of the Golyusherma section, lower part of Member A in the Baitugan beds of the lower Kazanian Substage: (1) dark gray sandstone; (2) gray-lilac sandstone; (3) ferruginate sandstone; (4) gray clay.

Kamyshlov Beds, Member "D"

(33) Yellowish green polymictic sandstone that is poorly lithified; the bed is 0.5 m thick.

(34) Talus; the unexposed interval is 0.5 m.

(35–38) Alternating beds of brown clay and sandstone; the apparent thickness is 3.8 m.

Turaevo Section (Site 894)

Tatarstan, Mendeleevsk district, Turaevo village; the quarry with rock exposures is located 1 km to the south of the village at the right side of the Kama River slightly above the Chuman River mouth (Fig. 1). The section is described from the base upward (Fig. 2).

Ufimian Stage

(1) Brown silty clay; the apparent thickness is 2.0 m.

Kazanian Stage, Baitugan Beds, Member "A"

(2) Gray to yellowish brown silty marl with abundant carbonized or ferruginate plant remains; large though rare fish scales are dispersed in rock. The coaly

interlayer near the top exhibits malachite and azurite incrustations. The bed is 0.25 m thick.

(3–5) Alternating lenticular beds of sandstone, siltstone, clay, and marl; gray to brown-gray fine-grained sandstone varieties are usually massive or horizontally bedded, bearing sporadic flattened pebbles (up to 3 cm long) of yellowish gray marl. Flaggy or foliated sandstone interbeds are less frequent. Sandstone beds yield carbonized or ferruginate plant detritus and small invertebrate shells. Beds of gray silty clay and marl yield scarce fish scales and carbonized plant remains. The total thickness is 4.40–4.65 m.

(6) Yellowish to greenish gray silty clay; the bed with vertical fucoids is 1.25–1,3 m thick.

Member "B"

(7) Dark gray clay; the bed is 0.05–0.07 m thick.

(8) Dark gray massive bituminous limestone; branching ferruginate "channels" pierce the bed in various directions. Carbonized plant remains show oblique or vertical orientation. The bed is 0.2 m thick.

(9) Variegated, gray, yellow, brown or black clay with coaly interlayers in the middle and near the top; rocks are horizontally bedded. The bed is 0.2 m thick.

(10) Gray fine-laminated bituminous limestone; the bed yields carbonized plant remains, bivalve casts, and fish scale. Its thickness is 0.15 m.

(11) Dark brown clay with horizontal bedding; fish scale, bivalve casts, and plant detritus are abundant. The bed is 0.1 m thick.

(12, 13) Clay and marl intercalated with brown-gray bituminous limestone; rocks showing horizontal bedding yield fish scale and carbonized plant remains. The total thickness is 0.25–0.3 m.

(14) Black coaly clay locally grading into coal; the seam is 0.05–0.08 m thick.

(15) Dark brown detrital limestone with carbonized plant detritus; the bed is 0.2 m thick.

(16) Brown clay yielding fish scales; the bed is 0.05 m thick.

(17–19) Brown-gray organogenic-detrital limestone beds with intercalations of gray and brown foliated silty marls; rocks yield bivalve shells, fish scale, and plant detritus; their total thickness is 0.68 m.

Member "C"

(20) Brown to gray sandstone; rock is fine- to medium-grained, clayey, vaguely laminated, enclosing coaly seams. Remains of bivalves, brachiopods, fishes, and plants are abundant. The bed is 1.1–1.3 m thick.

(21) Brown-gray fine-grained sandstone; rock is massive or thick-bedded, bearing plant remains. The bed is 1.0–1.1 m thick.

(22) Dark gray-brown silty clay showing horizontal bedding and yielding plant remains; the bed is 2.0 m thick.

(23) Gray fine-grained flaggy sandstone; vague lamination and broad ripple marks are characteristic of this bed that is 0.3 m thick.

Bondyuga Section (Site 895)

Tatarstan, Mendeleevsk district, Bondyuga Village (northeastern outskirts of the town); section is exposed in southeastern wall of the quarry adjacent to the village on the north (Fig. 1). The following bed succession is distinguished here beginning from the wall base and working up (Fig. 2).

Kazanian Stage, Baitugan Beds, Member "A"

(1) Gray-green bog clay; the apparent thickness is 0.5 m.

Member "B"

(2) Dark gray clay bed that is 0.15 m thick.

(3) Dark gray bituminous limestone; rock is very dense, horizontally laminated, pierced by a network of thin branching "channels." Fish remains *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, *Platysomus* cf. *striatus* Agassis, *Eurysomus* sp., and *Palaeoniscum kasanense* Geinitz et Vetter are identified in the bed that is 0.18 m thick.

(4–11) Gray limestones intercalated with gray clay interbeds and coal seams; rocks are horizontally bedded to foliated, yielding fish remains *Acentrophorus varians* (Kirkby), *Palaeoniscum kasanense* Geinitz et Vetter, *Watsonichthys* sp., *Kasanichthys golyushermensis* Esin, *Amblypterina* sp., *Elonichthys* sp., and *Platysomus striatus* Agassis in association with plant remains. Beds are 1.07 m thick in total.

(12–14) Gray dense limestones enclosing an interlayer of yellow silty clay; rocks yield abundant bivalve shells and fish scale of *Elonichthys contortus* Esin, *Platysomus striatus* Agassis, and *Amblypterina* sp. Beds are 0.75 m thick in total.

Member "C"

(15–16) Light gray massive detrital limestones; rocks are cavernous, showing fucoids and yielding brachiopod, gastropod, bivalve, bryozoan, and fish remains. *Palaeoniscum kasanense* Geinitz et Vetter, *Acentrophorus varians* (Kirkby), *Kasanichthys golyushermensis* Esin, *Watsonichthys* sp., *Elonichthys* sp., *Amblypterina* sp., and *Platysomus striatus* Agassis are identified among the latter. Beds are 3.15 m thick in total.

(17–20) Brown-gray bituminous limestones with brown clay interlayers; rock yield brachiopod, bivalve, bryozoan, fish, and carbonized plant remains. Beds are 0.65 m thick.

(21–27) Brown sandstones; rock is fine-grained, flaggy, weakly lithified, with carbonized plant detritus and fish remains *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, and *Palaeonisum kasanense* Geinitz et Vetter, with gray marl and limestone interbeds; carbonate rocks contain abundant cavities left by dissolved bivalve shells. The total thickness is 1.5 m.

(28–30) Brown-gray limestones; rocks bear fish scale and are cavernous because of dissolution of bivalve shells. Beds are 0.55 m thick.

(31) Brown-black marl with horizontal bedding; rock yields small (2–3 cm) bivalve shells, fish scale, and plant remains, mostly their carbonized detritus. The bed is 0.70–0.75 m thick.

(32, 33) Gray fine-laminated clay with a coal seam in the upper bed; rocks yield fish scale and ferruginate plant remains. Their total thickness is 0.8 m.

