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TYPE AND REFERENCE SECTIONS OF THE MIDDLE AND UPPER PERMIAN OF THE VOLGA AND KAMA RIVER REGIONS

AUGUST 16–20, 2015

A FIELD GUIDEBOOK

of XVIII International Congress
on the Carboniferous and Permian

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Detailed descriptions and new biostratigraphic, paleomagnetic, geochemical, chemostratigraphic, and sedimentological data on the most important type and reference sections of the Ufimian, Kazanian, Urzhumian, and Severodvinian stages are presented. The guidebook is intended for geologists and paleontologists who study Permian stratigraphy, paleontology and mineral resources, and for students and teachers of fieldwork techniques.

The publication was supported by the Russian Foundation for Basic Research and the Open Joint Stock Company 'Tatneft'.

On the cover: the sketch by Roderick I. Murchison 'The Gurmaya Hills, South Urals, approaching from the Steppes' (Murchison et al., 1845).

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PREFACE

Welcome to the Republic of Tatarstan and Kazan Federal University, for the XVIII International Congress on the Carboniferous and Permian and the field excursion ‘The Middle and Upper Permian of the Volga and Kama River Region’. This year, 2015, marks the 200th anniversary of the publication of the Geological Map of Britain by William Smith (1769–1839), heralded as the first nationwide geological map, and called ‘the map that changed the world’. The techniques used by Smith were soon applied in the vicinity of Kazan by the then recently founded Kazan University. Founded in 1804, Kazan Federal University has participated in vast “exploration surveys” of eastern European Russia and the Urals, and contributed to the development of the Earth Sciences since their early days. Coincidentally, 150 years ago, in 1865, Nicolay A. Golovkinsky was invited to be the first chair and professor of geology and paleontology at Kazan University — the host institute of XVIII ICCP. To meet the challenges of the modern world, and thanks to the generous financial support of the Russian Federal Government, KFU Faculty of Geology was transformed five years ago into the Institute of Geology and Petroleum Technologies. The experience of KFU geology over the past 210 years allows us to reflect on past geological exploration surveys and what we’ve learned. This field guide volume contains up to date information on Permian stratigraphy, sedimentology and paleontology in the Republic of Tatarstan. Geological information presented in the volume can trace its roots directly to the work of the early geological explorers. Perhaps, the best example of this comes from the field trip to Pechishchi Section (stratotype of the Upper Kazanian) and Cheremushka Gully (parastratotype of the Urzhumian), August 16, Stops 1 and 2. In this trip, the participants follow part of the 1841 survey route taken by Sir Roderick I. Murchison and Eduard de Verneuil as they explored the Permian succession along the Volga River between Kazan city and Sviyazhsk island-town.

The initial geological exploration survey was the starting point for subsequent works. The last investigation of these sections was undertaken in 2013–2015. These works were sponsored by the Russian Foundation for Basic Research (13-05-00642, 13-05-00592, 14-04-01128, 15-55-10007, 14-04-00115, 15-05-20579).

The trip also visits the Ufimian / Kazanian transitional arenaceous sediments of Southeastern Tatarstan. These geological formations were derived from the Ural Mountains and transported via rivers to the Ufimian / Early Kazanian Embayment and formed alluvial-lacustrine plains, bars, barrier islands, and deltas. These strata contain numerous natural resources to explore such as heavy and viscous oil, building and facing stone, gypsum, and fresh and mineral aquifers. Particularly, we visit the Shugurovo Petroleum Tar Plant, which was transformed in 2015 into the Memorial Park. This is the first Memorial Park for Geological Heritage in Tatarstan.

The publication of the field guidebook was co-sponsored by the Russian Foundation for Basic Research and by a donation from the Open Joint Stock Company ‘Tatneft’.

We would like to thank the authors and contributors for providing material for this guidebook. We would also like to thank the KFU Publication staff for their efficient high quality work.

Danis Nurgaliev

17 July 2015, Kazan, Republic of Tatarstan, Russia

Republic of Tatarstan

Coat of Arms of the
Republic of Tatarstan

Flag of the
Republic of Tatarstan

Coat of Arms of
Kazan

The Republic of Tatarstan is a subject of the Russian Federation. The head and most highly placed official of the Republic of Tatarstan is the President, Rustam Minnikhanov. The Prime Minister of the Republic of Tatarstan, Ildar Halikov, is appointed by the President and confirmed by the parliament of Tatarstan.

The highest representative and legislative organ of state power in the Republic of Tatarstan is the unicameral State Council (parliament). The speaker of the State Council of the Republic of Tatarstan is Farid Mukhametshin.

The Republic of Tatarstan comprises 43 administrative regions. The administrative regions include both geographic regions and cities of federal jurisdiction or with a separate status within the Republic (for example, Kazan and Naberezhnye Chelny).

Kazan is the capital of the Republic of Tatarstan in the Russian Federation and is located on the Volga River, approximately 800 kilometers from Moscow, in the East European Russia.

Kazan, a city with a thousand-year history and once the primary city of the Kazan Khanate, is considered the capital of all Tatars worldwide. The city owes its remarkable image to a uniquely tight weave of Tatar and Russian cultures and eastern and western influences, amazing all visitors. The city's juxtaposition of mosques and Russian Orthodox churches and the peaceful coexistence of Moslems and Christians on Kazan's common ground demonstrate to the world the possibility of interconfessional dialogue and mutual enrichment of the nations.

Kazan's natural surroundings – forests, rivers and lakes rich with fish, and first of all the Volga – are its pride and jewels.

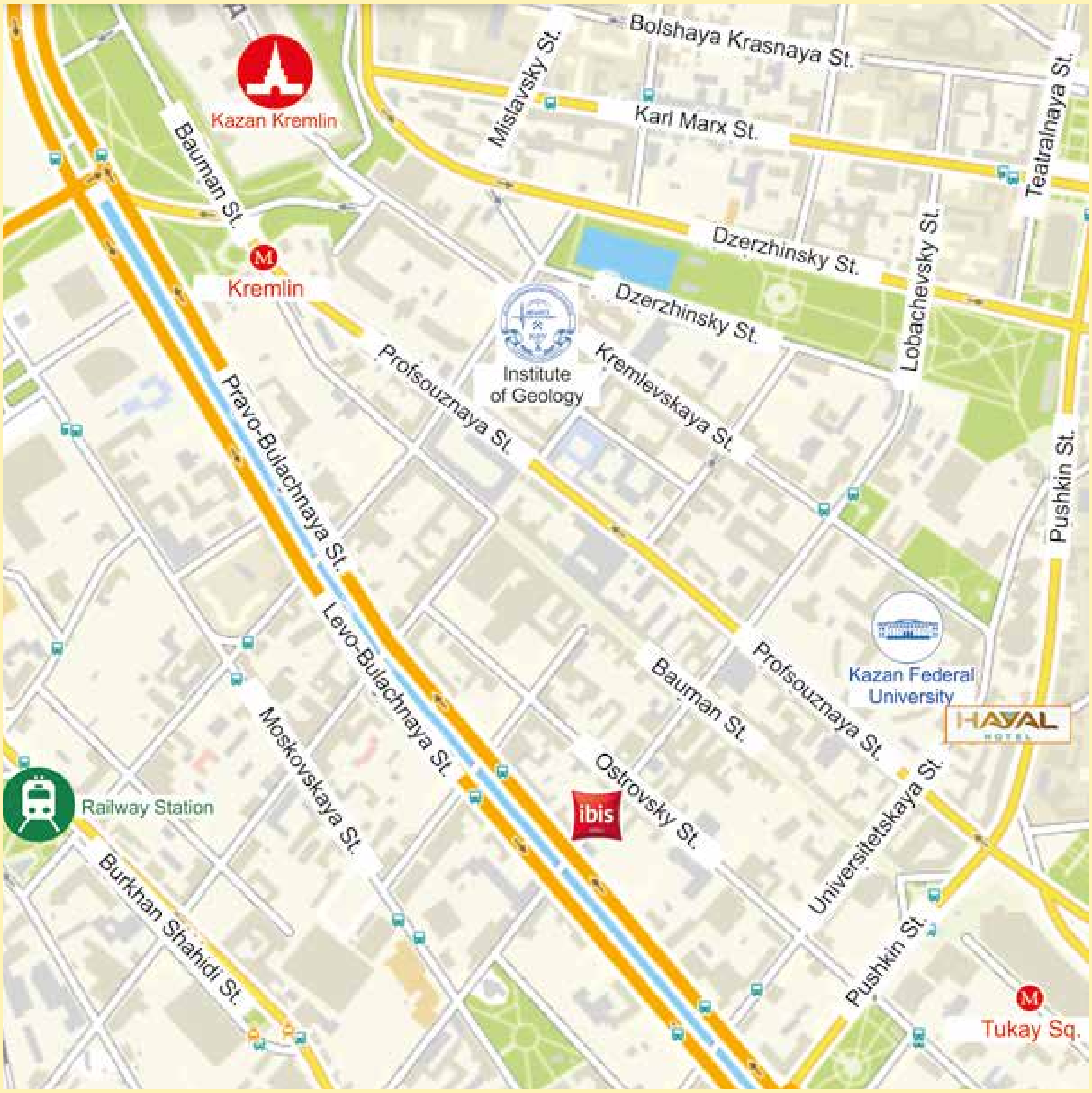
The name of the city ("kazan" means kettle in Turkic languages) fits the hot and bubbling rhythm of life in this remarkably beautiful city.

Historically, Kazan was a crossroads along many trade routes, including the Great Volga Route and Northern Fur Route. To this day, Kazan is a major railway, road and aviation center, the largest port on the Volga, and one of Russia's most dynamically developing business centers.

City area – 425.3 sq. kilometers.

Kazan's central districts are in a hilly area on the left bank of the Kazanka River; altogether, the city is divided into seven administrative districts. The new regions of Kazan are located, for the most part, on the right bank of the Kazanka River.

The city center is based around Kazan's whitestone Kremlin, from which the pedestrian Bauman Street, and the Kremlyovskaya, Bolshaya Krasnaya and Karl Marx streets all radiate. On the basis of its historical and cultural value and the preservation of its heritage, The Kazan Kremlin complex was listed as a World Heritage Site by UNESCO in 2000.



Map of the Kazan City Centre

Kazan Federal University

Kazan University has always attracted talented, active young people seeking deep knowledge, which is why a KFU diploma is so valued. Today our university has become federal. There are even more opportunities for a modern education, to prepare students for success in their profession. Some of the most popular and interesting specialties are available at the Institute of Geology and Petroleum Technologies. The Institute and its graduates have really good prospects. We invite students willing to become true professionals in their field!

Rector
Ilshat R. Gafurov

Main building of the Kazan Federal University

Institute of Geology and Petroleum Technologies

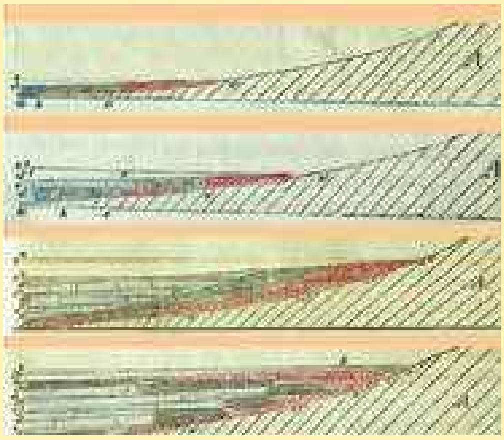
The Institute of Geology and Petroleum Technologies was established in 2011, based on the Geological Faculty of KFU. The Institute is the successor of the geological department.

The mission of the Institute is to provide high quality training in accordance with Russian legislation and international standards.

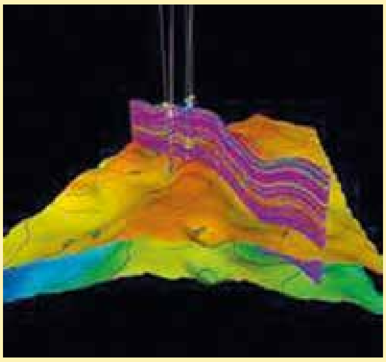
Institute of Geology and Petroleum Technologies is the leader of higher education in Russia in the fields of geological, geophysical, oil and gas technologies, engineering geology, hydrogeology and unconventional resources.

Main building of the Institute of Geology and Petroleum Technologies

Professor Nicolay Golovkinsky
(1834–1897)



Golovkinsky' principle of facies migration



Modern geological model

Kazan School of Geology is a combination of Innovative Technologies and the 200-year Traditions of a Classical University.

The internationally recognized Kazan school of geologists originated in the XIX century from the Faculty of Geology. The founder of the School was Professor Golovkinsky (1834–1897) who introduced the principle of facies migration in space and time (the basis of sequence stratigraphy).

Geological Museum

The Stuckenberg Geological Museum of Kazan University, is one of the oldest and most comprehensive natural history museums in Russia. The modern collection of the museum (400.000 units) includes sections on mineralogy, crystallography, paleontology, historical geology, fauna of the Ice Age, petroleum geology, geodynamic processes and human evolution. Its monographic collections are the basis of interdisciplinary research and training master's and PhD theses in all areas of geology.

Exhibition hall "Mammoth"

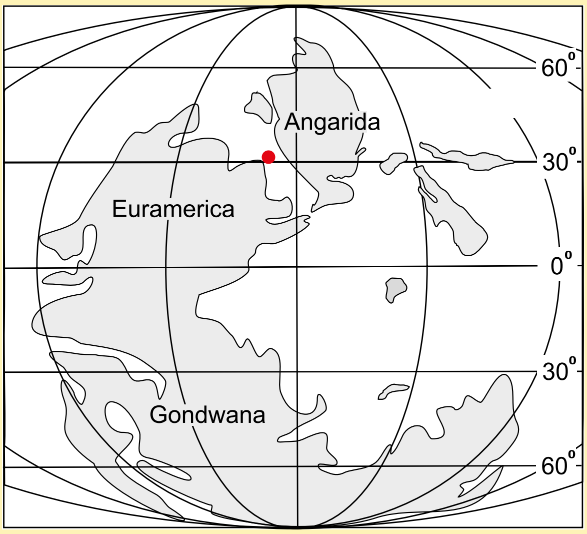
THE GEOLOGICAL SETTING AND PERMIAN STRATIGRAPHY OF THE VOLGA AND KAMA RIVER REGIONS

Geographic settings

The excursion area is a part of the Russian Plain. It includes the middle reaches of the Volga River that are confluent in this area with the Kama River (its left tributary), and the large tributaries of the Kama River, the Vyatka, Sheshma, and Zai rivers. The absolute altitudes range from 53 m (the Volga and Kama rivers) to 364 m. The maximum altitudes are located in the south-east of the area, where the Bugulminsko-Belebeevskaya Upland is situated. The route also includes the city of Kazan, the towns of Tetyushi, Elabuga, Naberezhnye Chelny, Almetyevsk – 'capital' of the Tatarstan oil-industry, Leninogorsk, and several large villages: Verkhnyi Uslon, Kamskoe Ustye, Mamadysh, Shugurovo, etc. The climate is continental. In August–September, the temperature is usually 20–25 C˚.

Geology and tectonics

The area of the excursion is a part of the East European (Russian) Platform. The crystalline basement of the platform is composed of Archean and Proterozoic rocks and located at a depth of 1500 to 2000 m and more. The sedimentary sheath is composed of Devonian, Carboniferous, Permian, Jurassic, Cretaceous, Neogene and Quaternary rocks. These deposits cover a large part of the East European Platform (about 2,000,000 km^2), spreading from the Barents Sea in the North to the Caspian Sea in the South, and vary in thickness from 1,500 m in the central part of the Volga-Ural Anteclise up to 20,000 m in the central part of the North Caspian Basin. In Tatarstan, the following rocks are exposed: Lower Permian (2–3 small outcrops), Middle and Upper Permian, Jurassic and Cretaceous (only in south-eastern Tatarstan) and Upper Pliocene (along the valleys of the Volga and Kama rivers and on the left bank of the Kama River). The horizontal bedding of the sedimentary rocks is disturbed by arches, domes, uplifts, troughs, and depressions. In Tatarstan, the major tectonic structures include the Tatarian Arch and Melekesskaya Depression, laid down with a deep series of Paleozoic and Neogene-Quaternary rocks. The uplifts contain oil deposits occurring in the Devonian and Carboniferous rocks. The basement and sedimentary sheaths are broken up by numerous faults of differing orientation, including shifts.

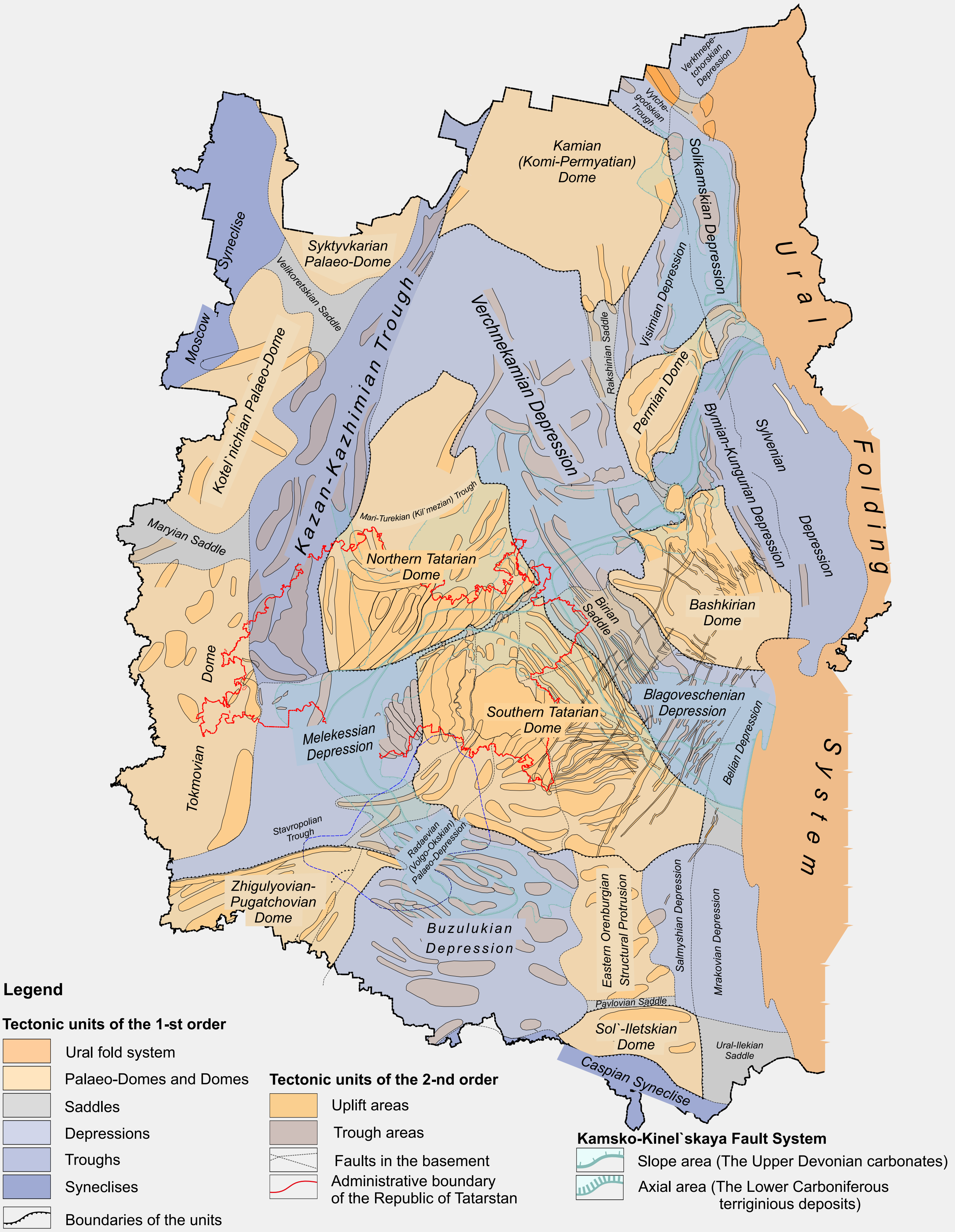


Paleogeography and position of the studied area. Paleogeography reconstruction of the Middle Permian modified after Ziegler et al. (1997)

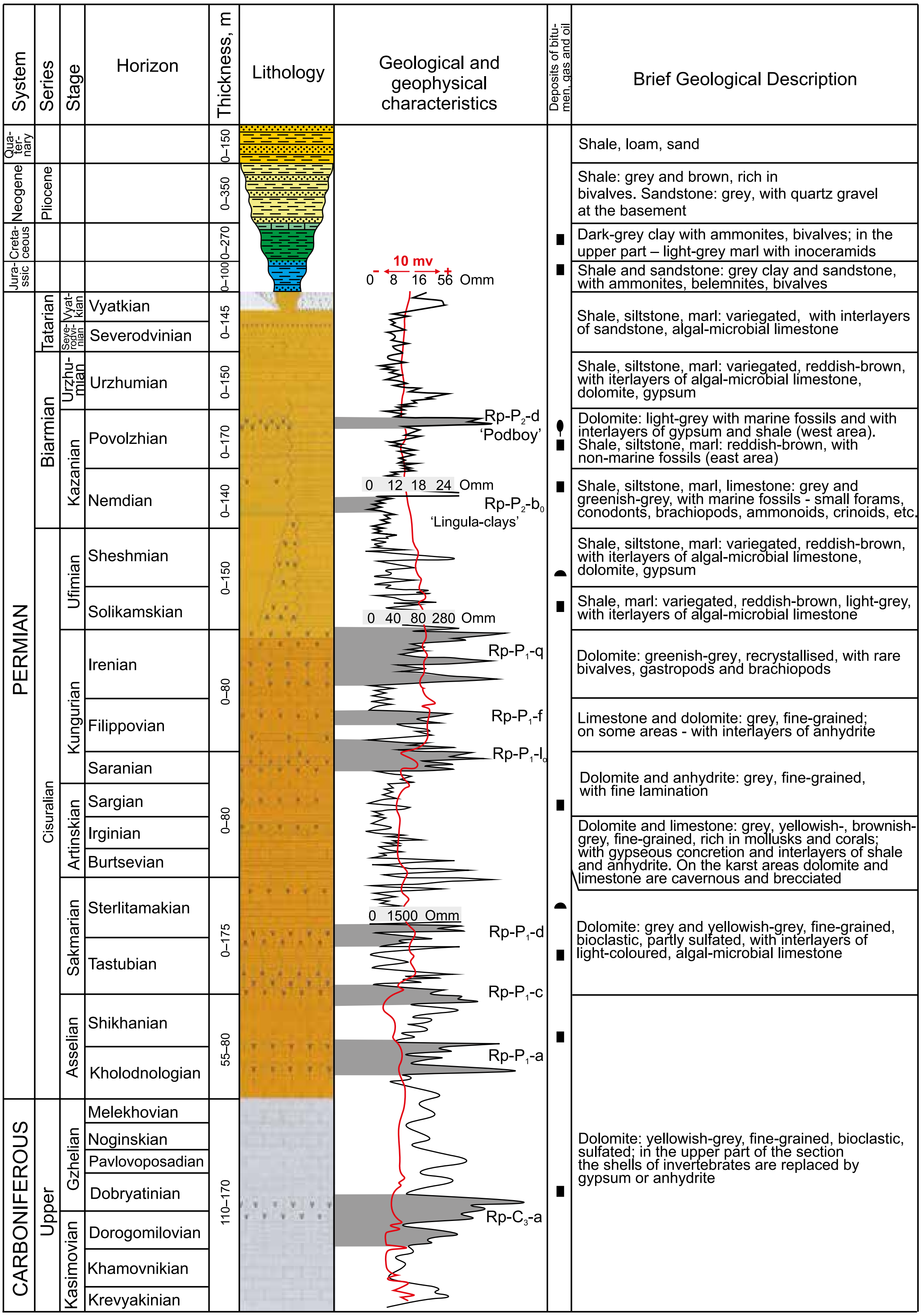
Middle and Upper Permian Stratigraphy

Historical overview

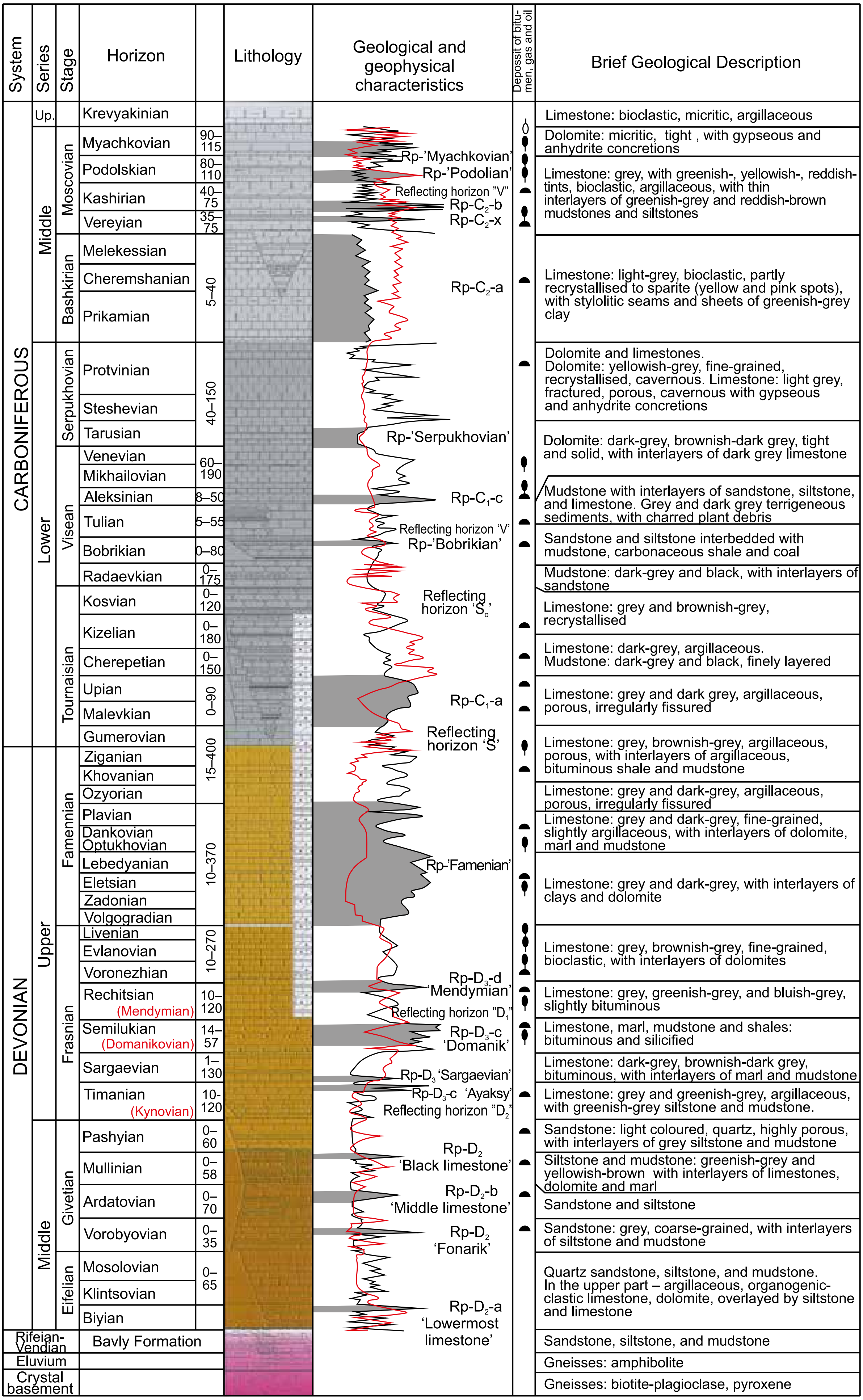
In Tatarstan and adjacent areas, the Middle and Upper Permian rocks have been studied over a period of 175 years by many geologists and paleontologists. The outstanding Scottish geologist and scientist Roderick I. Murchison (1845) as well as the founders of the Kazan Geological School, Professors Nicolay A. Golovkinsky (1868), Alexander A. Stuckenberg (1890), Petr I. Krotow (1894, 1900), Aleksey V. Netschaev (1894), Mikhail E. Noinsky (1899, 1924) were among the pioneers of the investigations. Significant contributions to the litho-, bio-, and magnetostratigraphy, to the facies analysis, paleogeographic and depositional environment reconstructions of the Permian were made by numerous famous researchers: D.I. Sokolov, E. Verneuil, E. Eichwald, S.N. Nikitin, V.P. Amalitzky, V.A. Tcherdyntsev, N.G. Kassin, E.I. Tikhvinskaya, L.M. Miropolsky, B.V. Selivanovsky, A.P. Bludorov, N.N. Forsch, M.G. Solodukho, V.I. Ignatiev, Yu.V. Sementovsky, A.K. Gusev, I.N. Tikhvinsky, V.P. Boronin, V.M. Vinokurov, B.V. Burov, N.K. Esaulova, V.M. Igonin, V.G. Khalimbadja and many others.



Tectonic Scheme of the Paleozoic Structural Stage of the Volga-Ural Anteclise (modified after Shargorodsky, Liberman, Kazakov et al., 2005)



Generalized Geological and Geophisical Section of the Tatarstan area for the Upper Carboniferous – Quaternary deposits (modified after Khisamov, Gatiyatullin, Tarasov et al., 2010)



Generalized Geological and Geophisical Section of the Tatarstan area for the Proterozoic – Upper Carboniferous deposits (modified after Khisamov, Gatiyatullin, Tarasov et al., 2010)

Permian International Stratigraphic Chart vs Permian stratigraphic scale of Russia

The International Stratigraphic (Chronostratigraphic) Scale (ISC) follows the concept of stratotype sections and their global stage boundaries (GSSP—Global Stratotype Section and Point Boundary), marked by the first occurrence of zonal index species in continuous phylogenetic lines with additional palaeomagnetic, geochronological and isotopic markers. In this scale, the Permian system is divided into three series: Cisuralian, Guadalupian and Lopingian. The Cisuralian consists of the ‘Russian’ stages: Asselian, Sakmarian, Artinskian and Kungurian. The Guadalupian is subdivided by North American stages, and the Lopingian, by the stages in South China. Their boundaries are defined by the First Appearance Datum (FAD) of index conodont species in a single phyletic line (Henderson et al., 2012; Shen et al., 2013).

The general stratigraphic scale of the Permian system of Russia has been significantly revised and modified in recent years. It is based on a modified regional scale of the East European Platform, which also includes three series but remains still substantially different from the ISC (Stratigraphic Code of Russia, 2006). The differences include the stratigraphic range of the Middle and Late Series, the grouping of stages within these series, and their naming.

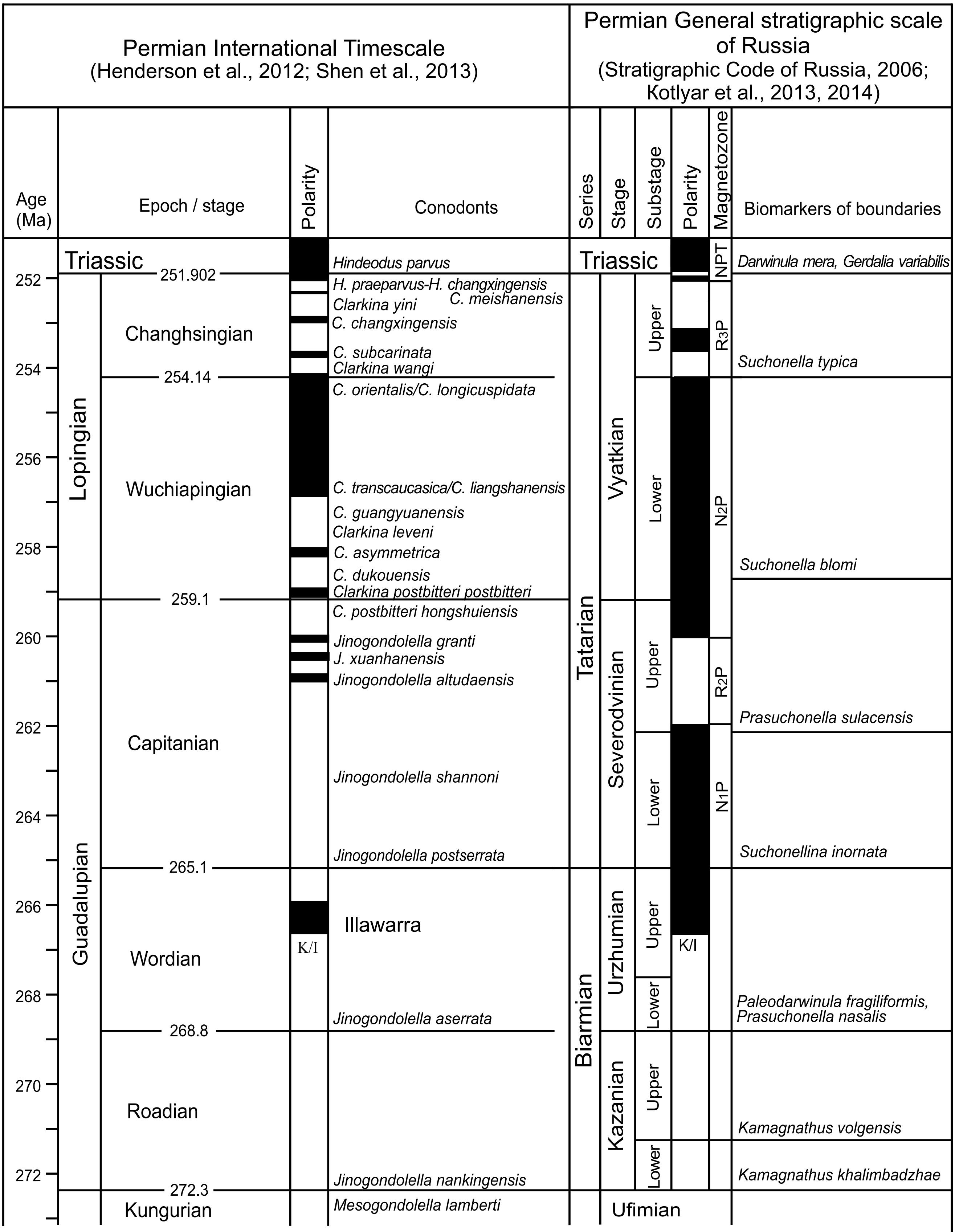
The Middle Permian of the regional scale of the East European Platform is defined as Biarmian Series divided into the Kazanian and Urzhumian stages. The Late Permian is represented by the Tatarian Series, which consists of the Severodvinian and Vyatkian stages. The lower boundaries of the stages, formed by continental red beds (Urzhumian, Severodvinian, Vyatkian), are marked by the first occurrence of non-marine ostracod species in continuous phylogenetic lineages (Kotlyar et al., 2013). The boundary between the Middle and Late Permian Series in the regional scale of the East European Platform does not coincide with the boundary between the Middle and Late Permian Series in the ISC. In the regional scale of the East European Platform, this boundary is defined as one stage below at the base of the Severodvinian. The lower boundary of the Kazanian Stage and Biarmian Series is defined by the first occurrence of the age-diagnostic conodont Kamagnathus khalimbadzhae. This FAD (First Apperance Data) was already detected in many localities of the East European Platform (Chernykh et al., 2001). A Roadian assemblage of ammonoids containing Sverdrupites harkeri, Sverdrupites amundseni, Biarmiceras esaulovae, Biarmiceras kremeshkense, Biarmiceras barskovi, Medlicottia sp. and Daubichites sp. appears in the section slightly above the lower boundary of the Kazanian, representing an additional biostratigraphic marker (Leonova, 2007).

The base of the Urzhumian Stage is best represented in the Krasny Ovrag (‘Red Ravine’) section (Orenburg Region), which is proposed as the regional GSSP marked by the FAD of the non-marine ostracods *Paleodarwinula fragiliformis* and *Prasuchonella nasalis* (Molostovskaya, 2009).

The base of the Severodvinian Stage is best represented in the Monastery Ravine section (Kazan Region), which is proposed as the regional GSSP marked by the FAD of the non-marine ostracod *Suchonellina inornata* (Minikh et al., 2009).

The evolutionary lineage of non-marine ostracods *Prasuchonella nasalis – Suchonella typica* has been chosen for the definition of stage boundaries within the Severodvinian and Vyatkian continental succession. The base of the Vyatkian Stage is best represented in the Mutovino Section on the Sukhona River (Vologda Region), which is proposed as the regional GSSP marked by the FAD of *Suchonella blomi* (Molostovskii, Minikh, 2001).

During recent years, many sections, containing the interval of the Permian-Triassic Boundary (PTB), have been extensively studied (Sennikov, Golubev, 2011, 2012; Golubev et al., 2012; Lozovsky et al., 2014). The continuity of the PTB (Permian-Triassic Boundary) sequence has been established due to this research. There is no regional gap in the PTB of the East European Platform as traditionally believed.



Stratigraphy of the Permian marine-continental and continental formations of the East European Platform in relation to the International Permian timescale

Regional Permian stratigraphic scale

During the field excursion, we will predominantly see the uppermost Lower Permian (Ufimian), Middle and Upper Permian deposits, which are subdivided into five regional stages: Ufimian, Kazanian, Urzhumian, Severodvinian and Vyatkian, which are further subdivided into smaller litho- and biostratigraphic units.

***Ufimian regional stage*.** The Ufimian presents the uppermost part of the Kungurian and is subdivided into two biostratigraphic horizons: Solikamsk and Sheshma.

Solikamskian Horizon. The stratotype section of the horizon is located outside Tatarstan, in the Solikamsk Depression of the Fore-Urals Trough, near the town of Solikamsk, Perm Krai of Russia. There, the Solikamskian Horizon is mapped as the Solikamsk Formation and is composed of two subformations: Lower and Upper.

The Lower Solikamsk Subformation. This subformation does not outcrop and is studied in boreholes in the course of mapping and prospecting the Verkhnekamsk potash salt deposits (Ivanov and Voronova, 1975; Kopnin, 1991, etc.). The subformation conformably overlies the saliferous Kungurian rocks of the Upper Permian. The lower boundary of the subformation coincides with the lower boundary of the Ufimian. It is marked by the appearance of the non-marine bivalves *Palaeomutela* Amalitzky, 1892 that are absent in the Lower Permian in this area.

The subformation is mainly composed of dark-grey shales and marls containing rare non-marine bivalves, and one to two thin interbeds with rare marine invertebrates (forams, bivalves, brachiopods, etc) (Silantiev, 1996a, 1998a). The thickness of the Lower Subformation is 170–200 m, and it is confined to the Solikamsk Depression.

The Upper Subformation. The Upper Solikamsk Subformation (50–230 m) uniformly overlies the Lower Subformation. The type section of the subformation is located on the right bank of the Kama River, 25 km to the north of the town of Solikamsk, near the village of Tyulkino. The section was studied by Varyikhina, Molin, Kanev and Koloda (Dedeev et al., 1981) and others. According to Silantiev (1996a, 1998a), in the section near the village of Tylkino, the Upper Subformation is composed of alternating shales, marls, and limestones with abundant non-marine fauna of ostracods and bivalves (*Palaeomutela, Sinomya, Redikorella,* and '*Concinella'*) (Silantiev, 2014), and also with the remains of insects, fishes, miospores and plants (Esaulova, 1998d; Esin, Mashin, 1998; Utting et al., 1997).

The Upper Subformation (= Solikamskie Plitnyaki or 'Solikamsk Platy Rocks') uninterrupted continues further westward and is also traced in the Tatarstan area. The western border of the area covered by the subformation (recognised as the Solikamsk Horizon) approximately follows the valleys of the Vyatka and Sheshma Rivers. In Tatarstan, the Solikamskian Horizon does not outcrop and was studied in boreholes. It is mainly composed of grey marl and dolomite, with a total thickness of up to 10–15 m. The fauna occurs very rarely and is represented only by the non-marine bivalves *Palaeomutela, Redikorella*, and '*Concinella'*.

Sheshmian Horizon. The type area of this horizon is the left bank of the Kama River, including the basin of the lower reaches of the Belaya River (with type sections on its right bank in Bashkortostan) (Silantiev, 1996b, 1998b) and the basins of the Syun, Ik, Menzelya, Zai, and Sheshma rivers. The beds of the Sheshmian Horizon in Tatarstan outcrop in the lower part of the banks of the Kama River (upstream of the mouth of the Vyatka River), and in Sheshma, Menzelya and Ik rivers. The full thickness of the horizon (170 m) is revealed by numerous boreholes. The horizon has been studied best in the basin of the Sheshma River (Bogov, 1973, 1977; Esaulova, 1996b, 1998a), from which it received its name. The horizon is composed of red-bed sandstone, siltstone, and shales, including rare interbeds of marl, algal-microbial limestone, dolomite, and gypsum. The sandstones often form thick lenses intercalated in the host rocks. Such sandstones are usually recognised as alluvial formations. Throughout the succession, various paleosols are widespread. They are identified by spots of gleisation, by numerous calcareous nodules, and by the slickensides.

General Strat. Scale of Russia: Series	Stage	Substage	Regional Strat. Scale: Magnetozone	Regional biostratigraphic horizon	Central Volga and Lower Kama region: lithostratigraphic units	Vyatka region: lithostratigraphic units (Fm)	Vyatka region: lithostratigraphic units (Mb)	Ostracod zones	Fish zones	Tetrapod zones	Bivalve zones based on Palaeomutela: *Palaeomutela umbonata* group	Bivalve zones based on Palaeomutela: *Palaeomutela castor* group
L.Triassic	Induan		R1T; NPT	Vokhmian		Vokhma Fm	Krasnye Baki Mb; Ryabi Mb; Astashikha Mb	Darwinula mera – Gerdalia variabilis	Blomolepis vetlugensis	Tupilakosaurus wetlugensis		
Tatarian	Vyatkian	Upper	R3P	Zhukovian	Fifth Fm	Vyatka Fm	Nefyodovo Mb	Suchonellina perelubica – Suchonella rykovi – Suchonella posttypica	Gnathorhiza otschevi – Mutovinia sennikovi	Scutosaurus: Archosaurus rossicus	P. golubevi	P. amalitzkyi
Tatarian	Vyatkian	Upper	R3P	Nefyodovian	Fifth Fm	Vyatka Fm	Nefyodovo Mb	Wjatkellina fragiloides – Suchonella typica	Toyemia blumentalis – Isadia aristoviensis	Scutosaurus: Scutosaurus karpinskii: Chroniosuchus paradoxus	P. curiosa	P. obunca
Tatarian	Vyatkian	Lower	N2P	Bykovian	Fifth Fm	Vyatka Fm	Bykovo Mb	Wjatkellina fragilina – Dvinella cyrta	Toyemia blumentalis – Strelnia certa	Scutosaurus: Scutosaurus karpinskii: Jarilinus mirabilis	P. curiosa	P. obunca
Tatarian	Severodvinian	Upper	R2P	Putyatinian	Fourth Fm	Kotel'nich Fm	Kalininskaya Mb; Putyatino Mb	Suchonellina inornata – Prasuchonella stelmachovi	Toyemia tverdochlebovi – Mutovinia stella	Scutosaurus: Proelginia permiana: Chroniosaurus levis; Chroniosaurus dongusensis; Deltavjatia vjatkensis	P. keyserlingi	P. fischeri
Tatarian	Severodvinian	Lower	N1P	Sukhonian	Fourth Fm; Third Fm	Kotel'nich Fm	Yurpalovo Mb; Filiny Mb; Slobodskoy Mb	Suchonellina inornata – Prasuchonella nasalis	Toyemia tverdochlebovi – Platysomus biarmicus	Titanophoneus: Suchonica vladimiri; Ulemosaurus svijagensis	P. ulemensis; P. numerosa	P. marposadica
Biarmian	Urzhumian		R1P	Urzhumian	Isheevo Fm; Second Fm; Sulitsa Fm; First Fm	Urzhum Fm	Syriany Mb; Belaya Kholunitsa Mb; Iliinskoe Mb	Paleodarwinula fragiliformis – Prasuchonella nasalis	Platysomus biarmicus – Kargalichthys efremovi	Titanophoneus: Estemmenosuchus uralensis	P. wohrmani; P. krotowi	P. doratioformis
Biarmian	Kazanian	Upper	R1P	Povolzhian	Morkvashi Beds; Verkhnyi Uslon Beds; Pechishchi Beds; Prikazan Beds	Maksimovtsy Mb; Belebey Fm (continental analogues of marine Kazanian)		Paleodarwinula fainae – Prasuchonella tichvinskaja	Kargalichthys pritokensis	Titanophoneus: Parabradysaurus silantjevi	P. quadri-angularis	P. olgae
Biarmian	Kazanian	Lower	R1P	Nemdian	Krasnyi Yar Beds; Kamyshla Beds; Baitugan Beds	Nemda Fm (marine Kazanian)		Paleodarwinula fainae – Prasuchonella tichvinskaja	Koinichthys ivachnenkoi	Titanophoneus: Parabradysaurus silantjevi	P. umbonata	P. olgae
Cisuralian	Ufimian		R1P	Sheshmian	Sheshma Fm			Paleodarwinula parallelo formis	Acropholis silantievi	Titanophoneus: Clamorosaurus nocturnus	P. ovatiformis	P. castor
Cisuralian	Ufimian		R1P	Solikamskian	Solikamsk Fm			Paleodarwinula onica - Faluniella prolata	Platysomus solikamskiensis – Ufalepis magnificus	Clamorosaurus nocturnus	P. ovatiformis; P. stegocephalum	P. larae

Middle and Upper Permian regional stratigraphic scale and the zonal distribution scheme of the area of the Field excursion

Fossils in the Sheshmian mainly comprise non-marine bivalves (*Palaeomutela* and '*Concinella*') and ostracods: *Palaeodarwinula forschi* (Kash.), *Prasuchonella kamischinkaensis* Pal., *Darwinuloides djurtjulensis* Pal., *Sinusuella pergraphica* (Mand.), etc. Fish remains, leaf imprints, pollen and spores occur rarely. During the excursion, the type section of the Sheshmian will be shown on the right bank of the Kama River, near the town of Elabuga (August 18, Stop 1), and in the upper reaches of the Sheshma River, near the villages of Shugurovo and Karkali (August 20, Stop 1 and 2).

Kazanian regional stage is subdivided into the Lower and Upper Kazanian.

Lower Kazanian Substage (= Nemdian Horizon). It outcrops mainly in the eastern part of Tatarstan, along the Kama River, and in the basins of the Sheshma, Zai, Menzela, and Ik rivers. The type sections of the substage are located in the north of the Samara Region, in the upper reaches of the Sok River. Forsch (1951, 1955) was the first to study these sections in detail. Later, Slyusareva (Grigorieva) (1960, 1962), Morozova (1970) and others extended the paleontological and lithological studies of these sections. Solodukho and Tikhvinskaya (1977), and Esaulova (1996a, 1998b) gave a bed by bed description of the sections, based on the material of the above workers. During the excursion, the reference sections of the substage will be observed on the right bank of the Kama River, near the town of Elabuga (August 18, Stop 1) and the village of Sentyak (August 19, Stop 1) and in the upper reaches of the Sheshma River, near the villages of Shugurovo and Karkali (August 20, Stop 1 and 2).

The Lower Kazanian Substage is subdivided into three bio- and lithostratigraphic units: Baitugan Beds, Kamyshla Beds, and Krasnyi Yar Beds (Solodukho, Tikhvinskaya, 1977; Gusev et al., 1993; Esaulova, 1998b).