(34) Gray marl; rock is fine-laminated to foliate, yielding fish scale of *Palaeoniscum kasanense* Geinitz et Vetter, *P. freiselebeni* Blainville, *Acentrophorus varians* (Kirkby), *Elonichthys contortus* Esin, *Watsonichthys* sp., *Platysomus striatus* Agassis, *Boreolepis jenseni* Aldinger, *Kasanichthys golyushermensis* Esin, *Acropholis kamensis* Esin, *Acr. stensioei* Aldinger, and plant detritus. Microphytofossils of the *Striatohaplopinites perfectus–Schizosporis permianus* palynological assemblage (PA V after Shelekhova and Golubev, 1993a, 1993b; PA IV after Shelekhova, 1996) are also detected in this marl grading laterally into limestone and sandstone. The bed is 0.02–0.04 m thick.

(35) Gray clay with coal seams and plant remains; the bed is 0.5 m thick.

(36–43) Alternating sandstone, clay, and limestone beds: sandstones are yellowish brown, fine-grained, flaggy, and weakly lithified; clays are brown; gray massive limestones are pierced by a system of thin channels. Rocks yield plant remains and fish scale of *Palaeoniscum kasanense* Geinitz et Vetter and *Acentrophorus varians* (Kirkby). Beds are 1.0–1.1 thick in total.

Beds 2–11 are well traceable in exposures at the right side of the Kama River, 1–2 km upstream off the Tikhie Gory Wharf (Mendeleevsk). At the Site 896 they overlie the following rocks: (2–3) gray bog clay that is horizontally laminated, intercalated with gray sandstone interlayers, and yields lingulid shells, plant detritus, and scale of *Palaeostrugia rhombifera* (Eichwald), *Acropholis* sp., and *Koinichthys ivachenkoi* Esin (6 m); (1) brown massive clay, the apparent thickness of which is 10 m.

CORRELATION

Correlating individual sections in the study region, one should take into account various characteristics of their beds and members, such as lithology, thickness, position in the section, and facies affinity. Similarity in each particular characteristic is however neither necessary nor sufficient criterion for correlation. Even if all the characteristics are comparable, it is impossible to guarantee the correct correlation, because we should bear in mind the widespread phenomenon of lateral facies changes. Consequently, several correlation schemes can be suggested for the studied region, and one of them is shown in Fig. 2. I consider this one as most realistic, because it requires a simplest scenario of its origin. It seems also most compatible with the established arrangement of several reference levels corresponding to important, geologically instant turning points in the regional sedimentation. The gist of this levels and their significance for the Kazanian Stage stratigraphy are principal objectives of this study.

FACIES CHARACTERISTICS

Kazanian deposits of the study region represent a complex facies family of a sea coastal zone with terrigenous sedimentation. The family is composed of continental, lagoonal, bar, and marine facies tracts (Fig. 5).

Open-sea facies tract characterizes sediments that have been deposited below the storm wave base (distal flood-beach zone) and above it (transitional flood-beach zone).[3] Deposits of the former zone are represented by light gray massive detrital limestones, which yield abundant bivalve, gastropod, brachiopod, and bryozoan remains (Bed 16 of the Bondyuga section). These rocks absolutely lacking lamination are intensively bioturbated. They evidently accumulated below the fair weather and storm wave base (Elliott, 1990a). The original clastic texture of the rocks obviously reflects the storm wave impact on sediments, but it is almost completely modified in the course of subsequent bioturbation. In beach zones with low wave energy, which are characteristic of lakes and closed seas, the fair weather wave base is about 5 m deep in average, and the storm wave base varies around the depth of 10 m. Largest waves may affect sediments therewith at the depth of 20 m (Brodskaya, 1952; Elliott, 1990a). The described deposits presumable accumulated within the depth range of 15–20 m.

Brownish gray to brown limestones represent deposits of the transitional flood-beach zone. These rocks are sandy to a various extent and often show horizontal lamination. In their members, thin (5 cm or less) and frequent interlayers of sandy limestones displaying horizontal or wavy lamination alternate with thicker beds (up to 50 cm) of massive limestones with vague lamination and variable bioturbation features. The former, more coarse-grained deposits apparently accumulated in stormy periods, and the latter characterize more quiet sedimentation environments (Elliott, 1990a). Abundant bivalve and brachiopod shells usually occur in coquina interlayers ("shelly pavements").

Deposits under consideration correspond to beds 17–20 and 28–30 of the Bondyuga section and to the

[3] In this work, I use terminology suggested by Elliott (1990a).

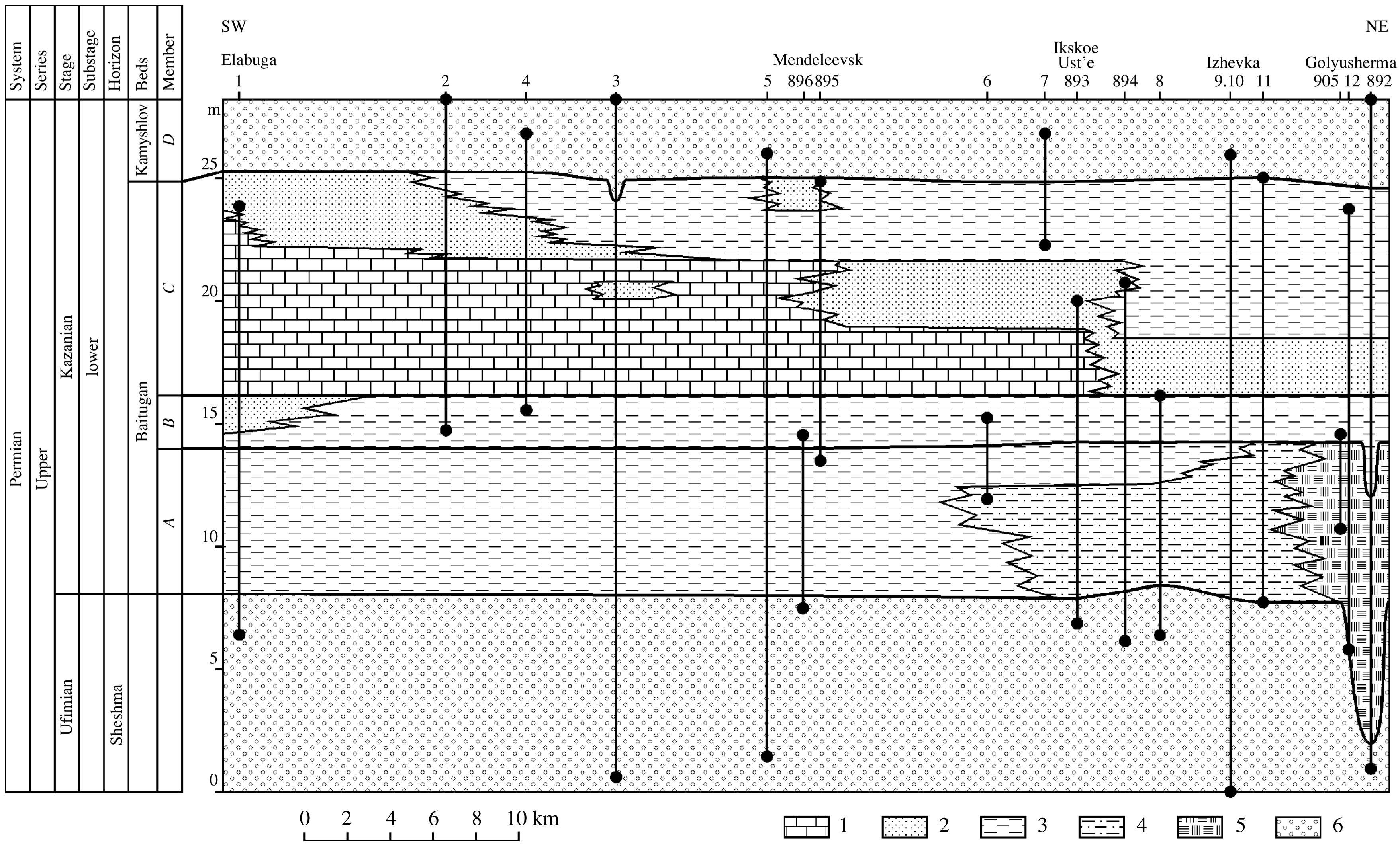

Fig. 5. facies structure of Upper Permian deposits in the Toima–Izh interfluve area (profile is leveled along the base of Member "C"): (1) open-sea facies tract; (2) bar facies tract; (3) lagoonal facies tract; (4) deposits of delta front; (5) deposits of delta plain; (6) continental facies tract.

2.5-m-thick member exposed near the Ikskoe Ust'e village at the right side of the Kama River (Bed 13, Site 893; see Fig. 2). The member and limestone bed 16 of the Bondyuga section characterize the same stratigraphic level. As for the Bondyuga site, it likely characterizes deposits of transitional zone, which accumulated within the depth range of 5–10 m. Near the Ikskoe Ust'e Village, they correspond to deeper facies (10–15 m), because the rocks are more massive here, and indications of their accumulation under wave activity are less frequent (sandy limestone interlayers with horizontal and wavy lamination are rare and thinner). In the last case, sediments were deposited very close to the front of barrier islands (Fig. 5). This bar zone of paleobasin was about 12 km wide and adjacent to the next lagoonal zone of about 55 km wide (Fig. 5). Consequently, limy sediments of Bed 13 accumulated, as I think, about 70 km away from shoreline. Thus, the bottom relief of the early Kazanian basin raised by 10–15 m along the distance of 70 km, i.e., it was very gentle, dipping at the angle of 0.5–0.7'. A relief like this can be observed now in the northern circum-Caspian depression.

Bar facies tract is very characteristic of Kazanian deposits in the study area. The corresponding rocks are yellow and brown fine- to medium-grained sandstones, which are massive or displaying horizontal and cross lamination. A variety of ripple marks is often characteristic of their bedding planes. Coquina interlayers (up to 2–3 cm) composed of bivalve and brachiopod shells are commonly confined to bedding planes separating large sandstone members. Fish scale and carbonized plant remains are also abundant in these rocks. The rocks in question (Golyusherma section, Bed 23; Turaevo section, beds 20, 21, 23; Ikskoe Ust'e site, beds 14–17; Bondyuga section, beds 21–27 and 36–43) accumulated under active hydrodynamic conditions characteristic of rear frontal areas of the flood and lower beach zones (Elliott, 1990a). In the facies profile, they occupy an intermediate position between normal marine and lagoonal deposits that is why I attribute them to the bar but not beach facies. Beach facies adjacent to the land are interconnected with continental facies.

In the Toima–Izh interfluve area, the greater part of the Kazanian Stage is composed of **lagoonal deposits** (Golyusherma section, beds 15–22 and 25–32; Turaevo section, beds 6–19 and 22; Ikskoe Ust'e site, beds 5–12; Bondyuga section, beds 1–14 and 31–35). This facies tract is most diverse in terms of lithology. Clay facies prevail here over marl and limestone facies. Siltstone, fine-grained sandstone, and coal occur in minor intercalations. Predominant gray to dark gray clays are horizontally laminated and intercalated with gray sandstone interlayers. They yield insect remains, fossil bivalves, and lingulid shells, which are locally concentrated in coquina lentils. Yellow or brown, similarly laminated clay varieties are less abundant. These have silty or sandy admixture and yield diverse fish scales. Coal seams are usually confined to these clay facies. Black to dark brown and gray limestones with horizontal or wavy lamination are often foliated, bituminous, having clay admixture. Fossils in these rocks are represented by bivalves (locally abundant), gastropods, ostracodes, conchostracans, brachiopods (rare), calcareous serpulid tubes, fish remains (scales and whole skeletons), and rare bones of terrestrial vertebrates. I noted the inverse relationship between the bituminization degree of rocks and fauna abundance and diversity.

The carbonate–clayey composition of rocks and their fine horizontal lamination suggest calm hydrodynamic environments of sedimentation. Wavy lamination points to periodic influence of wave activity. Consequently, sediments under consideration accumulated in shoal settings. The hydrological regime differed from that of normal marine basin. Judging from character of invertebrate fauna, the water mass was fresh or brackish. Faunal assemblages of low diversity are lacking forms typical of open-sea zones of the Kazanian basin (spiriferids, corals, crinoids, etc.). In contrast, they are rich in euryhaline bivalve, lingulid, ostracode, serpulid, gastropod, and some other taxa. Bivalves prevail over brachiopods and can be highly concentrated in coquina interlayers. In the last case, the host rocks are either light-colored bitumen-free limestones, or light gray clays. A good example of this is the uppermost part of Member "B" known as the *Pseudomonotis garforthensis* Limestone (Bludorov, 1938, 1964) and considered as local reference horizon. This limestone just slightly differs in lithology from limestones of the preceding facies tract, and many researchers used to believe in its marine origin (Noinskii, 1932; Egorov, 1932, Bludorov, 1938, 1964; Forsh, 1951, 1955; Tikhvinskaya, 1955, 1967; Ignat'ev *et al.*, 1970; Esaulova, 1986; Golubev, 1992). Now, I suggest the lagoonal origin of this rock in view of the following data. The limestone bed grades downward into highly bituminous and coaliferous deposits of distinctly lagoonal setting. The latter are weakly bioturbated and depleted in invertebrate fossils, representatives of which are dwarfed; in contrast, whole fish skeletons are quite abundant at this level. These observations suggest the stagnant sedimentation environments characteristic, in particular, of lagoons. In addition, the limestone bed grades into bar sandstone in the west (near Elabuga) and into coaliferous facies (deposits of coastal marshes with lotic waters) in the east. Thus, the *Pseudomonotis garforthensis* Limestone occupies an intermediate position between continental and bar deposits. Its lithological and paleontological similarity with deposits of transitional and flood beach zones is a consequence of sediment accumulation in a past lagoon poorly isolated from open sea. As it is shown below, deposits of Member "B" accumulated under conditions of a minimum sediment influx after the delta elimination "in the east." The deficient sediment influx resulted in wave abrasion of barrier islands located "in the west." As a result, lagoons, which were well isolated, became connected with open sea. Exactly this can be inferred, when one observes the upward lithological changes in Member "B."