Baitugan Beds. These beds (10–40 m) in Eastern Tatarstan unconformably overlie the red-bed terrigenous Ufimian rocks and have an additional basal member of bitumen-sandstone, known as the 'Shugurovo Sandstones Member' (5–20 m). In the Kazan District, Baitugan Beds overlie the carbonate-sulphate Sakmarian rocks. The beds are mainly composed of grey calcareous shales and muddy siltstones, usually with accumulations of inarticulate brachiopods (*Lingula*) on the bedding planes. Because of these accumulations, this part of the section is referred to as Lingula Shales Member. The Lingula Shales Member (5–15 m) is widespread over the entire territory of Tatarstan. It is readily recognisable in the outcrops and in borehole cores, and hence is a reliable marker interval in the correlation of the base of Middle Permian in the Volga-Ural Anteclise. Sometimes, shales and siltstones contain interbeds of marl, limestone, and dolomite. Apart from the lingulids (*Lingula orientalis* Gol. and *L. credneri* Gein.), all rock types, including shales, contain numerous articulate brachiopods, bivalves, bryozoans, crinoids, ostracods, and foraminifers. The Lingula Shales Member is usually overlain by a member of bioclastic or oolitic limestone (3–8 m), from which *Kamagnathus* multielement conodont apparatuses have been recovered (Chalymbadzha, Silantiev, 1997; Chernykh et al., 2001). In the type section on the Sok River, the lower part of the Baitugansk Beds contains a faunal complex dominated by the brachiopod *Licharewia rugulata* (Kut.). The brachiopod species *Cleiothyridina pectinifera* (Sow.) and *Beecheria netschajewi* Grig. are subdominant. The upper part of the beds usually contains the brachiopods *Licharewia rugulata* (Kut.) in association with *Aulosteges horrescens* (Vern.) and *Globiella hemisphaerium* (Kut.), which dominate in the complex.

Kamyshla Beds (15–30 m). These beds are composed of grey-bed shales, siltstones, sandstones, and marls with numerous lenticular beds and members (up to 5 m thick) of bioclastic limestones and dolomites. This part of the Lower Kazanian sequence contains more carbonates than the rest of the succession. All types of rocks of the Kamyshla Beds contain numerous large brachiopods, bivalves, bryozoans, crinoids, and foraminifers. The distinctive feature of the carbonates in the Kamyshla Beds is the predominance of the brachiopod species *Licharewia stuckenbergi* (Netsch.). Large specimens of this species abundantly occur together with *Globiella hemisphaerium* (Kut.) throughout this member.

Krasnyi Yar Beds. In the stratotype section on the Sok River, the beds consist of (from bottom to top) 1) grey shales with rare *Cancrinella* and *Beecheria* (9 m); 2) grey dolomites with bivalves and brachiopods (6 m); 3) grey obliquely laminated sandstones containing brachiopods, bivalves, and more rarely gastropods and bryozoans (4–8 m). In Tatarstan, the thickness of the beds ranges from 20 to 30 m.

The Krasnyi Yar Beds have an impoverished fossil complex characterised by reduced brachiopod and diverse bivalve assemblages. The beds lack corals, crinoids, *Globiella*, and other fossils which are widespread in underlying succession. The Lower Kazanian Age is established by sporadic occurrence of spiriferids *Licharewia rugulata*, the index species for the entire Lower Kazanian (Solodukho, Tikhvinskaya, 1977).

Along the latitudinal line from Kazan to Elabuga, to the east of the town of Chistopol, grey-bed argillaceous and sand-siltstone rocks of the Krasnyi Yar Beds are rapidly replaced by red-bed rocks. This complicates the recognition of the upper boundary of the Lower Kazanian in Eastern Tatarstan where the Upper Kazanian is represented by non-marine red-bed succession.

Upper Kazanian Substage (= Povolzhian Horizon (Gusev, Burov, Esaulova et al., 1993; Esaulova, 1998c)). In Tatarstan, the Upper Kazanian is widespread. It outcrops in the lower parts of the valleys of virtually all the rivers and streams.

The type area of the Upper Kazanian is the Kazan District. The type sections are located near the village of Pechishchi and on the right bank of the Volga River along the line Naberezhnye Morkvashi – Pechishchi – Verknyi Uslon. Professor Mikhail E. Noinsky (1899, 1924) was the first to describe this section that has been subsequently studied by many geologists. This section is included in the field program for students of the Institute of Geology and Petroleum Technologies of Kazan Federal University.

In stratotype, the lower boundary of the Upper Kazanian is placed at the base of the dolomite unit (Yadrenyi Kamen Member — according to Noinsky (1899, 1924)) that overlies the limestone bed with a typical Lower Kazanian brachiopod assemblage, including *Licharewia, Blasispirifer,* etc., and crinoids. Generally, the Upper Kazanian in the Kazan District is mainly composed of dolomites, including gypsiferous dolomites, which are separated by beds of shales, siltstone, and marl. It also frequently contains nodules, lenses, and laminae of gypsum. The thickness of the substage ranges from 45 to 50 m. Noinsky subdivided the Upper Kazanian in the Kazan District into eight members (from bottom to top): Member A — Yadrenyi Kamen Member, Member B — Sloistyi Kamen Member, Member C — Podboi Member, Member D — Seryi Kamen Member, Member E — Shikhany Member, Member F — Opoki Member, Member G — Podluzhnik Member, and Member H — Perekhodnaya Member. The members were grouped into three complexes which indicate three cycles in the evolution of the type area in the Late Kazanian: the first (= Members A+B+C), the second (= Members D+E+F) and the third (= Members G+H) (Noinsky, 1899, 1924). Each complex in its lower part is composed exclusively or mainly of carbonates with numerous remains of foraminifers, ostracods, molluscs, brachiopods, and conodonts. These beds are overlain by gypsiferous dolomites lacking fossils, and eventually by argillaceous-marly rocks with mostly non-marine fossils (bivalves and conchostracans) and terrestrial plant remains. Later, Solodukho and Tikhvinskaya (1977) recognised four litho- and biostratigraphic horizons (from bottom to top) in the Pechishchi section of the Upper Kazanian: Prikazan (= Members A+B), Pechishchi (= Members C+D+E), Verkhnyi Uslon (= Members F+G), and Morkvashi (= Members H). In their opinion, these litho- and biostratigraphic horizons indicate lithological cyclicity in the substage. Nowadays, these horizons are considered as ‘Beds with geographical names’ (Gusev et al., 1993). The subdivision of the Upper Kazanian into four units was confirmed by a Decision of the Interdepartmental Stratigraphic Committee (Reshenie…, 1990) and was used during the mapping in Tatarstan. Towards the east, the grey-bed, mainly marine and lagoonal rocks of the Upper Kazanian are gradually replaced by the synchronous red-bed continental (mainly lacustrine-alluvial) rocks that are assigned to the Belebey Formation. The eastern boundary of the beds, containing marine Late Kazanian fauna, is located approximately along the line Arsk–Kamskie Polyany.

BELEBEY FORMATION. This formation is composed of siltstones and alluvial sandstones containing comparatively rare thin interbeds of marl, algal-microbial limestone, and more rarely of dolomite and gypsum. Throughout all the succession, various paleosols are widespread. They are identified by spots of gleisation, by the numerous calcareous nodules, and by the slickensides. The rocks are mostly reddish-brown. Fossils are represented by the non-marine bivalves *Palaeomutela umbonata* (Fisch.), *P. olgae* (Gus.), *P. quadriangularis* (Netsch.), etc., by the non-marine ostracods *Palaeodarwinula irenae* (Bel.), *P. fainae* (Bel.), *P. varsanofievae* (Bel.), *P. chramovella* (Bel.), *Prasuchonella tichvinskaja* (Bel.), *Pr. onega* (Bel.), *Darwinuloides sentjakensis* (Sharap.) etc., by concostracans, fish scales and teeth, fragments of reptile bones, imprints of leaves and trees, and by pollen and spores. The thickness of the Belebeevskaya Formation is 60–100 m. In the course of the excursion, marine and lagoonal facies of the Upper Kazanian will be observed on the right bank of the Volga River, near the villages of Pechishchi and Naberezhye Morkvashi (August 16, 1 Stop 1). Continental red-bed facies of the Kazanian (Belebey Formation) will be observed in the section near the village of Sentyak (August 19, Stop 1) on the Kama River.

The Urzhumian regional stage was established by the Permian Commission of the Russian Interdepartmental Stratigraphic Committee in 2004 on the base of the Urzhumian Biostratigraphic Horizon (Fredericks, 1918) as the upper regional stage of Biarmian Series (Reshenie…, 2006).

In Tatarstan, the Urzhumian is widespread. It outcrops in the upper parts of the valleys of virtually all the rivers and gullies. The Urzhumian almost always overlies the slightly eroded surface of the Kazanian.

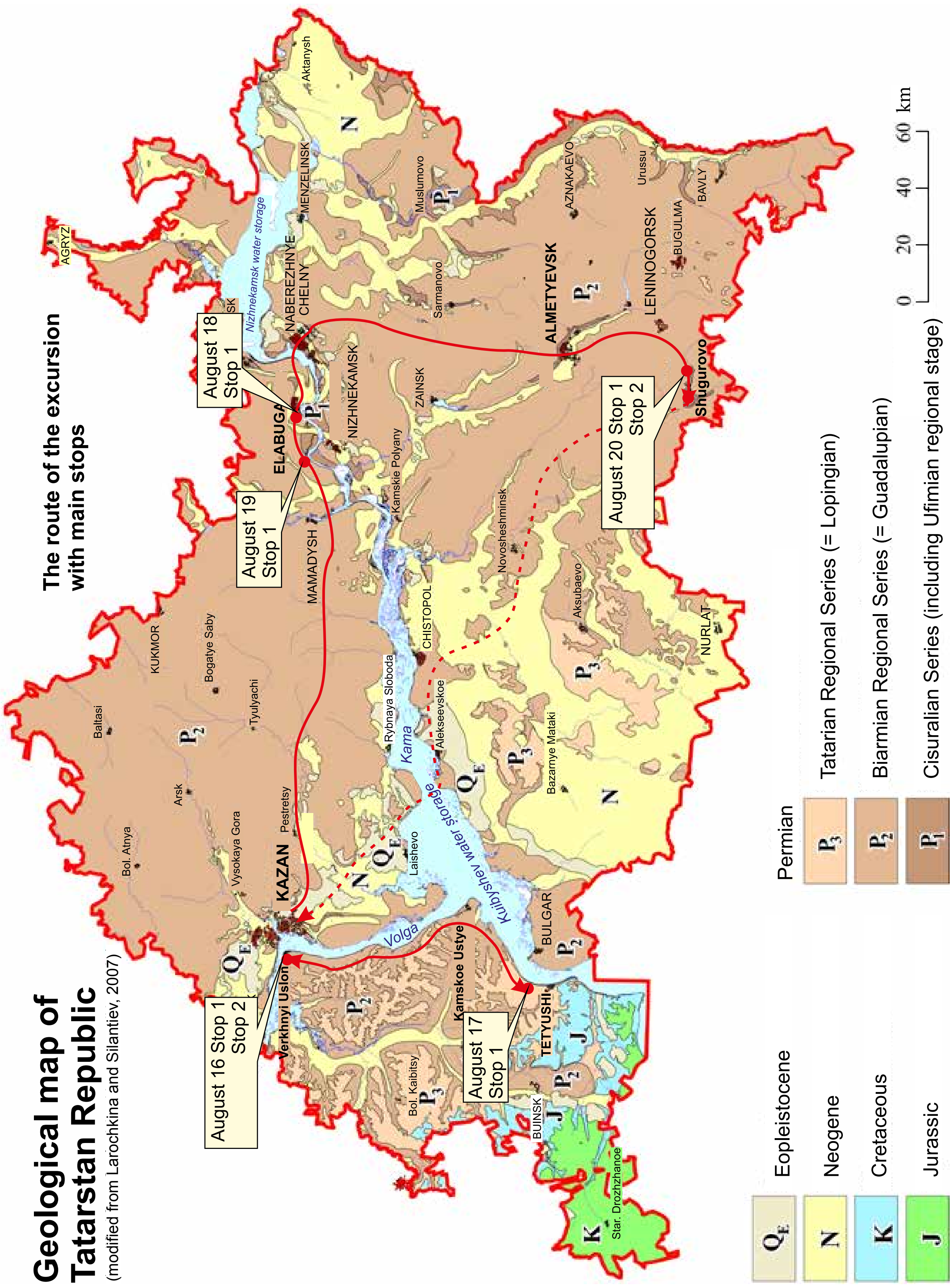
In Tatarstan, the reference sections of the Urzhumian are located in the Kazan District on the right bank of the Volga River: 1) 2 km upstream of the village of Pechishchi, in the Cheremushka Gully (August 16, Stop 2) – parastratotype section, and 2) 12 km upstream from the town of Tetyushi, in the Monastery Ravine – stratotype section (August 17, Stop 1). The section in the Monastery Ravinehave been described in detail by Silantiev and Esin (1993), and both the above sections, by Gusev (1996a, b; 1998a, b) and by Silantiev et al. in 2013–2014 (Arefiev, Silantiev, 2014; Silantiev et al., 2014a, b, etc.).

In Tatarstan, the Urzhumian is subdivided into two formations (Fm). The First Fm (or Sulitsa Fm) is 25–50 m thick and composed of red-bed argillaceous and terrigenous rocks with many marl and limestone intercalations. The Second Fm (or Isheevo Fm) is 50 m thick and characterised by well-defined cyclic interbedding of terrigenous and argillaceous-carbonate rocks. The most characteristic feature of the Urzhumian is the presence of quartzite sandstones and siltstones, which are absent in the Kazanian and Ufimian. Algal-microbial limestones and dolomites are usually riddled with numerous voids of plant roots *in situ*. Shales with greenish-grey and red spots (stains) of gleisation are usually overfilled with calcareous concretions (paleosol horizons). Shales with lenticular lamination contain numerous remains of ostracods, bivalves, fish scales and tetrapods.

The index fossils for the Urzhumian are the non-marine ostracods *Palaeodarwinula fragiliformis* (Kash.), *P. teodorovichi* (Bel.), *P. torensis* (Kotsch.), *P. defluxa* (Misch.), *P. elongata* (Lun.), *P. elegantella* (Bel.), *P. chramovi* (Gleb.), and *Prasuchonella nasalis* (Shar.), etc., and bivalves *Palaeomutela krotowi* Netsch., *P. doratioformis* (Gus.), *Prilukiella subovata* (Jones), *Pr. mirabilis* (Gus.), *Anadontella volgensis* (Gus.).

The lower boundary of the Urzhumian additionally is marked by the basement of *Platysomus biarmicus–Kargalichthys efremovi* fish zone. The Urzhumian coincides with the parts of *Estemmenosuchus uralensis* and *Ulemosaurus svijagensis* tetrapod zones. The common tetrapods in the Urzhumian are *Archaeosyodon, Biarmosuchus*, Bolosauridae, Deuterosauridae, Dissorophidae, Estemmenosuchidae, Lanthanosuchidae, Phthinosaurus, Pristerognathidae, Titanophoneus, Tryphosuchinae, Ulemosauridae, Venyukovioidea.

The Severodvinian regional stage was established by the Permian Commission of the Russian Interdepartmental Stratigraphic Committee in 2004 based on the Severodvinian Biostratigraphic Horizon (Tikhvinskaya, 1946; Stratigraphicheskie Skhemy…, 1962) as the lower regional stage of the Tatarian Series (Upper Permian) (Reshenie…, 2006). Stratotype sections are located along the Sukhona River in the north-eastern part of the Vologda Region. The Severodvinian is composed of red-bed argillaceous and terrigenous rocks with many marl and limestone intercalations. Algal-microbial limestones and dolomites are usually riddled with numerous voids of plant roots *in situ*. Shales with greenish-grey and red spots (stains) of gleisation are usually overfilled with calcareous concretions (paleosol horizons). Shales with lenticular lamination contain numerous remains of ostracods, bivalves, fish scales and tetrapods. In Tatarstan, the Severodvinian is widespread, mainly in the watersheds of the rivers.



Geological map of Tatarstan Republic
(modified from Larochkina and Silantiev, 2007)

The basement of the Severodvinian is best represented in the Monastery Ravine section (Kazan Region) (August 17, Stop 1), which is proposed as the regional GSSP marked by the FAD of the non-marine ostracod *Suchonellina inornata* (Minikh et al., 2009). The lower boundary of the Severodvinian coincides with the boundary of *Suchonellina inornata–Prasuchonella nasalis* ostracod zone, as well as the boundary of *Toyemia tverdochlebovi–Platysomus biarmicus* fish zone. The boundary of the paleomagnetic zones Kiaman and Illawarra is fixed near the lower boundary of the Severodvinian which, in general, includes two magnetozones (N_1P and R_2P).

The Severodvinian regional stage is subdivided into the Lower and Upper Severodvinian on the base of biostratigraphic and paleomagnetic data. The index tetrapods for the Severodvinian are *Ulemosaurus svijagensis, Suchonica vladimiri, Deltavjatia vjatkensis, Proelginia permiana, Chroniosaurus dongusensis Tverdochlebova, Chroniosaurus levis, Microphon*, as well as the representatives of Bradysauridae, Burnetiidae, Cryptodontidae, Dicynodontidae, Dvinosauridae, Galeopidae, Gorgonopidae, Ictidorhinidae, Karpinskiosauridae, Moschowhaitsiidae, Nycteroleteridae, Scaloposauria.

The Vyatkian regional stage was established by the Permian Commission of the Russian Interdepartmental Stratigraphic Committee in 2004 based on the Vyatkian Biostratigraphic Horizon (Ignatiev, 1962; Stratigraphicheskie Skhemy…, 1962) as the upper regional stage of the Tatarian Series (Upper Permian) (Reshenie…, 2006). Stratotype sections are located along the upper reach of the Vyatka River in the Kirov Region. The Vyatkian is composed of basal sandstone and conglomerate overlain by red-bed (speckled) argillaceous and terrigenous rocks with marl and limestone intercalations. Algal-microbial limestones are usually riddled with numerous voids of plant roots *in situ*. Shales with greenish-grey and red spots (stains) of gleisation are usually overfilled with calcareous concretions (paleosol horizons). Shales with lenticular lamination contain numerous remains of ostracods, bivalves, fish scales and tetrapods.

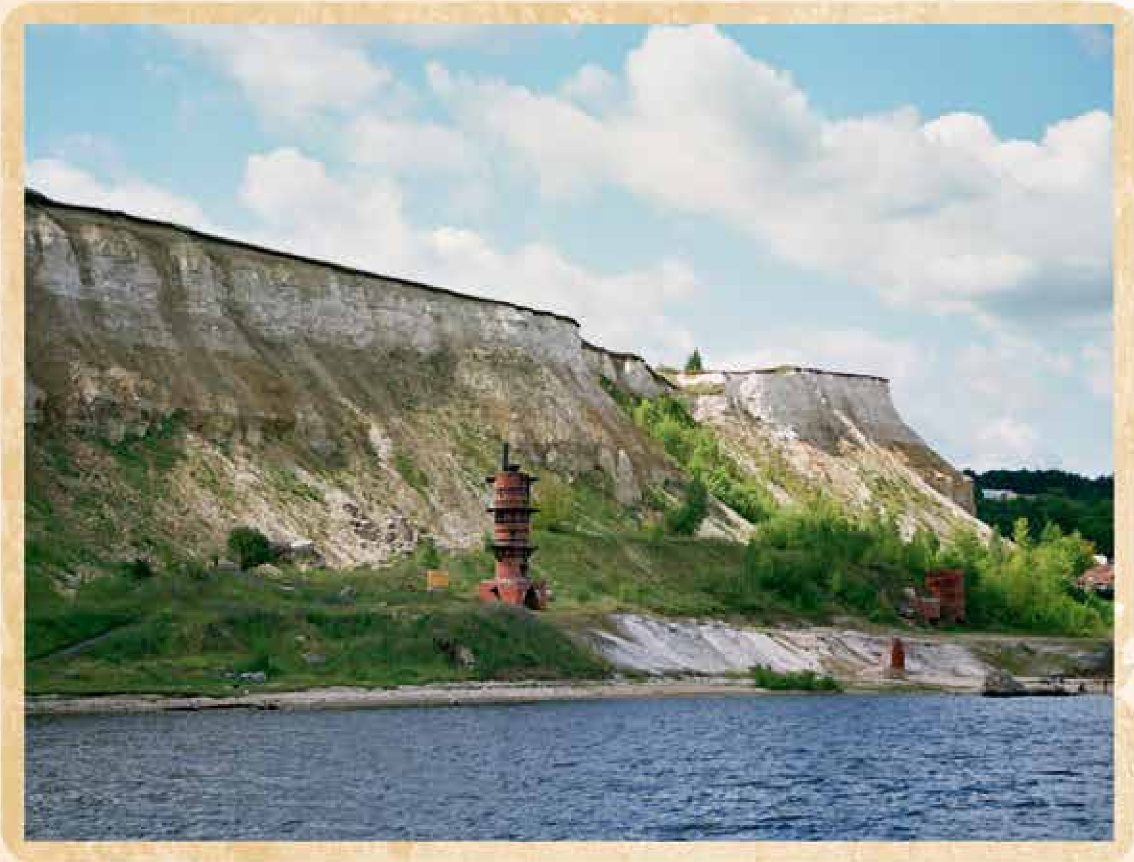
The lower boundary of the Vyatkian coincides with the boundary of *Wjatkellina fragilina–Dvinella cyrta* ostracod zone. Additional markers of the Vyatkian are represented by the basement of *Scutosaurus* karpinskii tetrapod zone and *Jarilinus mirabilis* tetrapod subzone. The Vyatkian contains three ostracod zones, three tetrapod zones, three fish zones, and two zones based on non-marine bivalves. In general, the Vyatkian coincides with two magnetozones (N_2P and R_3P). The uppermost part of the Vyatkian contains two subzones with normal and reverse polarity, respectively. These subzones correspond to the lower part of NPT magnetozone.

The Vyatkian regional stage is subdivided into the Lower and Upper Vyatkian.

The index fossils for the Lower Vyatkian are the non-marine ostracods *Wjatkellina fragilina* (Bel.), *Dvinella cyrta* (Zekina), fishes *Toyemia blumentalis* A. Minich and *Strelna certa* A. Minich, tetrapods *Jarilinus mirabilis* (Vjuschkov), bivalves *Palaeomutela curiosa* Amal. and *P. obunca* Netsch.

The Upper Vyatkian is characterised by ostracod assemblages belonging to two biostratigraphic ostracod zones: *Wjatkellina fragiloides–Suchonella typica* and *Suchonellina perelubica–Suchonella rykovi–Suchonella posttypica*. The Upper Vyatkian coincides with *Toyemia blumentalis–Isadia aristoviensis* and *Gnathoriza otschevi–Mutovinia sennikovi* fish zones, and with the *Chroniosuchus paradoxus* tetrapod subzone of *Scutosaurus karpinskii* tetrapod zone and *Archosaurus rossicus* tetrapod zone, respectively.

In Tatarstan, the Vyatkian regional stage is exposed only on the right bank of the Volga River, in the Tetyushi District of Tatarstan (August 17, Stop 1).



AUGUST 16

• PECHISHCHI SECTION
• CHEREMUSHKA SECTION

DESCRIPTION OF THE EXCURSION ROUTE AND THE MIDDLE PERMIAN SECTIONS IN THE VOLGA RIVER REGION NEAR KAZAN

The region of the Volga River near Kazan (Kazan Povolzhye) includes the area along the bank of the Volga River from the village of Pechishchi to the town of Tetyushi. The Middle and Upper Permian rocks form the right bank of the river valley and are accessible for studies in the slope of the bank and in numerous gullies and ravines.

The geological excursion starts in the vicinity of the village of Pechishchi where two sections will be shown for the participants. These are the stratotype of the Upper Kazanian, exposed on the steep bank of the Volga River and on the slopes of the Telegraphnyi ('Telegraph') Gully and Kamennyi ('Rocky') Gully (August 16, Stop 1), and the parastratotype of the Urzhumian regional stage exposed in the Cheremushka ('Bird Cherry') Gully (August 16, Stop 2).

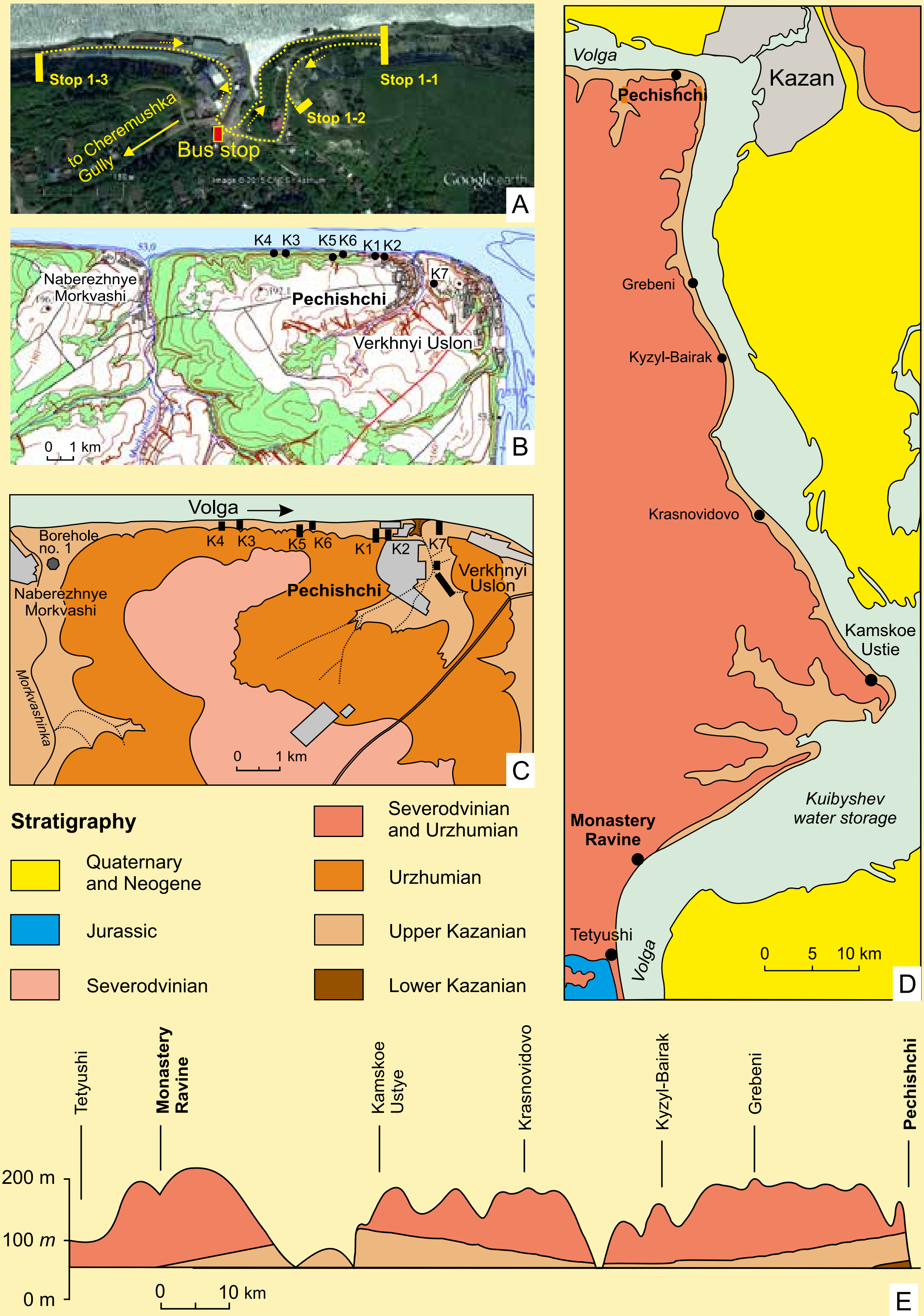
After visiting these sections, the excursion will go by a regular or special high-speed boat down the Volga River towards the town of Tetyushi. Along this route, one can observe from the boat continuous outcrops of the Kazanian and the Urzhumian, showing syncline and anticline structures with gently sloping flanks. The participants will see the stratotype of the Urzhumian exposed in the slopes of the Monastery Ravine and Il'insky Gully slightly upstream of the town of Tetyushi (August 17, Stop 1).

AUGUST 16 • STOP 1

PECHISHCHI SECTION. STRATOTYPE OF THE UPPER KAZANIAN SUBSTAGE

The stratotype outcrops are exposed on the right bank of the Volga River opposite the city of Kazan. The boundary between the Lower and Upper Kazanian and lower part of the succession (units 1–7) is exposed in the slope of the bank between the village of Pechishchi and Naberezhnye Morkvashi (outcrops K3 and K4). The overlying beds are quite well exposed on the right bank of the Volga River near the village of Pechishchi (outcrops K1 and K2), near the mouth of Cheremushka Gully (outcrops K5 and K6), and in the slopes of the Telegraphnyi ('Telegraph') Gully and Kamennyi ('Rocky') Gully (outcrop K7). The Kazanian–Urzhumian boundary is most accessible in the Cheremushka ('Bird Cherry') Gully (outcrop P01, August 16, Stop 2).

Noinsky (1899, 1924) first described the section, which he subdivided into eight series ('members' in modern terminology), united into three complexes. Solodukho and Tikhvinskaya (1977) gave a detailed paleontological description of Noinsky's complexes, recognised four complexes instead of three and gave them the rank of biostratigraphic horizons. At present, according to the Russian Stratigraphic Code (2006), these horizons are regarded as the *Beds with geographical names* (Gusev et al., 1993). The description of the section is based on data taken by all previous researchers and on data of recent studies undertaken in 2013–2014 (Silantiev et al., 2014a, b; Götz and Silantiev, 2014).

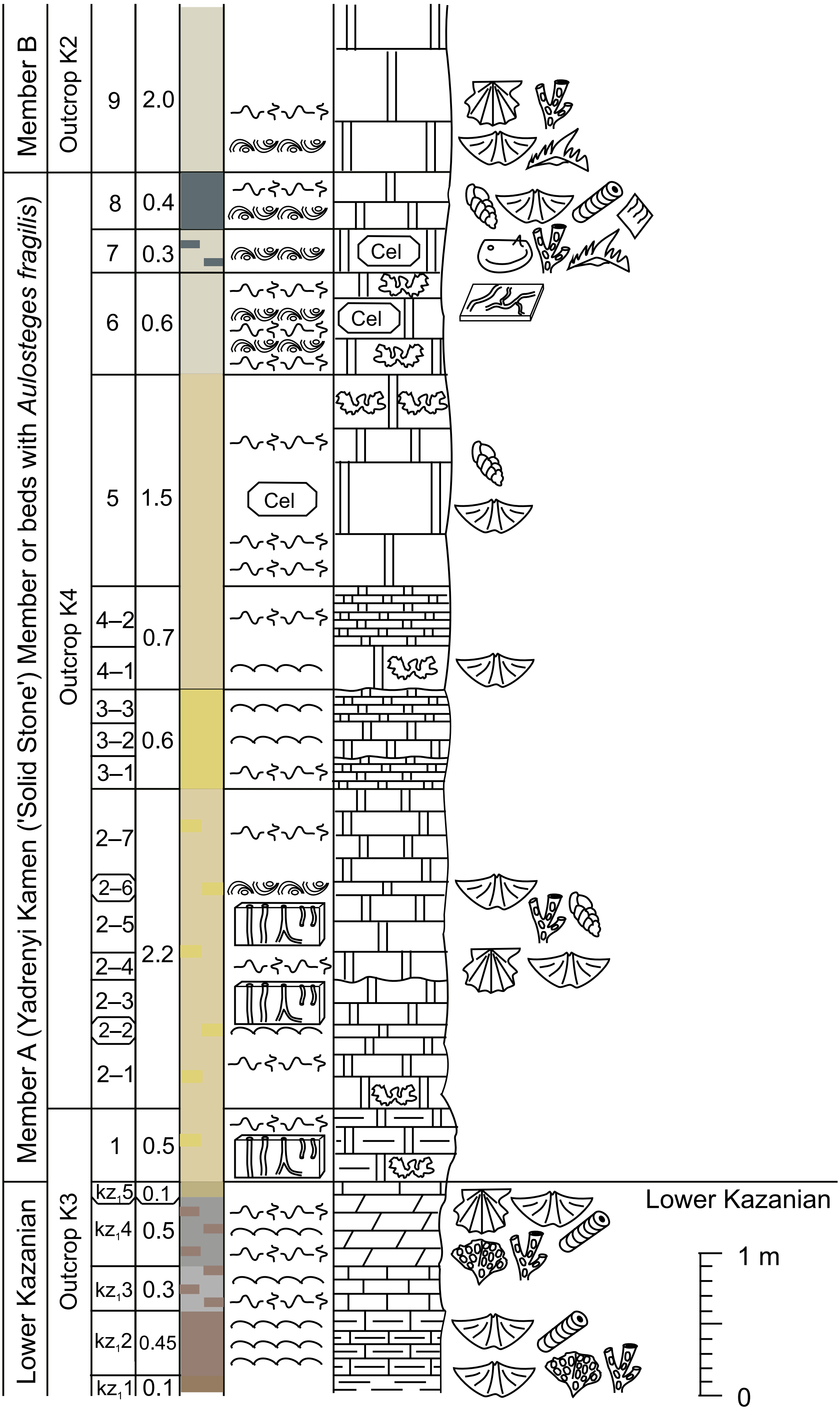


Study area: (A) space image of the village of Pechishchi (Image © CNES / Astrium) showing the locations of the excursion' stops; (B) geographical map showing the outcrops (K1-K7) sampled in 2013-2014; (C) generalized geological map of the Pechishchi–Cheremushka area; (D) generalized geological map of the Volga-Kama region near the town of Kazan, Republic of Tatarstan, and (E) generalized geological profile of the right bank of the Volga River between Pechishchi and Tetyushi

Pechishchi Section

Outcrops K3 and K4

Lower Kazanian/Upper Kazanian boundary



The description of the Kazanian beds exposed in the vicinity of the village of Pechishchi

Outcrop K3

GPS: 55.78263 N; 048.90687 E (WGS84). Datum: river water level at 53.0±3 m ASL. Right bank of the Volga River, 55 m upstream of the mouth of the Trekhglavyi ('Three-headed') Gully. The base of the Upper Kazanian Substage, as defined by Noinsky (1899, 1924), is exposed in 1.5 m above the river level and 54.5 m ASL. Beds are dipping south at 5°. Intervals in bed-by-bed description are measured from the base of outcrop K3 in each station. The measurements shown under the sample numbers indicate their position in meters from the base of each unit (e.g. sample K3/2 (0.22) was taken at 0.22 m above the base of unit K3/2).

Lower Kazanian Substage

Unit K3/$kz_1$1 Interval 0.00–0.10 m Thickness (visible) 0.10 m

Shale: brown to brownish grey, with numerous crushed brachiopods *Cancrinella cancrini* (Vern.), *Licharewia rugulata* (Kut.), *L. stuckenbergi* (Netsch.), *Blasispirifer multiplicostatus* (Netsch.), *Odontospirifer subcristatus* (Netsch.), and numerous fragments of bryozoans and crinoids. The shell structure is well preserved.

Unit K3/$kz_1$2 Interval 0.10–0.55 m Thickness 0.45 m

Limestone: pale grey, argillaceous, fine-grained, bedded, with disrupted subparallel sedimentary lamination. The lamination is also expressed on polished slabs as predominant horizontal orientation of bioclasts that locally imbricate to form "micro-pavements". Lamination planes show plant detritus, charophyte stalks, sparse *Cancrinella cancrini* (Vern.), and unidentified branching calcareous microtubules. The rock is microporous, soft, and waterlogged at 0.30–0.45 m of cumulative thickness.

Unit K3/$kz_1$3 Interval 0.55–0.85 m Thickness 0.30 m

Limestone: grey, weathers brownish, micritic (bioclastic wackestone to mudstone), weakly fissile, probably weakly argillaceous, with numerous *Cancrinella cancrini* (Vern.) on the bedding planes in the middle. Randomly oriented bioclasts indicate bioturbation. Bioclastic micro-pavements are locally preserved in the middle part of the unit.

Unit K3/$kz_1$4 Interval 0.85–1.35 m Thickness 0.50 m

Calcareous marl: dark grey, weathers brownish, unevenly hard, moderately fissile, laterally grading to the soft marly rock. Bioturbated bioclastic wackestone or calcimudstone with rare patches of bioclast micro-pavements.

Unit K3/$kz_1$5 Interval 1.35–1.45 m Thickness 0.10 m

Limestone: pale brownish grey, dolomitic, fine-grained, thin-bedded. Base conformable and gradational. This unit may be a part of the 'Chervotochina' Bed sensu Noinsky (1899, 1924). This unit can be described as a transition from fissile marl K03/$kz_1$4 to thick-bedded dolostone К3/1 marking a conformable contact of the Lower and Upper Kazanian in the type section.

Upper Kazanian Substage

<u>Prikazan Beds</u>

Member A (Yadrenyi Kamen ('Solid Stone') Member or beds with *Aulosteges fragilis*)

Unit K3/1 Interval 1.45–1.95 m Thickness 0.50 m

Bed no. 1, Chervotochina ('Worm-hole') of Noinsky (1899, 1924).

Dolostone: tan, probably argillaceous, preserving horizontal gently undulating lamination, riddled with characteristic vermiform voids (hence the name 'Chervotochina' – 'Worm-hole').

[Remark. The general section of the Upper Kazanian was made on the base of unit K4/2 exposed in outcrop K4; more detailed sampling was conducted in outcrop K03.]

LEGEND

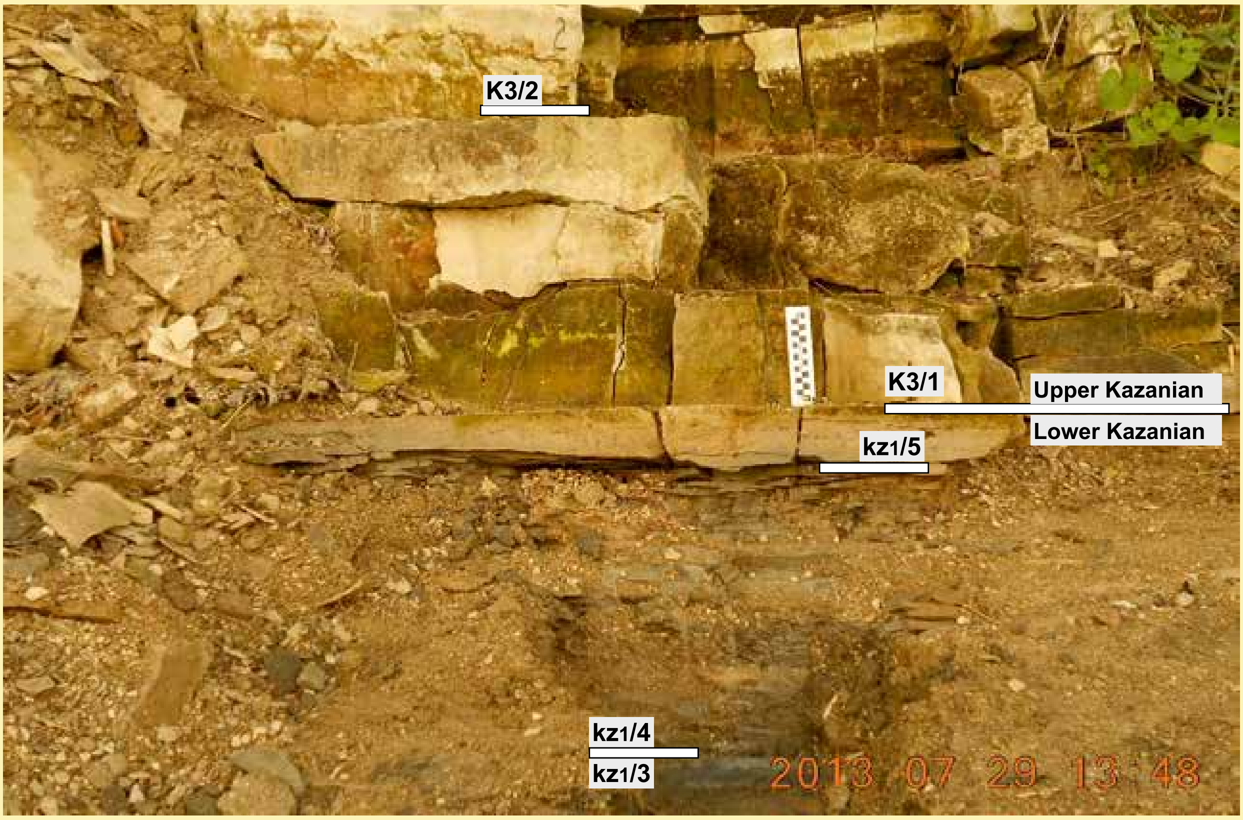
- Sands and sandstones
- Silts and siltstones
- Siltstones and sandstones
- Shales argillaceous
- a, b — Limestones (a), dolomites (b)
- a, b — Marls (a), dolomitic marls (b)
- Oolitic limestones and dolomites
- Argillaceous and silt limestone and dolomites
- Limestones and dolomites with stromatolites and calcareous algae
- Vuggy limestones and dolomites
- Dolomitic gravelites and conglomerates
- Dolomitic breccia
- Gravel, pebbles
- Gypsum lenses, gypsiferous rocks
- Calcareous concretions and calcareous recrystallisation
- Ciliceous concretions and quartz druses
- Celestine
- Silty-shale gruss, brecciated lamination
- Colours of the rocks in particular outcrops

- Horizontal and subhorizontal lamination
- Wavy lamination
- Short lenticular lamination
- Fissures of desiccation
- Slickensides
- Coquina
- Shell pavement
- Bioturbated structure
- Zone of gleying over the roots of plants
- Plant roots *in situ*
- Trace fossils oriented on the bedding oriented
- *Palaeophycus* trace fossils

Colours of the rocks in general profiles

- Redstones
- Grey-coloured rocks, rock with colours of gley spots, white and yellow sands
- Variegated rocks
- Dark grey rocks (shade of a pencil to black)
- Brown and greyish-green fluvial sands
- Dark-green rocks

- Forams
- Marine ostracods
- Non-marine ostracods
- Conchostracans
- Gastropods
- Marine bivalves
- Non-marine bivalves
- Inarticulated brachiopods
- Articulated brachiopods
- Bryozoans
- Crinoids
- Conodonts
- Fishes
- Tetrapods
- Leaves of higher plants
- Girogonites of charophytes
- Miospores



Outcrop K3. The Lower Kazanian / Upper Kazanian boundary

Unit K3/2 Interval 1.95–4.00 m Thickness 2.05 m

Bed no. 2, Yadrenye Porogi (‘Solid Thresholds‘) of Noinsky (1899, 1924).

Dolostone: pale grey, locally yellowish, calcareous, hard, thick-bedded, partly vuggy. The vugs contain white finely crystalline quartz and transparent calcite crystals. These vugs may be left after dissolution of anhydrite nodules. Sedimentary texture: calcimudstone with rare horizontally oriented bioclasts (sample К03/2 (0.00)); vaguely granular, ooid-like dolostone texture (sample К03/2 (0.22)). Bedding planes show numerous moulds of the bivalves *Schizodus*, *Permophorus*, *Pseudomonotis,* etc. Other identifiable fossils: rare foraminifers *Ichtyolaria fallax* (K.M.-Maclay), *Ich. longissima* (K.M.-Macl .) and brachiopods *Aulosteges fragilis* (Netsch.) with preserved shells.

[Remark. The overlying section is described 70 m upstream (N 55,78265; E 048,90576, 53.0 m ASL, 125 m upstream of Trekhglavyi Gully).]

Unit K3/3 Interval 4.00–4.70 m Thickness 0.70 m

Bed no. 3. Zheltaya Plita (‘Yellow Plate‘) of Noinsky (1899, 1924).

Dolostone: pale grey, yellowish, tight, massive, of medium hardness. Sample К03/3 (0,33) shows the boundary of two lithologies: the light coloured dolostone (calcimudstone tecture) with *Cancrinella* pavement in the upper part, overlain by yellowish grey dolostone with vague disrupted horizontal lamination and rip-up intraclasts. Sample К03/3 (0.59) shows dolostone with residual bioclastic wackestone texture and wavy lamination defined by bivalve valves and probably microbial laminae; moderate bioturbation; rare bryozoans.

Unit K3/4 Interval 4.70–5.30 m Thickness 0.60 m

Bed no. 4. Zvonkaya Plita (‘Ringing Plate‘) of Noinsky (1899, 1924).

Dolostone: pale grey, tight, hard, massive, locally vuggy, with rare brachiopods *Cancrinella cancrini* (Vern.). Sample К03/4 (0,06) shows mudstone texture with gently undulating lamination defined by horizontally oriented bioclasts and voids left by dissolved brachiopod spines.

Unit K3/5 Interval 5.30–7.40 m Thickness 2.10 m

Bed no. 5. Yadrenyi Rubets or Yadrenyi Kamen (‘Solid Seam‘ or ‘Solid Rock‘) of Noinsky (1899, 1924).

Dolostone: pale grey, calcareous, tight, hard, with smooth to gently conchoid fracturing. Grades laterally into ‘Brakovisty Kamen’ (‘Defective Stone‘) – the microporous relatively soft dolostone with numerous large (up to 15 cm) celestine nodules. Foraminiferal assemblage: *Paraglomospira simplicissima* K.M.-Maclay, *Ammodiscus* sp., *Globivalvulina bulloides* Brady, *Nodosaria suchonensis* K.M.-Maclay, *Pseudonodosaria lata* K.M.-Maclay, *Lingulina semivelata* Tscherd., *Ichtyolaria triangularis* (Gerke). Small brachiopods: *Cancrinella cancrini* (Vern.), *Rhynchopora geinitziana* (Vern.), and *Cleiothyridina pectinifera* (Sow.).

The overlying layers are poorly accessible in outcrop K3.

Outcrop K4. Dolostone with upright channels (A); (B) undulating and erosional top of bed K4/2-3 with pockets up to 3 cm deep; (C) bedding plane with charophyte remains

Outcrop K4

GPS: 55,78261 N; 048,90420 E (WGS84). Datum: river water level at 53.0±3 m ASL. The right bank of the Volga River in 225 m upstream of the mouth of the Trekhglavyi ('Three-headed') Gully. The base of the Upper Kazanian Substage as defined by Noinsky (1899, 1924) is exposed in 1.0 m above the river level and 54.0 m ASL. Upwards in the section, above the dolostone with vermiform voids (Chervotochina ('Worm-holes') of Noinsky (1899, 1924)), the sequence in outcrop K4 shows beds 2–8 of Member A (Yadrenyi Kamen) (from bottom to top).

Unit K4/1 Interval 1.80–1.95 m Thickness (visible) 0.15 m
Bed no. 1. Chervotochina ('Worm-holes') of Noinsky (1899, 1924).
Dolostone: tan, argillaceous, soft, with vermiform voids / channels.