The *Pseudomonotis garforthensis* Limestone characterizes the sedimentation period, when lagoons were poorly isolated from the sea.

The basal and topmost portions of Permian succession exposed in the study region are composed of variable **continental facies.** Clays predominant here associate with less abundant medium- to coarse-grained sandstones and subordinate gravelstones and small-pebbled conglomerates. Red color is a characteristic feature of these rocks. Cray-colored deposits infilling the erosional incisions represent an exception, Exactly they are rich in fossils, whereas red beds are almost lacking them. For instance, beds 2–11 of Golyusherma section yielded abundant fish remains, bones of terrestrial vertebrates, shells of fresh-water bivalves, and plant remains.

Most remarkable among continental deposits are deltaic sediments exposed near the Izh River mouth at the right side of the Kama River (Fig. 5). All principal members of deltaic facies family can be recognized here: facies of deltaic lowland, facies of delta front (prodelta), and facies of delta dying out (Elliott, 1990b). The delta plain above water level was dissected by a system of active and inactive streams into dry to semidry land areas and shoals (Elliott, 1990b). Deposits that accumulated in these settings are characteristic of Member "A" of the Kazanian section exposed near the Blagodat' Village. The basal part of the member is composed here of alternating lenticular beds of gray clays, siltstones, and sandstones, the total thickness of which is 4 m (Figs. 2, 3). These are deposits of delta flood plain (clay and siltstone beds with fish remains and leaf impressions) and of small short-lived scoring channels (thin elongated sand and sandstone lentils with horizontal and diagonal lamination, which yield fish remains, tetrapods bones, and fresh-water bivalves). Abundant root casts inside these beds (Fig. 4) suggest periodical exsiccations or episodes of considerably decelerated sedimentation rate.

Upward in the section, there is a comparatively thick sequence of coarse-grained cross-laminated sandstones. These are deposits of the main delta stream.

Farther westward, along the right bank of Kama River between Izhevka and Ikskoe Ust'e villages, there are exposed facies of the delta front (Turaevo section, beds 2–5; Ikskoe Ust'e site, beds 2–4). The basal gray-colored sequence of Member "A" (2.5–3.0 m) consists here of alternating clay, siltstone, and fine-grained sandstone lentils with ripple marks on bedding planes. This sequence grades upward into massive fine-grained sandstones. These deposits accumulated in a lagoonal setting, because they show marks of basinal processes, in particular, of wave activity, thus resembling deposits of fore-frontal flood beach zone. Nevertheless, their local distribution and spatial association with delta plain facies allow me to class them with deposits of delta front. Their succession is of regressive type that is very characteristic of prodelta deposits.

When delta dies out, its plain turns into marshy area favorable for accumulation of coaliferous deposits (Fig. 2). The lowermost coal seam directly above deltaic deposits is highly variable in thickness, suggesting an undulating relief before the accumulation time of coaliferous sediments (Fig. 6). Analyzing the undulation patterns, we can reconstruct disposition of delta-plain lobes at the terminal stage of delta existence. At the point located 1.5 km SSE of the Chernyi Klyuch Village (Fig. 6), the main delta stream bifurcated, and its northern branch flowed toward the Chumali Village. Bifurcation of the latter took place near the Muvazhi Village, 0.7 km southeastward of it, so that one branch extended northwestward across this village, and another one was oriented to the west. The southern branch of the main stream flowed toward the Blagodat' Village parallel to and northerly of the Pervye Prudki Ravine. Then it bifurcated again in front of the Shakhterskii Log Ravine, and its larger offshoot continued to the south, toward the Golyushurma area, leaving aside the termination of the Pervye Prudki Ravine. The lesser sublatitudinal channel was running slightly northward of the Blagodat' Village. Consequently, it was a lobate delta formed predominantly by fluvial activity outside the tideland and under a minor impact of wave actions (Selley, 1989; Elliott, 1990b).

When delta died out, terrigenous sedimentation in lagoonal settings gave place to accumulation of carbonate sediments (Member "B"). Abundance of organic matter and growing isolation were responsible for appearance of stagnant environments in lagoons, where bituminous limy sediments buried the intact fish skeletons. The decreased sediment runoff finally resulted in wave abrasion and subsequent breakup of the barrier island zone, after which lagoons got better connections with open sea.

The described facies tracts regularly replace each other in lateral direction. Detrital and organogenic-detrital limestone facies of open-sea zone grade eastward into loose sandstone facies of bar zone, which, in turn, are replaced by lagoonal facies of clays or marls and foliated bituminous limestones (Fig. 5). Further eastward, the lagoonal facies grade into continental deposits. Similar distribution patterns of different-type facies are characteristic of lower Kazanian deposits in the Volga River middle courses and Kama River lower reaches, as it was noted long ago by Forsh (1951, 1955).

The vertical facies succession is frequently lacking gradual transitions, being irregular in places. Gradation can be observed only between the marine and bar facies of Member "C." In other cases, boundaries separating different lithological varieties of sediments are sharp, and their normal succession is often violated. For instance, the open-sea deposits may directly underlie (Bondyuga section, beds 30, 31) or overlie the lagoonal sediments (the same section, beds 14–16; see also Fig. 5).

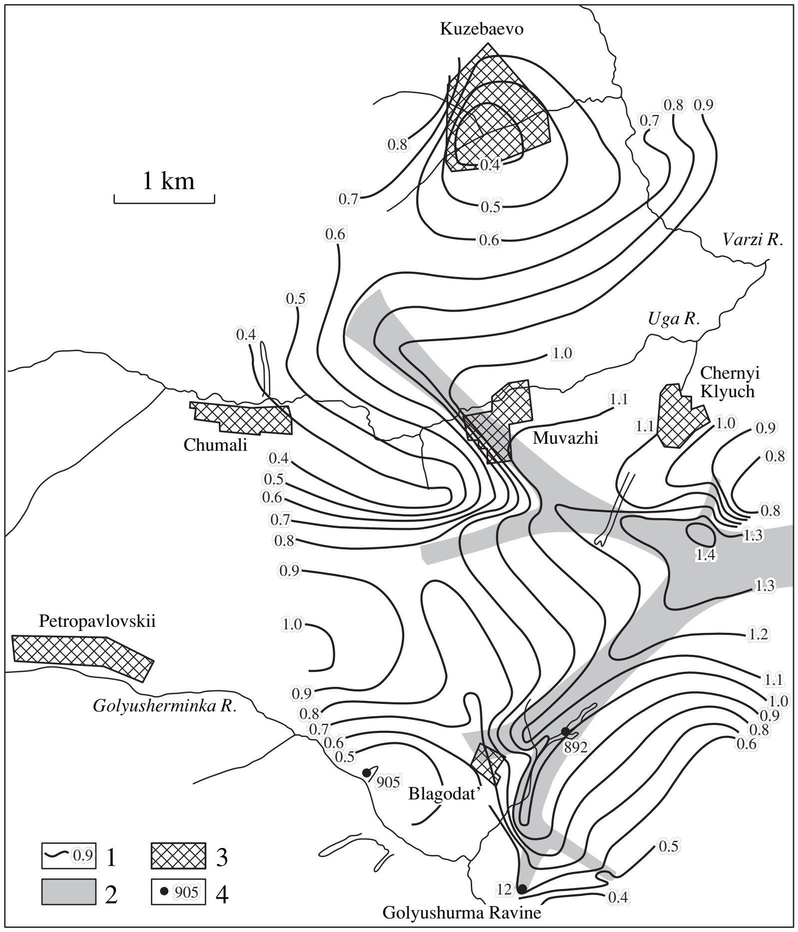

Fig. 6. Reconstructed delta of the early Kazanian time, surroundings of the Blagodat' Village (Alnash district of Udmurtia): (1) isopachs outlining thickness of lower coal seam (after Bludorov, 1938); (2) branches of delta stream; (3) settlements; (4) studied sections.

A MODEL OF KAZANIAN SEA DEVELOPMENT

Sharp and irregular facies changes mentioned above are extremely important indications elucidating the character of Kazanian sea evolution and, as a result, the Kazanian Stage stratigraphy. Both problems are however in need of considering first the known general trends of facies successions in coastal zones of shallow basins with terrigenous sedimentation.

A character of vertical and lateral facies successions in a sea-coastal zone of terrigenous sedimentation depends on many factors. Principal among them are the rate of sediment runoff (sedimentlogical factor), frequency of sea-level oscillations (eustatic factor), and subsidence rate (tectonic factor). The lateral succession of all four facies tracts appears in the section only in the case of a long-term supply of abundant terrigenous material. The vertical facies succession depends on the shoreline migration with time. It would be missing in the case of fixed shoreline position, but situations corresponding to such static shorelines have been hardly ever recognized in geological records (Elliott, 1990a; Selley, 1989).

As a rule, shorelines are mobile to a certain extent, and this mobility results in vertical facies changes. The character of changes is controlled by the rate and direction of shoreline movements, which are highly variable. When transgressive–regressive cycles develop slowly, the vertical transition from one facies to another is gradual (Selley, 1989), displaying alternation of beds characterizing both facies. In contrast, the quick shoreline displacement is responsible for appearance of abrupt stratigraphic boundaries and may disturb the normal facies succession (Johnson and Baldwin, 1990; Selley, 1989). This is a response to paleogeographic changes in sedimentation area, when they are faster than the sedimentation rate. Since this statement is of principal significance, I would like to clarify it by example.

Let us consider a sea-coastal zone of terrigenous sedimentation against the background of compensating subsidence at the rate of 1 mm per 1000 years. Assuming that the bar zone and lagoon are 15 and 40 km wide, respectively, let us take an observation point located 10 km seaward of the former and a following possible scenario. The shoreline had the quasi-stationary position during few tenth of thousands years, when its offshore and backward displacements were insignificant. During the subsequent regressive phase that lasted several hundreds years, the sea retreated by 80 km, and afterward there was another long-term period of quasi-stationary conditions. In this case, the regional paleogeography must be considerably changed during the short-term regressive phase so that continental sedimentation replaced the marine one in our observation area. This important phase was able to put itself on geological record as a negligible mark only, e.g., as a sedimentary layer less than 1 mm thick. As a result, the section at the observation point would mostly consist of sediments deposited during the quasi-stationary (quiet) periods. Its lower and upper portions would be composed of marine and continental facies, respectively. The vertical facies succession is violated in this case, because sediments of lagoon and bar zones are missing from it. Another important consequence is that the boundary between marine and continental deposits must be abrupt, because they accumulated under very contrast conditions.

Quick transgressions and regressions must always lead to appearance of abrupt stratigraphic boundaries between facies or facies tracts. These boundaries can separate beds of so different lithology that one may erroneously interpret them as indicating break in sedimentation. Actually, it would be a mistake, because we deal in this case not with a break in the process, but with a sharp change in its character.

As for the Kazanian deposits in the Toima–Izh interfluve, the sharp stratigraphic boundaries between their facies tracts and all violations of normal facies succession indicate that quick and recurrent shoreline migrations were very characteristic of the Kazanian sea evolution in the study region. The studied sections exhibit six levels corresponding to periods of most significant reorganizations in paleogeography of the region during the Kazanian time (Fig. 5).

(1) Lower boundary of Member “A”; this level is well manifested almost everywhere in the region, being distinct in facies aspect. The boundary separates the terrestrial red beds of the Ufimian Stage from the Kazanian gray lagoonal deposits. The level is nowhere marked by alternation of lagoonal and continental beds. The only exception is the Blagodat’ Village area, where Member “A” consists of continental deposits, the lower boundary of which is locally unclear. A good example is a section exposed in the nameless ravine, the left tributary of the Golyusherminka River 1.5 km upstream off the Takhtashur Creek mouth (Site 905). Lower horizons of Member “A” are composed here of vinous clay that is similar to underlying Ufimian sediments. In other places, where sediments of the member are colored gray (e.g., Site 892), lower boundary of the member is however quite distinct.

The boundary in question corresponds to the Kazanian sea transgression (t_1). In the study region, the shoreline displacement was about 30 km (distance between the Mendeleevsk and Blagodat’ sections) (Fig. 1). Moreover, the true magnitude of displacement could be much greater. The boundary is well traceable along the Kama River, downstream off the study region to the Vyatka River mouth. All along this distance, it outlines the top of continental red beds. Farther downstream, these red beds give place to the Bugul’ma Beds of gray sandstone (Esaulova, 1986) of the sea-beech facies type. Accordingly, the displacement magnitude of shoreline could be as great as 90 km.

(2) Boundary between members “A” and “B” is distinct throughout the study region despite its occurrence inside the single, lagoonal facies tract. It reflects changes in sedimentation environments in the period of decreased sediment runoff, appearance of stagnant sedimentation settings, and coastal marsh development “in the east.” It was a time of minor transgression (t_2), when shoreline advanced few kilometers inland, and coastal marsh replaced the former dry-land area at the Golyusherma site.