Unit K4/2 Interval 1.95–4.20 m Thickness 2.25 m
Bed no. 2. Yadrenye Porogi ('Solid Thresholds') of Noinsky (1899, 1924).
Dolostone: pale grey, weathers yellowish, calcareous, thick-bedded, tight and hard. Samples show bioclastic mudstone texture with predominantly horizontal to random orientation of bioclasts. Thin (< 1 mm) curved channels are observed in sample K4/2 (1.55). Fine poorly preserved plant detritus may be present. Observation on fossils and caverns similar to outcrop K3.
The altimeter reading at the top of K04/2 is 56.0 m ASL.
Unit K4/2 is logged 50 m downstream, between outcrops K03 and K04.
Bed K4/2-1 [0.00–0.50] Interval 1.95–2.45 m Thickness 0.50 m
Dolostone: pale grey, weathers yellowish, massive, hard, tight. An interval of vuggy dolostone (0.05–0.10 m) in 0.25 m above the base. The vugs are irregular, 2–5 cm in size, interpreted as anhydrite solution voids. No fossils.
Bed K4/2-2 [0.50–0.60] Interval 2.45–2.55 m Thickness 0.10 m
Dolostone: finely crystalline, microporous, fissile, locally preserving non-disturbed bioclast micro-pavements. No fossils.
Bed K4/2-3 [0.60–0.90] Interval 2.55–2.85 m Thickness 0.30 m
Dolostone: finely crystalline, tight, massive, with thin (< 5 mm in diameter) upright channels penetrating from top, showing spongy internal structure and bleached haloes . The top of this subunit is undulating, erosional, with pockets up to 3 cm deep.
Bed K4/2-4 [0.90–1.10] Interval 2.85–3.05 m Thickness 0.20 m
Dolostone: grey, calcareous, with granular bioclastic texture (grainstone?) hosting numerous hollow biomolds of brachiopods and mollusks. Thickness changes laterally from 0.10 to 0.20 m.
Bed K4/2-5 [1.10–1.50] Interval 3.05–3.45 m Thickness 0.40 m
Dolostone: yellowish grey, calcareous, massive, tight, and hard. Upright indistinctly branching solution channels of 1–2 cm in diameter are developed from top, interpreted as solution-enlarged burrows.

Return to outcrop K4 for further details of unit K4/2.
Bed K4/2-6 [1.50–1.60] Interval 3.45–3.55 m Thickness 0.10 m
Dolostone: pale grey, bedded, cavernous, with brachiopod bioclasts.
Bed K4/2-7 [1.60–2.25] Interval 3.55–4.20 m Thickness 0.65 m
Dolostone: pale grey, of medium hardness, probably with partly preserved primary lamination; distinct rectangular jointing with conchoid fracturing. This thick-blocky jointing makes it different from thinner bedded underlying units.
Unit K4/3 Interval 4.20–4.80 m Thickness 0.60 m

Bed no. 3. Zheltaya Plita (‘Yellow Plate‘) of Noinsky (1899, 1924).
Dolostone: pale grey, weathers yellowish, indistinctly bedded, massive, of medium hardness. The unit is composed of three parts:

Bed K4/3-1	[0.00–0.20]	Interval 4.20–4.40 m	Thickness 0.20 m

Dolostone: thin bedded (1 to 5 cm in thickness), relatively soft, massive, with bioturbated bioclastic wackestone texture (bioclasts include brachiopods and bivalves).

Bed K4/3-2	[0.20–0.40]	Interval 4.40–4.60 m	Thickness 0.20 m

Dolostone: with distinct bioclastic texture (packstone), vuggy, locally preserving subhorizontal wavy lamination with shell pavements. Predominant horizontal orientation of bioclasts defines lamination. Some bedding planes show mass charophyte stalks. Base likely erosional.

Bed K4/3-3	[0.40–0.60]	Interval 4.60–4.80 m	Thickness 0.20 m

Dolostone: relatively soft, fissile, with bioclastic mudstone-wackestone texture. Predominant horizontal orientation of bioclasts. Top erosional.

Unit K4/4	Interval 4.80–5.50 m	Thickness 0.70 m

Bed no. 4. Zvonkaya Plita (‘Ringing Plate‘) of Noinsky (1899, 1924).
Dolostone: pale grey, hard and tight, locally vuggy, with rare *Cancrinella cancrini* (Vern.). The unit can be divided into two parts:

Bed K4/4-1	[0.00–0.30]	Interval 4.80–5.10 m	Thickness 0.30 m

Dolostone: locally vuggy, retains bioclastic texture (packstone?) and lenticular lamination with shell pavements (including fragments and whole valves of *Aulosteges fragilis* (Netsch.). Base is possibly erosional. Laterally this bed obtains fissility, which is likely attributed to weathering (solution) processes.

Bed K4/4-2	[0.30–0.70]	Interval 5.10–5.50 m	Thickness 0.40 m

Dolostone: fissile to thin-bedded, retaining bioclastic wackestone texture and wavy lamination.

The interval of beds K4/3-K4/4 preserves the rhythmic tempestite bedding with normally graded beds composed of basal shell coquinas (rudstones) and overlying wackestones and packstones. In basal coquinas, shells imbricate and occur predominantly convex-side up.

Unit K4/5	Interval 5.50–7.00 m	Thickness 1.50 m

Bed no. 5. Yadrenyi Rubets or Yadrenyi Kamen (‘Solid Seam‘ or ‘Solid Rock’)) of Noinsky (1899, 1924).
Dolostone: very similar to K03/5. Massive to weakly laminated bioclastic wackestone with rare *in situ* brachiopods *Cancrinella cancrini* (Vern.), *Rhynchopora geinitziana* (Vern.), *Cleiothyridina pectinifera* (Sow.). At the top, the rock is vuggy and locally thin-bedded. The unit stands out in the outcrop due to its monolithic appearance.

Unit K4/6	Interval 7.00–7.60 m	Thickness 0.60 m

Bed no. 6. Solyanoi Rubets (‘Salt Seam’) of Noinsky (1899, 1924).
Dolostone: yellowish grey, fissile to thin-bedded, with finely to microcrystalline fabric (5–50 μm), microporous, locally vuggy, relatively soft. Moderately bioturbated to laminated bioclastic packstone and wackestone. Bedding / fissility planes show laminae enriched in charophyte stalks and laminae dominated by brachiopod fragments. Some brachiopods are preserved in life position (*Cancrinella*). Brachiopod coquinas (storm beds) at 0.20 m, 0.30 m, and 0.40 m above the base. These coquinas are disrupted by burrowing. Some bedding planes show darker coloured gently plunging and randomly curved burrows identified as *Planolites*.

Unit K4/7 Interval 7.60–7.90 m Thickness 0.30 m

Bed no. 7. Tolstyi Stul Siney Plity (‘Thick Chair of the Blue Plate‘) of Noinsky (1899, 1924).

Dolostone: calcareous, moderately argillaceous, yellowish grey with bluish mottles, fine-grained, rich in void-filling bluish large celestine crystals. Laterally grading into grey coloured recessive fissile calcareous marl. The marl facies contain cm-thick resistant limestone beds and lenses with shell coquinas and erosional surfaces indicative of tempestite rhythmicity. Macrofossils: bivalves, brachiopods of genera *Cancrinella*, *Aulosteges*, *Stenoscisma*, *Crurithyris*, and branching bryozoans.

Unit K4/8 Interval 7.90–8.30 m Thickness 0.40 m

Bed no. 8. Sinyaya Plita (‘Blue Plate‘) of Noinsky (1899, 1924).

Dolostone to limestone: bluish grey (hence the historic name Sinyaya plita), fine-grained, weathering rusty. The lower part is hard and monolithic, locally composed of weakly fissile bluish grey limestone. This limestone shows low-contrast sedimentary rhythmicity (bioclastic-micritic graded beds). The upper part is more argillaceous and slightly more recessive. Fossils: ostracods, fragmented brachiopods *Cancrinella cancrini* (Vern.), crinoid ossicles, ichthyolites, charophyte remains. Conodonts *Stepanovites meyeni* Kozur et Movsh.

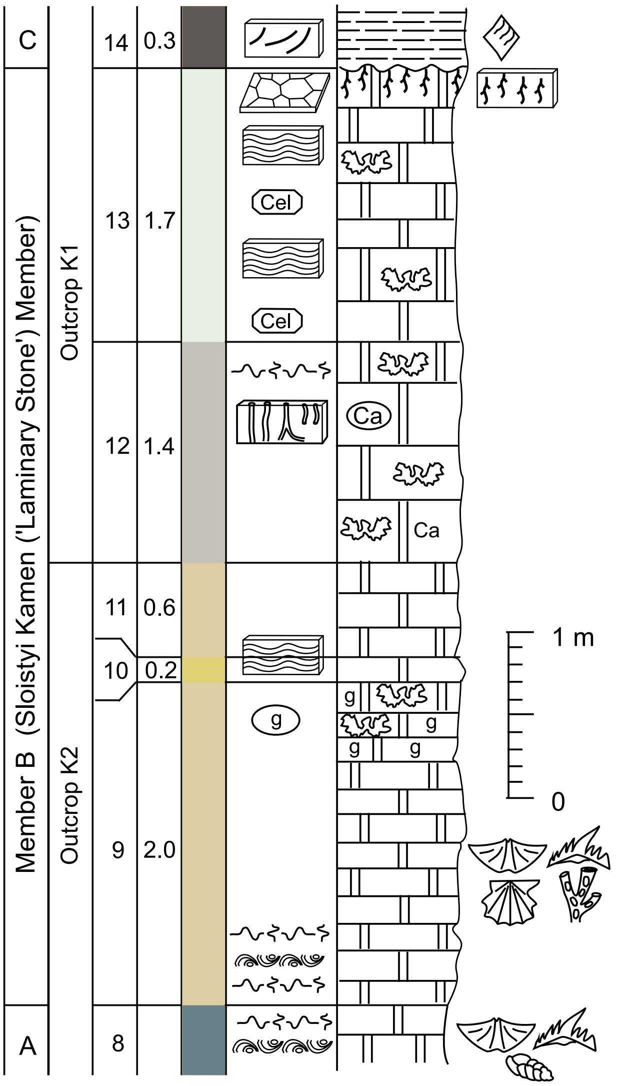
The overlying succession is more conveniently observed in outcrop K2.

Outcrop K4. Dolostone laterally graded into grey coloured recessive fissile calcareous marl. The marl facies contains cm-thick resistant limestone beds and lenses with shell coquinas and erosional surfaces indicative of tempestite rhythmicity

Pechishchi Section

Outcrops K1 and K2

Sloistyi Kamen •'Laminary Stone' • Member (B)



Outcrop K2. General view of the outcrop

Outcrop K2

GPS: 55,78283 N; 048,95148 E (WGS84). Datum: back (western) yard of the Flour milling plant at 58.0±3 m ASL. The right bank of the Volga River adjoining to the plant and bounding it from the north. The Upper Kazanian is exposed along the bank of the river at the distance over 100 m from bed no. 8, Sinyaya Plita ('Blue Plate') of Noinsky (basement lying at 58.0±3 m ASL) up to the upper part of the Podluzhnik Member ('Stone lying under the meadow' Member). The top of the Podluzhnik forms a terrace on the right bank of the Volga River at 100.0±3 m ASL.

Member B (Sloistyi Kamen ('Laminary Stone') Member)

Unit K2/9 Interval 8.30–10.30 m Thickness 2.00 m

Bed no. 9. Chetyre Rubtsa ('Four Seams') of Noinsky (1899, 1924).

Dolostone: pale grey, calcareous, fine-grained, tight and hard, with locally preserved bioclastic texture. The unit consists of four beds (hence the historic name Chetyre Rubtsa). The lower two beds contain unsorted, up to 6 mm in size, skeletal material that locally dominates the rock texture. The lower 0.5 m of the unit locally preserves graded bioclastic beds indicating its facies unity and conformable relation with the underlying bed no. 8. The upper part contains gypsum nodules and cavities left by their dissolution. Fossils: bivalves of the genera *Nuculana, Lithophaga, Pseudobakewellia, Schizodus, Permophorus, Pseudomonotis, Solemya, Alula*; brachiopods of the genera *Cancrinella, Pinegathyris*, and *Beecheria*; branching bryozoans and conodonts *Stepanovites meyeni* Kozur et Movsh.

Unit K2/10 Interval 10.30–10.50 m Thickness 0.20 m

Bed no. 10. Voshchanaya Plita ('Waxed Plate') of Noinsky (1899, 1924).

Dolostone: yellowish grey, hard and tight, breaking along smooth to gently conchoid surfaces, locally showing thin undulating bedding. No fossils.

Unit K2/11 Interval 10.50–11.10 m Thickness 0.60 m

Bed no. 11. Sukhoi Rubets ('Dry Seam') of Noinsky (1899, 1924).

Dolostone: pale grey, calcareous, microporous, soft, finely crystalline, medium bedded, preserving non-sorted (up to 2 mm in size) bioclasts showing predominant horizontal orientation.

The overlying succession is described in outcrop K1.

Outcrop K1. Unit K1/13, dolostone with "teepee" structure (A); (B) general view of the boundary between Member B (Sloistyi Kamen ('Laminary Stone') Member), unit K1/13 and Member C (Podboi Member), unit K1/14, Rukovodyashchaya Glina ('Marker shale') of Noinsky (1899, 1924)

Outcrop K1

GPS: 55,78263 N; 048,94973 E (WGS84). Datum: the right bank of the Volga River adjoining the back (western) yard of the Flour milling plant; 40 m west of outcrop K2 (up the stream). The base of package K1/12 occurs at 61.0±3 m ASL.

Unit K1/12 Interval 11.10–12.50 m Thickness 1.40 m

Bed no. 12. Rakovistyi Rubets (‘Hollowed Seam‘) of Noinsky (1899, 1924).

Dolostone: dull grey, finely crystalline, of medium hardness, cavernous, with rusty ferruginous crusts produced on weathered surfaces and geodes of ferruginised calcite crystals. Unconfirmed presence of poorly preserved biomolds up to 1.5 mm in size. Polished slabs show calcimudstone texture with variously preserved horizontal microlamination and vertical *Scolithos* burrows, at the top more bioturbated with small curved burrows. Locally, dolostone grades into dark grey crystalline limestone likely representing dedolomite.

Unit K1/13 Interval 12.50–14.20 m Thickness 1.70 m

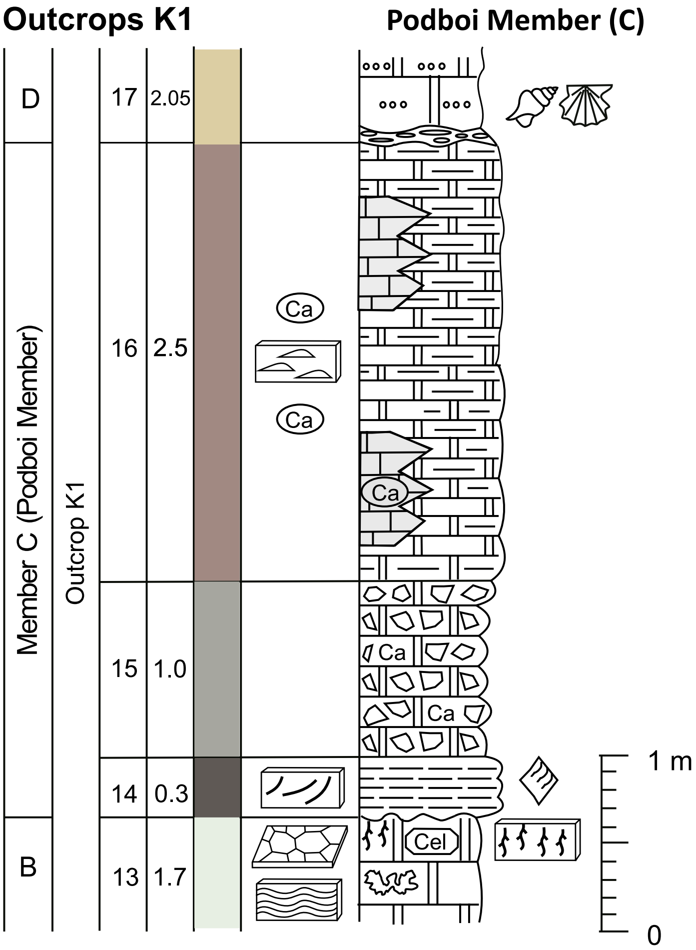
Bed no. 13. Sloistyi or Belyi Kamen (‘Laminary or White Rock) of Noinsky (1899, 1924).

Dolostone: very pale grey (almost white), finely crystalline and microporous, soft, retaining fine lamination with occasional preservation of buckled and “teepee” structures and rip-up intraclastic breccias. The tidal-flat desiccation and buckled features become more important towards the unit top. Rare small (less than 0.5 mm) bioclasts. Celestine-filled and empty vugs after dissolved anhydrite / gypsum. The bed top is textured by desiccation polygons and root-like branching structures. No distinct alluvial shale coatings or stringers at the top despite the overlying shale (package K1/14).

Outcrop K1. Unit K1/13, dolostone with buckled structure forming rip-up intraclastic breccia (polished slab, natural size)

Pechishchi Section

Outcrops K1



Outcrop K1. The boundary between units K1/15 and K1/16, dolostone breccia and dolostone

<u>Pechishchi Beds</u>

Member C (Podboi Member)

Unit K1/14 Interval 14.20–14.50 m Thickness 0.30 m

Bed no. 14. Rukovodyashchaya Glina ('Marker shale') of Noinsky (1899, 1924).

Shale: greenish to brownish grey, ductile, intensely slickensided with coaly detritus and fish scales (*Palaeoniscum* sp.). From base to top the bed can be divided into three parts: 0–0.05 m – greyish brown shale with coaly detritus, rare fish scales, and poorly preserved shell fragments; small fragments of dolostone in the very base pointing to a moderate weathering of the underlying bed; 0.05–0.15 m – pigeon grey shale with brownish partings; 0.15–0.30 m – dark brownish grey shale with admixture of sooty material, intensely slickensided from the top.

Unit K1/15 Interval 14.50–15.50 m Thickness 1.00 m

Bed no. 15. Brekchiya Nizhnego Mylnika ('Breccia of Lower Soapstone') of Noinsky (1899, 1924).

Dolostone breccia: rubble of various hardness, non-bedded, locally cemented by calcite and partly converted into dedolomitic limestone. Polished slabs from dolostones fragments show horizontal lamination and several levels containing presumable *Scolithos* burrows.

Unit K1/16 Interval 15.50–18.00 m Thickness 2.50 m

Bed no. 16. Nizhniy Mylnik ('Lower Soapstone') of Noinsky (1899, 1924).

Dolostone: dull buff, probably argillaceous, microporous, of medium hardness, thin-bedded, retaining thin sedimentary lamination and calcimudstone texture with rare small biomolds; breaking into rhombohedral blocks. Contains small (2–3 mm) ovoid nodules of sparry calcite. The rock is locally dedolomitised into dark grey secondary calcite. A cavernous coarsely crystalline secondary limestone (apparently dedolomite) has been observed between outcrops K1 and K2.

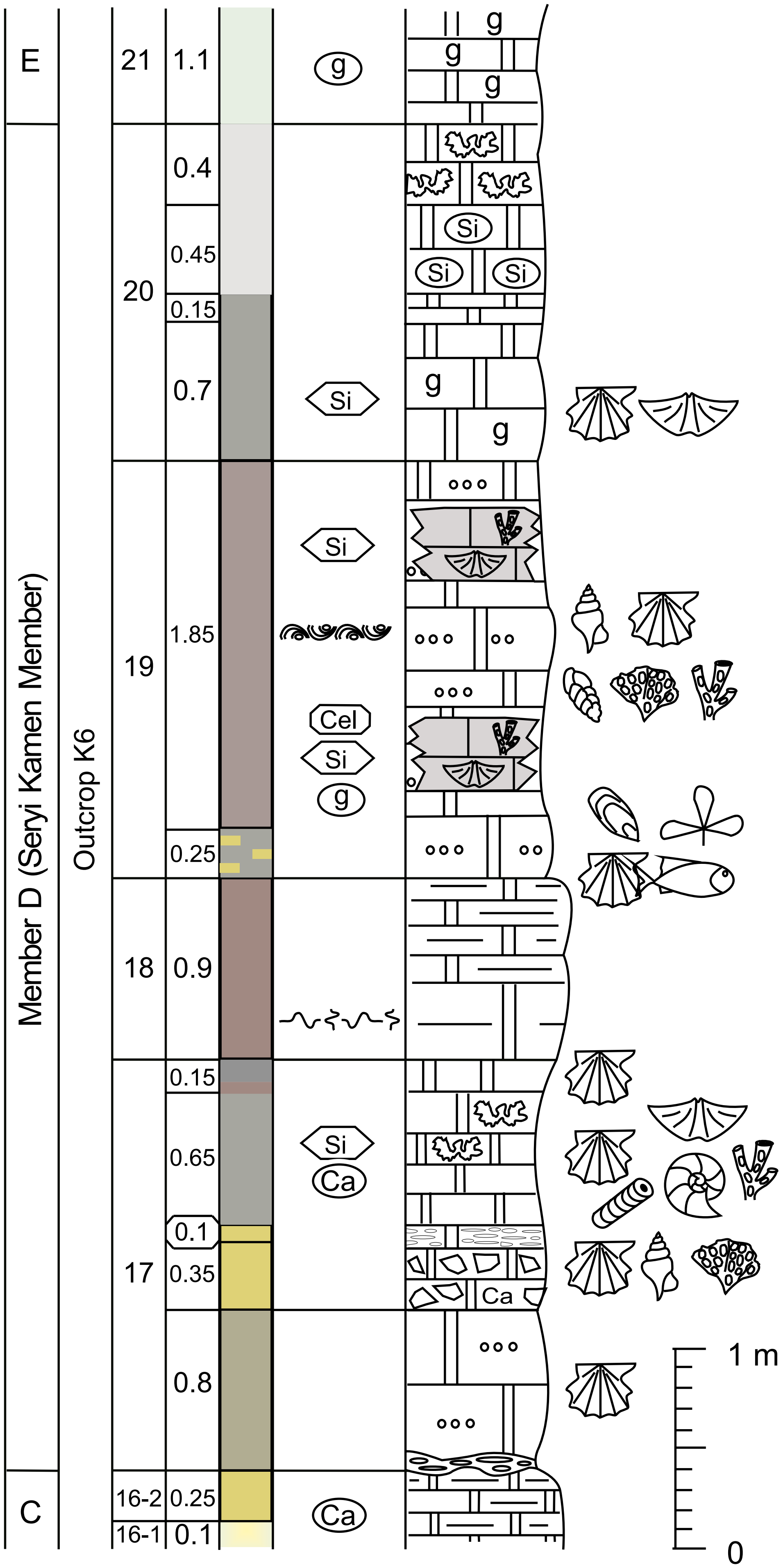
The overlying succession is described in outcrop K6 located near the mouth of the Cheremushka ('Bird Cherry') Gully.

Outcrop K1. Unit K1/15 , dolostone breccia converted into dedolomitic limestone

Pechishchi Section

Outcrops K6

Seryi Kamen • 'Grey Stone' • Member (D)



Outcrop K6

GPS: 55,78269 N; 048,92961 E (WGS84). Datum: river water level at 53.0±3 m ASL. The right bank of the Volga River 110–120 m east of the mouth of the Cheremushka Gully (downstream). Upper boundary of unit K6/16 (Member C, Podboi) is exposed directly above the towpath, 1.0 m above the river level and 54.0±3 m ASL.

Unit K6/16 Interval 17.65–18.00 m Thickness (visible) 0.35 m
Bed no. 16. Nizhniy Mylnik ('Lower Soapstone') of Noinsky (1899, 1924).
Here the upper 0,35 m of unit 16 is described as hard pale yellowish grey fine-grained dolostone (17.65–17.75 m) grading upwards into grey thin-bedded fine-grained dolostones with molds after bivalve shells (17.75–18.00 m). In polished slabs, retains fine-grained laminated ooid grainstone texture.

Member D (Seryi Kamen ('Grey Stone') Member)

Unit K6/17 Interval 18.00–20.05 m Thickness 2.05 m
Bed no. 17. Nizhniy Peschanyi Kamen ('Lower Sandy Stone') of Noinsky (1899, 1924).
Dolostone: grey to yellowish, buff, very fine grained and finely crystalline (0.2 mm) idiotopic, seemingly impregnated with organic matter, microporous, relatively soft; locally retains ooidal and bioclastic-ooidal texture and inclined to horizontal lamination sets; the ooids are sometimes internally leached. Brecciation and small (up to 8 mm) pebbles of carbonate rocks in the middle (1.0–1.25 m from base). The upper part above the pebble horizon shows numerous bivalves and vugs. Numerous macrofossils, preserved as biomolds: gastropods *Goniasma* and *Baylea*, bivalves *Schizodus*, nautiloids, brachiopods *Aulosteges wangenheimi* (Vern.), *Cleiothyridina pectinifera* (Sow.), and *Beecheria* sp., fenestellid and branching bryozoans, and crinoid ossicles. The erosional base (ravinement) locally hosts conglomerate with small dolostone and dolomarl pebbles. At the top buff dolostone, moderately argillaceous.

Unit K6/18 Interval 20.05–20.95 m Thickness 0.90 m, off-station locally increases to 2.0 m.
Bed no. 18. Verkhniy Mylnik ('Upper Soapstone') of Noinsky (1899, 1924).
Dolostone: argillaceous and buff-coloured, microporous, thick-bedded and grading at the top into thin-bedded, showing characteristic rhombohedrical jointing and lenticular pattern. In polished slabs, vague horizontally trending features may be an expression of primary lamination or lithostatic compaction. Diverse macrofauna, encountered only in the uppermost part: the bivalves (molds) *Pseudomonotis (Trematiconcha) noinskyi* (Lich.), *Pseudomonotis (Pseudomonotis) permianus* Masl., *Solemya (Janeia) biarmica* (Vern.), *Parallelodon kingi* Vern., spines and shell fragments of *Cancrinella*, fish scales of *Platysomus* sp., *Acentrophorus varians* Kirkby, *Kasanichthys* sp., the inarticulate brachiopods *Orbiculoidea konincki* (Gein.), and *Conularia hollebeni* (Gein.) (the only occurrence of conularians in the section), branched trace fossils *Palaeophycus insignis* (Gein.). The unit seems to laterally grade into fine-grained ('sandstone-like') dolostones similar to packages above and below.

Unit K6/19 Interval 20.95–23.05 m Thickness 2.10 m
Bed no. 19. Verkhniy Peschanyi Kamen ('Upper Sandy Stone ') of Noinsky (1899, 1924).
Dolostone: grey, very fine-grained ('sandstone-like'), locally mottled, medium to thick bedded. Nodules and secondary open-space large crystals of gypsum. From base to top: grey and yellow-mottled, weakly fissile dolostone with faintly laminated mudstone texture (0.00–0.25 m); brownish grey thick-bedded dolostone with fissile top, partly cross-laminated, showing fine-grained bioclastic-oolitic grainstone texture (0.25–2.10 m). Two bivalve horizons at 0.30–0.40 m and 1.35–1.40 m above the base. Gastropod and bivalve molds are locally abundant, some of them filled by gypsum and chert. Local presence of 1–2 m thick partly dolomitised buildups with bryozoan framework and massive ooidal-bioclastic matrix. Frame-building bryozoans: *Tabulipora ordinata* Moroz., *Fenestella permulta* Moroz. and other species. Other fauna in buildups: *Aulosteges wangenheimi* (Netsch.), *Pseudomonotis garforthensis* (King), foraminifers.

Unit K6/20 Interval 23.05–24.75 m Thickness 1.70 m

Bed no. 20. Seryi Kamen (‘Grey Stone‘) of Noinsky (1899, 1924).

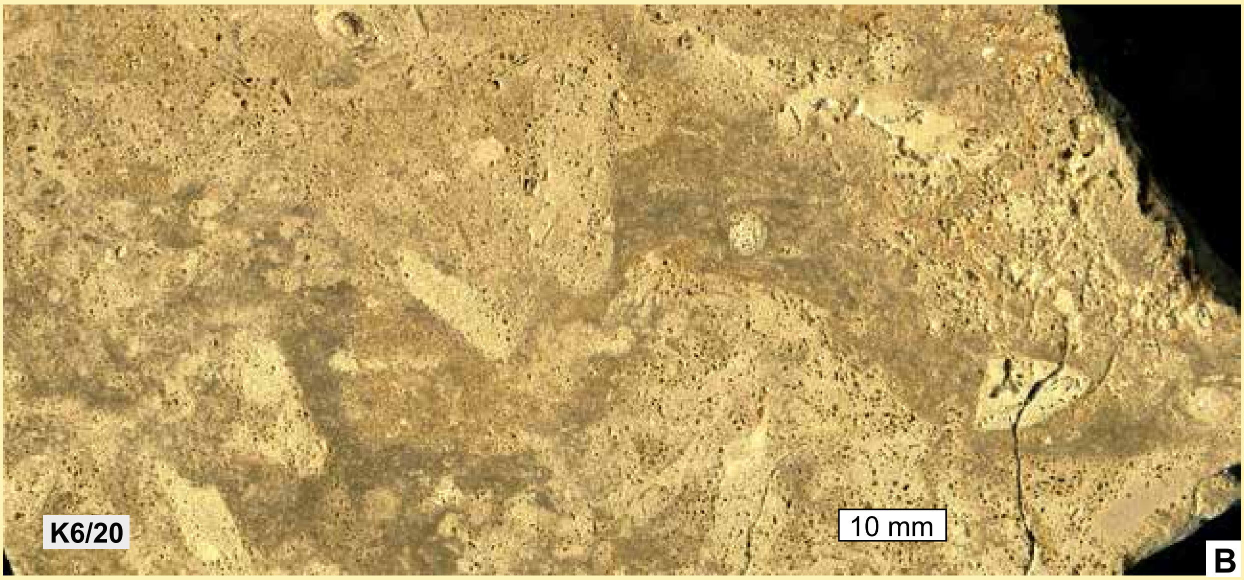
Dolostone: grey, fine-grained, tight to locally vuggy, partly chertified and dedolomitised into a crystalline limestone. The base yields rare bivalves *Nuculana kasanensis* (Vern.), *Pseudomonotis (Ps.) permianus* Masl., *Pseudobakewellia ceratophagaeformis* Noin., the brachiopods *Cancrinella cancrini* (Vern.), *Cleiothyridina pectinifera* (Sow.), *Beecheria netschajewi* Grig., and branching bryozoans. The upper part (0.85–1.30 m) bears numerous ellipsoidal chert nodules (0.30 x 0.40 m) and quartz druses; the 40 cm at the top is notably vuggy, with gypsum nodules.

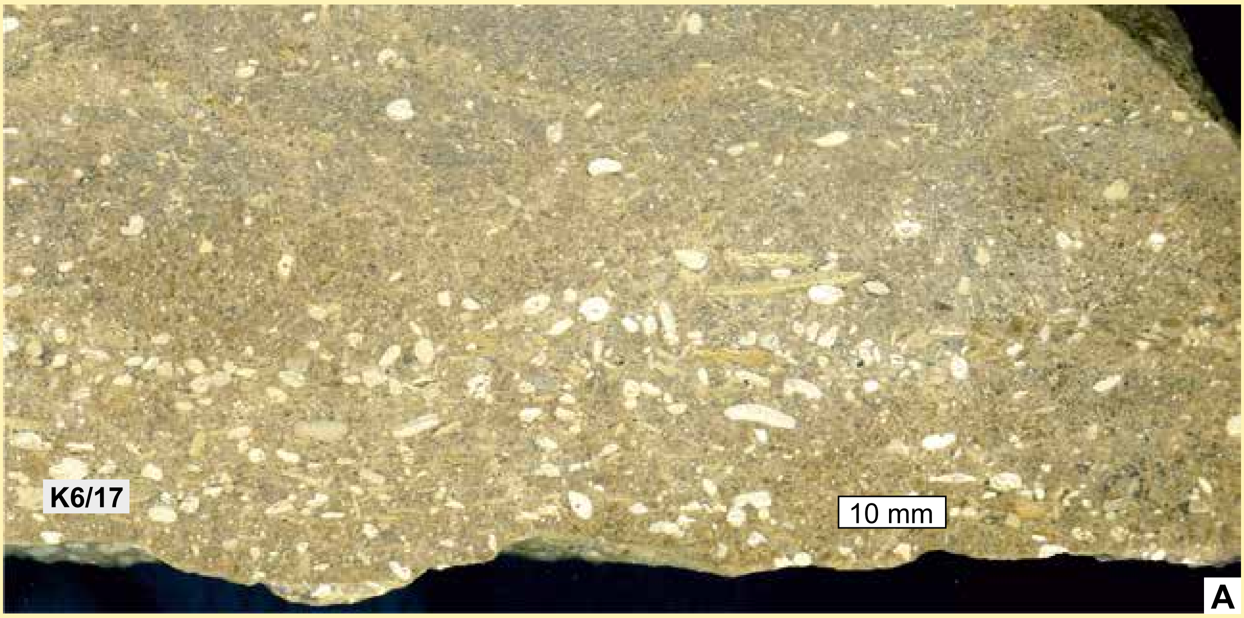
Member E (Shikhany Member)

Unit K6/21 Interval 24.75–26.45 m Thickness (visible) 1.70 m

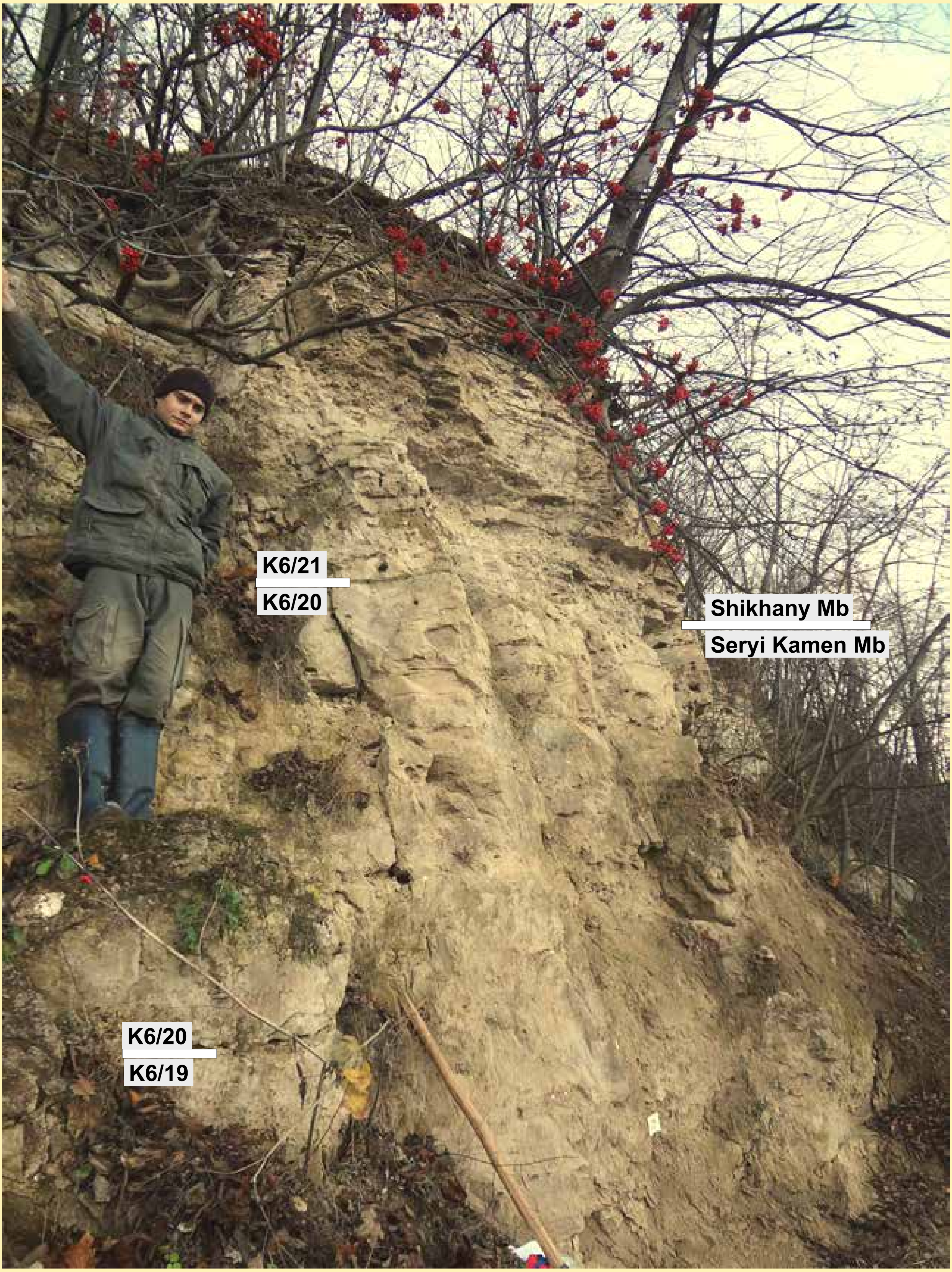
Bed no. 21. Shikhany of Noinsky (1899, 1924).

Dolostone: white to pale grey, unevenly crystalline, porous, relatively hard, with thin buckled lamination, rich in granules, nodules and flakes of gypsum (originally anhydrite). The latter locally dominates the rock in the upper part of the unit. Some rock slabs show, typical for sabkha, chickenwire fabric with gypsum nodules displacing and contorting dolomite partings. The rock is vuggy and soft where the gypsum is weathered out. Gypsum nodules contain celestine crystals. Common elliptical chert nodules. The bed top textured by desiccation polygons.





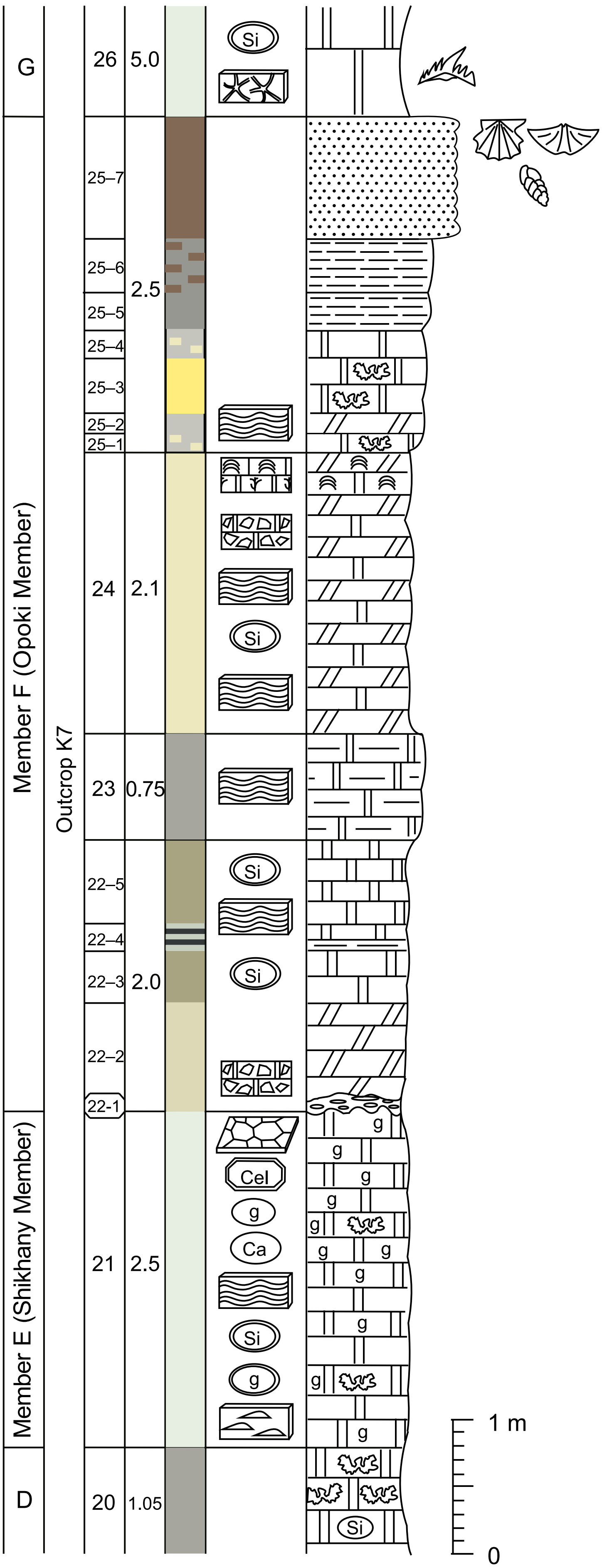
Outcrop K6. Unit K6/17, dolostone with small (up to 8 mm) pebbles of carbonate rocks (A); (B) unit K6/20, dolostone with high level of bioturbation (polished slabs)



Outcrop K6. General view of the upper part of the outcrop

Pechishchi Section
Outcrops K7

Shikhany Member (E) and Opoki • 'Silica Clay' • Member (F)



Outcrop K7

GPS: 55,7870 N; 048,96159 E (WGS84). Datum: the right slope of the Telegraphnyi ('Telegraph') Gully near its mouth. Uppermost beds of Member D (Seryi Kamen ('Grey Stone') Member) and the whole succession of Member E (Shikhany Member) form rocky exposures in the middle of the slope. The overlying Member F (Opoki Member) is accessible in vertical cutting for approx. 8 m. Slightly beneath the edge of the slope, relatively soft deposits of Member F (Opoki Member) are overlain by hard dolostones of Member G (Podluzhnik ('Stone lying under the meadow') Member). The lower boundary of unit K7/21 (Shikhany Member) is exposed in 70.0±3 m ASL.

Member E (Shikhany Member)

Unit K7/21 Interval 24.75–27.25 m Thickness 2.50 m
Bed no. 21. Shikhany of Noinsky (1899, 1924).
Dolostone: the same as in unit K6/21.
Complete thickness of Member E (Shikhany Member) varies from 2 to 4 m.

<u>Verkhnyi Uslon Beds</u>

Member F (Opoki ('Silica Shales') Member)

Unit K7/22 Interval 27.25–29,25 m Thickness 2.00 m
Dolostones and marls with faint buckled lamination and local rip-up breccia. Base unconformable, erosional. The unit can be divided into five parts, from base to top:
Bed K7/22-1 [0.00–0.10] Interval 27.25–27.35 m Thickness 0.10 m
Conglomerate of flat subrounded clasts (up to 1 cm in size) of marls and shales in silty shale matrix, up to 20 cm in thickness, grading laterally to dolomarl with floating dolostone clasts.
Bed K7/22-2 [0.10–0.80] Interval 27.35–28.05 m Thickness 0.70 m
Dolomarl: soft pale, yellowish grey, locally with breccia fabric, in polished slabs showing faint buckled lamination.
Bed K7/22-3 [0.80–1.20] Interval 28.05–28.45 m Thickness 0.40 m
Dolostone: yellowish grey, resistant, with vugs and rusty staining in 25 cm from the base.
Bed K7/22-4 [1.20–1.40] Interval 28.45–28.65 m Thickness 0.20 m
Alternation of pale grey dolostones and dark grey dolomarls forming 2–3 cm thick laminae; the dark grey laminae contain sooty organic matter.
Bed K7/22-5 [1.40–2.00] Interval 28.65–29.25 m Thickness 0.60 m
Dolostone: yellowish grey, with small (2–3 cm) chert nodules in the middle, enriched in horizontally oriented bioclasts.

Unit K7/23 Interval 29.25–30.00 m Thickness 0.75 m
Dolostone: grey, argillaceous, locally with fine sand admixture, fine-grained, with faint undulating lamination, with rare bioclasts, with shale 2–3 cm thick seams in the middle. Polished slabs from the base show very fine-grained laminated oolitic texture with rare bioclasts. The main part of the bed above the base shows mudstone texture. No fossils.

Unit K7/24 Interval 30.00–32.10 m Thickness 2.10 m
Dolomarl-dolostone alternation: yellowish grey, recessive dolomarls are darker and resistant dolostones are lighter coloured. Dolostones are mostly soft, locally cherty, include 2–3 cm thick beds of harder fragile partly cherty dolostones. A 10 cm thick cherty stromatolithic dolostone at the top. Polished slabs show fine grainy texture and levels of buckled lamination with teepee structures.

Unit K7/25 Interval 32.10–34.60 m Thickness 2.50 m

Dolostone: grey, argillaceous, very fine-grained, finely fractured, with ferruginised fracture planes, more argillaceous and grading to sandstone at the top. The upper sandstone locally hosts numerous bivalve and brachiopod valves. Bivalves: *Pseudobakewellia, Pseudomonotis*. Brachiopods: *Cancrinella, Rhynchopora, Cleiothyridina.* Foraminifers: *Glomospira, Ammodiscus, Pseudoammodiscus*.

The unit can be divided into seven parts, from base to top:

Bed K7/25-1 [0.00–0.15] Interval 32.10–32.25 m Thickness 0.15 m

Dolostone: grey-yellowish, locally vuggy.

Bed K7/25-2 [0.15–0.30] Interval 32.25–32.40 m Thickness 0.15 m

Dolomarl: grey, fissile.

Bed K7/25-3 [0.30–0.70] Interval 32.40–32.80 m Thickness 0.40 m

Dolostone: bright yellow, probably sandy, with fine wavy lamination, locally vuggy and fractured.

Bed K7/25-4 [0.70–0.90] Interval 32.80–33.00 m Thickness 0.20 m

Hard recessive yellowish grey dolostone with faint wavy lamination and no fossils.

Bed K7/25-5 [0.90–1.20] Interval 33.00–33.30 m Thickness 0.30 m

Shale: dark grey, crumbly.

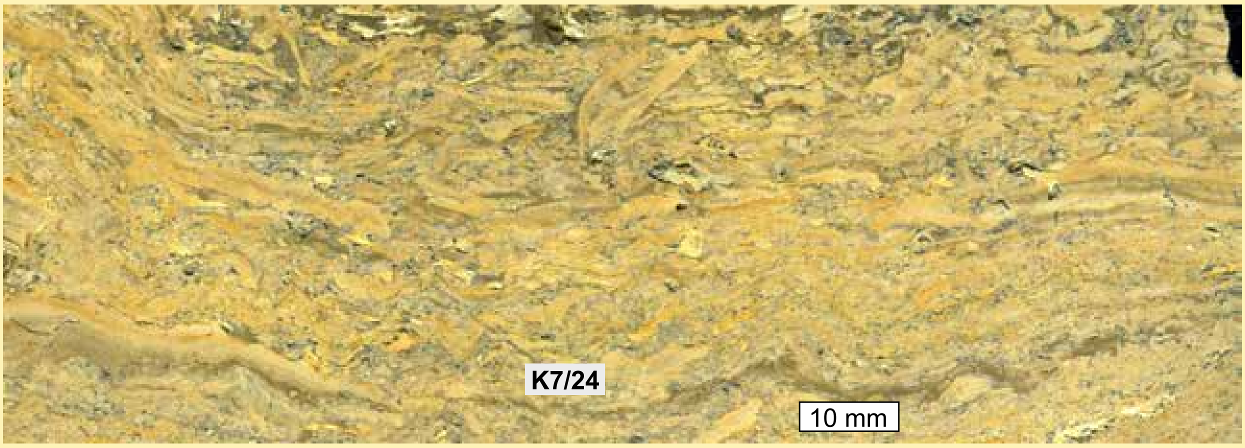
Bed K7/25-6 [1.20–1.60] Interval 33.30–33.70 m Thickness 0.40 m

Shale: dark buff, sandy, fissile and laminated with ferruginous Liesegang rings.