(3) Boundary between member “B” and “C” is also distinct in the whole region. In the west, it separates the marine and lagoonal deposits (an abnormal vertical succession of facies), whereas in the east it is distinguished between the bar and lagoonal facies. The bar deposits are recognized in the upper part of Member “B” in the Elabuga area. At the base of Member “C,” their equivalents appear in the Turaevo section and extend to the Blagodat’ Village. Consequently, the distance between Elabuga and Turaevo sites (about 40 km) defines the magnitude of inland migration of shoreline (transgression t_3).

(4) Level that separates beds 16 and 17 in the Bondyuga section, beds 13 and 14 at the Ikskoe Ust’e site, and beds 21 and 22 in the Turaevo section is defined as indicator of the first regression phase (r_1). This boundary separates the bar and lagoonal deposits of the Turaevo section and the marine and bar facies at the Ikskoe Ust’e site. In the Bondyuga section, it runs between beds deposited in the marine transitional and distal flood-beach settings. The regression magnitude was about 15 km (the distance between Bondyuga and Turaevo sites).

(5) Boundary between beds 30 and 31 in the Bondyuga section; this boundary separating the marine and lagoonal facies tracts is not very distinct, because the beds are composed of genetically close sediments deposited near the bar zone. The bar facies appear above this level slightly westward off Mendeleevsk. They can be observed in outcrops of the Kama River near the Elabuga (Egorov, 1932) and Naberezhnye Chelny (Zaitsev, 1878). One more exposure with sediments in question is known near the Klyuchevka Ravine at the right side of the Korinka River (right tributary of the Toima River). Below the boundary, a lateral

transition from bar to lagoonal sediments has been observed along the Ikskoe Ust'e–Turaevo profile (Fig. 5). Consequently, the fifth level marks the regression phase (r_2), by which the shoreline moved c.a. 20 km off its former position.

(6) The upper boundary of Member "C" is as distinct as level 1. Throughout the region, it separates gray coastal marine deposits from overlying red beds of continental origin. Red beds overlying this level have been traced along the Kama River to the Sentyak Village (Forsh, 1966; Esaulova, 1986; Silant'ev *et al.*, 1998), where they show initial signs of gradation into coastal-marine deposits. The exact area, where the uppermost lagoonal facies of Member "C" are completely replaced by continental deposits, is unknown yet, and amplitude of the regression phase (r_3) can be estimated just approximately. At any rate, the distance of shoreline displacement was not less than 70 km (distance between the Sentyak and Golyusherma sites).

Thus, in the history of Kazanian sea basin within the study region, there were comparatively long periods, when its shoreline had stable position or migrated slowly. These periods alternated with short-term transgressive and regressive events responsible for quick changes in the regional paleogeography. The distinguished six stages can be considered as three larger ones. The first of the latter corresponds to the deposition time of members "A" and "B." Its commencement corresponded to the quick transgression (t_1) that transformed the continental sedimentation settings into the coastal-marine ones. Afterward, the shoreline position was stabilized for a long time. The whole period can be considered as transgressive, as it terminated with the next large transgression (t_3) that began simultaneously with the second large regressive stage of the basin evolution. Characteristic of this regressive stage was gradual sea retreat from the study region, which consisted of two, somewhat accelerated regression phases (r_1 and r_2). The more significant regression (r_3) was final in the sea history and restored the continental regime of sedimentation in the region. All stages can be united into a high-rank transgressive–regressive cycle of sedimentation signifying the Kazanian transgression peak. Data characterizing the subsequent development of the basin under consideration have not been considered here, but its whole history can be reconstructed on the basis of the Kazanian Stage sections located downstream along the Kama River.

The shoreline migration can be evoked by changes in the sediment runoff (sedimentological factor), by sea-level oscillations (eustatic factor), and by crustal movements of various signs (tectonic factor). The latter were formerly considered as most probable cause of oscillatory shoreline displacements around the Kazanian sea, and consequently, of the cyclic structure of the Kazanian Stage (Forsh, 1955, 1966; Ignat'ev, 1976). I believe, however, that such frequent and abrupt oscillations of large amplitude (contraction of sea basin by dozens or even hundreds kilometers across and concurrent shoaling by tenth of meters) in response to tectonic factor are hardly credible for the epicontinental basin. In addition, the cyclic structure of the Kazanian Stage is similar in structurally different areas of the East European platform, e.g., in the Moscow syneclise and Volga–Ural anteclise (Forsh, 1955, 1966; Ignat'ev, 1976). The impact of sedimentological factor is improbable as well. Any possible change in intensity of terrigenous material supply from surrounding land cannot be responsible for the momentary shoreline displacements by dozens of kilometers and for the necessary cyclicity of sedimentation (Forsh, 1955; Ignat'ev, 1976) within a vast region extending from upper to middle courses of the Volga River, and farther into the Kama River lower reaches (about 500000 square kilometers). Thus, the established transgressions and regressions of the Kazanian sea and the related cyclic structure of the Kazanian Stage were controlled by eustatic sea-level oscillations of the global scale, because the sea was connected in the north with the oceanic water mass.

STRATIGRAPHIC ASPECTS

In terms of geological time, large transgressions and regressions described above are the momentary events. It is clear as well that stratigraphic levels corresponding to these events can be successfully used in practice of stratigraphic subdivision and correlation. Significance of a given level is proportional to the event extensiveness, i.e., to the dimension of area, where we detect the required records. It is an ideal case when we are able to detect a particular level throughout the study region. In fact, it is variably manifested in different areas of the region depending on the concrete combination of sedimentological, paleogeographic (e.g., the basin floor inclination), and tectonic factors. As a rule, boundaries that originated in response to minor sea-level fluctuations are traceable within separate areas (not necessarily adjoining), whereas markers of more extensive events can be of regional to interregional significance. As is shown above, the first, third, and sixth levels distinguished in Kazanian deposits of the study region correspond to shoreline displacements of comparatively high magnitude and, apparently, to quite significant sea-level changes. Accordingly, we may assume it possible to recognize them in all sections of the lower Kazanian Substage and to use these markers even for correlation of remote sections via the intermediate ones. Such an approach is used below for correlation of studied bed successions with the stratotype of the lower Kazanian Substage, the more so as judgments upon the subject are diverse as yet.

The Kazanian Stage stratotype near the Baitugan Village of the Klyavlino district, Samarskaya Oblast' (Sok River head, Fig. 1) has been recurrently described in a series of publications (Forsh, 1951, 1955, 1966; Ignat'ev *et al.*, 1970; Solodukho and Tikhvinskaya, 1977; *Korrelyatsiya…*, 1981; Esaulova, 1996). It is divided into three transgressive–regressive cyclothems known as the Baitugan, Kamyshlov, and Barbashino beds (Forsh, 1951).[4] The lower part of the Baitugan Beds (elements I and II) is composed of the 30-m-thick sequence of bluish gray clay (Fig. 7) that yields abundant shells of *Lingula orientalis* Gol. in association with less abundant brachiopod shells. The sequence is known under the name Lingulid Clay. The overlying coquina bed (2 m) is composed of brachiopod shells associated with bryozoan, crinoid, solitary coral, and bivalve remains (Element III). The topmost marl member of the Baitugan Beds (Element IV) is 6 m thick, characterized by the same, though impoverished, faunas. The Kamyshlov Beds consist of greenish gray clay (3–5 m), bearing lingulids and small bivalves, and of gray marl and dolomite (22 m) with diverse assemblages of marine invertebrates (as compared to Element III of the Baitugan Beds, diversity of fossils is lower, and bivalve remains are more abundant among them). The Barbashino Beds include the lowermost unit of greenish gray clay with rare lingulid shells (9 m). Above this unit, there was distinguished the yellowish gray sandy dolomite (6 m) and sandstone (4 m), both yielding assemblages of brachiopods and abundant bivalves. The overlying deposits are represented by coastal-marine and continental facies of the upper Kazanian Substage.

In opinion of Forsh (1955), the Baitugan Beds include all gray colored deposits of the Toima–Izh interfluve, the upper boundary of which is at the base of Bed 32 in the Golyusherma section, and at the top of Bed 43 in the Bondyuga section (Fig. 2).

Bludorov (1964) divided the lower Kazanian deposits of the study region into seven units: Member I or the Lingulid Clay; Member II or the middle Spiriferid Limestone; members III, IV, and V; Member VI or the upper Spiriferid Limestone; and Member VII. In his opinion, only three lower units are exposed in the Toima–Izh interfluve. Member I (Lingulid Clay) corresponds here to beds 2–19 of the Golyusherma section, to beds 2–7 of the Turaevo section, to beds 2–5 of the Ikskoe Ust'e site, to beds 1 and 2 of the Bondyuga section, and to beds 2–4 of the Tikhie Gory site. Member II (middle Spiriferid Limestone) includes beds 20–22 of the Golyusherma section, beds 8–19 of the Turaevo section, beds 6–13 of the Ikskoe Ust'e site, beds 3–20 of the Bondyuga section, and beds 5 and 6 of the Tikhie Gory site. Member III spans the ranges of beds 23–32 in the Golyusherma locality, 20–23 in the Turaevo section, 14–17 at the Ikskoe Ust'e site, and 21–43 in the Bondyuga section. The overlying, predominantly terrigenous red beds represent, in opinion of Bludorov, the Belebeevo Formation of the upper Kazanian Substage. Consequently, all lithostratigraphic units distinguished by Bludorov have diachronous boundaries.

All the members have been traced far to the south along the Kama River tributaries up to the Sok River head. Bludorov published the isopach maps for the studied deposits without correlation scheme of individual sections. Considering their possible correlation on the basis of published maps (Bludorov, 1964; Figs. 20–26), one would come to the following stratigraphic relationships characterizing the Sok River head: Member I is represented here by gray clay and the *Lingula* Marl (25 m); Member II corresponds to brachiopod limestone (9 m); Member III consists of clay with marl intercalations (15 m); Member IV is of dolomite composition (about 16 m); Member V is composed of brachiopod limestone (about 8 m); Member VI includes marl strata (about 5 m); and Member VII consists of limestone intercalated with marl and clay interbeds (about 7 m). Thus, it is possible to state, thought with reservations, that Bludorov correlated member I and II with the Baitugan Beds, members III and IV with the Kamyshlov Beds, and members V–VII with the Barbashino Beds.

Tikhvinskaya (1967) considered her Member "A" as a unit of the lower Kazanian horizon corresponding, in her opinion, to the first Kazanian cyclothem, i.e., to the Baitugan Beds in the subdivision scheme suggested by Forsh. The middle lower Kazanian members "B" and "C" would correspond in this case to the Kamyshlov Beds and the upper Member "D" to the Barbashino Beds.

In the area under consideration, Ignat'ev *et al.* (1970) distinguished the lower (Kz_1^1) and middle (Kz_1^2) horizons of the Kazanian Stage, the former corresponding to members I and II discussed above, and the latter comprising Member III and overlying deposits of the Belebeevo Formation. In their work, the lower and upper horizons are correlated with the Baitugan and Kamyshlov beds, respectively. This opinion was shared by later researchers (Kalyazin, 1976; Esaulova, 1986).

The cited works show that their authors variably interpreted the boundary level between the Baitugan and Kamyshlov beds placing it at the top of first, second, or third members of the Bludorov's scheme. This variety of opinions clearly demonstrates disadvantages of traditional stratigraphic approach to correlation of distant section by means of tracing beds via intermediate sections. In my opinion, the problem can be solved now with the help of levels marking quick transgressive and regressive event.

Beginning the correlation procedure, we should analyze first the stratotype section of the lower Kaza-

[4] The Baitugan Beds of the stratotype area overlie a sequence of gray fine-grained bituminous sandstones locally saturated with tar ("Shugur Sandstones"). The latter yield scarce foraminifers, ostracodes, lingulids, brackish-water bivalves, and plant remains. Formerly, the Shugur Sandstones were attributed to the Ufimian Stage (Noinskii, 1932; Raspopov, 1932; Forsh, 1955; Bogov, 1977), but in later schemes (Ignat'ev, 1977; *Reshenie…*, 1990) they turned out to be incorporated first in the Bugul'ma Beds (sequence or horizon), and then into the Baitugan Beds of the Kazanian Stage (Esaulova, 1996). In this work, I accept the Ufimian age of the Bugul'ma Beds without special consideration they need in.