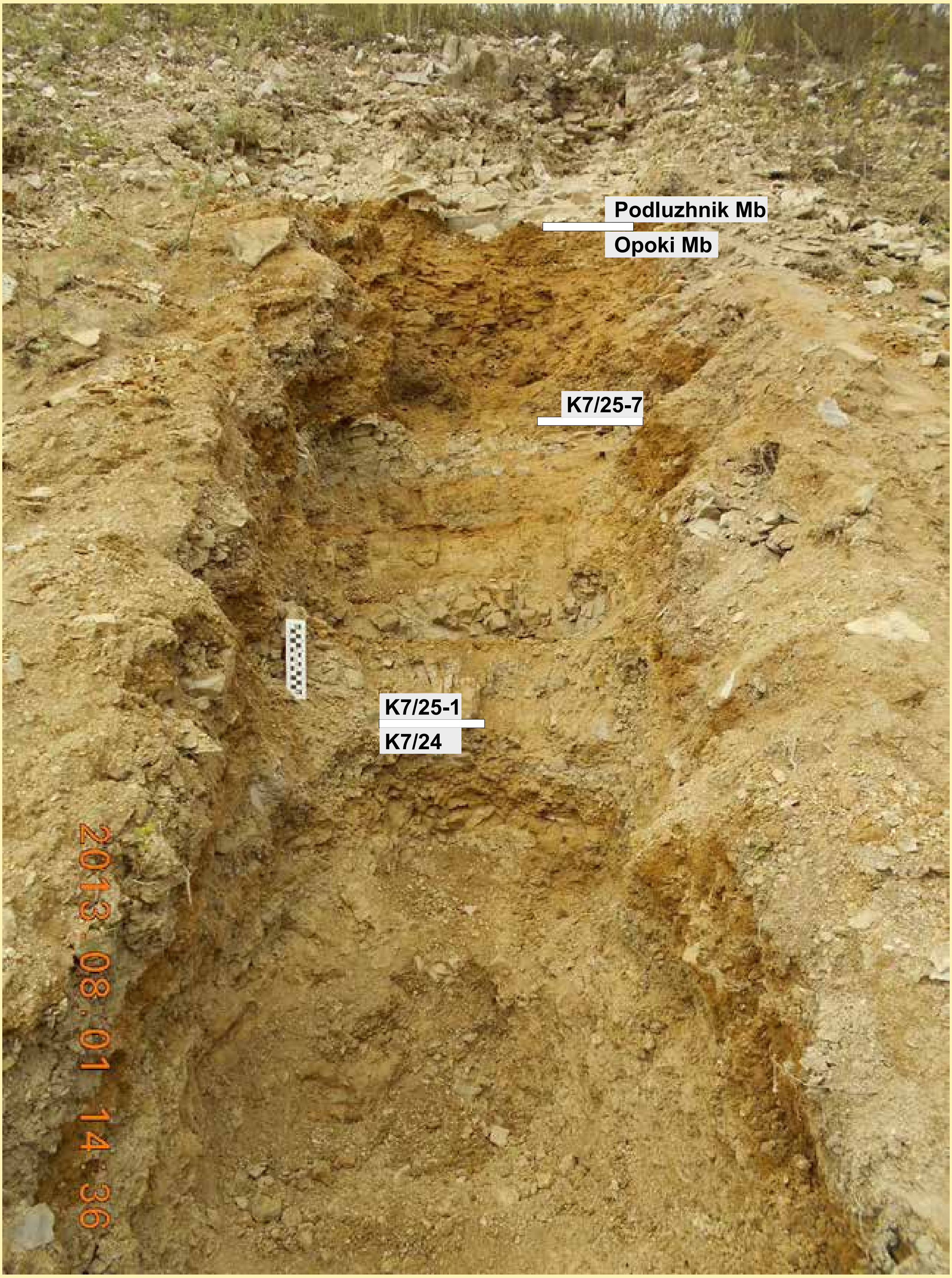
Bed K7/25-7 [1.60–2.50] Interval 33.70–34.60 m Thickness 0.90 m

Sandstone: buff, poorly lithified, with grey argillaceous seams.

The unit is overlain by the moderately slumped dolostone of the Podluzhnik Member (1.30 m) and the soil profile on the gully ledge. Total thickness of Member F (Opoki (‘Silica Shales’) Member) is 7.35 m. The overlying succession is described in outcrop K5 located on the right bank of the Volga River near the mouth of the Cheremushka (‘Bird Cherry’) Gully.



Outcrop K7. Unit K7/24, chertified stromatolithic dolostone with buckled lamination and teepee structures (polished slab)

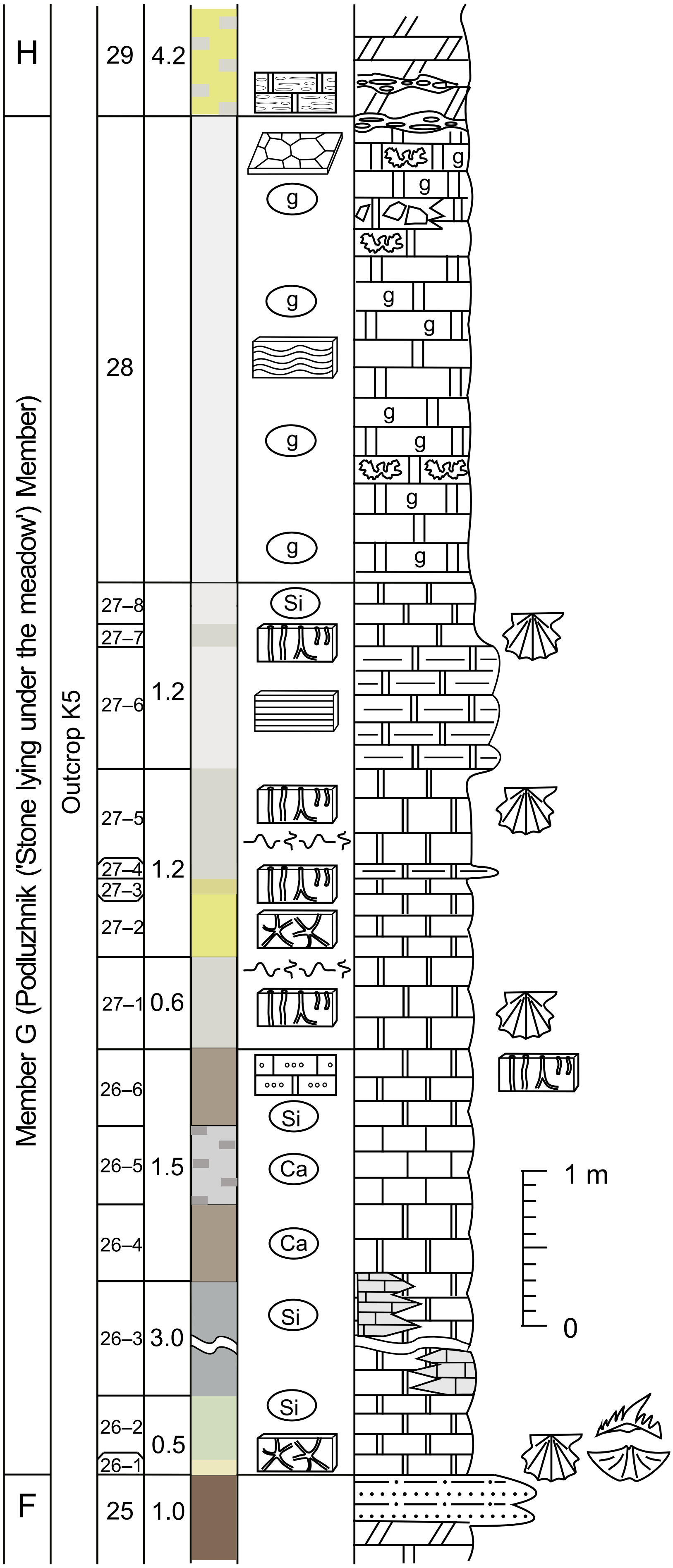


Outcrop K7. Uppermost beds of Member F (Opoki (‘Silica Shales’) Member) and its contact with Member G (Podluzhnik (‘Stone lying under the meadow’) Member)

Pechishchi Section

Outcrops K5

Podluzhnik • 'Stone lying under the meadow' • Member (G)



Outcrop K5

GPS: 55,78249 N; 048,92585 E (WGS84). Datum: the right bank of the Volga River, the middle part of the slope, 180 m west of the mouth of the Cheremushka (‘Bird Cherry’) Gully. Uppermost beds of Member F (Opoki (‘Silica Shales’) Member) and the whole succession of Member G (Podluzhnik (‘Stone lying under the meadow’) Member) and Member H (Perekhodnaya (‘Transitional’) Member) are exposed in the middle of the slope. The overlying Urzhumian deposits are accessible in vertical cutting for approx. 10 m. The upper boundary of unit K5/25 (Member F (Opoki)) is exposed in 78.0±3 m ASL.

Verkhnyi Uslon Beds

Member F (Opoki (‘Silica Shales’) Member)

Unit K5/25 Interval 33.60–34.60 m Thickness (visible) 1.00 m
Sandstone: buff, poorly lithified with grey argillaceous seams. The same as in subunit K7/25-7.

Member G (Podluzhnik (‘Stone lying under the meadow’) Member)

Unit K5/26 Interval 34.60–39.60 m Thickness 5.00 m
Dolostone: pale grey, argillaceous, thick-bedded, with chert nodules. Bivalves preserved as casts and impressions: *Nuculana, Schizodus, Netschajewia, Pseudomonotis*. Brachiopods: *Cancrinella, Beecheria, Spiriferellina, Odontospirifer*. Fish scales and conodont elements of the genus *Kamagnathus*. The unit can be subdivided into six parts, from base to top:

Bed K5/26-1 [0.00–0.10] Interval 34.60–34.70 m Thickness 0.10 m
Dolostone: yellowish grey, finely crystalline, with abundant remains of brachiopods, bryozoans, and mollusks, with trace fossils *Palaeophycus insignis* (Gein.).

Bed K5/26-2 [0.10–0.50] Interval 34.70–35.10 m Thickness 0.40 m
Dolostone: pale grey, finely crystalline, with cyan hue.

Bed K5/26-3 [0.50–3.50] Interval 35.10–38.10 m Thickness 3.00 m
Dolostone: grey, recessive recrystallised, preserved as rubble.

Bed K5/26-4 [3.50–4.00] Interval 38.10–38.60 m Thickness 0.50 m
Dolostone: brownish grey, resistant, finely crystalline, split by numerous fractures filled with calcite spar.

Bed K5/26-5 [4.00–4.50] Interval 38.60–39.10 m Thickness 0.50 m
Dolostone: pale grey, mottled, finely crystalline, with mottling imparted by uneven hardness and crystallinity.

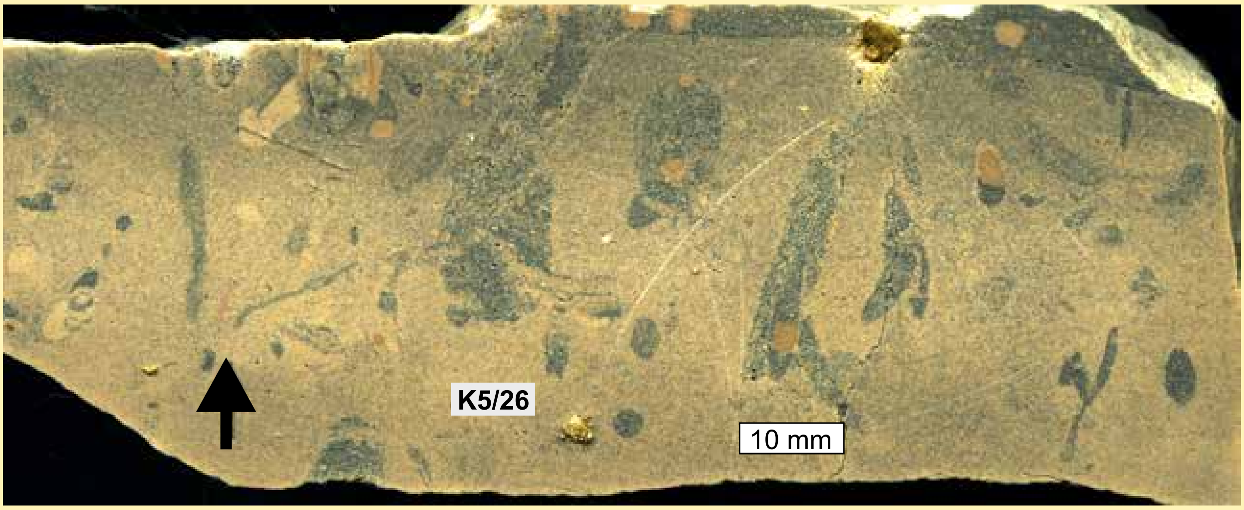
Bed K5/26-6 [4.50–5.00] Interval 39.10–39.60 m Thickness 0.50 m
Dolostone: brownish grey, resistant, unevenly crystalline, with 5–10 cm thick bedding, bluish and brownish chert nodules in the middle, with partly preserved laminated ooidal grainstone texture and *Scolithos* burrows in the upper part.

Unit K5/27 Interval 39.60–42.60 m Thickness 3.00 m
Dolostone: pale grey, microcrystalline, locally clotted, with chert horizons; alternation of massive and laminated intervals, the latter showing ripple marks on bedding planes. Cherts preserve sedimentary texture of birds-eye micritic laminite; cherts at 2.80–2.85 m from the base contain bivalves and probably foraminifers.
The unit can be subdivided into six parts, from base to top:

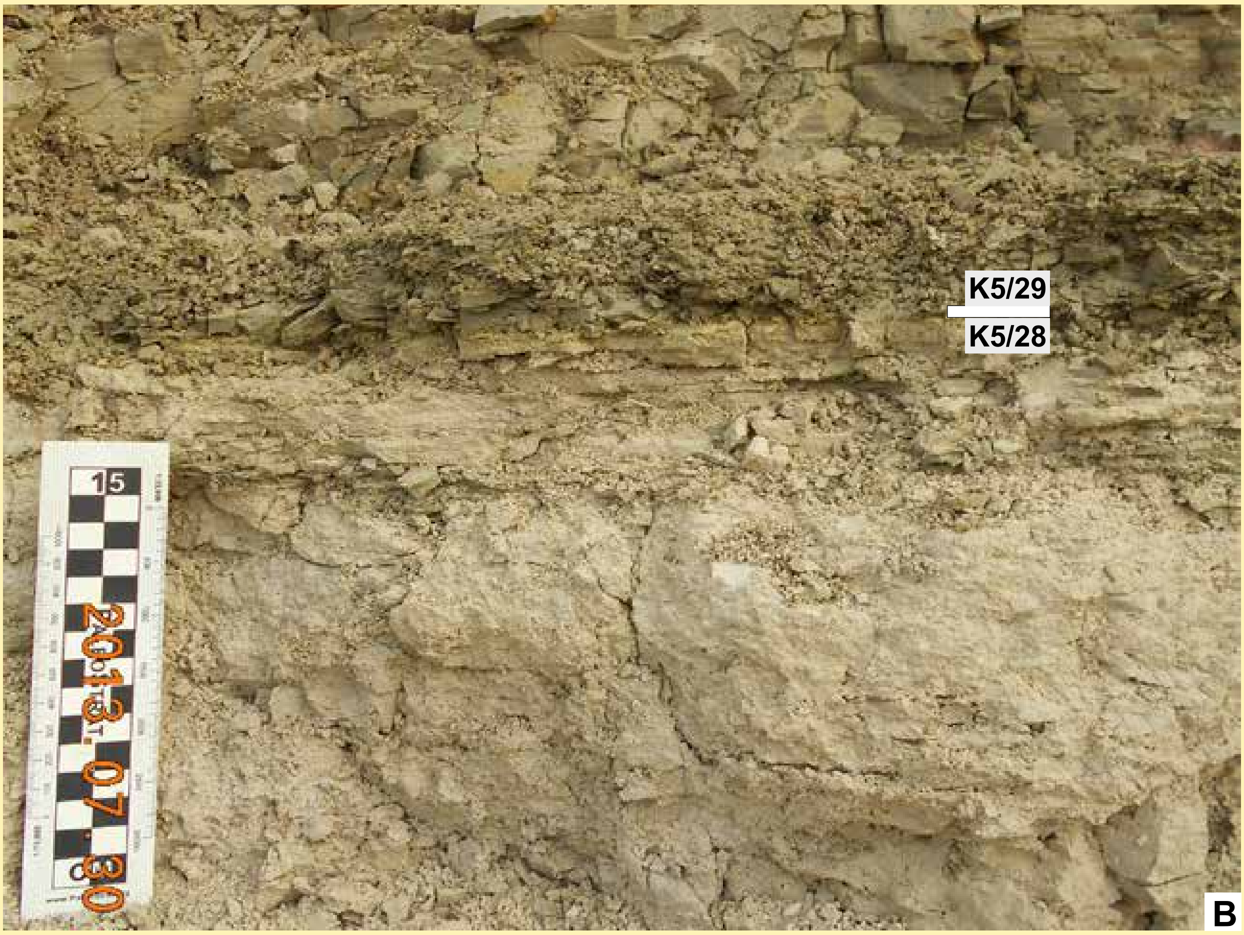
Bed K5/27-1 [0.00–0.60] Interval 39.60–40.20 m Thickness 0.60 m
Dolostone: grey, resistant, thick-bedded (20 cm), with conchoid fracturing, with preserved cross-lamination at the base and massive at the top, alternation of calcimudstone and very fine-grained ooid grainstone; rare *Pseudomonotis* presumably preserved in life position and vertical and shallow plunging burrows 3–5 mm in diameter.

Bed K5/27-2 [0.60–1.00] Interval 40.20–40.60 m Thickness 0.40 m
Dolostone: pale yellowish grey, mudstone sedimentary texture, with burrows *Palaeophycus insignis* up to 5 mm in diameter and a system of vertical and curved burrows with oval section about 2 mm in average diameter.
Bed K5/27-3 [1.00–1.10] Interval 40.60–40.70 m Thickness 0.10 m
Dolostone: pale yellowish grey, resistant, with rare bivalve molds and horizontal disrupted lamination.
Bed K5/27-4 [1.10–1.20] Interval 40.70–40.80 m Thickness 0.10 m
Dolostone: grey, argillaceous, with thin *Scolithos* burrows penetrating from the top.
Bed K5/27-5 [1.20–1.80] Interval 40.80–41.40 m Thickness 0.60 m
Dolostone: very similar to bed K5/27-1 (interval 0.00–0.60 m), with rare bivalve and brachiopod molds.
Bed K5/27-6 [1.80–2.60] Interval 41.40–42.20 m Thickness 0.80 m
Dolostone: grey, argillaceous, moderately fissile to thin-bedded.
Bed K5/27-7 [2.60–2.75] Interval 42.20–42.35 m Thickness 0.15 m
Dolostone: very similar to bed K5/27-1 (interval 0.00–0.60 m), with rare bivalve and brachiopod molds.
Bed K5/27-8 [2.75–3.00] Interval 42.35–42.60 m Thickness 0.25 m
Dolostone: grey, notably hard, recessive, with large (10 x 30 cm) nodules of grey and bluish grey laminated chert.
The overlying succession is described 25 m west in vertical cutting for approx. 3 m.

Unit K5/28 Interval 42.60–45.60 m Thickness 3.00 m
Dolostone: pale grey, microcrystalline, fragile, massive to microlaminated, rich in seams and nodules of white and pinkish gypsum; vuggy and locally disintegrated into powder where the gypsum is weathered out. The top is textured by desiccation polygons; the uppermost 0.15 m contains solution breccias and flat-pebble intraclastic conglomerates.



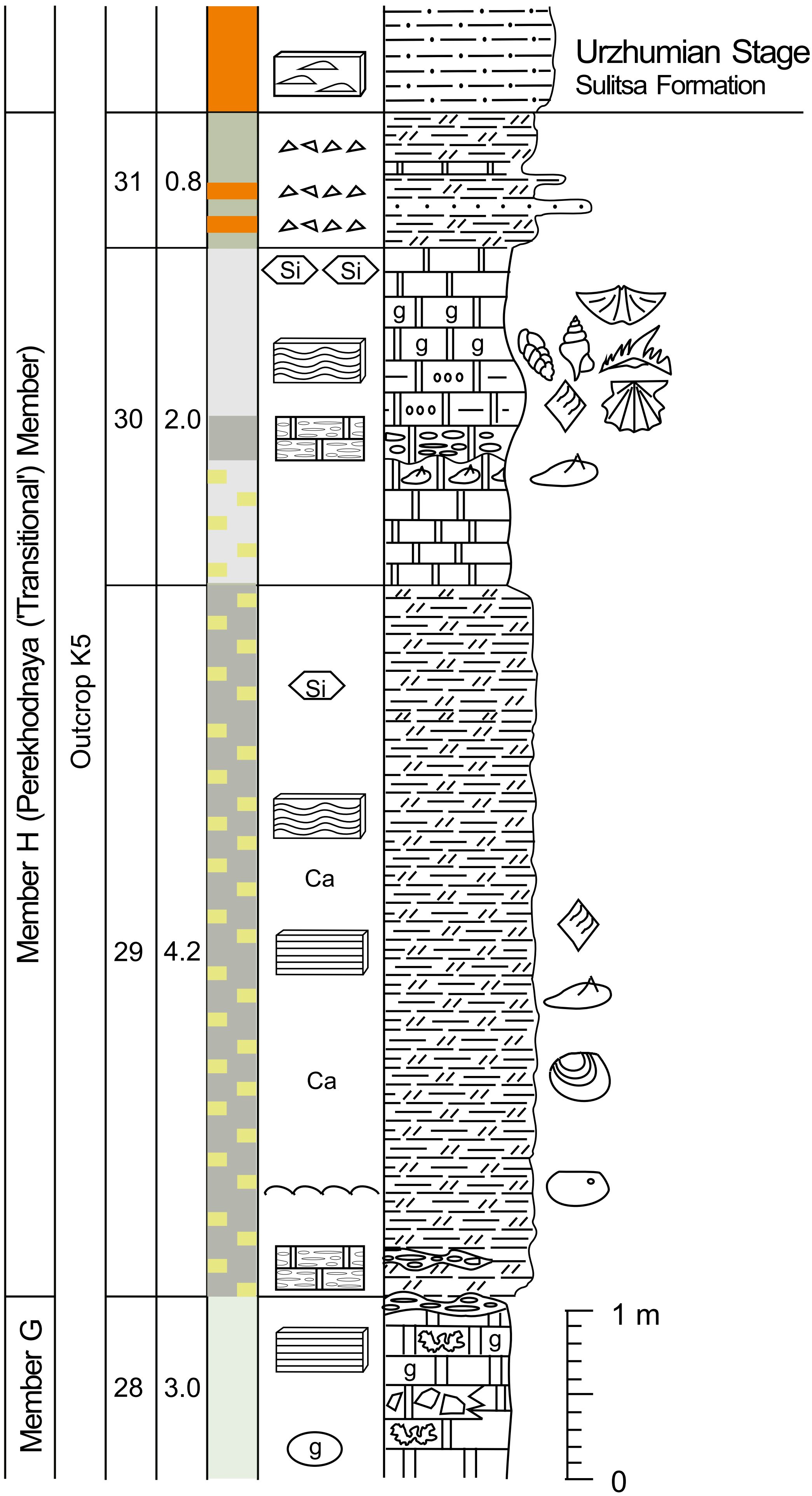
Outcrop K5. Bed K5/26-1, dolostone with vertical trace fossils (polished slab)



Outcrop K5. General view of the outcrop (A); (B) the boundary between Member G (Podluzhnik ('Stone lying under the meadow') Member) and Member H (Perekhodnaya ('Transitional') Member)

Pechishchi Section

Outcrops K5



Morkvashi Beds

Member H (Perekhodnaya ('Transitional') Member)

Unit K5/29 Interval 45.60–49.80 m Thickness 4.20 m

Dolomarl: mottled yellowish grey, microcrystalline (dolomudstone), with dolostone conglomerates in basal 10–20 cm. The upper half shows low-contrast alternation of recessive dolomarls and resistant argillaceous dolostones. The rock shows fine undulating lamination defined by slim shale partings. A thin (3–4 cm) graded bed enriched in fine-grained (0.1–0.3 mm) bioclasts and polymicric sand at 0.6–0.7 m above the base. Fossils: conchostracans, non-marine ostracods *Palaeodarwinula, Prasuchonella*, and other genera, non-marine bivalves *Palaeomutela*, fish scales, and plant detritus.

Unit K5/30 Interval 49.80–51.80 m Thickness 2.00 m

Dolostone: pale grey, microcrystalline, thick-bedded, partly sandy and argillaceous, with fine undulating lamination, slickensided. The basal part shows microbrecciation in polished slabs and contains the abundant non-marine bivalves *Palaeomutela*. The upper one-half of the unit hosts abundant marine fossils: the bivalves *Lithophaga* (= *Modiola*), *Schizodus*, *Pseudomonotis*, the brachiopods *Cancrinella*, *Beecheria*, and the conodonts *Kamagnathus volgensis* Chern. The occurrence of numerous *Lithophaga* (= *Modiola*) has defined the historic name '*Modiola Horizon*'.

The upper part of the unit contains nests of loose chalcedony-quartz rhombs, indicating the former presence of anhydrite nodules.

Unit K5/31 Interval 51.80–52.60 m Thickness 0.80 m

Dolomarl with interlayers of dolostone and packbreccia. In 15 cm above the chalcedony-quartz rhomb horizon, there is a 5–6 cm thick packbreccia of subrounded grey-coloured dolomite clasts embedded in red-coloured argillaceous matrix.The top of this breccia locally shows colour inversion to red clasts and gley matrix. Red-coloured clasts are also encountered at the base of this breccia. The breccia is overlain by a rounded-grain intraclastic calcarenite (1–2 cm), which is in turn succeeded by red shale and a second horizon of fine-grained argillaceous-dolomitic breccia, very similar in its appearance to the lower horizon.

The overlying succession presents Urzhumian red-stones similar to package P01/2 of Argillo-Arenaceous Member (Sulitsa Formation).

Outcrop K5. Unit K5/29, recessive dolomarl with fine lamination

Outcrop K5. Uppermost part of the outcrop, the Kazanian / Urzhumian boundary

Paleomagnetic studies

Paleomagnetic studies have been conducted by Kazan University since 1964. Pursuing the study of the Upper Permian and the Lower Triassic of the east of the East-European Platform, the scientists of the laboratory investigated in detail all magnetic zones of the Permian and revealed the complex structure of the Kiaman-Illawarra Hyperzone boundary (Burov et al., 1998).

The following main results of these magnetostratigraphic investigations, performed by the Laboratory of Paleomagnetism at Kazan University, are based on the unified standard complex of analysis permitting the most complete separation of components of residual magnetisation (Burov et al., 1986). The paleomagnetic studies involved are: a) study of the temperature dependence of induced magnetisation, b) study of coercive spectra for induced and residual magnetisation, c) analysis of J_n value and direction over a range from room temperature to Curie point, separation of components of magnetisation, d) temperature cleaning of all the specimens, e) analysis of variations of the J_n value and direction with linearly increasing alternating magnetic field strength.

Residual magnetisation has been measured on a computer-aided spinner magnetometer, arranged in large square coils which prevent substantial action of the geomagnetic field on the specimens. Statistical analysis of the results has been based on standard computer programs. Stereoscopic images of J_n vectors are given in the system of Kovraisky polar equidistant stereographic projections. Symbols for figures and units of quantities, used in paleomagnetism, are as follows:

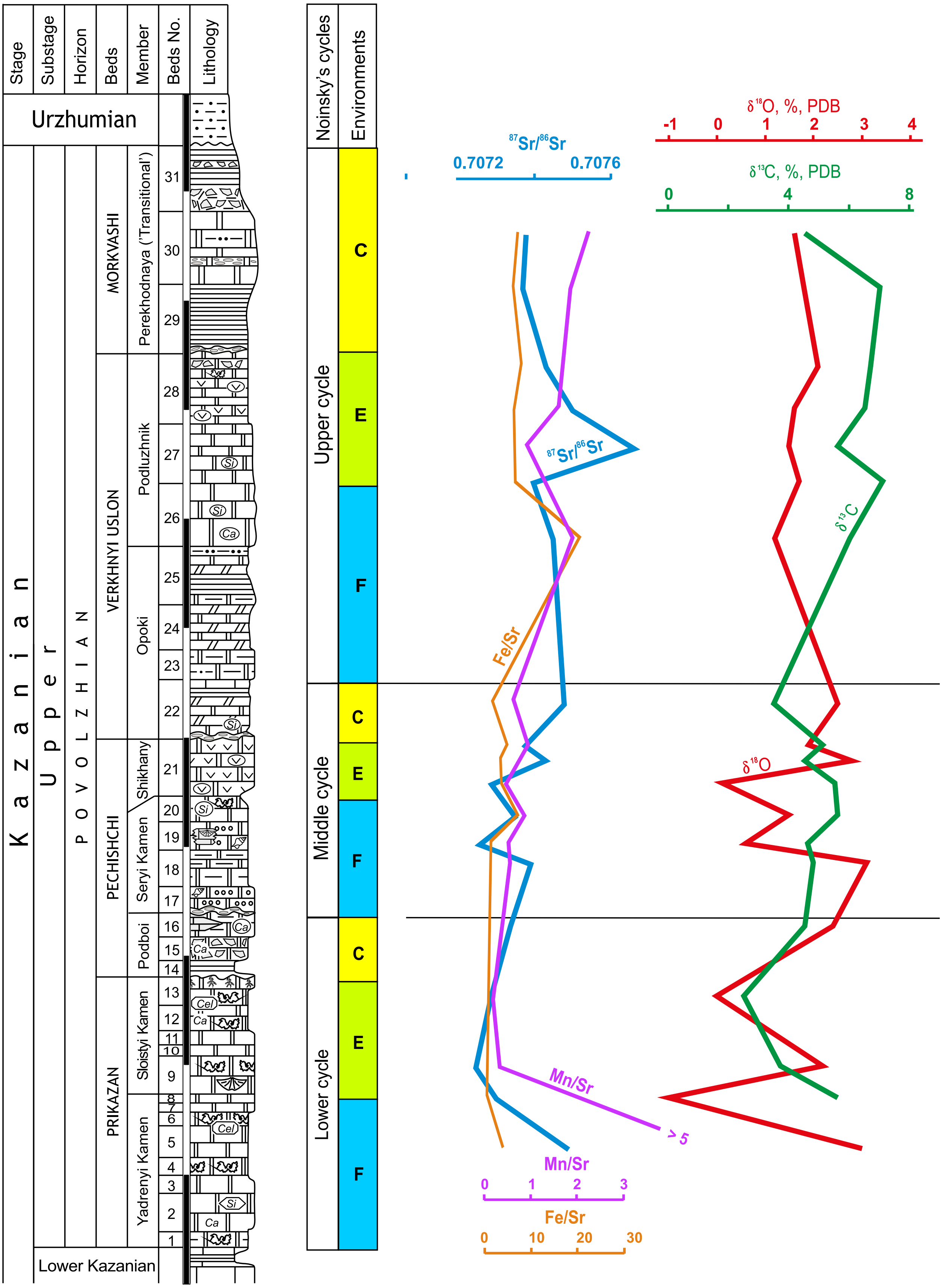
J_n – natural residual magnetisation NRM;
J_n^o – primary (ancient) component of NRM;
J_n^h – secondary (present) component of NRM;
$J_n rv$ – component of viscous NRM;
χ – magnetic susceptibility;
Q_n – Koenigsberger ratio, factor Qn= J_n/(xHT);
D, I – declination and inclination of geomagnetic field;
d, i – declination and inclination of NRM-vector;
φ, λ – geographic coordinates of sampling;
Φ, Λ – coordinates of paleomagnetic pole in present geographic coordinates;
φ_m, φ_m^o – geomagnetic latitude;
N – number of vectors considered in statistical analysis;
K – precision parameter
α_{95} – confidence circle radius for mean pole (vector) with probability p = 0.95
θ_1, θ_2 – semiaxes of confidence oval for a mean pole in degrees
R, r – reversed polarity magnetic zones
N, n – normal polarity magnetic zones
X, Y, Z – coordinates of exterior orientation (by magnetic or geographic poles)
x, y, z – coordinates of interior orientation (relative to specimen ribs).

In most cases, the natural residual magnetisation of the studied rocks represents a vector sum of present and ancient components of the geomagnetic field, i.e. a two-component system. In most cases the presence of many components is a function of mineralogical or structural peculiarity of fixing the present and the ancient directions. Many existing field and calculating methods of reconstruction of the direction of ancient fields are based on an assumption of a two-component system of NRM.

The Upper Kazanian type section near the village of Pechishchi is mainly represented by carbonate and sulfate rocks which are of little use in paleomagnetic reconstructions. Nevertheless, the section has been sampled by Yuriy P. Balabanov at 0.3–0.5 m intervals. The rocks are paleomagnetically metastable and unstable. Temperature cleaning (120° and 200°) "draws" J_n of most specimens to the direction close to the ancient component of reversed polarity belonging to Kiaman Hyperzone (Burov et al., 1998; Balabanov, 2007).

Section / ages	N	Direction of J_n^o – ancient component of natural residual magnetisation		Precision of J_n^o vectors		Paleomagnetic pole in present geographic coordinates		Geomagnetic latitude, φ_m^o
		D	I	α_{95}	K	Φ	Λ	
Pechishchi / Upper Kazanian	30	225	– 45	5.1	25	47	162	26

Pechishchi Section
General Profile with geochemical data



Sedimentological and geochemical data

Methods. The values of isotope ratios have been obtained using the Finnigan MAT-261 multiple collector mass-spectrometer at the Institute of Precambrian Geochronology of the Russian Academy of Sciences, simultaneously recording ion currents of all isotopes. The isotope study has been performed as whole-rock bulk analyses.

The degree of preservation / alteration of carbonates has been estimated using published criteria (Banner and Hanson, 1990; Brand and Veizer, 1981; Khabarov et al., 2000; Veizer, 1989). The separation of samples with disturbed and undisturbed isotopic systems has been performed using the following Mn/Sr and Fe/Sr values: <5 and <20 for limestones and <10 and <60 for dolomites, respectively. A differentiated approach to determining the effect of post sedimentation alterations on primary $^{87}Sr/^{86}Sr$ ratios and carbon and oxygen isotopic compositions is used due to the fact that strontium more easily enters the crystalline lattice of calcite than that of dolomite and, for this reason, strontium concentrations in limestones can be almost ten times higher than in dolomites.

The carbon and oxygen analyses have been performed using the reaction of 100–140 mg of powdered carbonate with anhydrous phosphoric acid at 73°C in individual reaction vessels of an online, automated Kiel-type device coupled to a mass spectrometer; whereas the samples have been reacted at 90°C in an automated carbonate device (common acid bath). The samples have been calibrated using standards NBS-18 and NBS-19, and reported as promille on the PDB scale. An external precision of better than 0.1 promille is typically achived for both the $\delta^{18}O$ and the $\delta^{13}C$.

The Rb-Sr classification of carbonates has been studied using the bulk carbonate component after dissolving a weighed portion of the crushed sample in 10 % acetic acid. Rb and Sr have been conventionally separated by the ion exchange technique using Dowex AG50Wx8 cation exchanger (200 to 400 bags) and 2.5N HCl as an eluent (Kuznetsov et al., 2003). Rb and Sr contents have been determined by the mass-spectrometric method of isotope dilution using a mixed ^{87}Rb-^{84}Sr indicator. The Sr isotopic composition, determined as the $^{87}Sr/^{86}Sr$ average ratio normalised to $^{86}Sr/^{88}Sr = 0.1194$ in the standard SRM 987 sample, is 0.71025±0.00001.

Material. The samples for isotope studies (Nurgalieva et al., 2007, 2015) have been taken from the beds No. 5, 8, 9, 13, 16, 18, 19, 20, 21, 22, 26, 27, 28 and 30 of Noinsky (1899, 1924). The samples have been collected from the most representative, least altered carbonate intervals.

Pechishchi is a unique section that was formed in the Kazanian Ancient Sea with its axial zone stretching from the lower reaches of the Mezen River through the upper reaches of the Vychegda River, lower reaches of the Kama River and upper reaches of the Sheshma and Sok rivers southwards to Buzuluk. This zone includes the most complete Kazanian marine sections characterised by rich paleontological assemblages (Kotlyar and Stepanov, 1984; Nurgalieva et al., 2015). Shallow-water and coastal deposits containing gypsums and salts occur west and south of the basin axis (Samara Luka area), and the marine, lagoonal and red terrigenous deposits are replaced by the Belebey continental formation east of it. The Pechishchi section clearly features three of Noinsky's cycles (Noinsky, 1924) associated with the cycles of the Kazanian Sea. Each of Noinsky's cycles consists of three components. Lower component – carbonate (rich in marine faunas – indicated by the letter 'F'), middle component – evaporate (carbonates with gypsum and anhydrite – indicated by the letter 'E') and upper component – terrigenous rocks (shales and marls – indicated by the letter 'C'). These components reflect alternation of environments from normal marine ('F') through higher salinity ('E') to lake and lagoon conditions ('C').

Results. The distribution of isotope ratios, as well as Mn/Sr and Fe/Sr ratios provides the following conclusions. The obtained values can be considered as justified data by the test criteria Mn/Sr < 10 and Fe/Sr < 60.

In the Kazanian, the values of the strontium ratio are much lower than in the Lower Permian (Nurgalieva et al., 2007) and are estimated as 0.70769 in the Early Kazanian; and 0.70725 (bed No. 9) and 0.70766 (bed No. 27) in the Late Kazanian. The rocks of Member H (Perekhodnaya ('Transitional') Member) are characterised by a 87Sr/86Sr ratio of 0.70737–0.70738 (bed No. 30) corresponding to the boundary between the Kazanian and Urzhumian dated as ca. 266.8 Ma (Gradstein et al., 2004) and ca. 268.8 Ma (Henderson et al., 2012), respectively.

Lower Kazanian rocks with the values of $^{87}Sr/^{86}Sr$ ratios generally correspond to the globally lower values of $^{87}Sr/^{86}Sr$ in the oceanic water at that time (Nurgalieva et al., 2007).

The Upper Kazanian isotope image, in which values of the strontium isotope ratio are expectedly low, but higher than on the global curve, can be explained by the local features of the Middle Permian sedimentation in the eastern part of the East European Platform (the evaporate trend and considerable isolation from the ocean) and by the problems of chronostratigraphic positioning of the Phanerozoic $^{87}Sr/^{86}Sr$ curve and local $^{87}Sr/^{86}Sr$ curves for the Permian (Nurgalieva et al., 2007).

Geochemical data of the Upper Kazanian in the Pechishchi section

Beds №	**δ^{13}C,** ‰ PDB	**δ^{18}O,** ‰ PDB	**^{87}Sr/^{86}Sr**	Mn/Sr	Fe/Sr
30	4.5	1.6	0.70738	2.22	6.99
30	7	1.8	0.70737	1.88	5.89
28	6.7	2.1	0.70743	1.67	7.69
28	6.5	1.6	0.7075	1.57	6.10
27	5.6	1.5	0.70766	0.91	6.39
27	7.1	1.7	0.7074	1.18	6.54
26	6.0	1.2	0.70745	1.88	20.24
22	3.5	2.5	0.70748	0.61	1.56
21	5.1	1.9	0.70738	0.91	4.90
21	4.5	2.8	0.70743	0.75	3.30
21	5.5	0.1	0.70729	0.41	3.37
20	5.6	1.5	0.70735	0.87	6.91
19	4.6	0.6	0.70726	0.43	1.06
18	4.8	3.1	0.70739	0.52	1.13
16	4.5	2.4	0.70734	0.35	0.76
13	2.5	0	0.70729	0.16	0.48
9	3.7	2.2	0.70725	0.29	0.44
8	5.6	-1.0	0.7073	0.04	0.26
5	-	3	0.70749	8.16	3.86

The values of δ^{13}C range from 2.5 to 7.1 ‰ PDB. The values of δ^{18}O range from –1 to 3.1 ‰ PDB. The obtained isotopic values are higher in comparison to global curves, explained by considerable regional effects of sedimentary environments, localisation and isolation from ocean and arid climate trends during the Kazanian (Nurgalieva et al., 2015).

Isotope variations fit with the three of Noinsky's cycles, reflecting the continuous isolation of sedimentary environments from the ocean.

Within the first cycle, one can observe lower values of $^{87}Sr/^{86}Sr$. Within the second and third cycles, the values of this ratio generally increase, including two lower components in the third cycle. The decrease of the strontium ratio opposite of shales component in the Upper cycle can be explained by a prominent global decrease of this ratio (Veizer, 1989; Nurgalieva et al., 2007).

The values of δ^{18}O and δ^{13}C also generally increase upward the section, reflecting an arid climate trend and possible global change (positive shift) of isotopic composition of carbon dioxide in the atmosphere (Kump, 1989).

Direct correlation between δ^{18}O and δ^{13}C (in the lower parts of each Noinsky's cycle) can be the evidence of marine environments (Stephens et al., 2003).

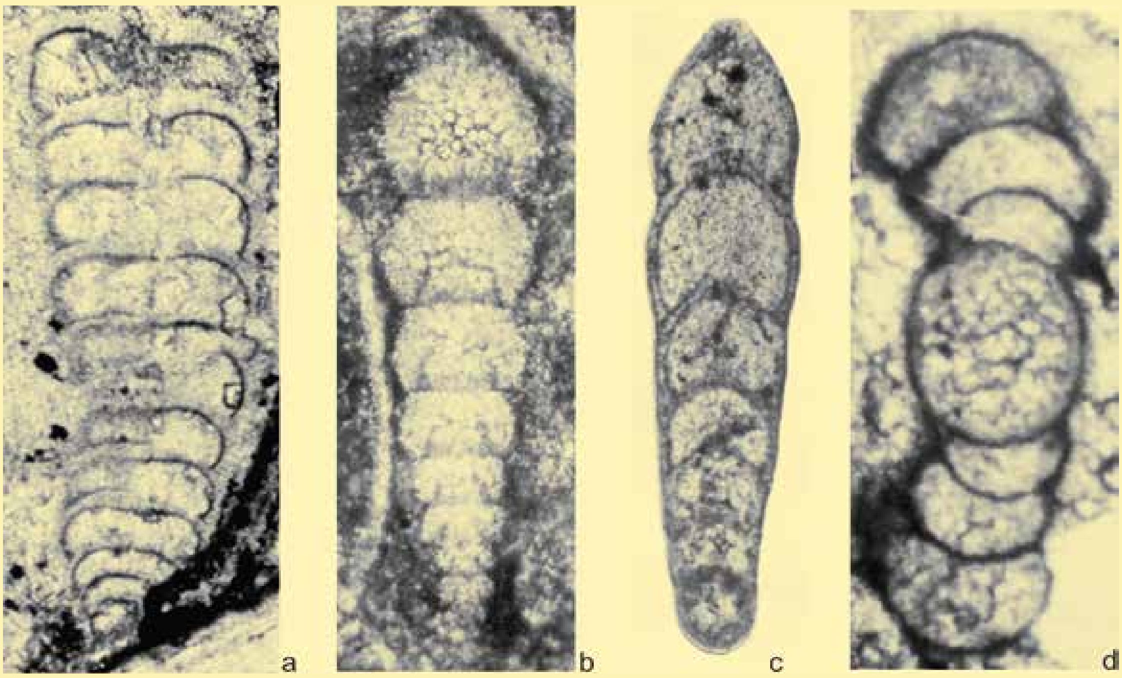
Reversal correlation between δ^{18}O and δ^{13}C is observed in evaporites and shales intervals of the cycles. It can be explained by evaporate processes and continental influx.

BIOSTRATIGRAPHY

The Upper Kazanian conformably overlies the underlying rocks. However, bedding planes usually contain desiccation cracks, bioturbidites and sometimes show marks of erosion, which are more distinct at the top of the Morkvashi Beds, i.e., at the boundary between the Kazanian and Urzhumian.

Solodukho and Tikhvinskaya (1977), Esaulova (1998c, d), Chalimbadja and Silantiev (1997), Silantiev et al. (2007a), Götz and Silantiev (2014) and other colleagues have extensively studied fossils from all members of the section. The Upper Kazanian is well exposed along the banks of the Volga River from the village of Pechishchi to the village of Karsnovidovo. The members are well documented in this outcrop. The fossil assemblage is more diverse because of facies changes.

Prikazan Beds. These beds comprise Member A (Yadrenyi Kamen (‘Solid Stone’) Member or beds with *Aulosteges fragilis*) and Member B (Sloistyi Kamen (‘Laminary Stone’) Member). These beds contain the following taxa that do not continue upward the section: *Geinitzina postcarbonica* Spand., *G. spandeli* Tscherd., *Hemigordius hemigordiformis* Tscherd., *Nodosaria elabugae* Tscherd., *N hexagona* Tscherd., A. *suchonensis* K. M-Maclay, *Aulosteges fragilis* (Netsch.), *A. horrescens* (Vern.), *Spiriferina* (?) *parvula* (Netsch.), *Janeia normalis* Howse, and *Capulus* (?) *permocarbonicus.*

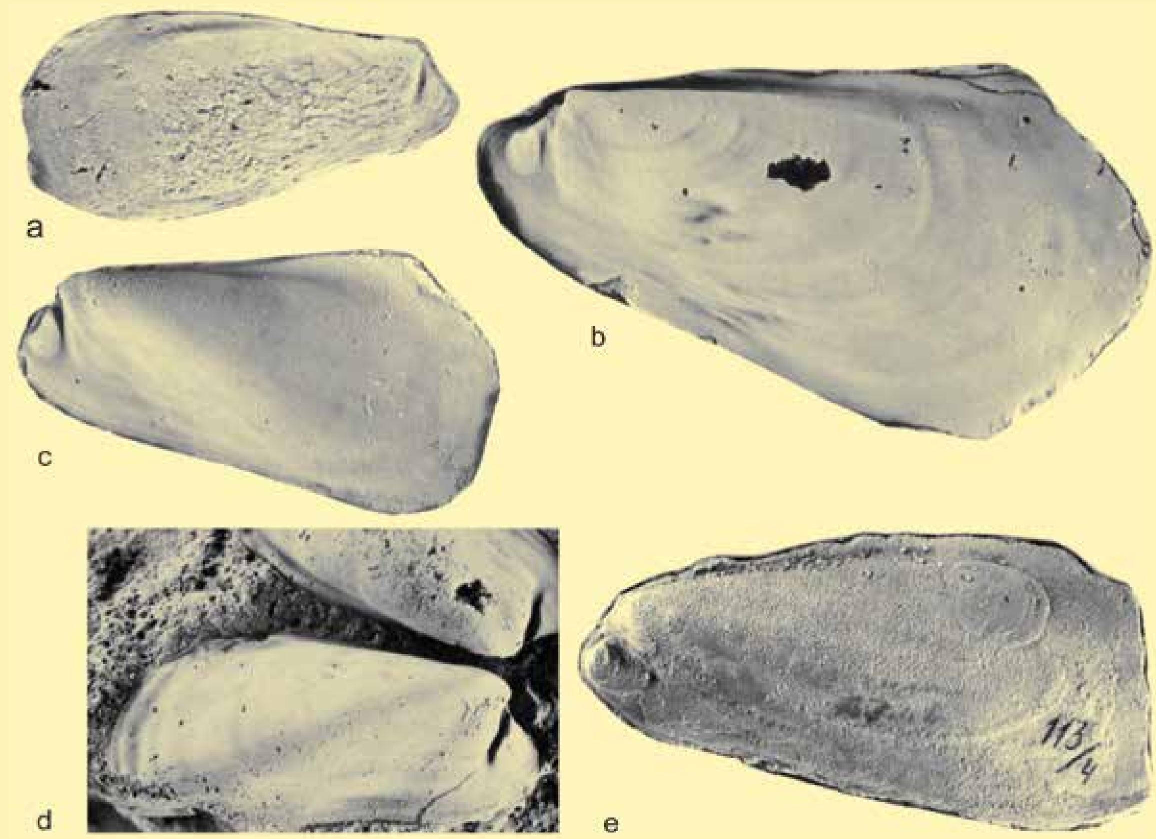


Foraminifers from The Kazanian reference section

Borehole 1, Naberezhnye Morkvashi: a – *Geinitzina angusta* Tscherd. (100.8 m), b – *Nodosaria elabugae* Tscherd. (54.0 m), c – *Lingulonodosaria clavata* Paalzow (96.9 m), d – *Pseudoammodiscus megasphaericus* (Gerke) (59.0 m). All specimens from the Lower Kazanian

The lower part of the Prikazan Beds (Member A) includes *Aulosteges fragilis* (Netsch.), and abundant *Cancrinella, Beecheria,* and *Cleiothyridina.* Upward the section, in Member B, *Aulosteges* do not occur. Fossils are represented by molds and imprints of the small-sized *Cancrinella, Beecheria, Stenoscysma, Rhynchopora,* and by many bivalves (mainly *Pseudomonotis* and *Schizodus).* These strata also yield the bryozoans *Pseudobatostomella decora* Moroz. and fragmented colonies of *Fenestella permutula* Moroz. Bed no. 9, Chetyre Rubtsa (‘Four Seams‘), of Noinsky (1899, 1924) contains the conodonts *Stepanovites meye*ni Kozur et Movsch. At the very top of the beds fossils are absent.

Pechishchi Beds. These beds comprise three members (Member C (Podboi Member)), Member D (Seryi Kamen ('Grey Stone') Member), and Member E (Shikhany Member)). The index fossils for these beds are *Lingula* ex gr. *media* Tscherd. *Nodosaria krotovi* Tscherd., *Conularia hollebeni* Gein., *Fistulipora dybowsky* Gorjun., *Tabuliopora ordinata* Moroz., *Streblascopora fasciculata* (Bassler), *Fenestella microretiformis* (Moroz.), *Beecheria angusta* (Netsch.), *Solenomorpha parvula* (Netsch.), *Crurithyris nucella* (Netsch.), *Pseudomonotis garforthensis* King, and *Liebea septifera* King. The following fossils first appear in the Pechishchi Beds and continue to the Verkhnyi Uslon Beds: *Rhombotrypella superangustata* Moroz., *Dyscritella incrustata* Moroz., *Wjatkella wjatkensis* (Netsch.), *Polypora keyserlingi* Netsch., *Aulosteges wangenheimi* (Vern.), *Spiriferellina netschajewi* (E. Ivanova), *Pseudomonotis elegantula* Netsch., *Prospondilus golowkinskyi* Netsch., *Loxonema* (?) *altenburgensis* Gein., *L.* (?) *kazanensis* Netsch., and *Subulites* (?) *permianus* Netsch.



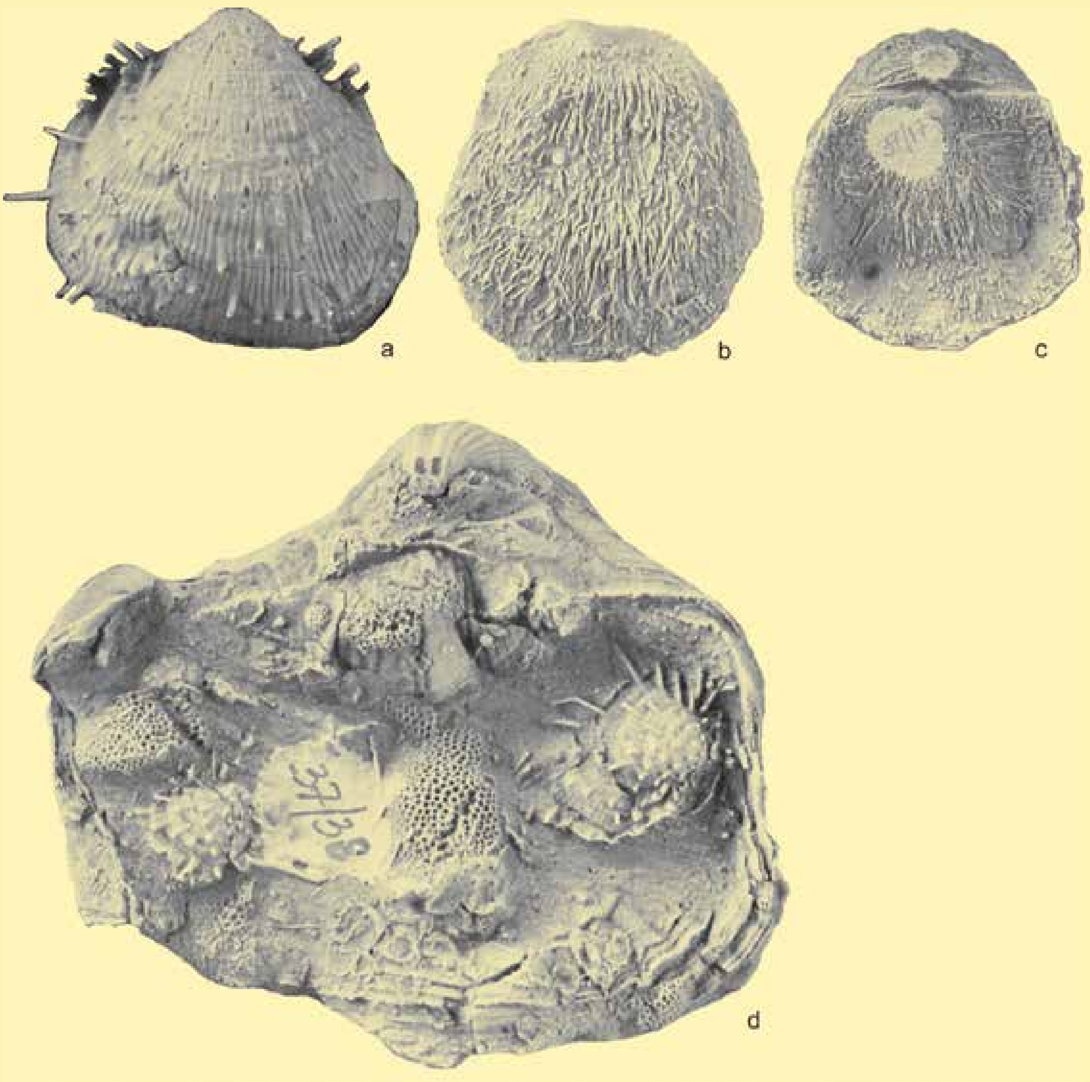
Marine bivalves of Netschajewia Licharew from the Upper Kazanian

a, b – Netschajewia alata (Netsch.), c, d – Netschajewia teploffi (Vern.), e – Netschajewia elongata (Netsch.)

The species *Orbiculoidea konincki* (Gein.), *Netschajewia alata* (Netsch.), W. *elongata* (Netsch.), *N. oblonga* (Netsch.), *Natica* (?) *minima* Broun., *Glyptoasmussia exigua* (Eichw.) appear at this level and continue further upwards in the section up to the Morkvashi Beds. These fossils are unevenly distributed in the rock. Bed no. 17, Nizhniy Peschanyi Kamen ('Lower Sandy Stone'), of Noinsky (1899, 1924) yields *Alula* (?) *kutorgana* (Vern.), *Pseudomonotis elegantula* (Netsch.), *Goniasma subangulata* (Vern.), *G. lata* (Gol.) and other numerous gastropods. Only bed no. 18, Verkhniy Mylnik ('Upper Soapston'), of Noinsky (1899, 1924) shows bioherm associations of bryozoans and gastropods. In the lower part of bed no. 20, Seryi Kamen ('Grey Stone'), of Noinsky (1899, 1924) there are scarce remains of *Cancrinella, Cleiothyridina, Beecheria, Pseudomonotis,* and *Pseudobakewellia.*

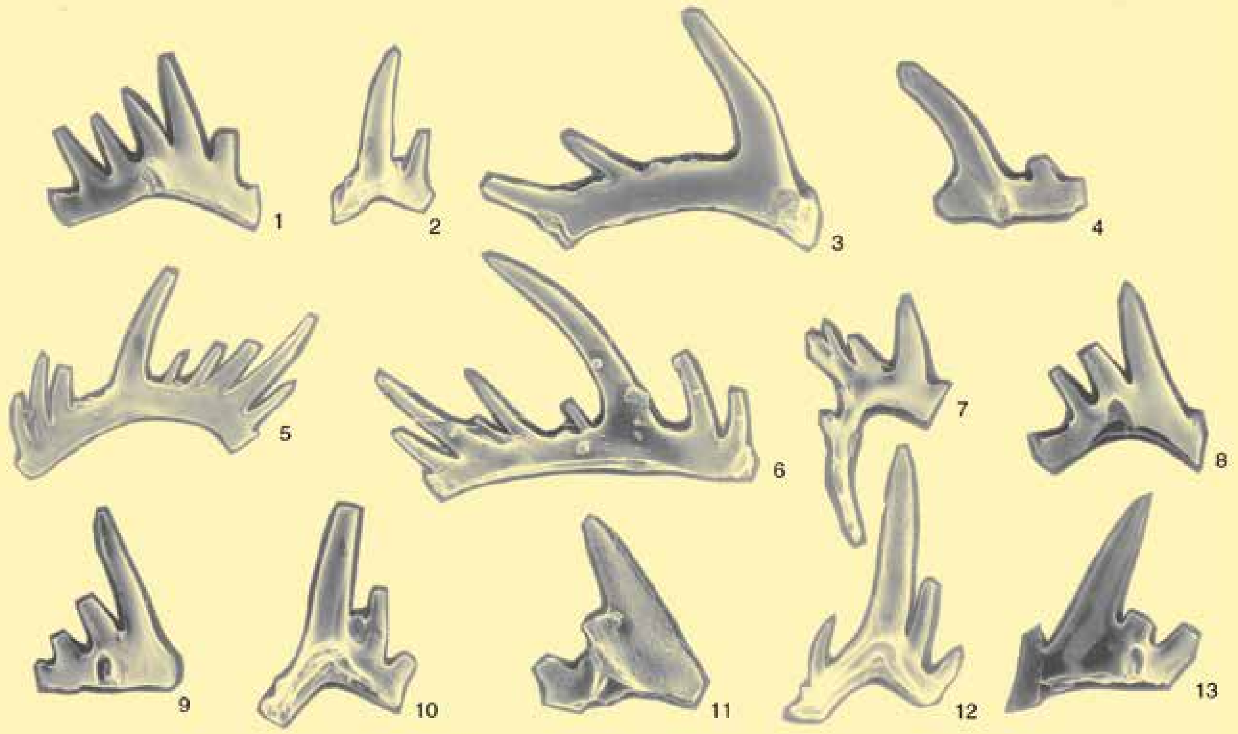
The ‘Shikhany’ Member, which is largely gypsiferous, contains virtually no fossils.

Verkhnyi Uslon Beds. These beds are composed of two members (Member F (Opoki (‘Silica Shales’) Member) and Member G (Podluzhnik (‘Stone lying under the meadow’) Member). The lower member, Member F (Opoki (‘Silica Shales’) Member), contains scarce fossils, whereas Member G (Podluzhnik (‘Stone lying under the meadow’) Member) contains (especially in its lower part) numerous fossils: 10 foraminiferal taxa, 13 bryozoan taxa, 10 brachiopod taxa, 40 bivalve taxa, 24 gastropod taxa, altogether more than 100 taxa, generally indicative of the entire Upper Kazanian. The index fossils for the Verkhnyi Uslon Beds are *Hemigordius gordiformis* Tscherd., *H. perturbata* Tscherd., *Paraioclema multispinosum* Moroz., *Fenestella schurae* Moroz., *Polypora sparsa* Moroz., *P. kazanensis* Moroz., *Reteporidea qasimispora* Moroz., *R. atarensis* Moroz., *Odontospirifer subcristatus* (Netsch.), *Janeia kazanensis* (Stuck. et Netsch.). *Siphogrammysia kazanensis* (Gein.), *Aviculopecten hiemalis* Salter, *Lima* (?) *retiferiformis* Netsch. *Bellerophon permianus* Netsch., *B.* (?) *piktorskyi* Netsch., *Loxonema* (?) *gibsoni* Brown, *L.* (?) *ornamentaria* Netsch., *L.* (?) *planoverticum* Netsch., *Soleniscus permicus* (Netsch.), *Dentalium* (?) *speyeri* Gein. The species *Pleurotomaria subpenea* Netsch., *Baylea* (?) *taylorianus* (King.), *B.* (?) *thomsonianus* (King.), *Loxonema (?) fasgata* King., and *Permonautilus cornutus* (Golowk.) first appear in these beds and continue to the Morkvashi Beds.



Brachiopods from The Kazanian reference section

A – *Cancrinella cancrini* (Verneuil) – species of brachiopods, named by Edouard de Verneuil in honor of Count Yegor F. Kankrin, Finance Minister of the Russian Empire 1823–1844, who supervised the expedition of Roderick I. Murchison in Russia; B, C – *Aulosteges fragilis* (Netsch.): ventral (a) and dorsal (b) valves with well-preserved needles; D – *Licharewia rugulata* (Kutorga): interior of the dorsal valve, filled by small “spiny” shells of *Cancrinella cancrini* (Vern.) and fenestrated bryozoans *permiana* King

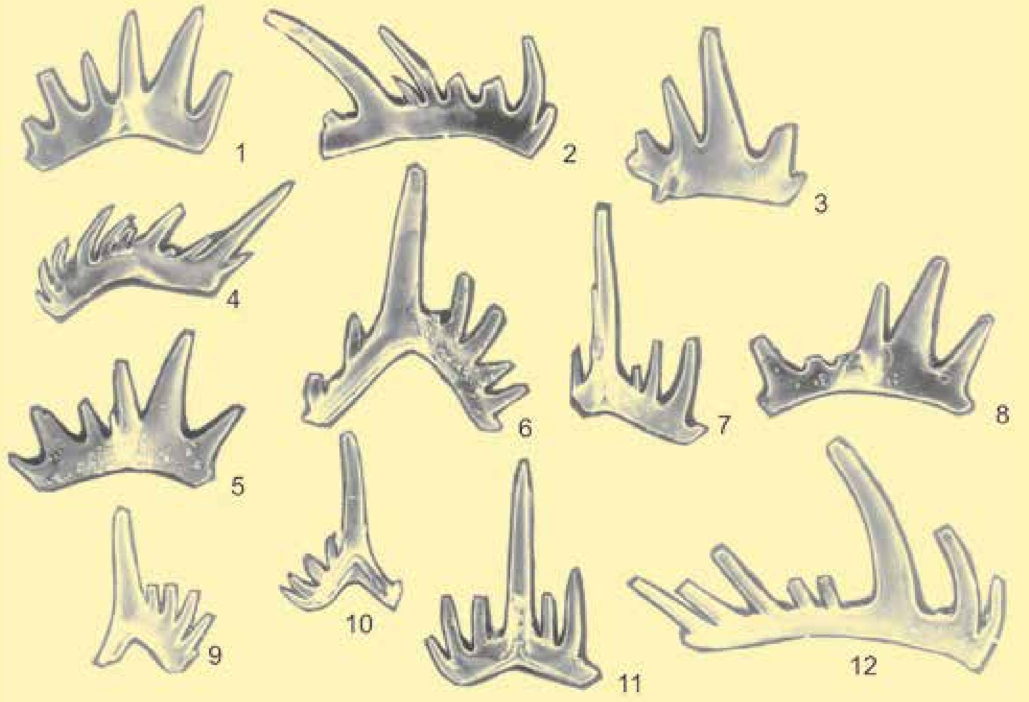


Conodonts *Kamagnathus volgensis* Chernykh, 2001

1 – Pa element, holotype, 2 – Pa element, 3 – Pa element, 4 – Sb element, 5 – Pa element, 6 – M element, 7 – Sa-element, view from the posterior process, 8 – Pa element, Pechishchi section, Upper Kazanian, Member H (Perekhodnaya ('Transitional') Member), bed no. 30, 'Modiola Horizon' of Noinsky (1899, 1924); 9 – M element, 10 – M element, 11 – Sa element, view from the posterior process, 12 – Sc element, the right bank of the Volga River, Pechishchi section, Upper Kazanian, Member G (Podluzhnik ('Stone lying under the meadow') Member). All views x 80

Morkvashi Beds. These beds contain numerous shells of *Glyptoasmussia exigua* (Eichw.), remains and scales of ganoid fishes, molds of *Lithophaga ('Modiola') consobrina* (Eichw.) (hence the name *'Modiola"* Horizon). Besides, the beds contain bryozoans of the order Trepostomida, the brachiopods *Cancrinella, Rhynchopora, Stenoscysma,* and *Beecheria,* the bivalves *Nuculopsis, Nuculana, Schizodus, Pseudobakewellia, Netschajewia,* etc., the gastropods *Bayelia, Goniasma,* and *Loxonema,* the conodonts *Kamagnathus volgensis* Chern. Generally, the marine fauna of this assemblage is impoverished.

The cyclic pattern of the Upper Kazanian indicates the cyclic evolution of the geochemical environment and salinity of the basin. The sedimentary environments of the basin near the village of Pechishchi during the Pirkazan Age, at the beginning of the Pechishchi Age and at the beginning of the Verkhnyi Uslon Age are close to normal marine. Gradually, the deep shelf environment is replaced by that of inner shelf and finally by shallow-marine to lagoonal.

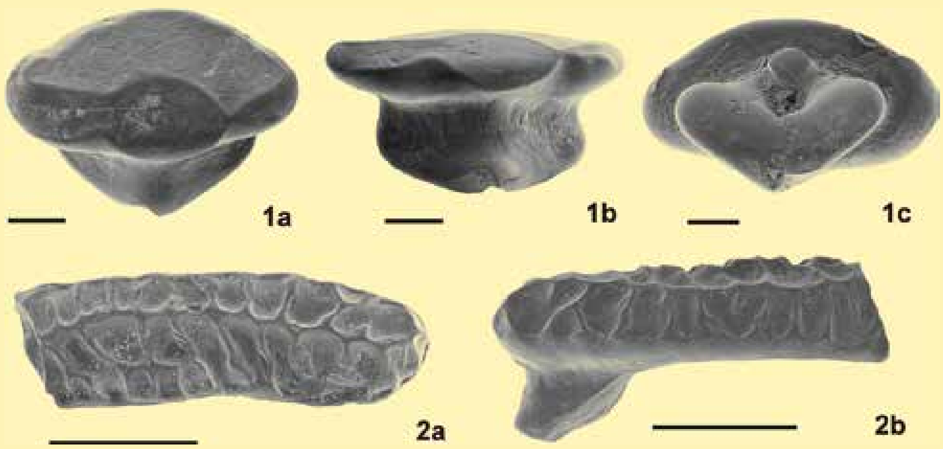


Conodonts *Kamagnathus khalimbadzhae* Chernykh, 2001

1 – Pa element, holotype, 2 – M element, 3 – Sa element, 4 – Sa element, 5 – Sb element, 6 – Sc element, 7 – Pa element, view from the well-preserved lateral process, the right bank of the Kama River, Elabuga, Lower Kazanian, Baitugan Beds; 8 – Pa element, 9 – Pa element, 10 – M element, the right bank of the Kama River, Sentyak settlement, Lower Kazanian, Baitugan Beds; 11 – Pa element, 12 – M element, Borehole 2 (222 m), Lower Kazanian, Baitugan Beds; 13 – Pa element, left bank of the Kama River, Prosti settlement, Lower Kazanian, Baitugan Beds. All views x 80

Fishes

The fish microremains are found in the Kamyshlinskian regional stage, Early Kazanian of the locality Pechishchi. The isolated chondrichthyan teeth of neoselachian *Cooleyella amazonensis* Duffin, Richter & Neis; hybodontiform Sphenacanthidae gen. et sp. nov. and "*Polyacrodus*" sp., and euselachian scales, as well as actinopterygian teeth and scales of *Alilepis* sp. and Elonichthyidae indet. are reported form this locality. *Cooleyella amazonensis* occurs in the Kazanian of Russia and Roadian of Texas, USA but is firstly described from the Late Pennsylvanian of Brazil (Ivanov, 2011).



Chondrichthyan teeth from the locality Pechishchi.

1 – *Cooleyella amazonensis Duffin, Richter & Neis, a – occlusal, b – lingual and c – basal views; 2 –* **"***Polyacrodus***"** sp., a – occlusal and b – lingual views. Scale bars – 0.2 mm

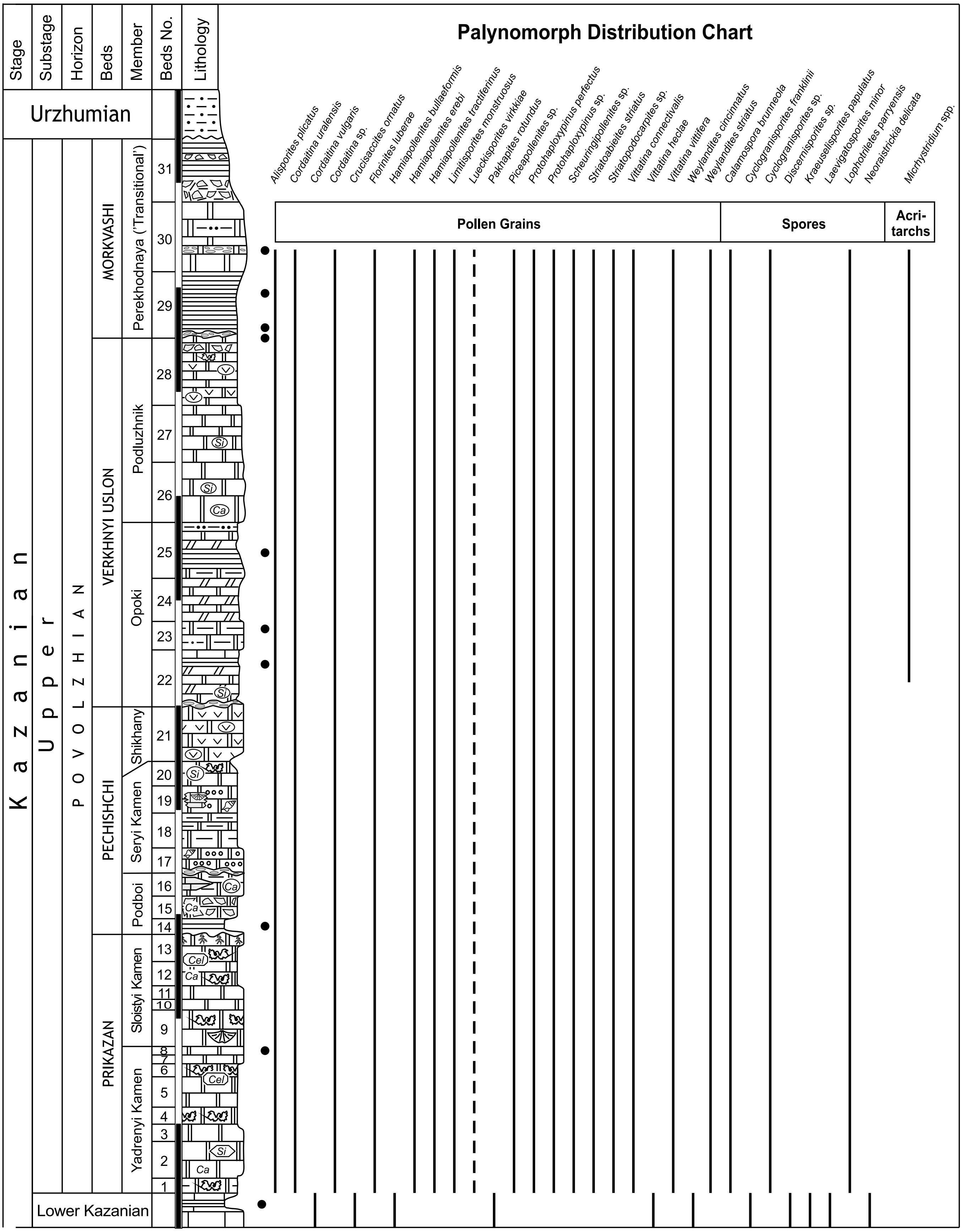
Palynology

Palynostratigraphy

Palynological studies are very important to establish a biostratigraphic scheme to be applied in both marine and non-marine depositional environments. Previous works include detailed palynological data for the Permian of European Russia (Bogov, 1971; Varyukhina, 1971; Molin and Koloda, 1972; Chuvashov and Dyupina, 1973; Faddeyeva, 1974; Gayazova 1974; Varyukhina et al., 1975; Virbitskas, 1983; Gomankov, 1992), providing the general stratigraphic ranges of identified taxa without proposing range zones for interregional correlation. On the other hand, comparisons of the Permian assemblages from Russia with those from other parts of the world remain difficult, due to the different taxonomic treatment adopted by the different palynological 'schools'. Utting et al. (1997) addressed this point in the most recent publication on the palynology of Permian type sections in Russia. These authors also discussed the differences between palynomorph assemblages from the Middle Permian stages of Russia and those of the Canadian Arctic and other circumpolar regions (the southern Barents Sea, Mangerud, 1994; Greenland, Balme, 1979), hindering interregional correlation. It was concluded that the recognised differences are most likely the result of variations in the parent flora related to different palaeoclimatic conditions.

In 2014, we focused on the Kazanian Stage (Götz and Silantiev, 2014) with new palynological data from the latest Early Kazanian and entire Late Kazanian (Povolzhian), exposed in a section near the village of Pechishchi. The palynomorph assemblage is dominated by pollen grains and a major change in composition occurs at the Lower-Upper Kazanian substage boundary with the last occurrence of *Cordaitina* spp., *Crucisaccites ornatus*, *Hamiapollenites bullaeformis*, *Pakhapites rotundus*, *Vittatina heclae*, and *Weylandites cincinnatus* as well as the last occurrence of the spores of *Cyclogranisporites franklinii*, *Discernisporites* sp., *Kraeuselisporites papulatus*, and *Neoraistrickia delicata*. The pollen grains *Alisporites plicatus*, *Cordaitina uralensis*, *Florinites luberae*, *Hamiapollenites erebi*, *Hamiapollenites tractiferinus*, *Limitisporites monstruosus*, *Lueckisporites virkkiae*, *Piceapollenites* sp., *Protohaploxypinus* spp., *Scheuringipollenites* sp., *Striatoabieites striatus*, *Striatopodocarpites* sp., *Vittatina connectivalis*, *Vittatina vittifera*, and *Weylandites striatus* as well as the spores *Calamospora brunneola* and *Lophotriletes parryensis* first occur in the Late Kazanian. Marine phytoplankton (*Micrhystridium* spp.) is only present in the upper part of the Late Kazanian.

Makarova (2007) studied palynological assemblages from a borehole (No. 1. Naberezhnye Morkvashi) and an outcrop section close to the village of Pechishchi and described four assemblages (assemblage 1 and 2 indicating the Early Kazanian Age, assemblage 3 and 4 indicating the Late Kazanian Age). This dataset shows the general dominance of bisaccate, striate pollen grains, and the increase of this pollen group is observed upward the section. Spores are rare elements in the entire succession (Götz and Silantiev, 2014).

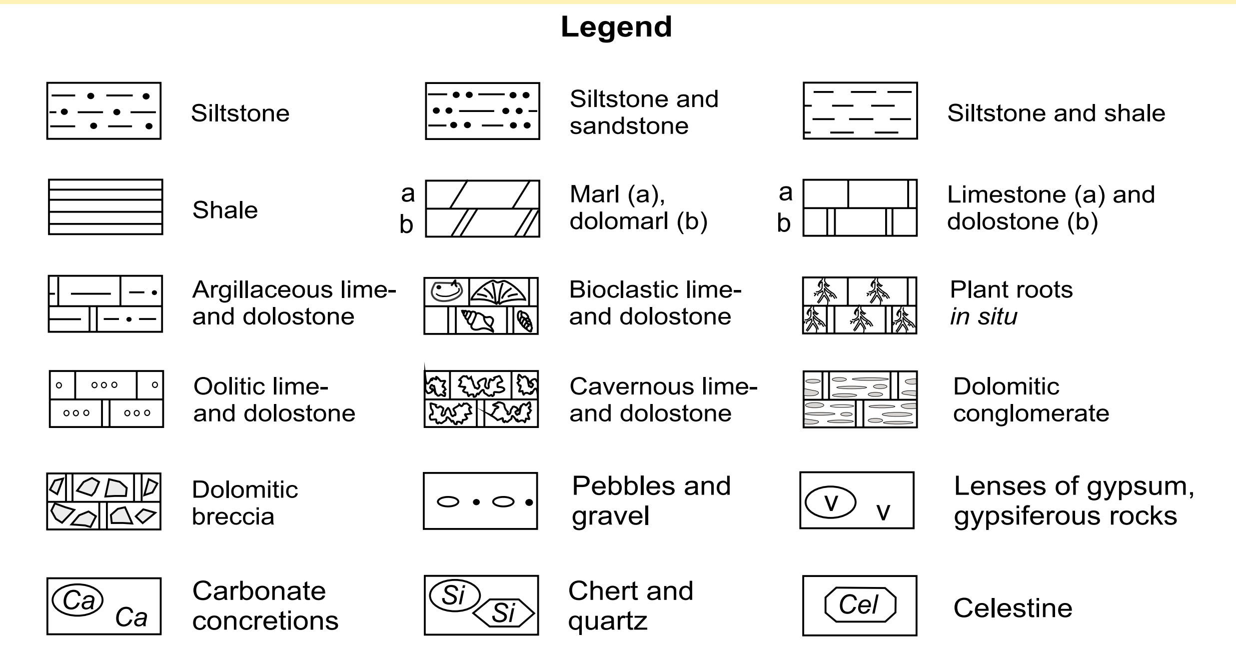


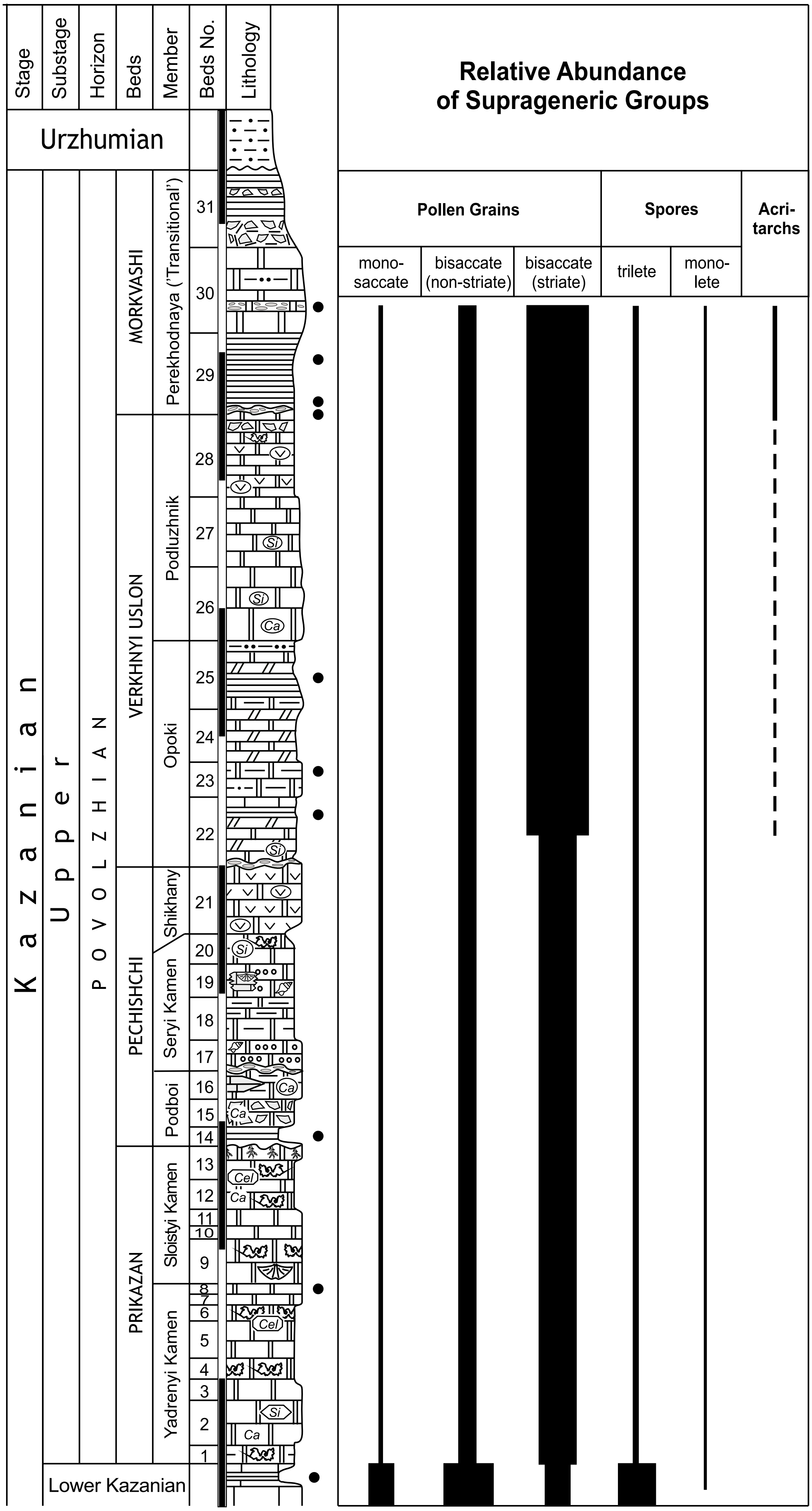
Palynomorph distribution chart of the Pechishchi section. The total thickness of the studied interval is about 50 m, scale bars 5 m each. Sample horizons are marked by black dots (Götz and Silantiev, 2014)

Palaeoenvironmental and palaeoclimatic implications

The palynomorph assemblages studied show a very striking trend within the section: the lower part is dominated by trilete spores and monosaccate and bisaccate, non-striate pollen grains. The upper part of the section clearly shows the increase of bisaccate, striate pollen grains dominating the assemblage in the uppermost part. The dominance of bisaccate, striate pollen grains and the increase within the Kazanian have been also reported by Makarova (2007).

Different relative abundances of sporomorphs indicate changes in the upland and lowland vegetation related to changes in the palaeoenvironment, e.g. development of lake and river systems, moving of the shoreline, uplift in the hinterland, as also documented in the sedimentological record. Besides these palaeoenvironmental (short-term) changes recognised, a long-term trend is interpreted in terms of climate change from a warm temperate to a warm dry climate. This change is documented in the sedimentological record by e.g. an increase of gypsiferous dolomites upward the section and also reflected in geochemical signatures (Larochkina and Silantiev, 2007). The palynological data show this climatic signal by the change of a fern and horsetail lowland community and an upland conifer community dominated by monosaccate-producers to a gymnospermous flora of striate bisaccate-producers. Such changes inferred from palynomorph assemblages reflecting the vegetation of a specific area have been recently detected in many other Permian and Triassic settings (e.g., Ruckwied et al., 2008; Götz et al., 2011; Götz et al., 2013; Götz and Ruckwied, 2014) and climatic signals recorded in palynomorph assemblages have been recently also successfully applied to cross basin correlation (Ruckwied et al., 2014). The new palynological data from the Kazanian stratotype section show the potential to perform high resolution palaeoclimatic reconstructions based on changes in the palynomorph assemblages (Götz and Silantiev, 2014).





Relative abundance of suprageneric groups (pollen, spores, acritarchs) based on counts of 200 specimens. The total thickness of the studied interval is about 50 m, scale bars 5 m each. Sample horizons are marked by black dots (Götz and Silantiev, 2014)

Palaeoenvironment, palaeoclimate and depositional model

The field trip area is a part of the eastern flank of the former Kazan Sea, and the entire Kazan Sea area is subdivided into seven distinct depositional environments from the West to the East (Forsh, 1955; Golubev, 2001; Silantiev, 2001). The Pechishchi section represents the depositional areas 2, 3, and 4. Terrestrial palynomorphs were mainly transported from the eastern hinterland (depositional area 7) by wind (pollen grains) and by river and delta systems into the adjacent lagoonal and open marine settings. Marine phytoplankton (acritarchs) is characteristic of restricted (lagoonal) and open marine settings. Palynofacies are dominated by terrestrial particles (pollen grains, spores) including phytoclasts of different sizes and shapes, and different preservation states (opaque, translucent). The large number of phytoclasts indicates an eastern hinterland with lush vegetation.

1. *West Bank of the Kazan Sea*. A flat, plateau-like area formed by Carboniferous and Early Permian carbonate rocks (‘White desert’). This area is characterised by intense erosion due to weathering. The climate was hot and dry (arid). River systems hardly developed. Minor soil-forming processes and only sparse vegetation are assumed. Faunal elements are rare, only small vertebrates were represented, by lizard-like forms.

2. *Hypersaline, protected lagoons*. The influx of freshwater and terrigenous material from the western shore of the Kazan Sea was strongly limited. The salinity of the water in the lagoons was periodically increased. During these times, gypsum and salt were accumulated. The climate was hot and fairly dry (arid). Faunal elements are rarely represented by microbial bioherms. The characteristic lithologies are wavy-bedded limestones interbedded by gypsum and rock salt.

3. *Bioherms and reefs*. Large reefal bodies formed by bryozoans, crinoids, corals and brachiopods. In places these build-ups raised above the sea surface and built ridges separating lagoons with increased salinity from the open ocean. It is assumed that the islands were covered with sparse vegetation. Faunal elements include ammonites, conodonts, and fishes (sharks’ teeth and spines).

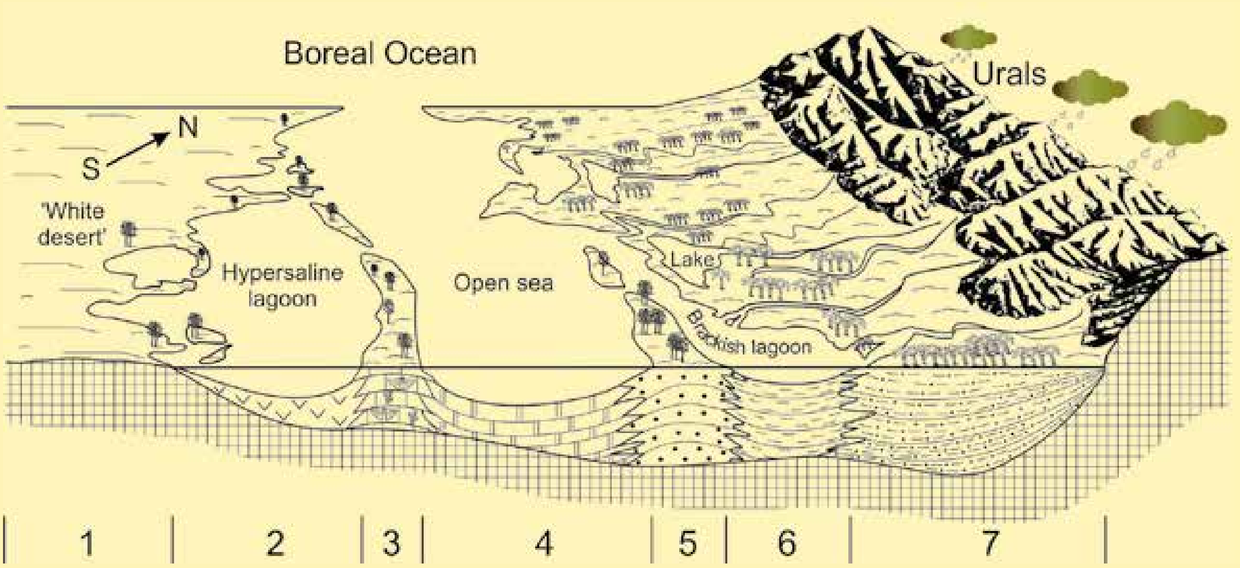
4. *Open Sea*. A very narrow zone with predominantly carbonate sedimentation. The dominant lithologies are limestones and secondary dolomites. A high degree of bioturbation points to an oxic environment with diverse benthic biota.

5. *Bars and barrier islands*. These large ribbon-like sand bodies were elongated parallel to the coast, separating the open sea from the brackish lagoons. Due to humid climate conditions, the vegetation is diverse and lush. Invertebrates include various shallow-water forms of brachiopods and bivalves. The dominant lithologies are sandstones with wave ripple marks and oolitic limestones; the latter characterise the transitional zone from sand bars to the open sea.

6. *Brackish lagoons and deltas*. Deltaic successions contain deposits of copper ore (copper sandstones), coal and bitumen. Floral and faunal elements are similar to those known from the alluvial plains. Lagoons were characterised by varying desalination. In some lagoons, shales and organic-rich sediments were accumulated; other lagoons contained mainly carbonate sediment. This depositional zone is characterised by shallow basins with a less agitated hydrological regime, partially or completely isolated from the open sea by sand bars and spits. Stagnant conditions periodically arose in these basins. Predominant lithologies are limestones with fine horizontal lamination, shales with thin layering, and numerous thin seams of coal. Limestones are often bituminous to varying degrees; coquinas are common. Faunal elements include euryhaline invertebrates (bivalves, gastropods, serpulids), insects, numerous fish (often complete skeletons) and exclusively aquatic tetrapods (amphibians).

7. *Alluvial-lacustrine plains* forming the east bank of the Kazanian Sea. Vast lowland characterised by a perfectly aligned relief gradually rising towards the Urals. The climate is sub-humid and probably seasonal.

This is an important feature of the east bank and different from the west bank zone. Climatic differences between the east and west banks determine the asymmetric facial profile of the Kazanian Sea: a large amount of terrigenous sediments, sand bars, lagoons rich in organic matter, marshes and swamps, diverse and abundant terrestrial floral and faunal elements in the East; bioherms, saline lagoons, terrestrial environments with sparse vegetation in the West. Due to the high humidity, the eastern area was characterised by lush vegetation. Localities of fossil flora (including wood fragments in fluvial sandstones) are known from deposits which have been formed in lakes, oxbow lakes, floodplains and river channels. Fossil invertebrates (ostracods, conchostracans, non-marine bivalves) are abundant. Also, localities of fish and terrestrial vertebrates (amphibians and therapsids) are known in many places representing this eastern area, dominated by cross-bedded sandstones, sandstones with ripple marks, fluvial conglomerates, and paleosols.



Depositional model of the study area, modified after Golubev (2001) and Silantiev (2001).

1 – West Bank of the Kazan Sea (‘White desert’); 2 – Hypersaline, protected lagoons; 3 – Bioherms and reef buildups; 4 – Open Sea; 5 – Bars and barrier islands; 6 – Brackish lagoons and deltas; 7 – Alluvial-lacustrine plains

AUGUST 16 • STOP 2

CHEREMUSHKA SECTION. PARASTRATOTYPE OF THE URZHUMIAN STAGE

We will travel about 2 km by bus from Bus Stop-1C (Pechishchi Section of the Kazanian Stage near the Flour milling plant) to the head of the Cheremushka ('Bird Cherry') Gully. A high telephone mast is situated near this place and serves as a reference point.

Cheremushka ('Bird Cherry') Gully cuts the right side of the Volga River Valley and has a length of about 500 m.

Based on interests, the excursion can be divided into two groups. A group of participants interested in fish and tetrapod fossils can start from the upper part of the section known for several vertebrate localities. A physically fit group of participants with an interest in stratigraphy can start from the lower part of the section.

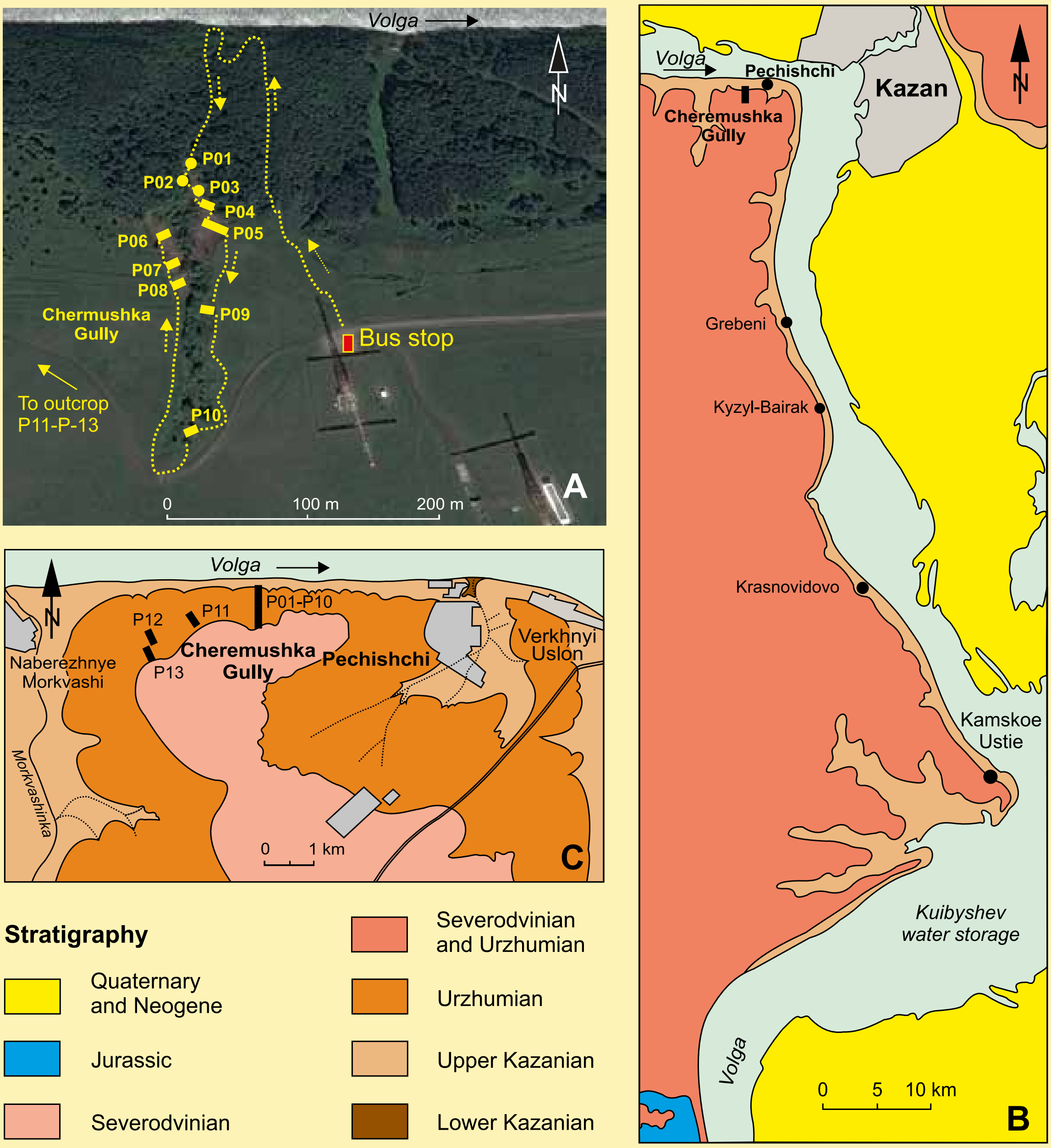
The second group walks down to the bank of the Volga River and then hikes up the gully examining the Upper Kazanian to Urzhumian succession. Fragments of the Seryi Kamen' ('Grey Stone'), Shikhany, Opoki, Podluzhnik, and the Kazanian-Urzhumian boundary beds are exposed on both sides of the gully. Then we can observe the overlying red-mottled continental succession of the Urzhumian Stage.