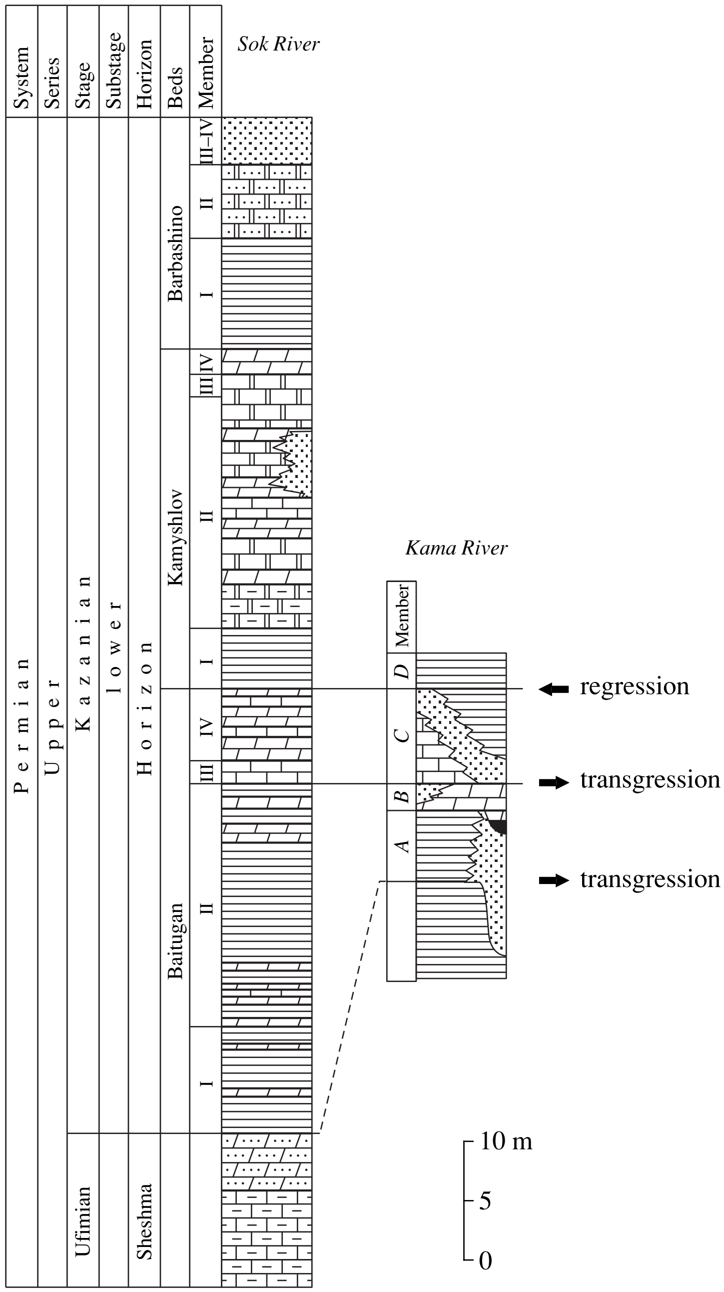

Fig. 7. Correlation scheme for lower Kazanian deposits in the Kama River lower courses and the substage stratotype in the Sok River head, Samarskaya oblast (symbols as in Fig. 2).

nian Substage, where the Baitugan Beds correspond to the peak phase of the Kazanian transgression. Exactly these beds yield abundant and diverse fossils of marine invertebrates showing the least evident affinity with euryhaline taxa (Forsh, 1951, 1955). The lower boundary of the beds is very distinct (Forsh, 1951, 1955; Ignat'ev *et al.*, 1970; Esaulova, 1986), corresponding to an abrupt change in sedimentation characterizing the Bugul'ma and Baitugan periods. The beach sandstone facies that accumulated in the Bugul'ma time yield scarce remains of euryhaline "marine" invertebrates found in occasional localities (Esaulova, 1986). In contrast, deposits of the Baitugan time accumulated in normal marine settings with the diverse invertebrate population. They yield even spiriferids, the most distinct representatives of marine brachiopods, which populated the Kazanian sea and whose occurrence suggests that the sea coast was located far in "the east." Thus, the initial Baitugan period was a time of a considerable (many tenth of kilometers) and quick transgression (T_1). Afterward, the shoreline position was stabilized (elements I and II). Element III corresponds to beds rich in diverse marine fossils found in abundance and observable nowhere else in the region except here. It marks the peak transgressive phase of the Kazanian sea and yields some taxa suggesting the salinity growth in the basin (the normal salinity was never attained however, because the Kazanian deposits are lacking ammonoids, trilobites, and echinoids, while diversity of coexisting conodonts is low). It is likely as well that the corresponding shoreline migration by dozens of kilometers was not as impressive as before. The lower boundary of Element III is abrupt, indicative of a quick advance of transgression (T_2). During the subsequent period of more stable environments, the shoreline slowly migrated seaward, as it is evident from decreasing diversity of brachiopod assemblages upward in the Element IV section. The fossil assemblage of marine invertebrates from basal clays of the Kamyshlov Beds is much less diverse than that from the Lingulid Clay. Accordingly, the terminal Baitugan time marks a quick regression R_1 that was more extensive than the preceding transgression T_2.

Thus, the Baitugan Beds and gray coastal-marine deposits in the Toima–Izh interfluve show the identical formation histories corresponding to the following event succession (Fig. 7): initial large transgression (t_1 and T_1)—transgression stasis—second quick transgression (t_3 and T_2) of lesser magnitude than the first one ($t_3 < t_1$, $T_2 < T_1$)—peak phase of the Kazanian sea transgression—regression stasis— first large regression (r_3 and R_1) exceeding by magnitude the second transgression ($r_3 < t_3$, $R_1 < T_2$). Sections of both regions recorded the same events in the Kazanian sea evolution: $t_1 \sim T_1$, $t_3 \sim T_2$, and $r_3 \sim R_1$. Accordingly, the lower Kazanian deposits studied in the Kama River basin can plausibly be correlated with the substage stratotype in a following manner (Fig. 7): the base of Member “A” corresponds to that of the Baitugan Beds; basal levels of Member “C” and Baitugan Element III appear to be concurrent; the top of Member “C” corresponds to that of the Baitugan Beds.[5] The suggested correlation scheme is compatible with the Forsh’s scheme (1955).

One more point should be noted before conclusion. Available paleontological data do not suggest breaks in sedimentation of the early Kazanian time within the study region, but lithological evidences in favor of such an assumption are quite convincing. Nevertheless, this work shows that distinct lithological boundaries, which can be traced over long distances, may appear within the rock succession even in the case of continuous sedimentation.

CONCLUSION

(1) The Kazanian sea represented a vast shallow basin, where bottom inclination was extraordinary gentle, corresponding to 0.5–0.7' in some places. In the north of the Russian plate, the sea was connected with the open ocean.

(2) Sea level changes in the Kazanian sea have been controlled by eustatic oscillations in the “northern” ocean, and corresponding transgressions and regressions spanned extensive areas (magnitude of the early Baitugan transgression in the Kama River basin was greater than 100 km).

(3) Quick transgressive and regressive phases alternated with longer quasi-stationary periods of shoreline stabilization, when the latter experienced only insignificant (first kilometers) displacements in space.

(4) Deposits of the Kazanian Stage accumulated in quasi-stationary periods, and epochs of quick transgressions and regressions are recorded in their sections as abrupt stratigraphic boundaries. These boundaries are most distinctly manifested in sections of diverse coastal-marine facies, which offer a possibility to reconstruct the history of transgressions and regressions in the Kazanian sea.

(5) In terms of geological time, the recorded transgressive and regressive events were momentary, and boundaries corresponding to them are isochronous, enabling the direct correlation between individual sections.

(6) Three levels separating very contrast lithofacies are recognizable in the Kazanian Stage sections of the Mendeleevsk area in Tatarstan (Kama River lower courses). They correspond to large and quick two transgressions and one regression. The same levels genetically related with the same events are distinguishable in the Kazanian Stage stratotype and thus enable correlation between the Baitugan Beds and gray marine to coastal marine Kazanian deposits in the Kama River lower courses. Red beds overlying the latter are analogues of the Kamyshlov Beds, whereas red deposits below them correspond to the Ufimian Stage.

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