The section is measured on the right bank of the Volga River between the villages of Pechishchi and Naberezhnye Morkvashi, in the Cheremushka ('Bird Cherry') Gully (outcrops P01–P10), Trekhglavyi ('Three-Headed') Gully (outcrop P11), and Strela ('Arrow') Gully (outcrop P12–P13).

This section has been revisited many times, by Kazan geologists in particular, since the pioneering work of Roderick I. Murchison (1845). Alexey K. Gusev, Senior Lecturer at Kazan University, provided the first detailed lithological and paleontological description in the 1950s. His bed by bed fossil collections were later expanded and refined. Later, A.K. Gusev (1996a, 1998a) distinguished two formations (Sulitsa and Isheevo) and several stratigraphic members. The same section was the subject of paleomagnetic studies by A.N. Khramov, V.P. Boronin, and B.V. Burov. The most detailed paleomagnetic work was conducted by I.Ya. Zharkov, whose material is used in the description of the section.

In 2013–2015, the parastratotype of the Urzhumian regional stage was studied again by the Laboratory of Stratigraphy, Kazan Federal University (Silantiev et al., 2014b; Bulanov et al., 2014; Mouraviev et al., 2015, etc.).

The large-scale profiles of the section are shown below. Names of lithological units, their composition and bed numbers are given after Gusev (1998a).

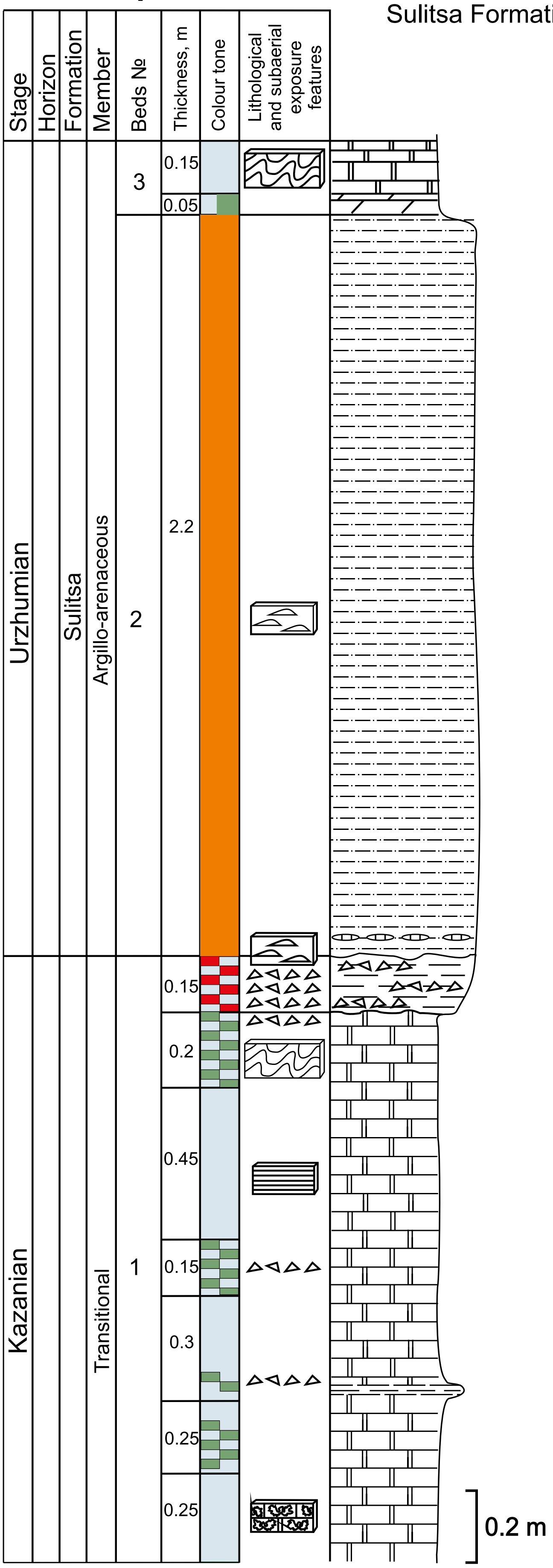


Study area: (A) space image of the Cheremuska Gully (Image © CNES / Astrium) showing the locations of the sections (P1–P10) sampled in 2013–2014; (B) generalised geological map of the Volga–Kama region near the town of Kazan, Republic of Tatarstan, and (C) generalised geological map of the Pechishchi–Cheremushka area

Upwards in the section, above the grey fossiliferous dolomites of the Perekhodnaya (‘Transitional’) Member of the Upper Kazanian, the sequence in the Cheremushka Gully shows the following beds (from bottom to top).

Cheremushka Gully outcrop P01

Kazanian-Urzhumian Boundary;
Sulitsa Formation, Argillo-Arenaceous Member



Light-grey, pinkish-brown, wavy laminated, dolomitic marl and dolomite

Greyish-brown calcareous, muddy siltstone

Breccia, consisting of rounded-angular fragments of light-bluish dolomite arranged in greenish-grey and red shale matrix

Light-grey dolomite with greenish-grey lenses of shales

Light-grey, muddy, fine-grained, thickly bedded vuggy dolomite

Outcrop P01

GPS: 55.78047 N, 048.92753 E (WGS84). Datum: right slope of the Cheremushka Gully near the thalweg (valley line), 280 m south of the mouth of the gully. The base of the Urzhumian regional stage, as defined by Gusev (1998), is exposed in 2.0 m above the thalweg level and 98.0 m ASL. Beds dip east at 2°. Intervals in the bed-by-bed description are measured from the base of outcrop P01 in each station.

Kazanian Stage, Upper Kazanian Substage

Perekhodnaya ('Transitional') Member

Package P01/1 Interval 0.00–1.75 m Thickness (visible) 1.75 m

Dolomite: light-grey and greenish-grey, with lenses of greenish-grey shales, preserving horizontal gently undulating lamination; several thin intervals (0.15–0.35 m) of breccias, consisting of rounded-angular fragments of light-bluish dolomite arranged in greenish-grey and (or) red shales matrix (in the upper part of the interval).

Sulitsa Formation

Argillo-Arenaceous Member

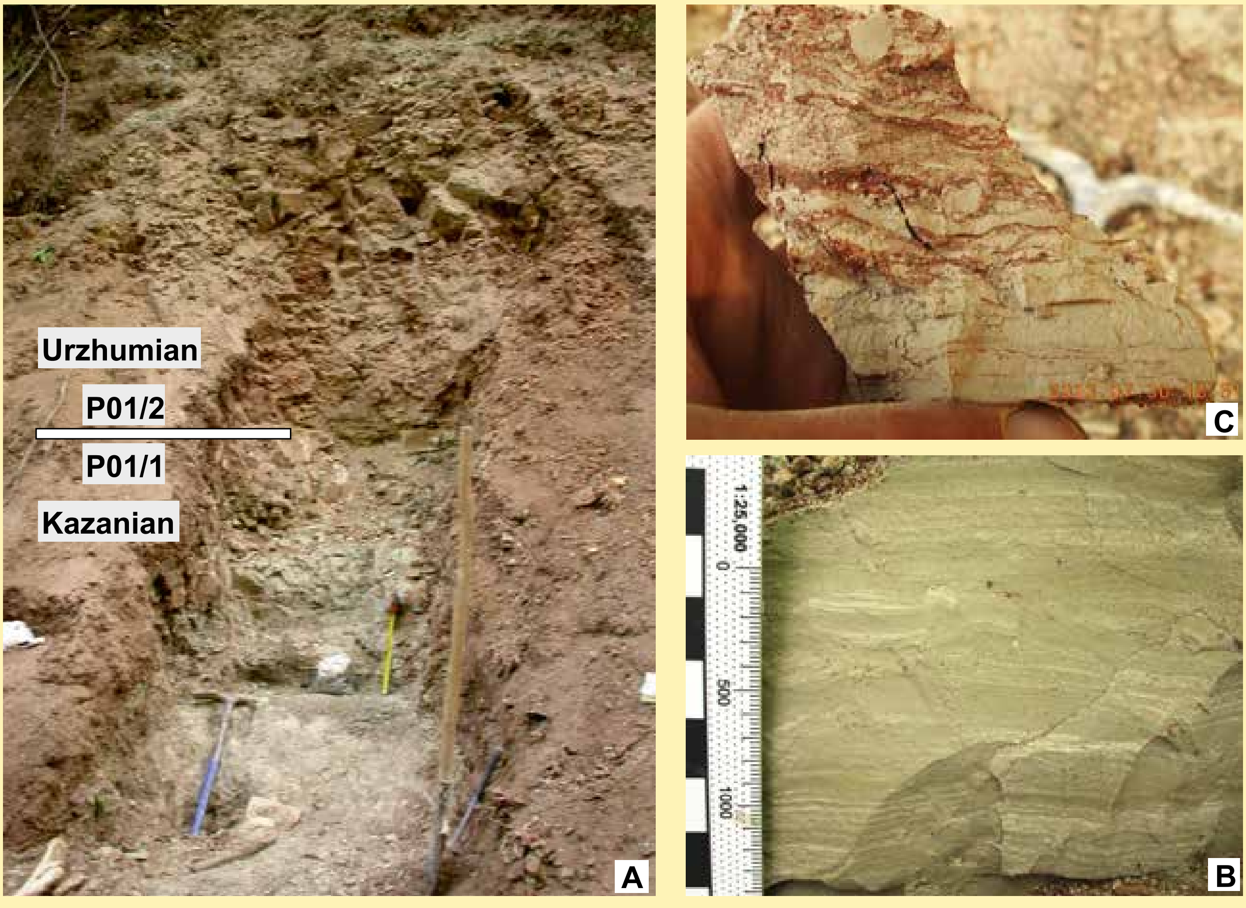
Package P01/2 Interval 1.75–3.95 m Thickness 2.20 m

Siltstone: brownish, greyish-brown, calcareous, lenticular or wavy laminated; thin lenses of limestone gravelite at the bottom.

Package P01/3 Interval 3.95–4.15 m Thickness 0.20 m

Dolomite and dolomitic marl: light-grey, greenish-grey, pinkish-brown, wavy laminated.

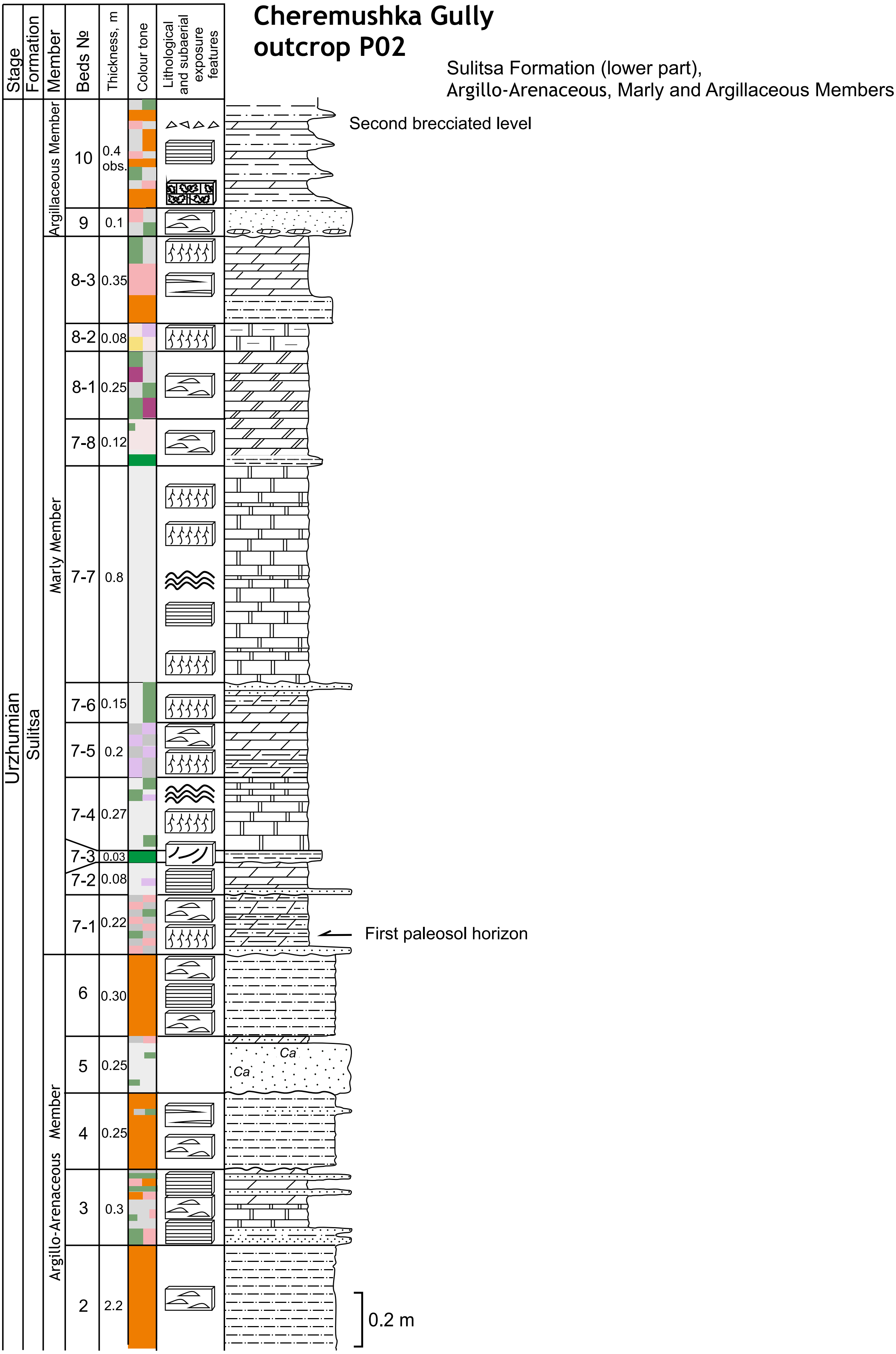
The overlying succession is more conveniently observed in outcrop P02.



Outcrop P01. General view of the outcrop (A), (B) greenish-grey dolomite with horizontal gently undulating lamination (middle part of bed P01/1), and (C) breccias from the top of bed P01/1; scale bar 1 cm.

Cheremushka Gully outcrop P02

Sulitsa Formation (lower part), Argillo-Arenaceous, Marly and Argillaceous Members



Outcrop P02

GPS: 55.78030 N, 048.92736 E (WGS84). Datum: left slope of the Cheremushka Gully near the thalweg (valley line), 15 m south of outcrop P01 (up the thalweg). The base of outcrop P02 is exposed in 1.5 m above the thalweg level.

Sulitsa Formation

Argillo-Arenaceous Member

Packages P02/2–P02/6 Interval 1.75–5.05 m Thickness 3.30 m

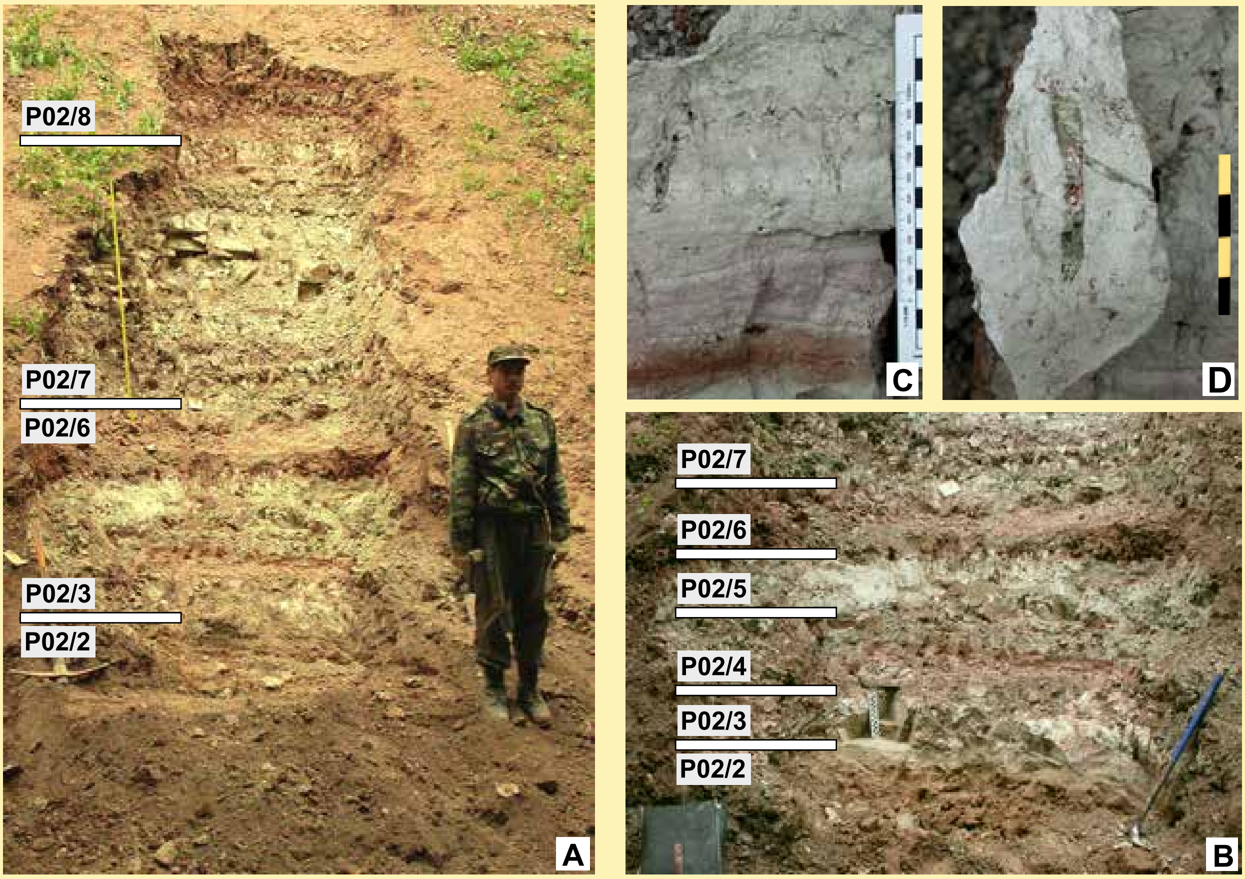
Siltstone: greyish-brown, more rarely greenish-grey, calcareous, muddy, with subordinate beds of greenish-grey sandstones and marls; various lenticular lamination.

Marly Member

Packages P02/7–P02/8 Interval 5.05–7.60 m Thickness 2.55 m

Dolomite and dolomitic marls with subordinate thin beds of shales and sandstones. Dolomite and dolomitic marls: light-grey, greenish, pinkish, algal-microbial, riddled with numerous voids of plant roots *in situ;* horizontally or wavy laminated, platy.

The overlying succession is more conveniently observed in outcrop P03.



Outcrop P02. General view of outcrop P02 (A), (B) speckled succession of beds P02/2–P02/7, (C and D) marl of bed P02/8-3 riddled with numerous voids of plant roots *in situ;* scale bar 1 cm

Cheremushka Gully, outcrop P03

Sulitsa Formation (middle part),
Argillaceous and Dolomitic Members

Outcrop P03

GPS: 55.78006 N, 048.92749 E (WGS84). Datum: left and right slopes of the Cheremushka Gully near the thalweg (valley line), 15 m south of outcrop P02 (up the thalweg).
At this station, the layers overlying bed P02/8 are exposed as in the left slope (outcrop up to 5 m, slightly covered with thin screes), as well as in the right slope (stretching along the thalweg approx. for 30 m).

Sulitsa Formation

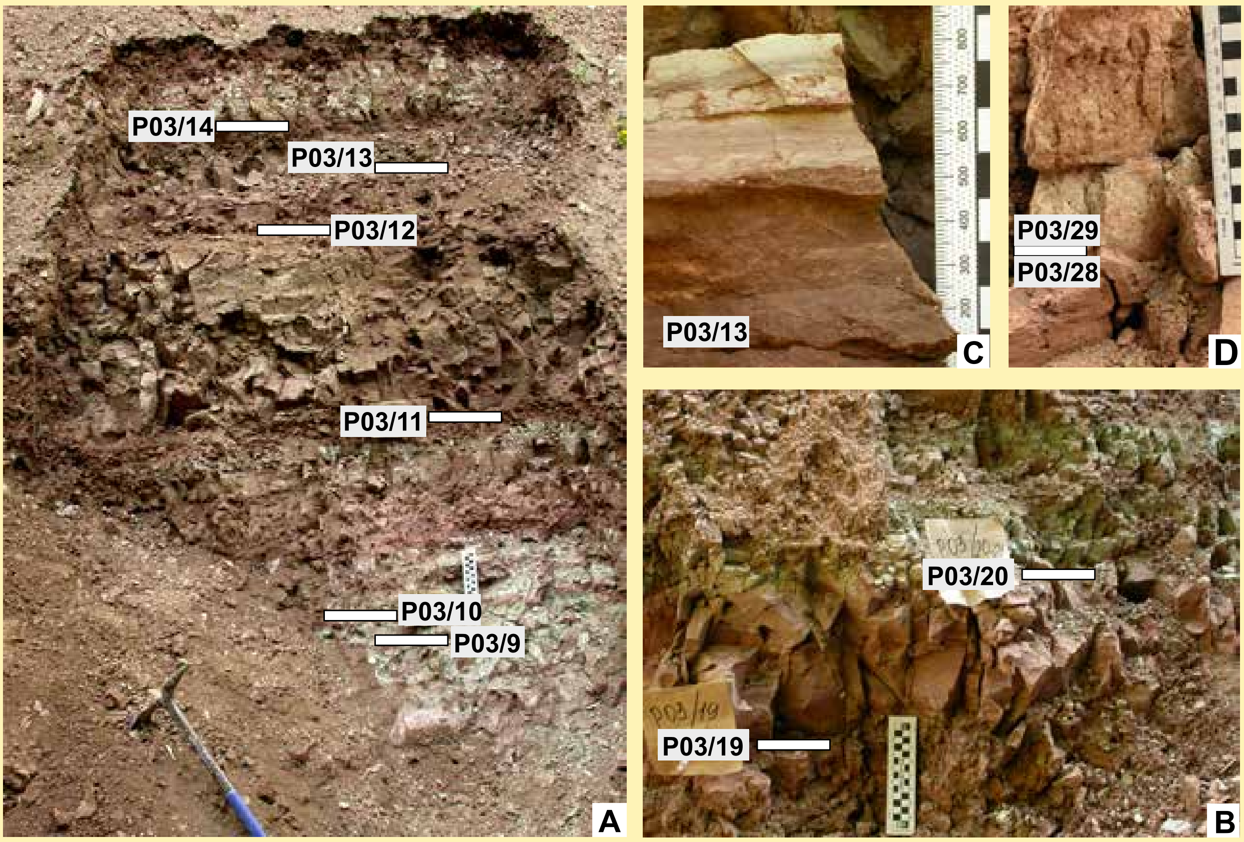
Argillaceous Member

Packages P03/9–P03/18 Interval 7.60–11.75 m Thickness 4.15 m
Siltstone and shale: brown, calcareous, lenticular and horizontal laminated, with thin (0.15–0.25 m) interbeds of pink and grey marl. Marl sometimes is riddled with numerous voids of plant roots *in situ*. Brecciated structure in marls and shales is identified at six thin (first cm) intervals. Shales contain rare fish scales.

Dolomitic Member

Packages P03/19–P03/31 Interval 11.75–16.30 m Thickness (visible) 4.55 m
Dolomite and dolomitic marl: light-grey, pinkish-grey, greenish-grey, algal-microbial, wavy laminated, pitted, with numerous voids of plant roots *in situ*; interbeds (0.1–0.2 m) of reddish-brown shales, containing rare fish remains or bluish gleying spots (probable paleosol horizon).

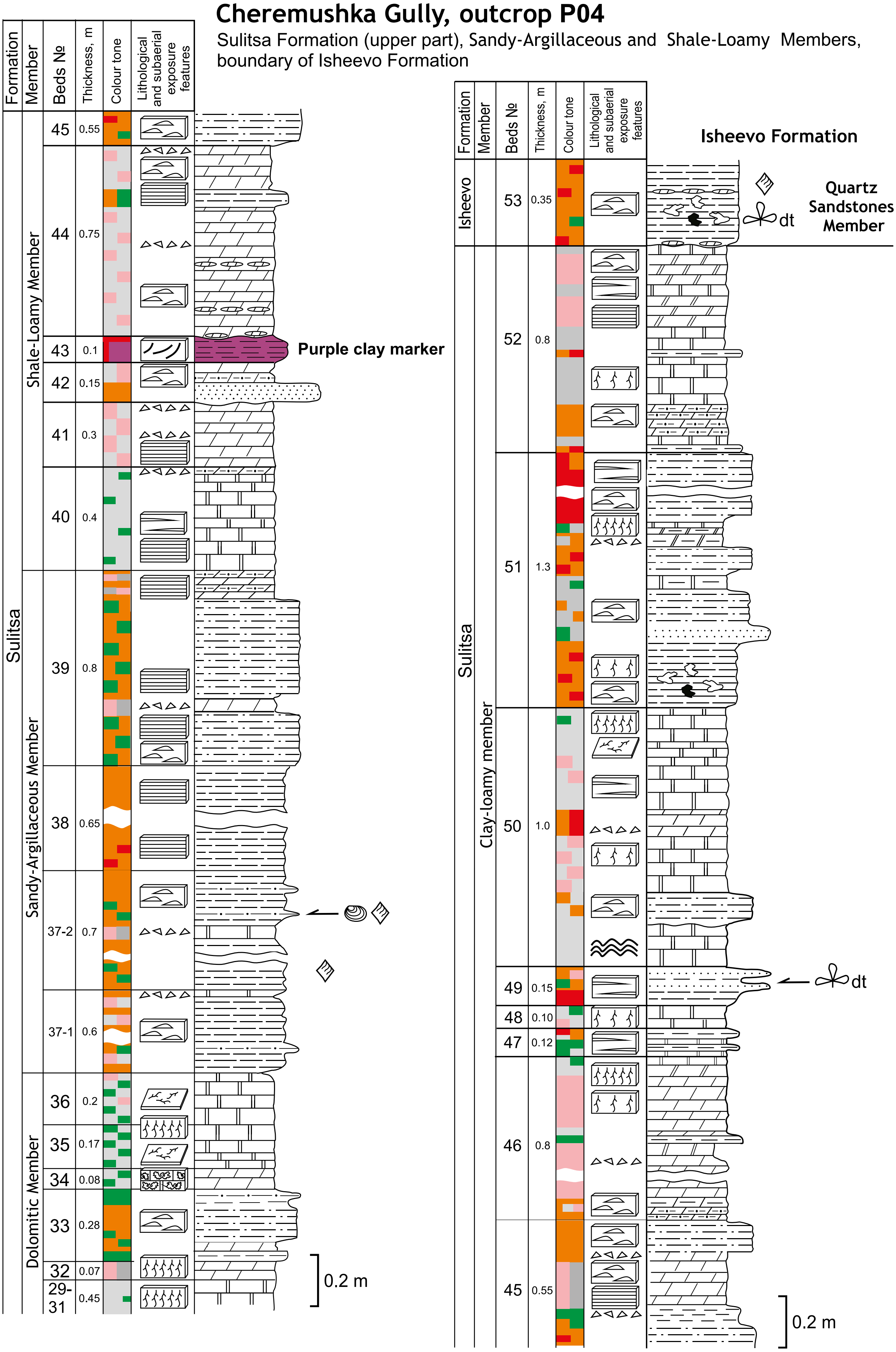
The overlying succession is more conveniently observed in outcrop P04.



Outcrop P03. General view of the outcrop, the basal part of the Argillaceous Member (A); (B) the basal part of the Dolomitic Member; (C) the boundary between brown siltstone and pinkish-grey marl with brecciated lamination (bed P03/13), and (D) marl of bed P03/28 and limestone of bed P03/29 riddled with numerous voids of plant roots *in situ*; scale bar 1 cm

Cheremushka Gully, outcrop P04

Sulitsa Formation (upper part), Sandy-Argillaceous and Shale-Loamy Members, boundary of Isheevo Formation



Outcrop P04

GPS: 55.77978 N, 048.92744 E (WGS84). Datum: right slope of the Cheremushka Gully near the thalweg, 20 m south of outcrop P03 (up the thalweg); vertical cutting for approx. 18 m.

Sulitsa Formation

Dolomitic Member (continuous)

Packages P04/32–P04/36 Interval 16.30–17.10 m Thickness 0.80 m

Dolomite and dolomitic marl: light-grey, pinkish-grey, greenish-grey, algal-microbial, wavy laminated, riddled with numerous voids of plant roots *in situ* and possessed allochthonous plant roots on the bedding planes; single interbed (0.25 m) of greenish-brown shales.

Total thickness of *Dolomitic Member* in outcrops 3 and 4 is 5.35 m.

Sandy-Argillaceous Member

Packages P04/37–P04/39 Interval 17.10–19.85 m Thickness 2.75 m

Siltstone and shale: greyish-brown, compact, horizontal and lenticular laminated, with thin laminae (5 cm) of pinkish-grey dolomites and marls characterised by brecciated lamination. The bedding planes of bed 37-2 possess scattered conchostracan shells and rare fish remains.

Shale-Loamy Member

Packages P04/40–P04/52 Interval 19.85–26.35 m Thickness 6.50 m

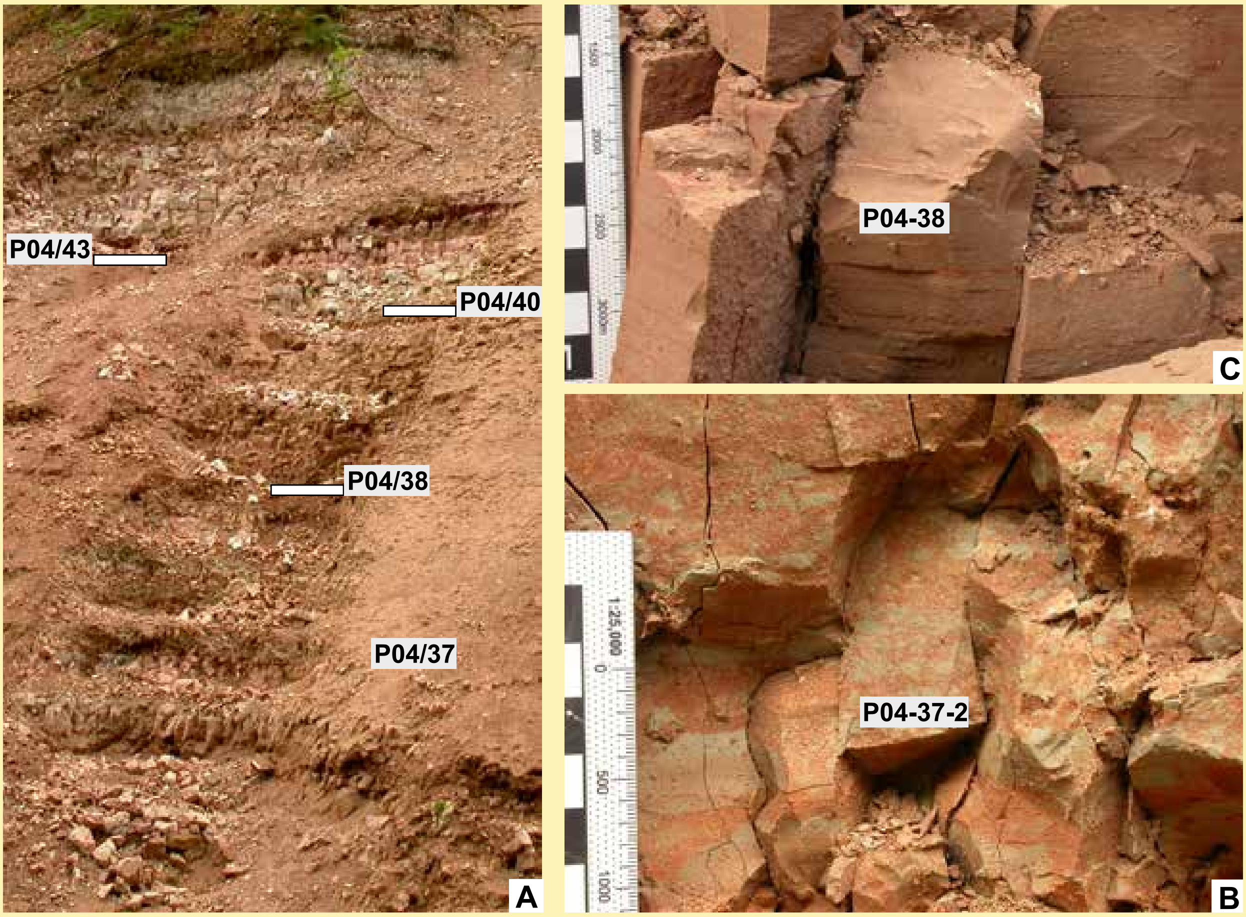
Dolomite, marl, dolomitic marl: light-grey, pinkish, greenish-grey, algal-microbial, compact, horizontal and lenticular laminated, platy, riddled with numerous voids of plant roots *in situ* and with allochthonous plant roots on the bedding planes; several thin intervals (0.15–0.20 m) of breccias; thin interbeds of reddish-brown and purple siltstone and shales.

Isheevo Formation

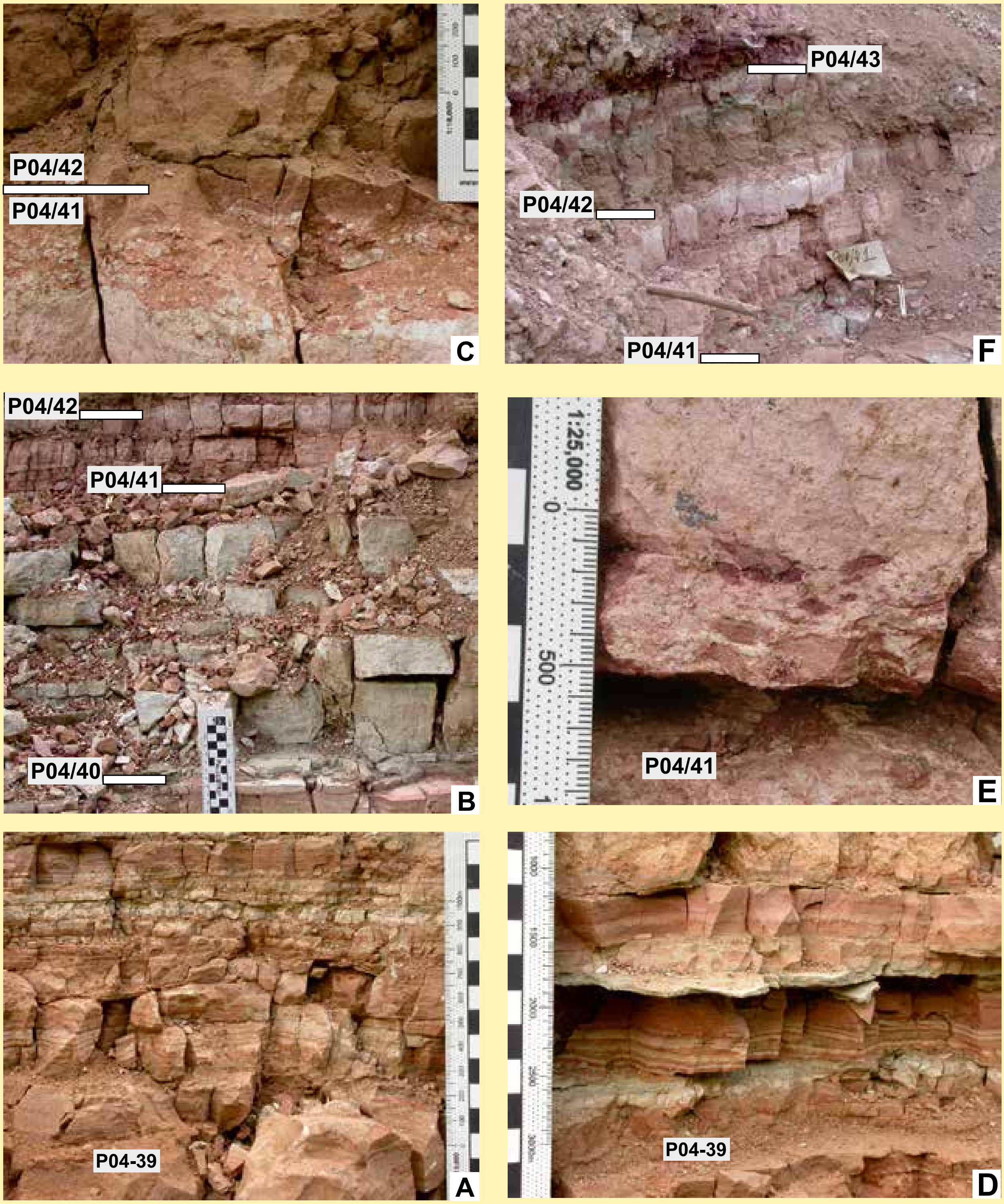
Quartz Sandstone Member

Packages P04/53 Interval 26.35–26.65 m Thickness (visible) 0.35 m

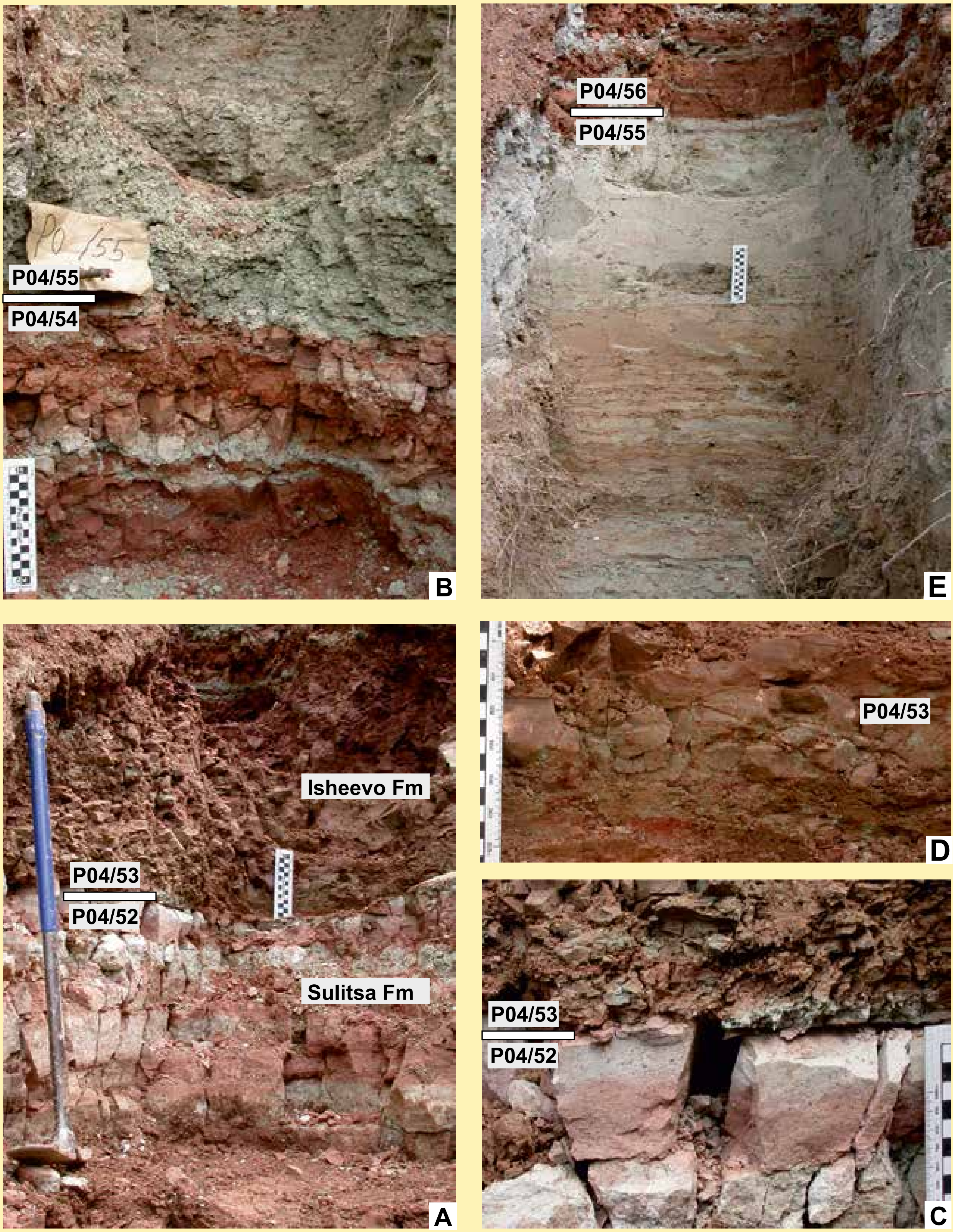
Shales: reddish-brown, with greenish-grey spots of gleisation; rare fish remains and plant detritus.



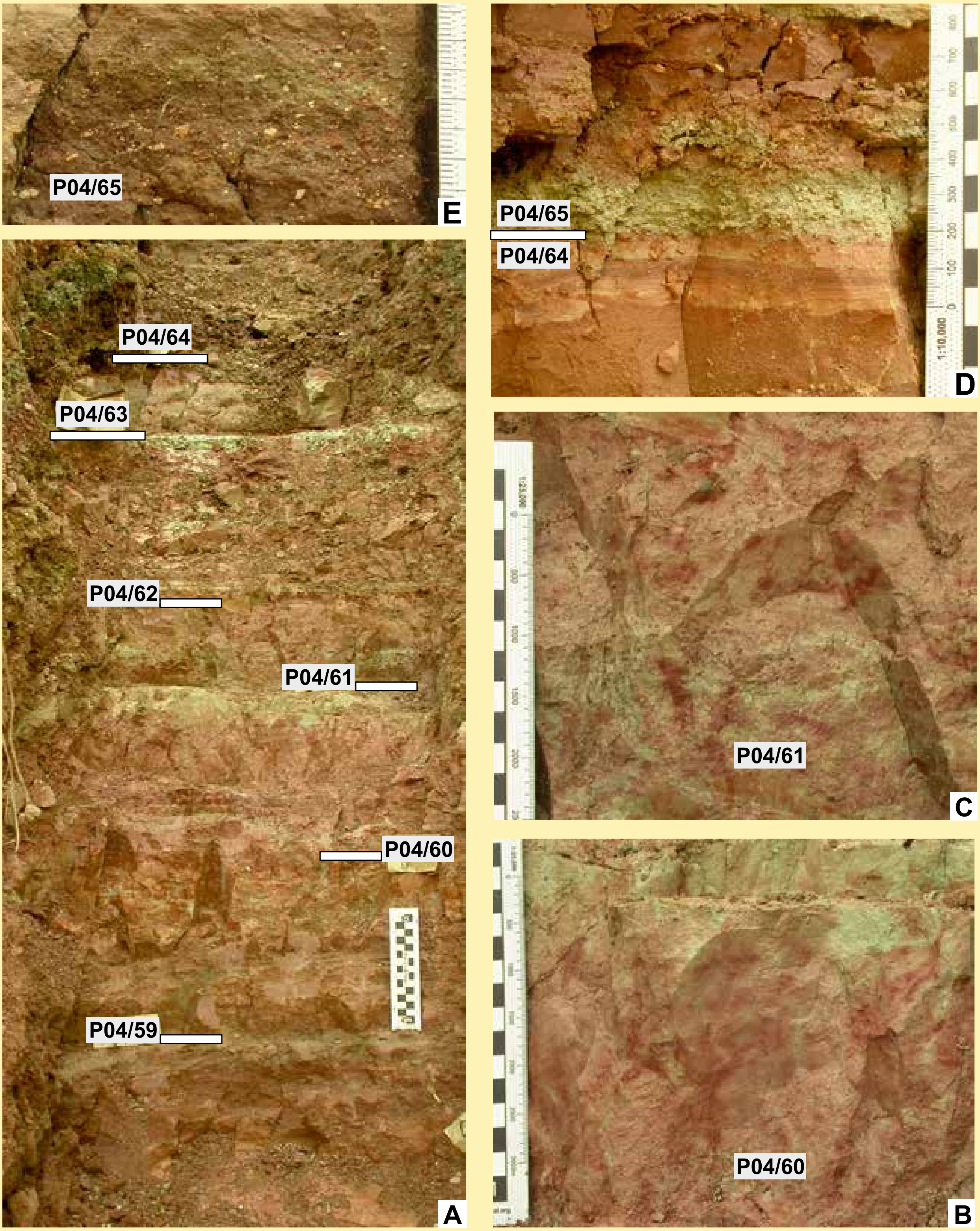
Outcrop P04. General view of the lower part of outcrop P04 (A); (B) brecciated shales of bed P04/37-2, and (C) reddish-brown shales with horizontal lamination, bed P04/38; scale bar 1 cm



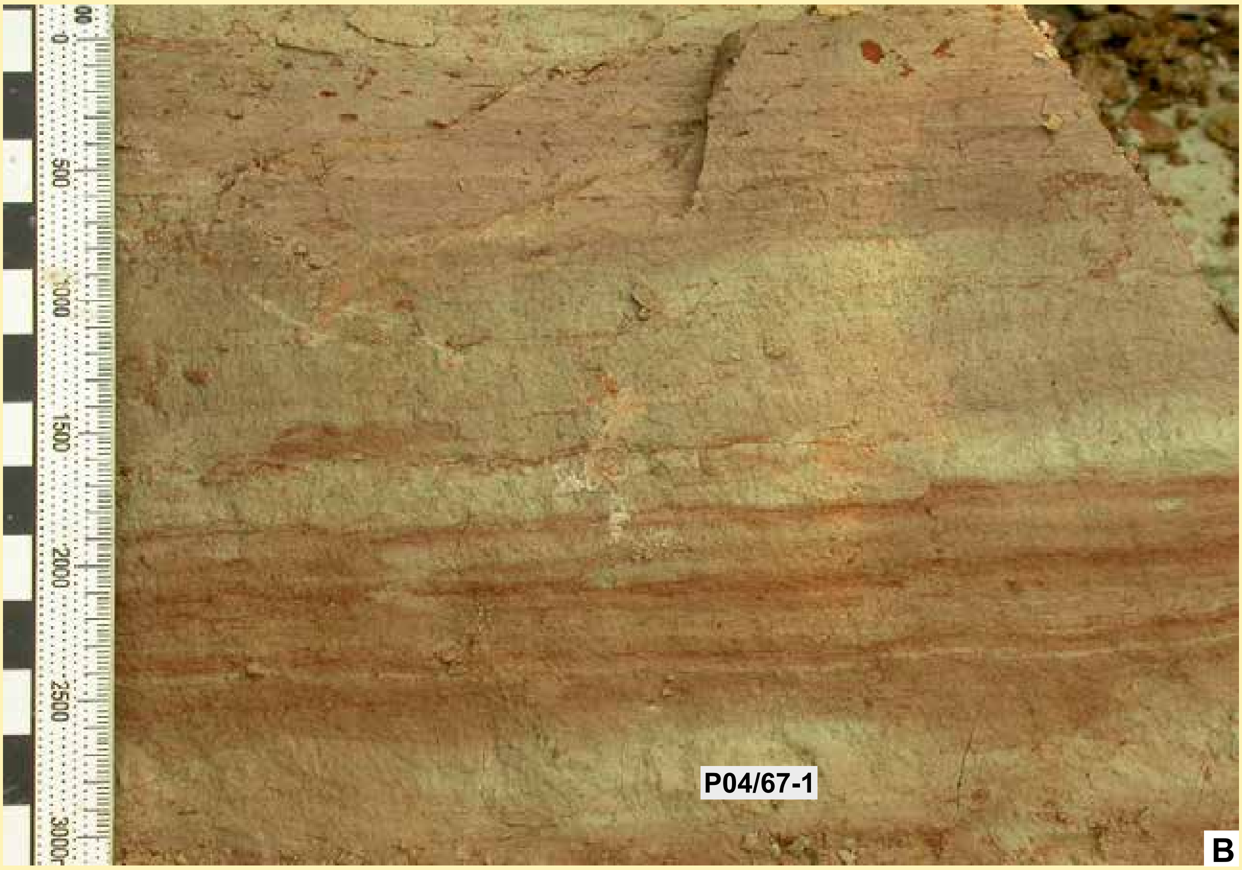
Outcrop P04. Platy speckled succession of pinkish-grey marls and light-grey dolomites, beds P04/39–P04/42 (A and B); (C) the rough surface between brecciated marl and overlaying brown sandstone, (D) the fragment of bed P04/39, thin bands of grey sandstone stress the cyclicity of succession, (E) brecciated calcareous shales from bed P04/41, and (F) the succession of Shale-Loamy Member containing Purple shale marker (bed P04/43); scale bar 1 cm General view of the lower part of outcrop P04 (A); (B) brecciated shales of bed P04/37-2, and (C) reddish-brown shales with horizontal lamination, bed P04/38; scale bar 1 cm



Outcrop P04. The boundary between platy speckled succession (bed P04/52, Sulitsa Fm) and reddish-brown shales with greenish-grey spots of gleisation (bed P04/53, Isheevo Fm) (A, C, D); (B) the rough surface between shales (bed P04/54) and overlaying greenish-grey quartz sandstone (bed P04/55), (E) the greenish-grey and brownish-grey (argillaceous) quartz sandstone (bed P04/55) overlaid by brown lenticular laminated siltstone (bed P04/56); scale bar 1 cm



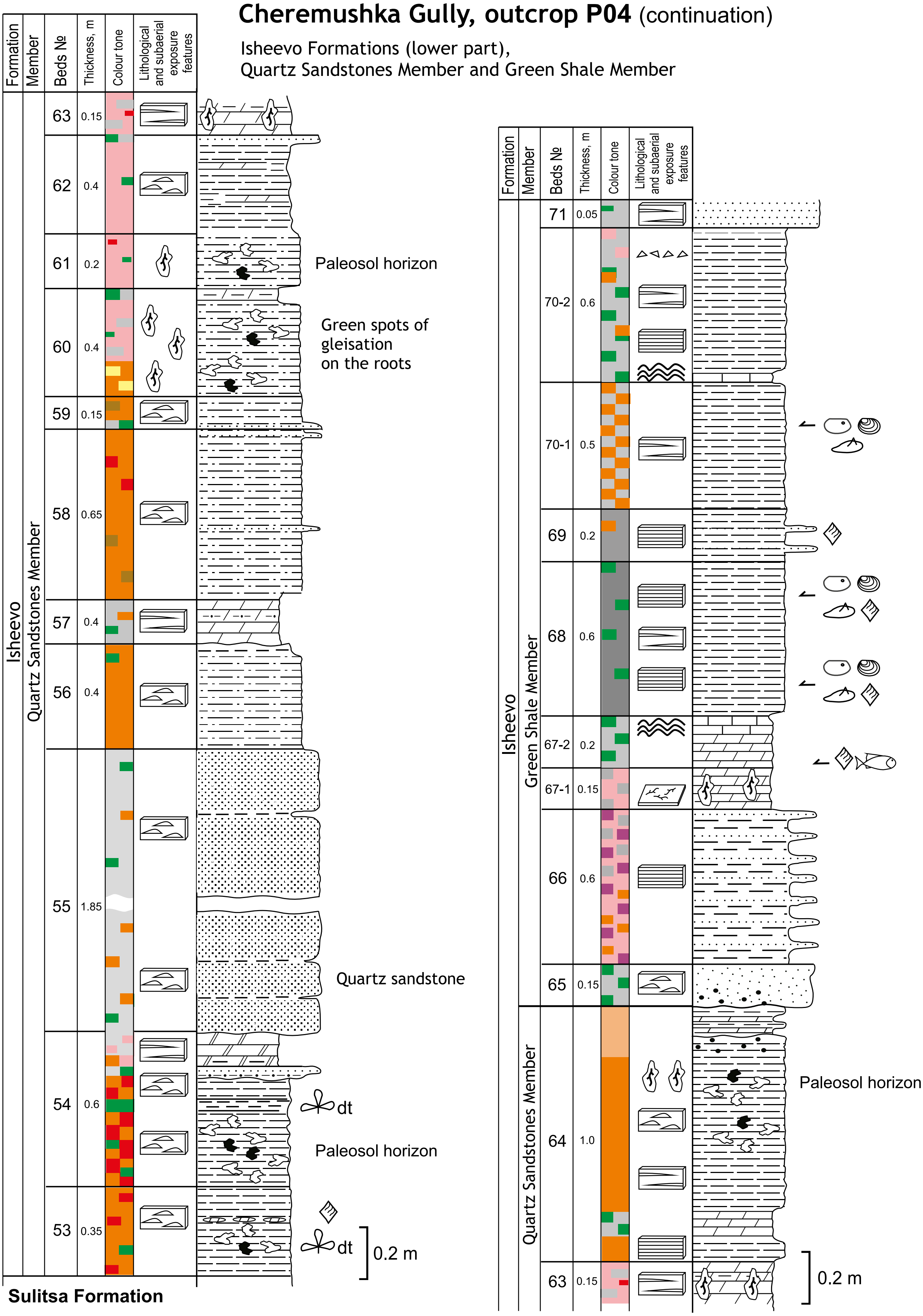
Outcrop P04. General view of the middle part of outcrop P04, Isheevo Fm (A); (B and C) pinkish-green shales with the spots of gleisation (bed P04/60 and bed P04/61), (D) contact between Quartz Sandstone Member (bed P04/64, shales with brecciated lamination) and Green Shale Member (bed P04/65, basal greenish-grey sandstone); scale bar 1 cm



Outcrop P04. The fragment of the lower part of the Green Shale Member (A); (B) pinkish-green marl with lenticular lamination at the lower part of the specimen and with gleisation on the allochthonous traces of plant roots (?), resembling red spots, at the upper part of the specimen (bed P04/67-1); scale bar 1 cm

Cheremushka Gully, outcrop P04 (continuation)

Isheevo Formations (lower part),
Quartz Sandstones Member and Green Shale Member



Outcrop P04 (continuation)

GPS: 55.77978 N, 048.92744 E (WGS84). Datum: right slope of the Cheremushka Gully near the thalweg, 20 m south of outcrop P03 (up the thalweg); vertical cutting for approx. 18 m.

Isheevo Formation

Quartz Sandstone Member

Packages P04/53–P04/64 Interval 26.35–32.90 m Thickness 6.55 m

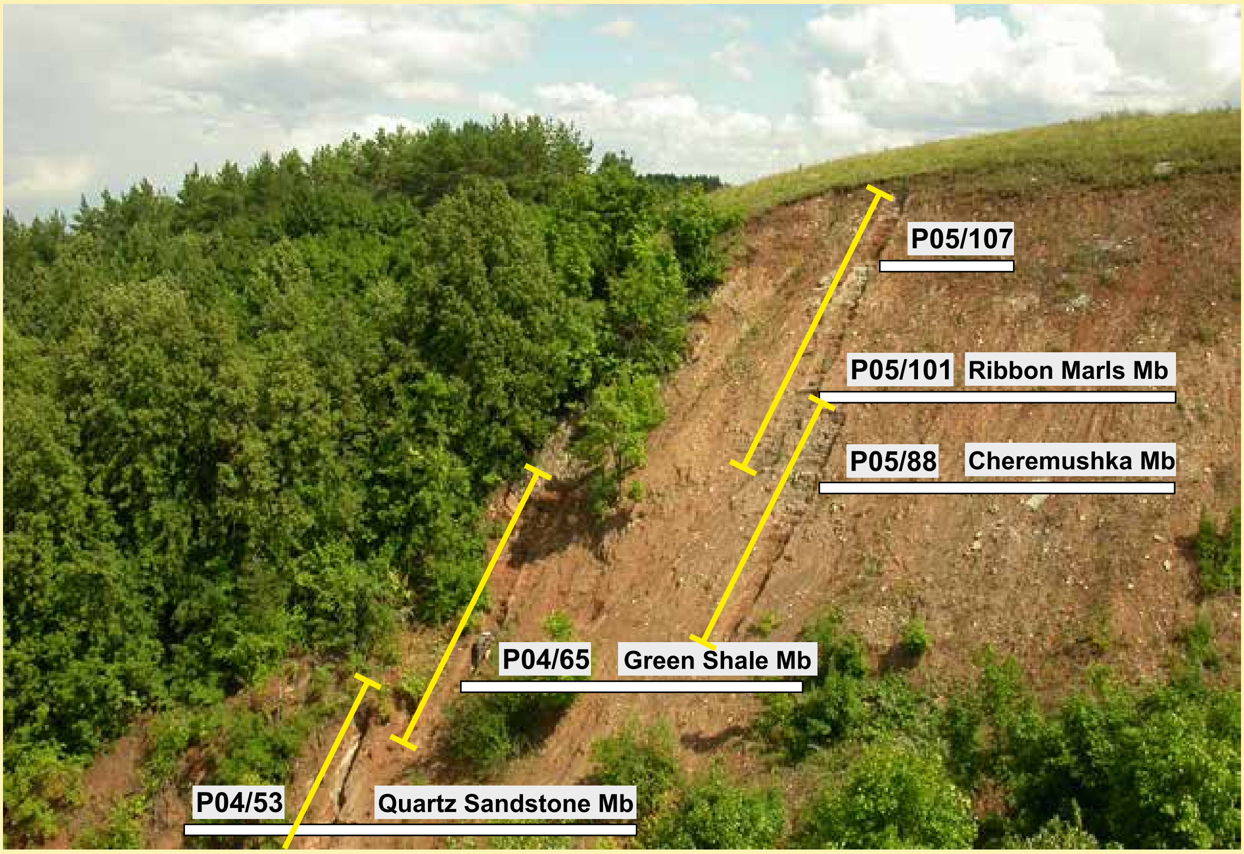
Shale, siltstone and sandstone with subordinate interbeds of marls. Shale: light-brown, yellowish, pinkish, reddish, calcareous, lenticular laminated, with greenish-grey and red spots (stains) of gleisation on the vertical traces of plant roots (paleosol horizons). Sandstone (1.85 m): light-grey, yellowish-orange, quartz, obliquely laminated, loosely cemented by muddy-carbonate cement ('Quarts sandstone'). Siltstone: reddish-brown with lenticular lamination and stains of bright-red and green shales. Marls: grey, greenish, cream-coloured, massive, silty and sandy, with gleisation on the vertical traces of plant roots.

Green Shale Member (lower part)

Packages P04/65–P04/70 Interval 32.90–35.90 m Thickness 3.00 m

Shales: greenish-grey, brownish-grey, mudstone-like, compact, thinly horizontally laminated with ochreous stains on bedding planes. Shales contain numerous remains of bivalves, ostracodes, conchostracans, and fishes. The bivalves: *Palaeomutela wohrmani* Netsch., *P. krotowi* Netsch., *P. doratioformis* (Gus.), *P. vjatkensis* (Gus.), *Prilukiella subovata* (Jones), *Anadontella volgensis* (Gus.); ostracodes: *Paleodarwinula elongata* (Lun.), *P. teodorovichi* (Bel.), *P. tichonovichi* (Bel.), and *Prasuchonella nasalis* (Shar.); plant remains: *Paracalamites frigidus* Neub., *Annularia* cf. *parvula* Neub., *Phyllotheca* sp., *Tschernovia striata* Neub., *Sphenophyllum* sp. At the base of the member there is a bed of brownish-red and violet siltstone (0.60 m thick). The siltstone is horizontally laminated, interbedded with greenish-grey, polymict, fine-grained sandstone. Immediately above this siltstone bed there are pinkish-grey and greenish-grey marls and algal-microbial limestones (0.35 m thick) with gleisation on the allochthonous traces of plant roots.

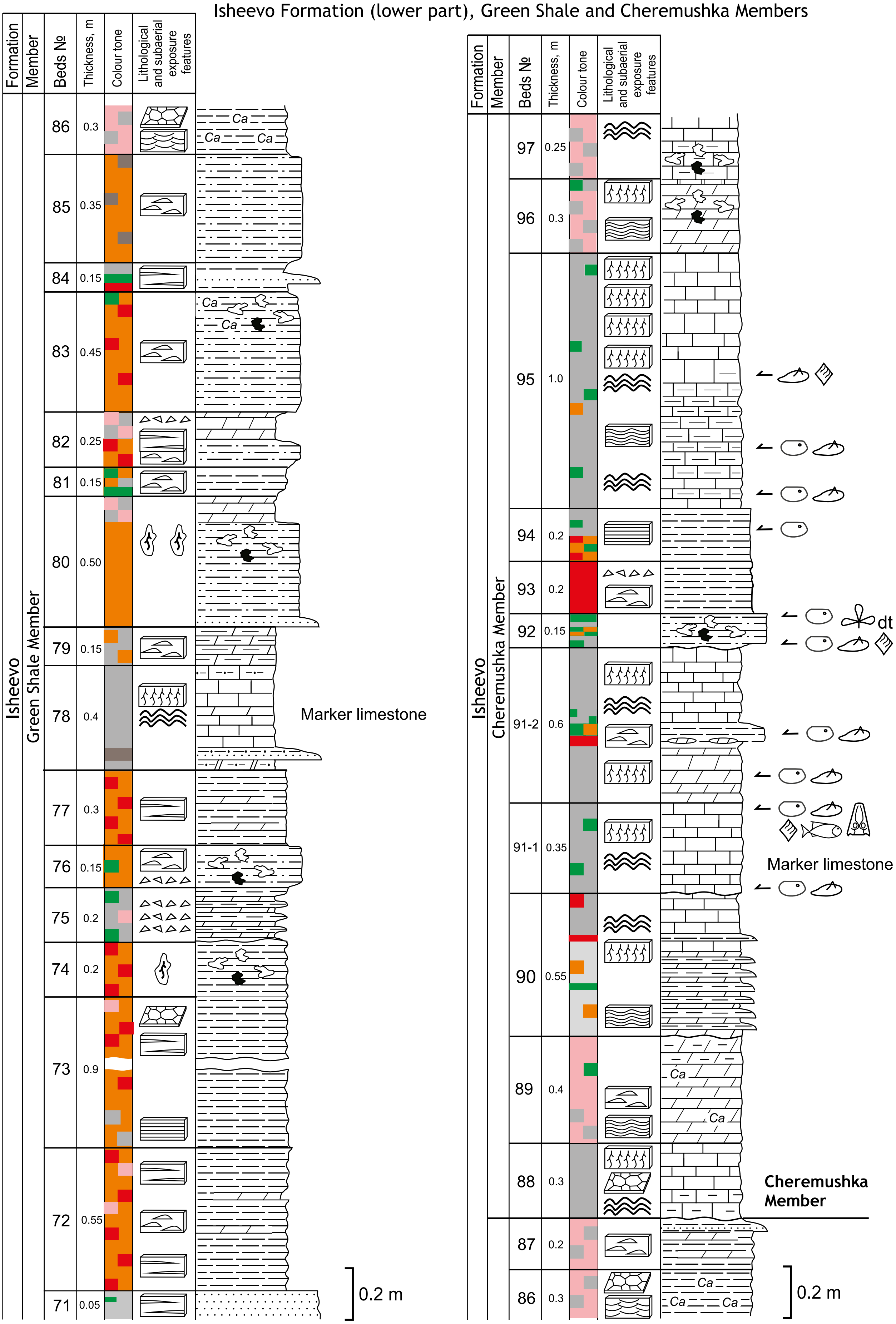
The upper part of the *Green Shale Member* is observed in outcrop P05.



Right slope of the Cheremushka Gully and location of outcrops P04 and P05

Cheremushka Gully, outcrop P05

Isheevo Formation (lower part), Green Shale and Cheremushka Members



Outcrop P05

GPS: 55.77987 N, 048.92747 E (WGS84). Datum: middle part of the right slope of the Cheremushka Gully, 10 m south of the top level of outcrop P04; the lower half of vertical cutting for approx. 20 m up to the edge of the slope.

Isheevo Formation

Green Shale Member (upper part)

Packages P05/71–P05/87 Interval 35.90–41.15 m Thickness 5.25 m

Shales with subordinate interbeds of marls and limestones. Shales: brownish-red, pinkish-red, with lenticular lamination and stains of bright-red and green shales.

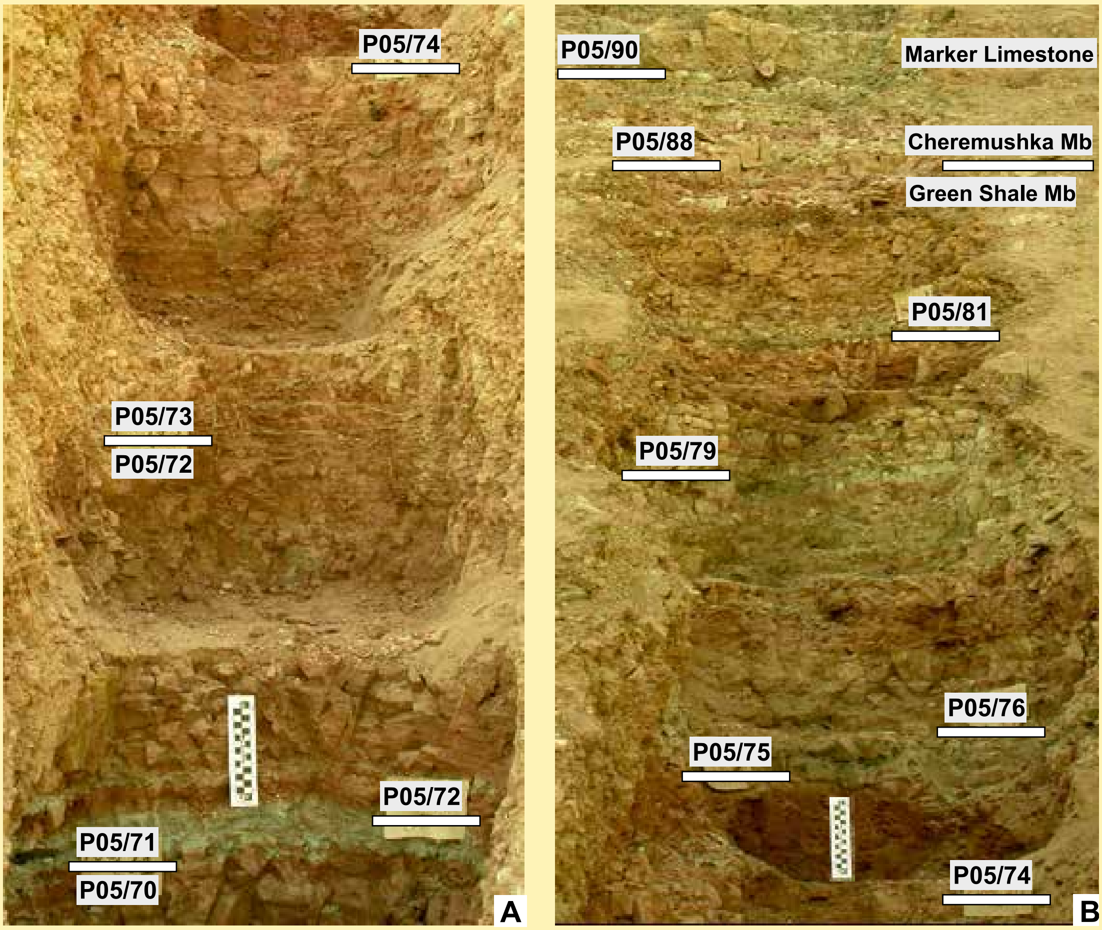
Marls and limestones: greenish-grey, pinkish-grey, algal-microbial, riddled with voids of plant roots *in situ*; several thin intervals (0.1–0.2 m) of shale-loamy breccias.

Total thickness of *Green Shale Member* is 8.25 m.

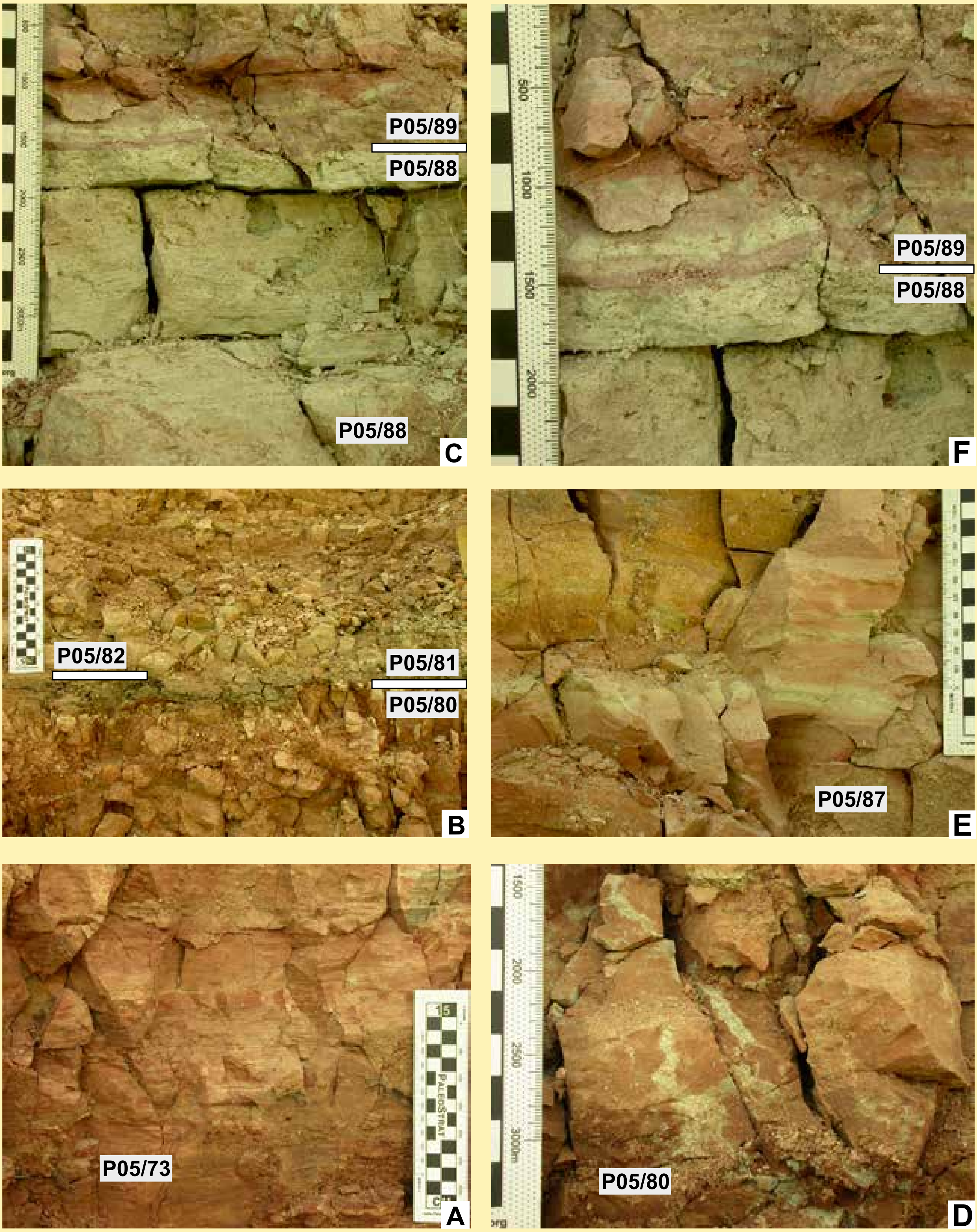
Cheremushka (argillaceous-carbonate) Member (lower part)

Packages P05/88–P05/97 Interval 41.15–45.45 m Thickness 4.30 m

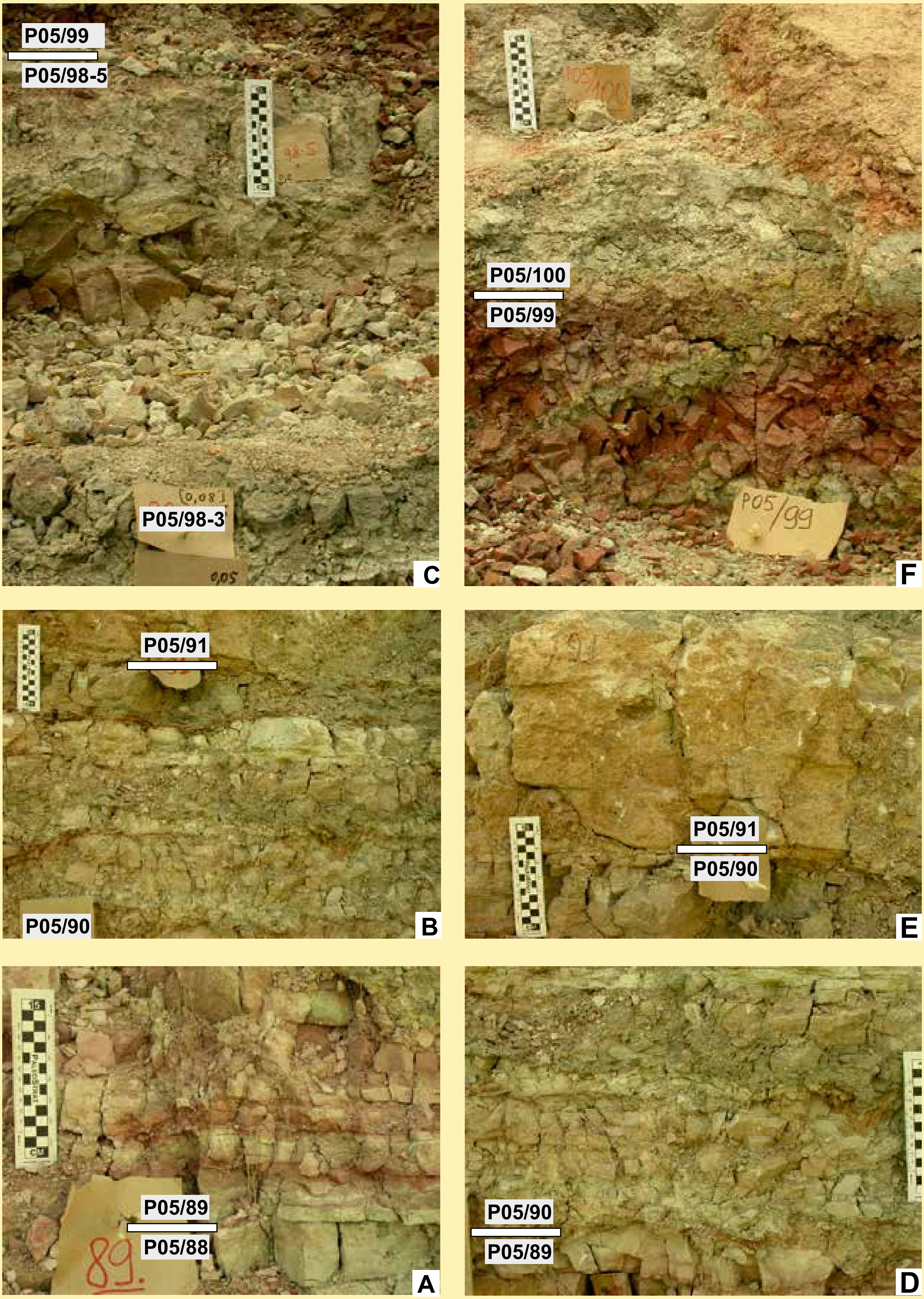
Limestone and marl. Limestone: dark- and light-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. Marls: grey, greenish or pinkish, with interbeds of red shales and siltstone. Rocks contain ostracods, bivalves, fish scales, small amphibian bones and charophytes. Bivalves are represented by *Palaeomutela extensiva* (Gus.), *P. wohrmani* Netsch., *P. vjatkensis* (Gus.), *P. krotowi* Netsch., *P. doratioformis* (Gus.), *Prilukiella subovata* (Jones), *Anadontella volgensis* (Gus.), *etc.,* amphibians by *Chroniosuchus* sp., ostracodes by *Paleodarwinula fragiliformis* (Kash.), *P. elongata* (Lun.), *P. teodorovichi* (Bel.), *P. torensis, P. elegantella, Prasuchonella nasalis* (Schar.), *Permiana elongata* Posn., *etc.,* and charophytes *Luichara luoii* Kis., *Cuneatochara amara* Said., *Stomochara diserta* Said., *Stm. constricta* Kis., and *Stm. lubrica* Said. Few thin intervals (0.1 m) of shale-loamy breccias and fissures of desiccation.



Outcrop P05. General view of the lower parts of the Green Shale Member (A), (B) upper part of the Green Shale Member and its contact with Cheremushka Member; scale bar 1 cm



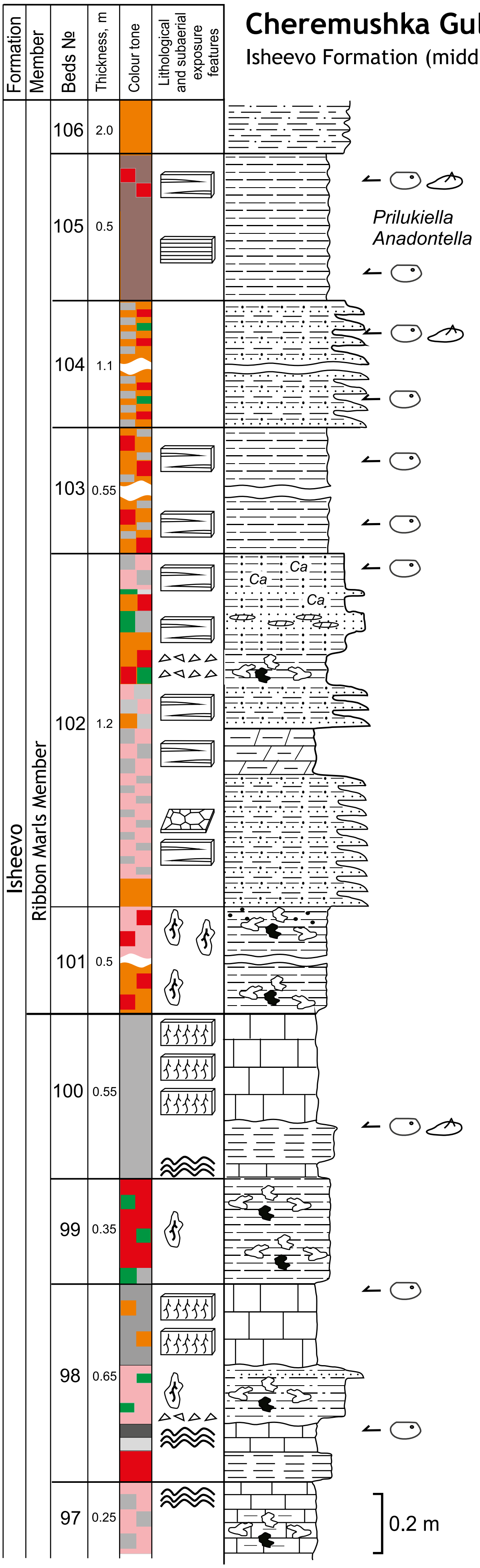
Outcrop P05. Typical shales of the upper part of the Green Shale Member with thin horizontal and lenticular lamination (A), (B) thin band of green shales (bed P05/81) within brownish-grey succession of siltstones, (C) platy limestones of the basal part of the Cheremushka Member, (D) shales of the upper part of the Green Shale Member with the gleisation on the plant roots *in situ*, (E) the uppermost shales of the Green Shale Member (bed P05/87) with lenticular lamination, (F) the fissures of desiccation at the boundary surface between limestone (bed P05/88) and pinkish-grey marl (bed P05/89), the fissures are infilled by pinkish-grey marl and look like pinkish-grey anastomotic network in vertical section; scale bar 1 cm

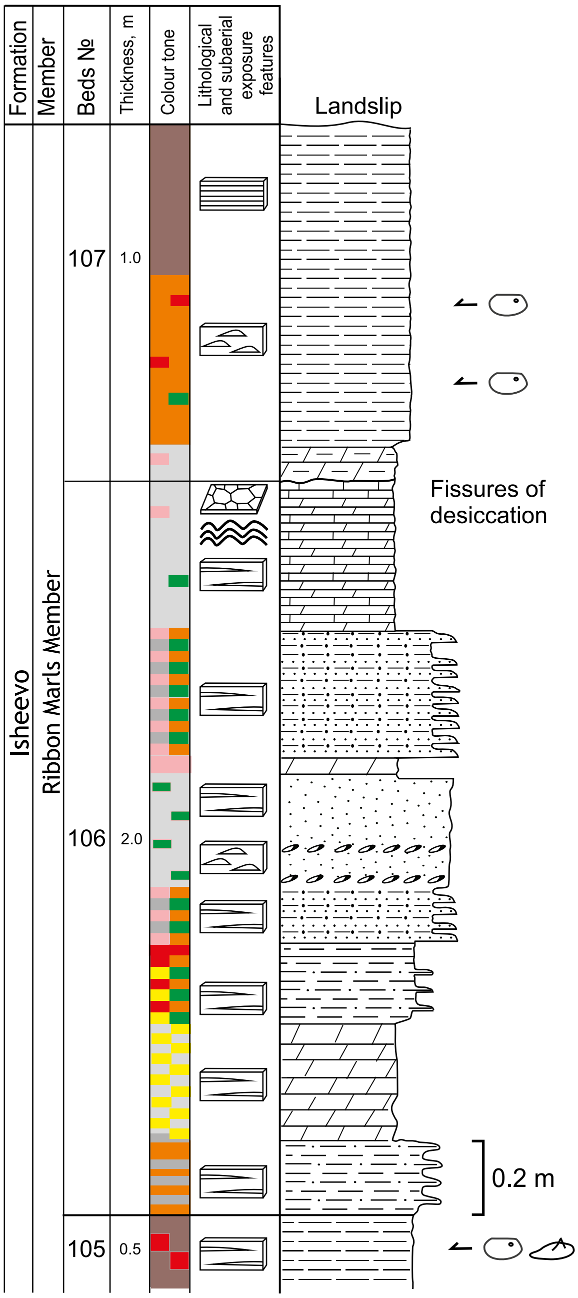


Outcrop P05. Lower part of the Cheremushka Member, the intercalation of limestone and marl with subordinate bands of greenish-grey and brownish-red shales, beds P05/88–P05/91 (A, B, D, E); and (C, F) the uppermost beds (P05/98–P05/100) of the Cheremushka Member; scale bar 1 cm

Cheremushka Gully, outcrop P05 (continuation)

Isheevo Formation (middle part), Ribbon Marls Member





Outcrop P05 (continuation)

GPS: 55.77987 N, 048.92747 E (WGS84). Datum: middle part of the right slope of the Cheremushka Gully, 10 m south of the top level of outcrop P04; the upper half of vertical cutting for approx. 20 m up to the edge of the slope.

Isheevo Formation

Cheremushka (argillaceous-carbonate) Member (upper part)

Packages P05/98–P05/100 Interval 45.45–47.00 m Thickness 1.55 m

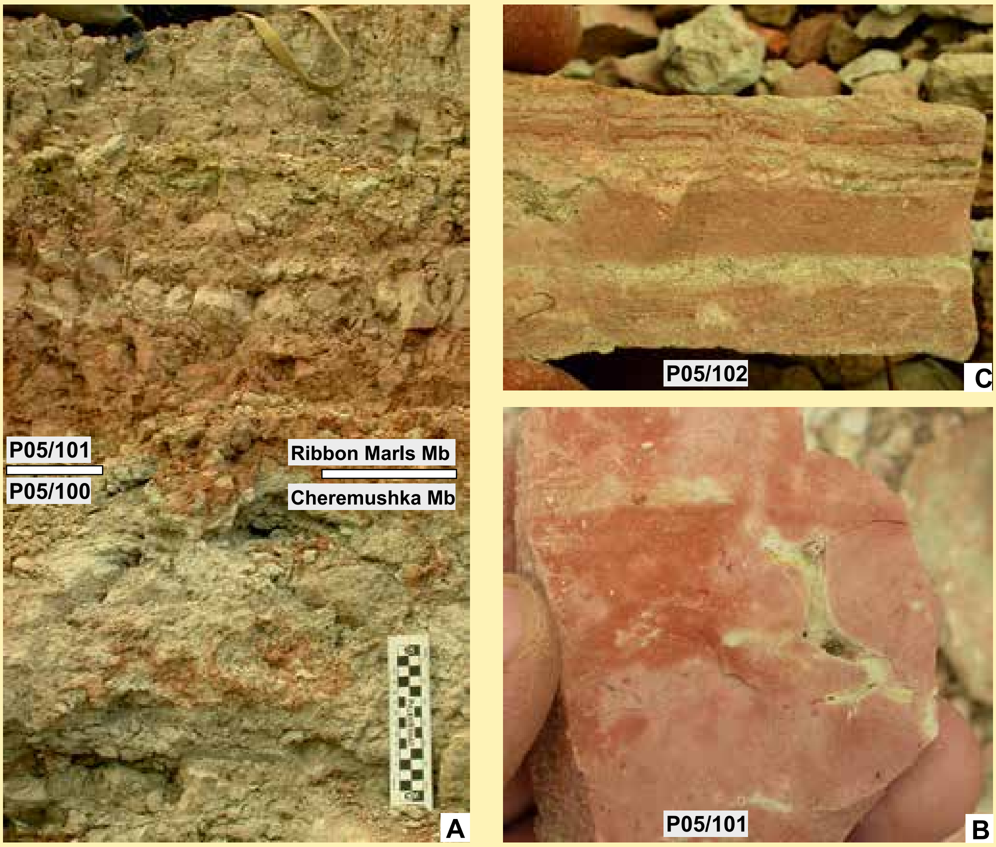
Limestone and shale. Limestone: dark- and light-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. Shales: red, pinkish-red, with green spots of gleisation on the *in situ* traces of plant roots. Limestones and subjacent grey shales contain scattered remains of ostracods, small bivalves, remains of fishes, and charophytes. Total thickness of *Cheremushka Member* is 5.85 m.

Ribbon Marls Member (lower part)

Packages P05/101–P05/107 Interval 47.00–53.85 m Thickness (visible) 6.85 m

Sandy-loamy member with ribbon (banded) marls. Shales: brown, reddish-brown, pinkish, yellowish, compact, mainly thinly horizontally or lenticular laminated with laminae of greenish-grey fine-grained sandstone and brown siltstone. The middle part of the member contains several beds (each of 0.4 m) of yellowish-grey and pinkish-grey (ribbon), horizontally thinly laminated, platy marls. Shales and marls contain numerous remains of conchostracans, the ostracods *Palaeodarwinula fragiliformis* (Kash.), *P. elongata* (Lun.), *P. obvia* (Mol.), *P. arida* (Mol.), *Prasuchonella nasalis* (Shar.), *Permiana elongata* Posn., etc., the bivalves *Palaeomutela doratioformis* (Gus.), *Palaeomutela (Palaeanodonta) cf. longissima Netsch., Anadontella volgensis* (Gus.)., *A. uslonensis* (Gus.), *Prilukiella subovata* (Jones), *Pr. pugnatoria* (Gus.), *Pr. mirabilis* (Gus.), etc., and fish remains.

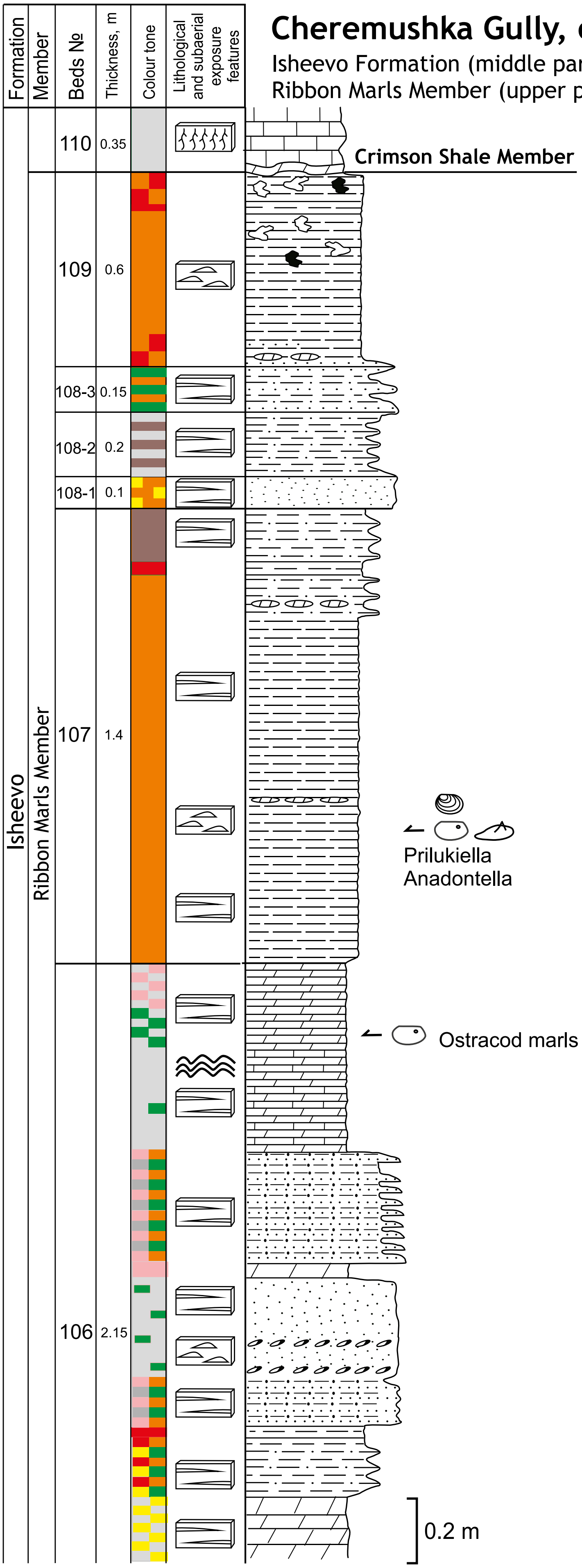
Bed 107 is cut off by a landslip of the slope edge. The upper beds of the *Ribbon Marls Member* and its contact with overlaid *Crimson Shale Member* are observed in outcrop P06.



Outcrop P05. The boundary between the Cheremushka Member and the Ribbon Marls Member (P05/100–P05/101) (A), (B) red shales (bed P05/101) with the gleisation on the plant roots *in situ*; (C) the intercalation of shales (brown) and marl (light-grey) with 'brecciated '('broken') lamination (bed P05/102); scale bar 1 cm

Cheremushka Gully, outcrop P06

Isheevo Formation (middle part),
Ribbon Marls Member (upper part)



Outcrop P06

GPS: 55,77957 N, 048,92701 E (WGS84). Datum: upper part of the left slope of the Cheremushka Gully, 210 m north of the gully head; the vertical cutting approx. in 4.0–9.0 m lower the edge of the slope.

Isheevo Formation

Ribbon Marls Member (upper part)

Packages P06/106–P06/109 Interval 53.85–58.45 m Thickness (visible) 4.60 m

Sandy-loamy member with ribbon (banded) marls. Shales: brown, reddish-brown, pinkish, yellowish, compact, mainly thinly horizontally or lenticular laminated with laminae of greenish-grey fine-grained sandstone and brown siltstone. The middle part of the member contains several beds (each of 0.4 m) of yellowish-grey and pinkish-grey (ribbon), horizontally thinly laminated, platy marls. Shales and marls contain numerous remains of conchostracans, ostracods, bivalves, and fish remains.

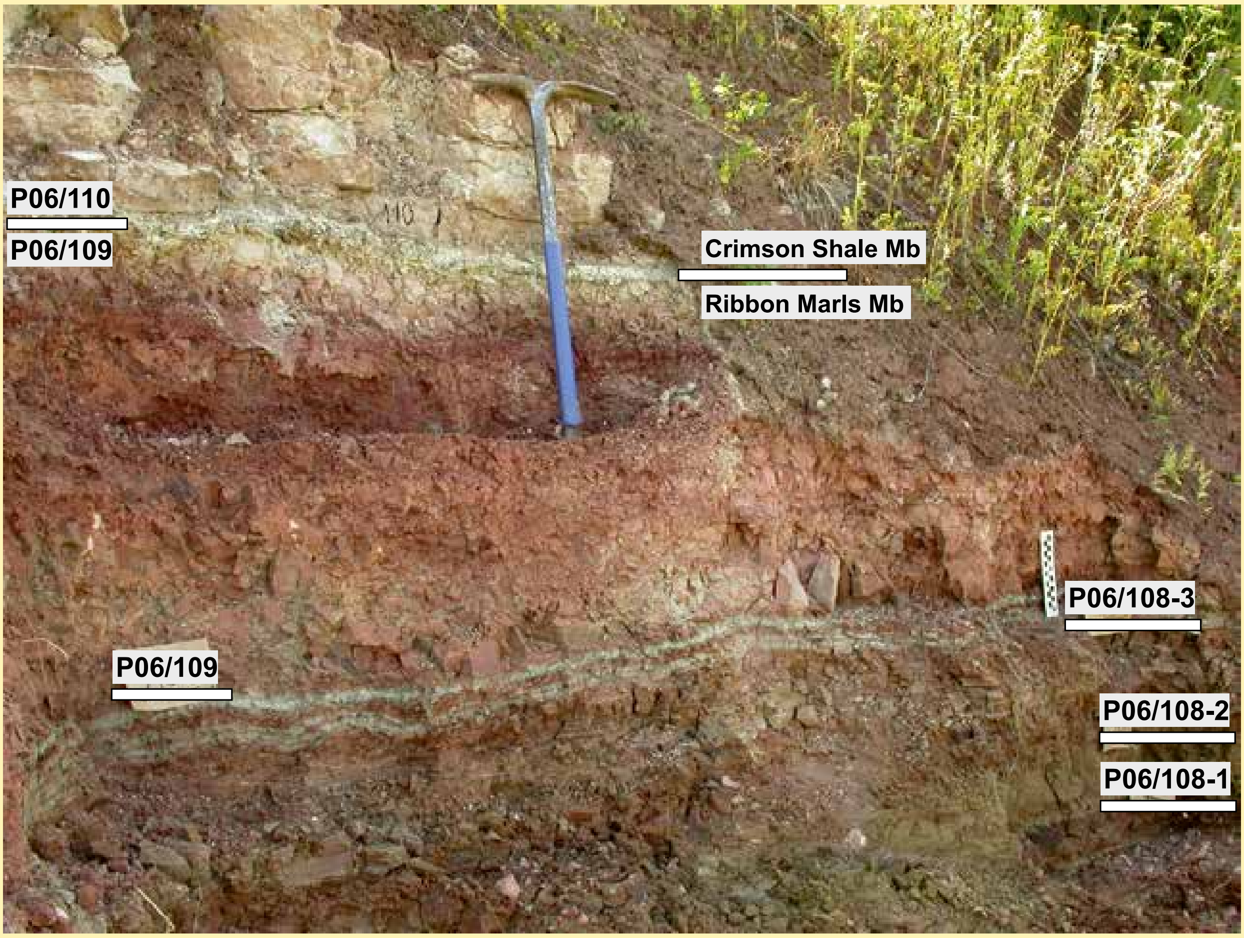
Total thickness of *Ribbon Marls Member* is 8.45 m.

Crimson Shale (argillaceous-carbonate) Member (basal part)

Packages P06/110 Interval 58.45–58.80 m Thickness (visible) 0.35 m

Limestone: light-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*.

The full succession of the *Crimson Shale Member* is observed in outcrops P07 and P08.

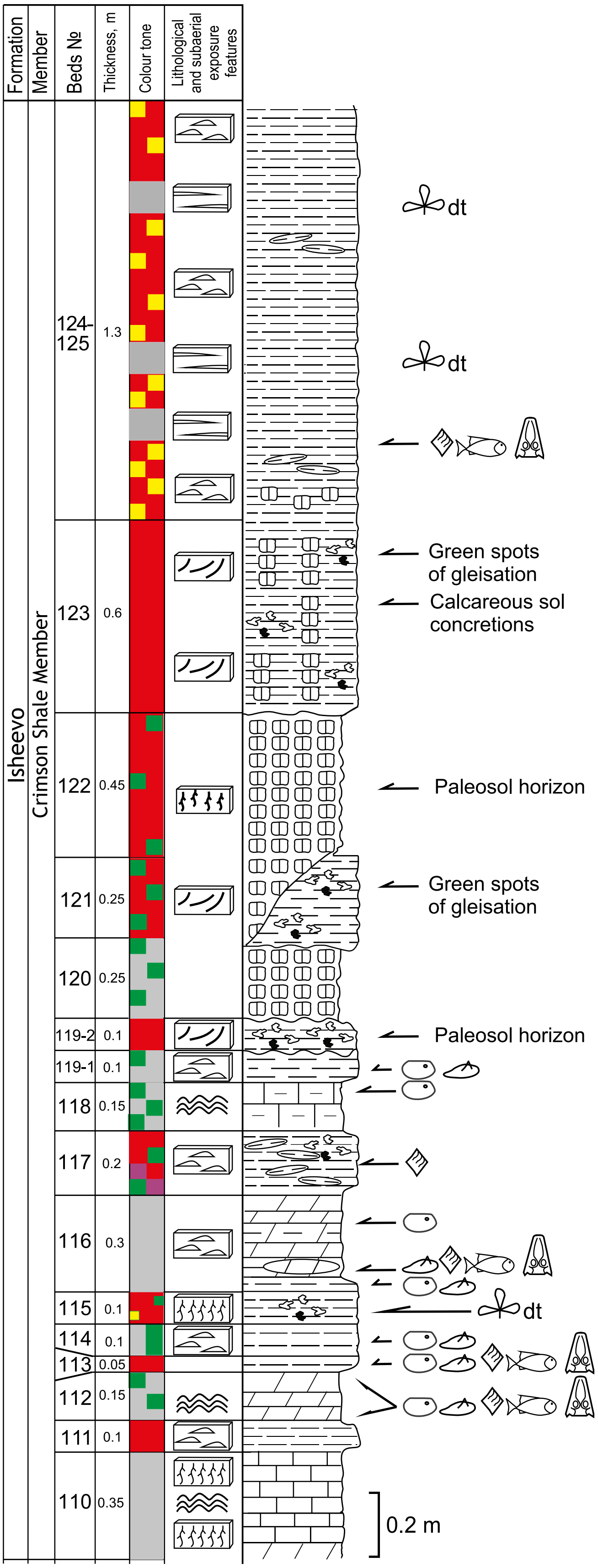


Outcrop P06. General view of the upper part of outcrop P06, the boundary between the Ribbon Marls Member and the Crimson Shale Member (P05/109–P05/110)

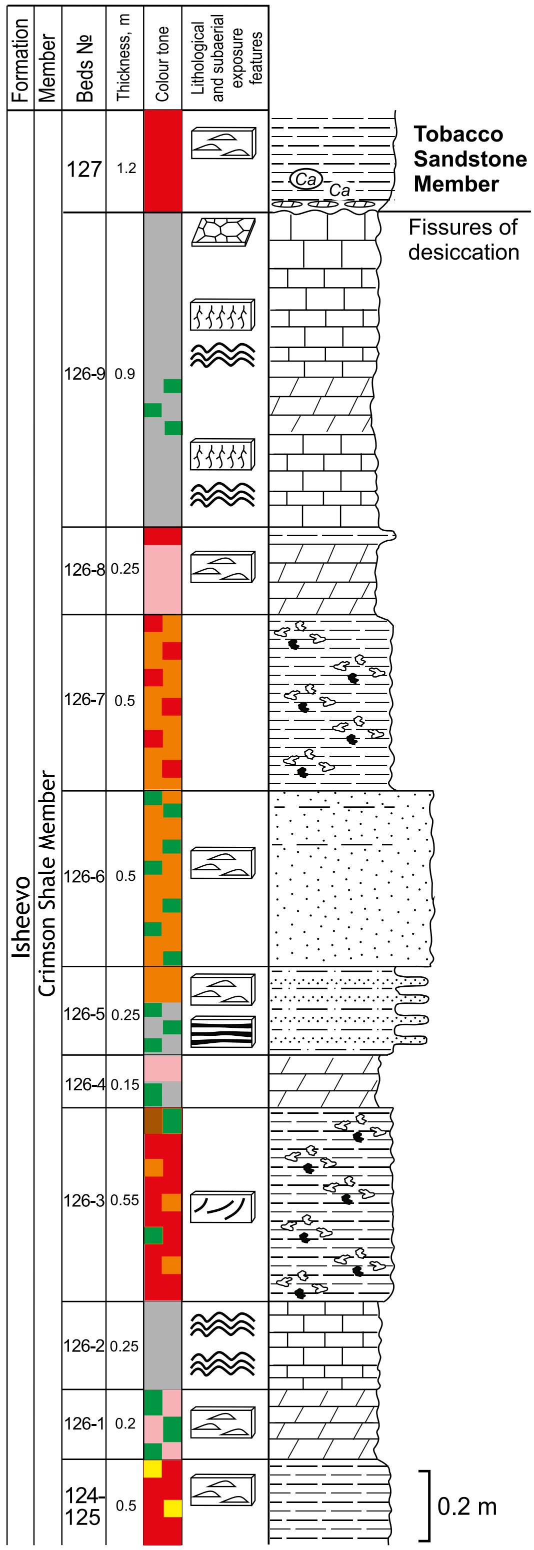
Cheremushka Gully

Isheevo Formation (middle part), Crimson Shale Member

outcrop P07



outcrop P08



Outcrops P07 and P08

Outcrop P07, GPS: 55,77936 N, 048,92719 E (WGS84). Datum: upper part of the left slope of the Cheremushka Gully, 185 m north of the gully head, 25 m south of outcrop P06; the vertical cutting approx. in 1.0–6.0 m lower the edge of the slope; the edge of the slope is 161 m ASL, the bottom of bed 110 is 155 m ASL. **Outcrop P08,** GPS: 55,77916 N, 048,92732 E (WGS84). Datum: upper part of the left slope of the Cheremushka Gully, 160 m north of the gully head, 25 m south of outcrop P07; the vertical cutting approx. in 1.0–6.0 m lower the edge of the slope.

Isheevo Formation

Crimson Shale Member

Packages P07/110–P08/126 Interval 58.45–66.85 m Thickness 8.40 m

Alteration of limestone, marl and shale with subordinate interbeds of siltstone and sandstone. Limestone is light- or dark-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. Shale: bright red, bright green, greenish-grey, calcareous. Shale with lenticular lamination contains numerous remains of ostracods, bivalves, fish scales and tetrapods. Shale with greenish-grey and red spots (stains) of gleisation is overfilled with calcareous concretions (paleosol horizons). Rocks contain numerous conchostracans, the ostracods *Palaeodarwinula fragiliformis* (Kash.), *P.* cf. *elongata* (Lun.), *P.* cf. *tuba* (Misch.), *Prasuchonella nasalis* (Shar.), etc., the bivalves *Palaeomutela extensiva (*Gus.), *P. wohrmani* Netsch., *P. vjatkensis (*Gus.), *Prilukiella mirabilis* (Gus.), *Pr. nitida* (Gus), etc., fish remains and bones of small reptiles.

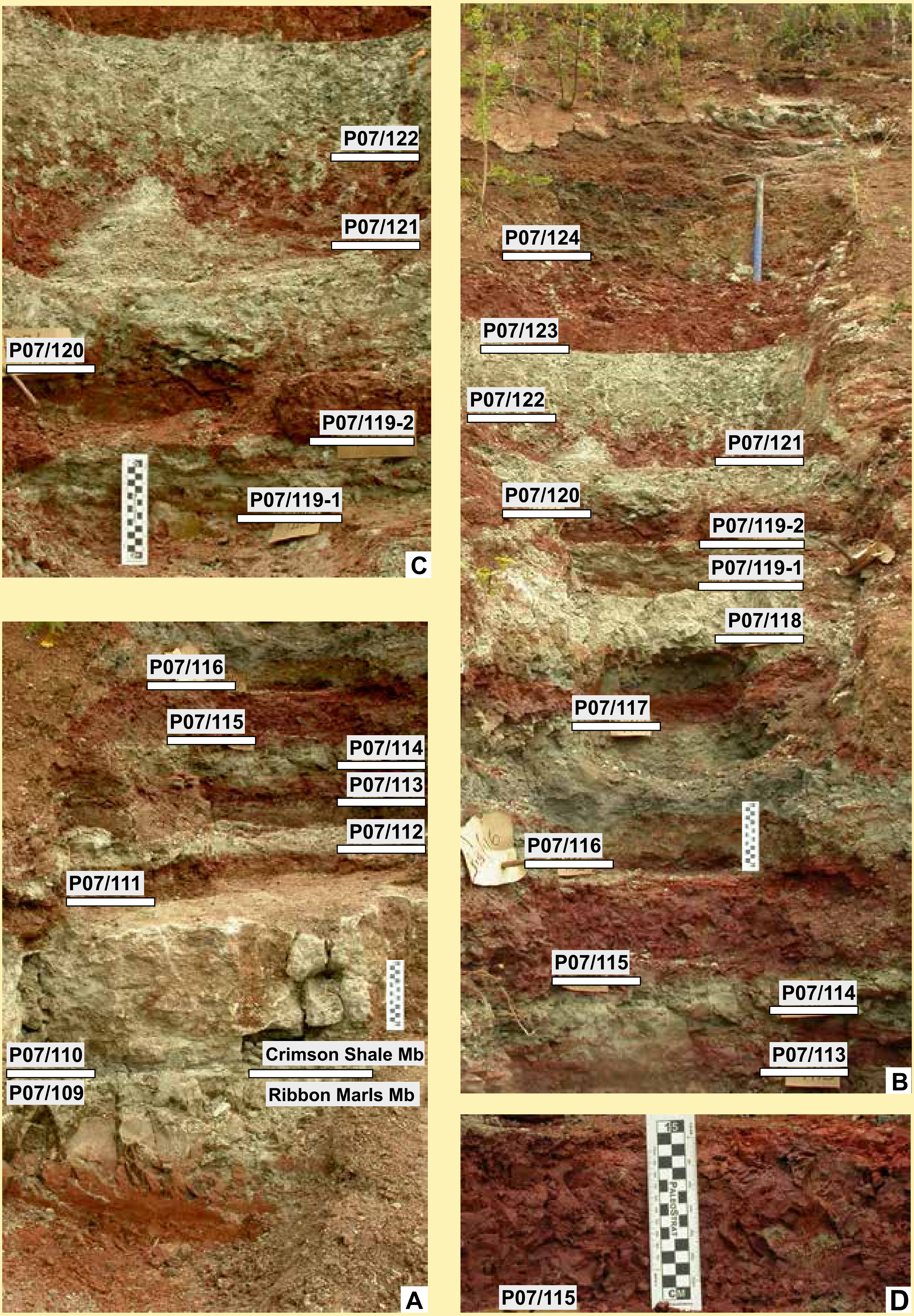
Tobacco Sandstone Member (basal part)

Package P08/127 Interval 66.85–67.40 m Thickness (visible) 0.55 m

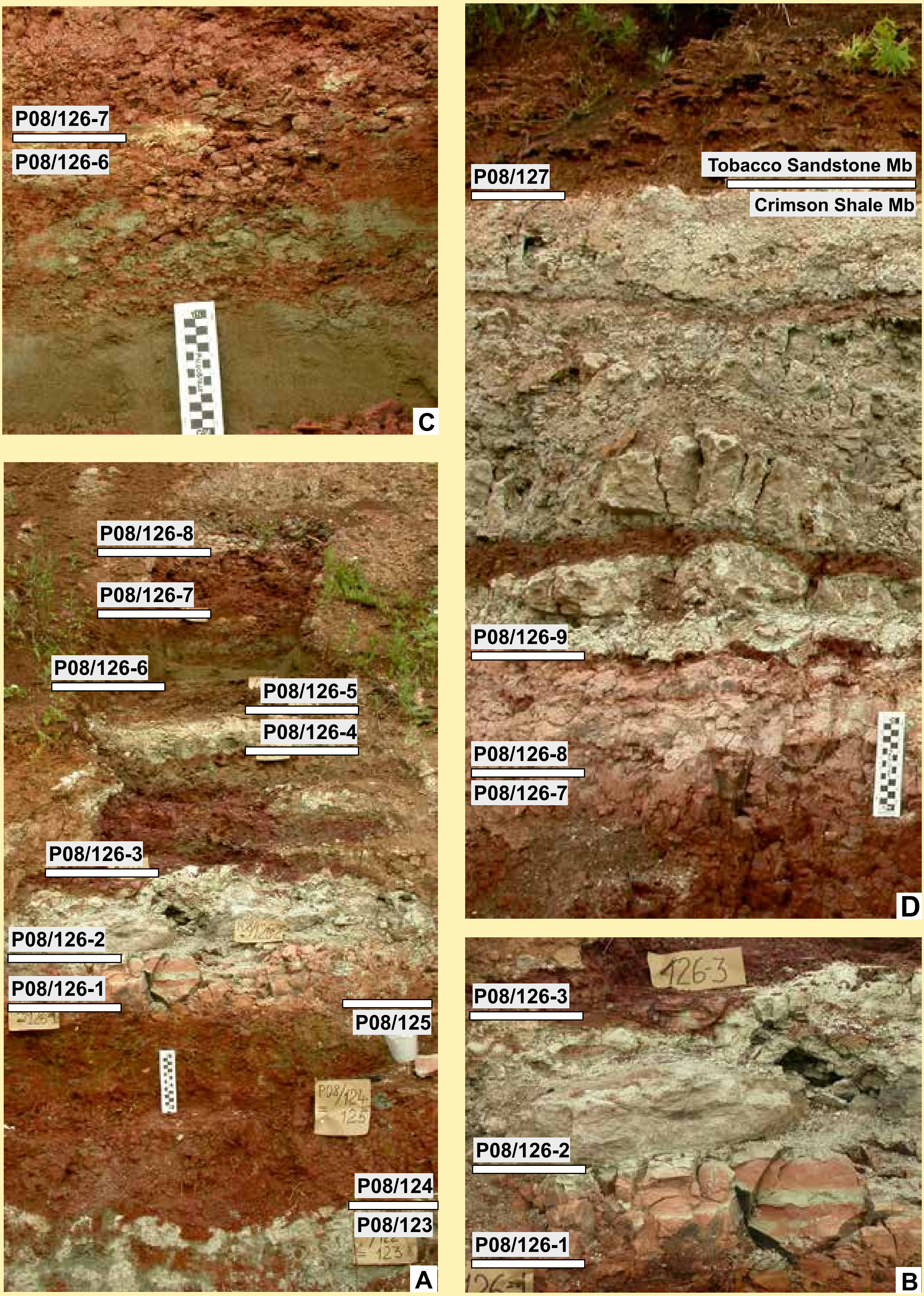
Mudstone: bright brick-red, platy, mainly thinly horizontally or lenticular laminated with laminae (1–2 cm) of greenish-grey and grey fine-grained sandstone. Alteration of strongly calcareous, compact, solid interbeds and more soft argillaceous laminae as well as honeycomb structure of desiccation fissures (?) are more conveniently observed on the weathered surface of the package.

The further succession of the *Tobacco Sandstone Member* is observed in outcrop P09.

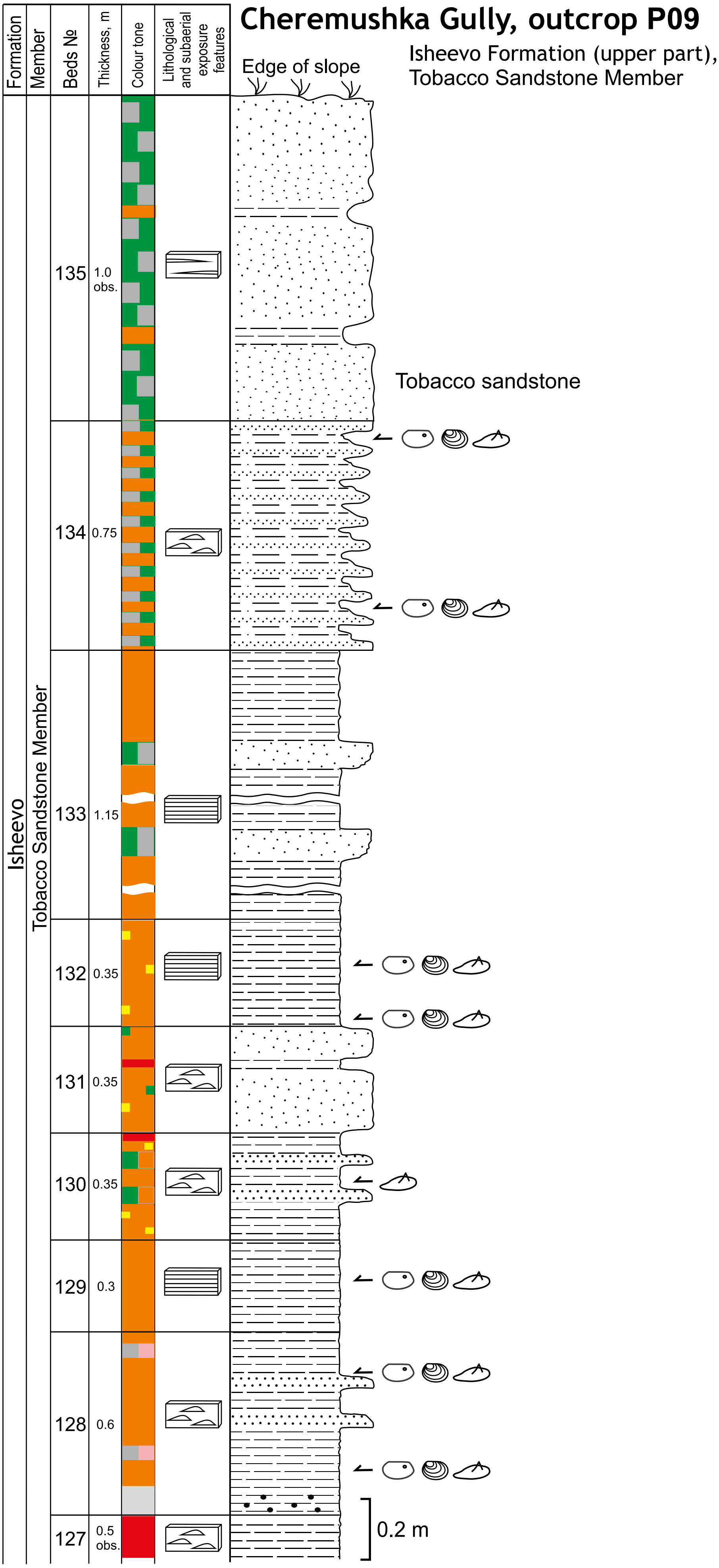
Outcrop P07. General view of the lower part of outcrop P07, the boundary between the Ribbon Marls Member and the Crimson Shale Member (P05/109–P05/110)



Outcrop P07. General view of the lower part of the Crimson Shale Member (A, B), (C) shales with greenish-grey and red spots (stains) of gleisation overfilled with calcareous concretions (paleosol horizons, beds P07/119–P07/122), (D) red (crimson) shales with greenish-grey spots (stains) of gleisation; scale bar 1 cm



Outcrop P08. General view of the upper part of the Crimson Shale Member (A), (B) pinkish-grey marl (bed P09/126-1) and light- grey algal-microbial limestone (bed P07/126-2), (C) greenish-grey sandstone (bed 126-6) gradually replaced by crimson shales (bed P08/126-7), and (D) uppermost algal-microbial limestone of the Crimson Shale Member (bed P08/126-9) and its boundary with the Tobacco Sandstone Member; scale bar 1 cm


Cheremushka Gully, outcrop P09
Isheevo Formation (upper part), Tobacco Sandstone Member
Edge of slope
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Isheevo
Tobacco Sandstone Member
135
1.0 obs.
134
0.75
133
1.15
132
0.35
131
0.35
130
0.35
129
0.3
128
0.6
127
0.5 obs.
Tobacco sandstone
0.2 m

Outcrop P09

GPS: 55,77892 N, 048,92783 E (WGS84). Datum: upper part of the right slope of the Cheremushka Gully, 140 m north of the gully head, the vertical cutting approx. in 0.5–6.0 m lower the edge of the slope.

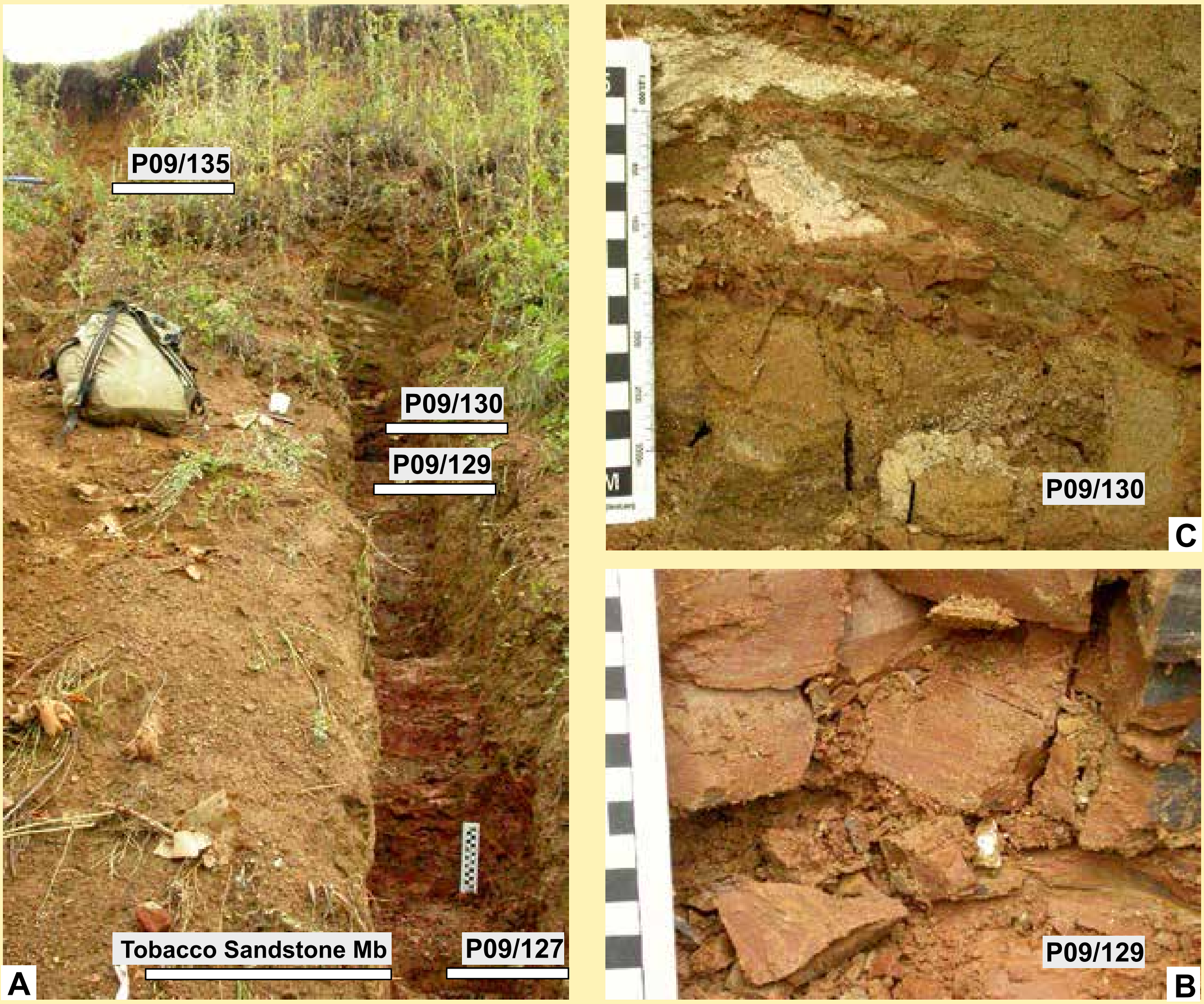
Isheevo Formation

Tobacco Sandstone Member (lower part)

Packages P09/127–P09/135 Interval 66.85–72.20 m Thickness (visible) 5.35 m

Shale and sandstone. Shales: reddish-brown (chocolate-brown), brownish-red, yellowish, compact, horizontally bedded. Sandstones: greenish-grey (tobacco) polymict, inequigranular, obliquely laminated. The shales contain many (especially right below the sandstones) remains of the bivalves *Palaeomutela (Palaeanodonta) cf. longissima Netsch., P. (P.)* cf. *rhomboidea* (Netsch.), *Anadontella volgensis* (Gus.), *A. uslonensis* (Gus.), *Prilukiella subovata* (Jones), *Pr. pugnatoria* (Gus.), etc., the conchostracans *Eustheria eos* (Eichw.), *Pseudestheria sukhonensis* Novoj., *Estheriina kawasakii* (Ozawa et Wei), *Trigonestheria angulata* (Lutk.), and the ostracods *Palaeodarwinula fragiliformis* (Kash.), *P. elongata* (Lun.), and *Prasuchonella nasalis* (Shar.).

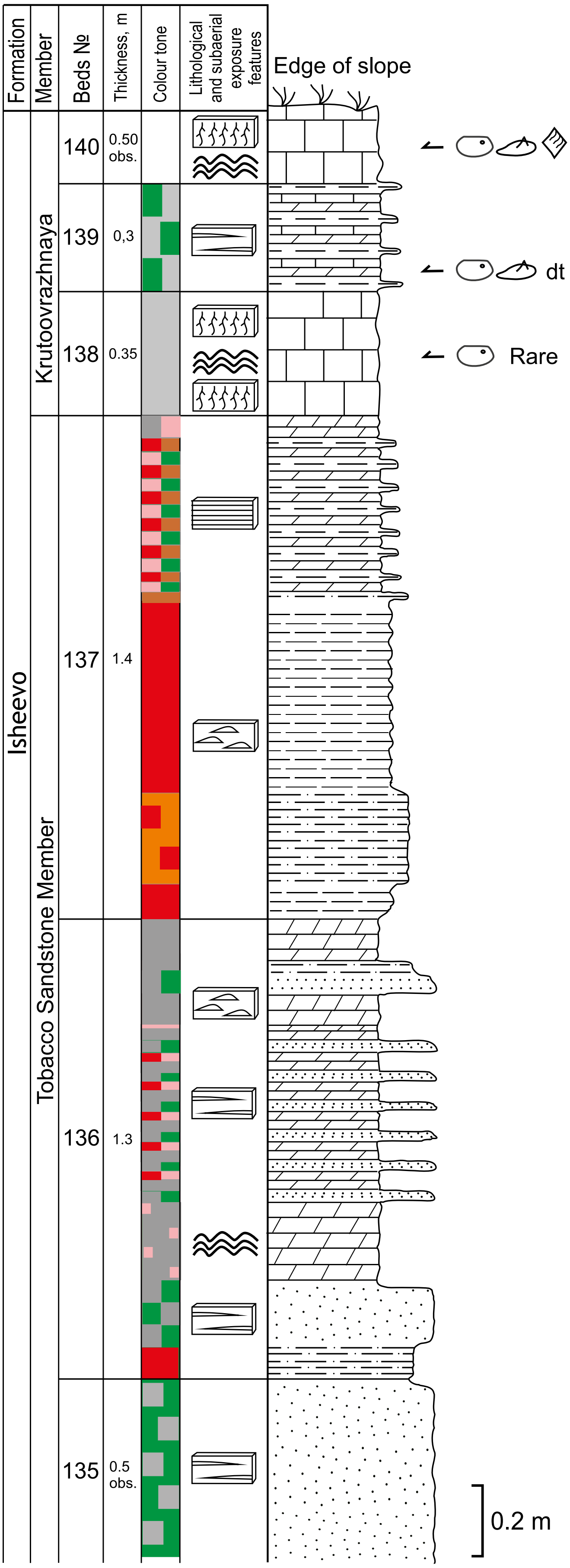
Outcrop P10 contains the slide-rocks of overlaid succession. Upper part of the *Tobacco Sandstone Member* and *Krutoovrazhnaya ('Steep Gullies') Member* are observed in the heads of Trekhglavyi and Strela gullies (outcrops P11–P13). We can visit these outcrops if sufficient time is available.



Outcrop P09. General view of the lower part of the Tobacco Sandstone Member (A), (B) reddish-brown shales with horizontal lamination (bed P09/129), (C) greenish-grey sandstone (bed 130) with the lenses of reddish-brown shales and light-grey marls; scale bar 1 cm

Trekhglavyi ('Three-Headed') Gully, outcrop P11

Isheevo Formation (upper part),
contact of Tobacco Sandstone Member and
Krutoovrazhnaya Member



Outcrop P11

GPS: 55.77715 N, 048.91199 E (WGS84). Datum: right slope of the right head of the Trekhglavyi ('Three-Headed') Gully, the vertical cutting approx. in 0.5–5.0 m lower the edge of the slope.

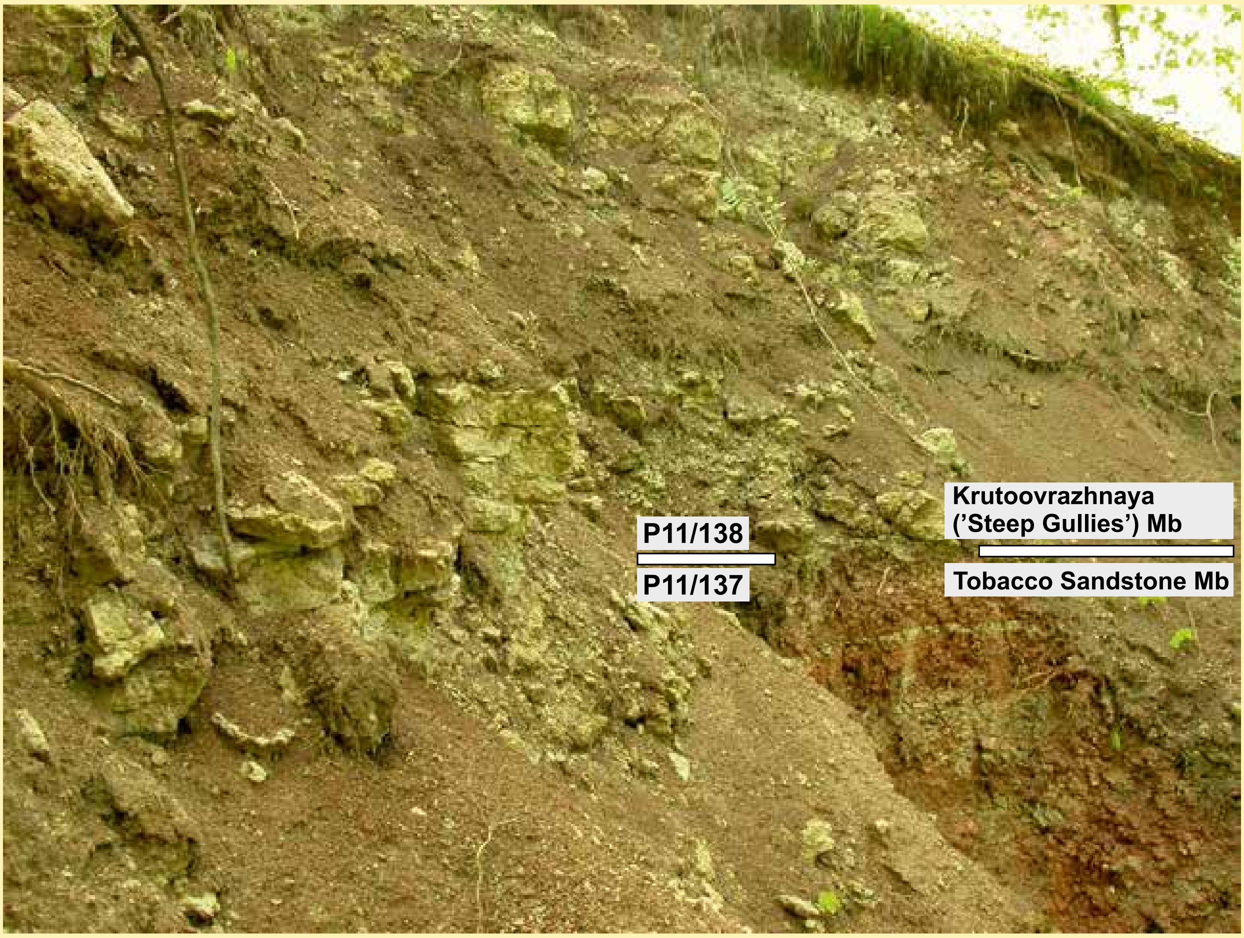
Isheevo Formation

Tobacco Sandstone Member (upper part)

Packages P11/136–P11/137 Interval 72.20–74.90 m Thickness (visible) 2.70 m
Sandstone and shale. Sandstone: greenish-grey (tobacco) polymict, obliquely laminated. Shale: red, brownish-red, compact, lenticular laminated. Generally, above the sandstones, there are two marker beds of an alternation of thinly bedded variegated shales, sandstones and marls.
Total thickness of *Tobacco Sandstone Member* is 8.05 m.

Krutoovrazhnaya ('Steep Gullies') Member (basal part)

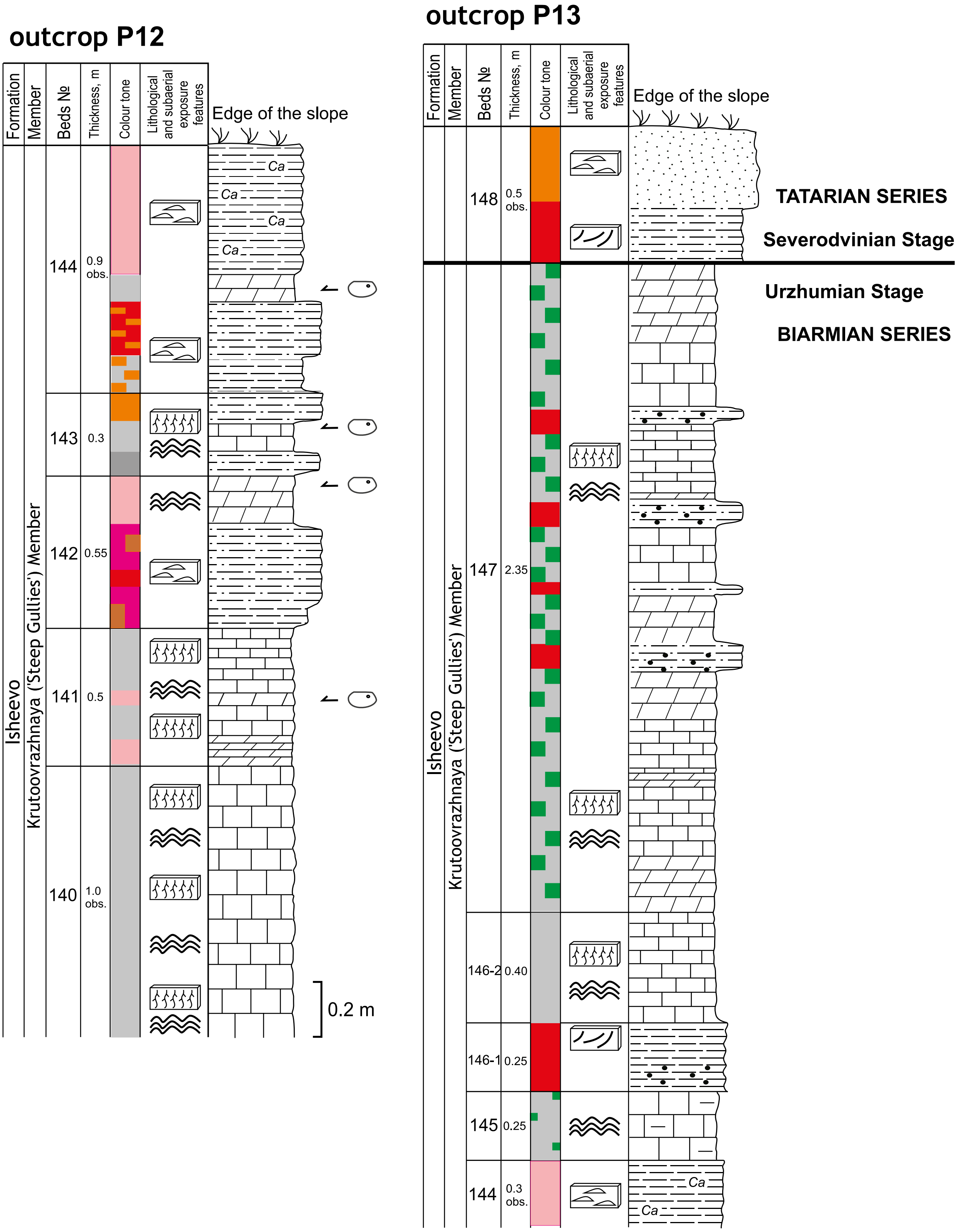
Packages P11/138–P11/140 Interval 74.90–76.05 m Thickness (visible) 1.15 m
Limestone: light-grey, hard, solid, algal-microbial, riddled with numerous voids of plant roots *in situ;* in places replaced by greenish-grey marls and shales. The rocks contain numerous ostracods of *Palaeodarwinula fragiliformis* (Kash.), *P.* cf. *chramovi* (Gleb.), *P. elongata* (Lun.), *P.* cf. *tuba* (Misch.), *Prasuchonella nasalis* (Shar.), *Permiana elongata* Posn.*, Suchonellina inornata* (Spizh.) and others, the bivalves *Palaeomutela wohrmani* Netsch.*, P. extensiva (Gus.), P. numerosa (Gus.), Prilukiella* sp., fish scales, charophytes *Cuneatochara amara* Said.



Outcrop P11. General view of the lower part of the Krutoovrazhnaya ('Steep Gullies') Member (algal-microbial limestone, bed P11/138) and of its boundary with underlying Tobacco Sandstone Member (intercalation of sandstone and shales, bed P11/137)

Strela ('Arrow') Gully

Isheevo Formation, Krutoovrazhnaya ('Steep Gullies') Member
and the boundary between Biarmian and Tatarian Series



Outcrop P12 and P13

Outcrop P12, GPS: 55,77283 N, 048,88943 E (WGS84). Datum: right and left slopes of the Strela (‘Arrow’) Gully, 340 m north of the head of the gully; the vertical cutting approx. 5.0 m near the thalweg.
Outcrop P13, GPS: 55,77180 N, 048,89077 E (WGS84). Datum: the right slope of the Strela (‘Arrow’) Gully, 200 m north of the head of the gully; the vertical cutting approx. 4.0 m just below the edge of the slope.

Isheevo Formation

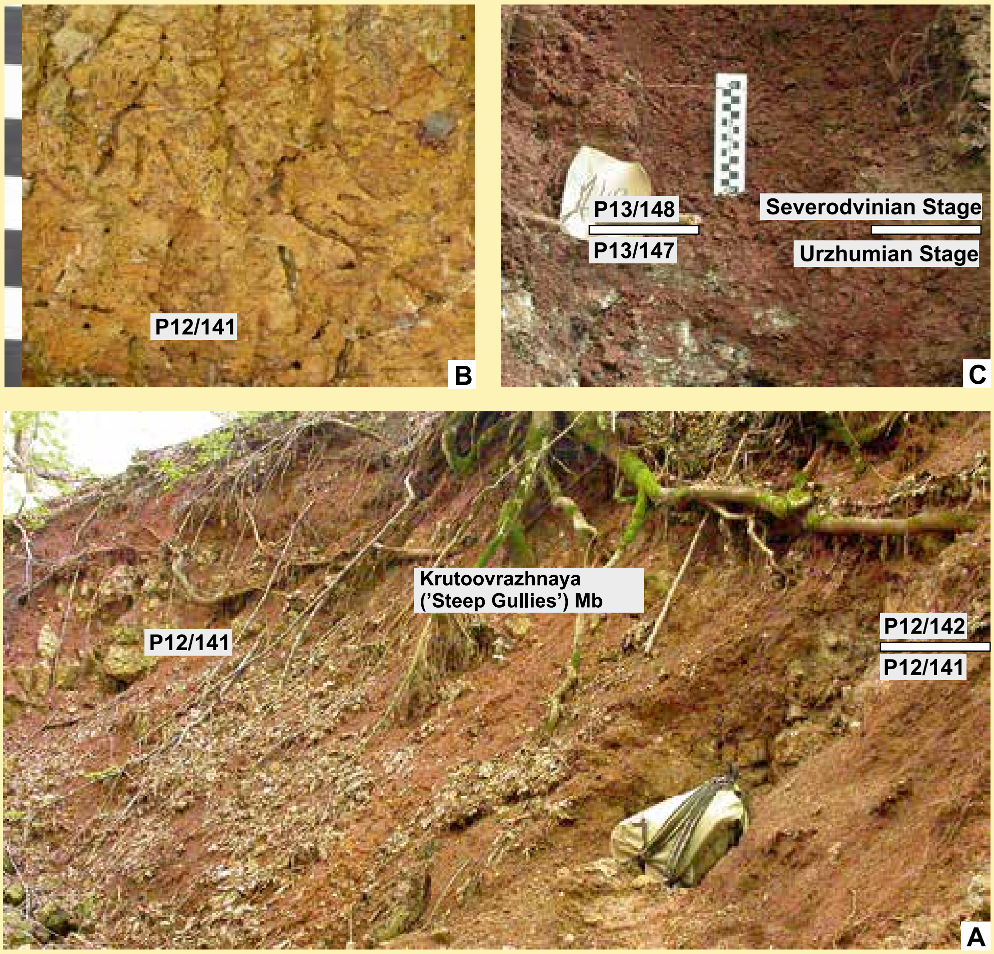
Krutoovrazhnaya (‘Steep Gullies’) Member (main part)

Packages P12/141–P13/147 Interval 76.05–81.60 m Thickness (observable) 5.55 m
Limestone and marl with subordinate interbeds of shale and siltstone. Limestones: light- and dark-grey, hard, solid, algal-microbial, riddled with numerous voids of plant roots *in situ.* Marls: grey, pinkish, and violet. Siltstones: bright red, brown, grey, indistinctly bedded, with calcareous nodules. Rocks contain scattered ostracods *Palaeodarwinula fragiliformis* (Kash.), *P. elongata* (Lun.), *P. torensis* (Kotsch.), *P. chramovi* (Gleb.), *Prasuchonella nasalis* (Shar.), *P. stelmachovi* (Spiz.), *Suchonellina inornata* (Spiz.), *Permiana elongata* Posn., and the charophytes *Cuneatochara* sp. The total thickness of *Krutoovrazhnaya (‘Steep Gullies’) Member* is 6.70 m.
The total thickness of the Urzhumian regional stage is about 80.0 m.

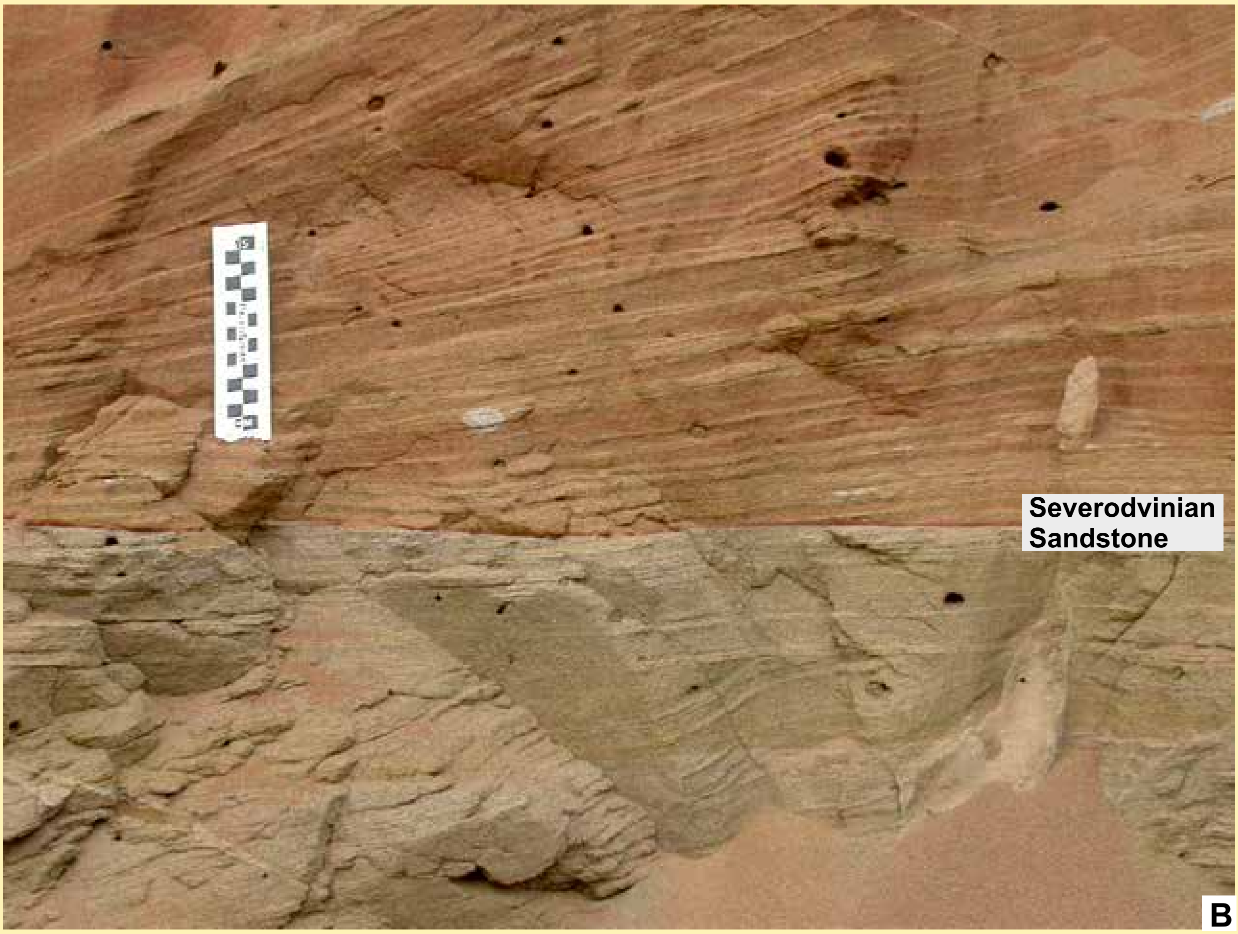
Tatarian Regional Series

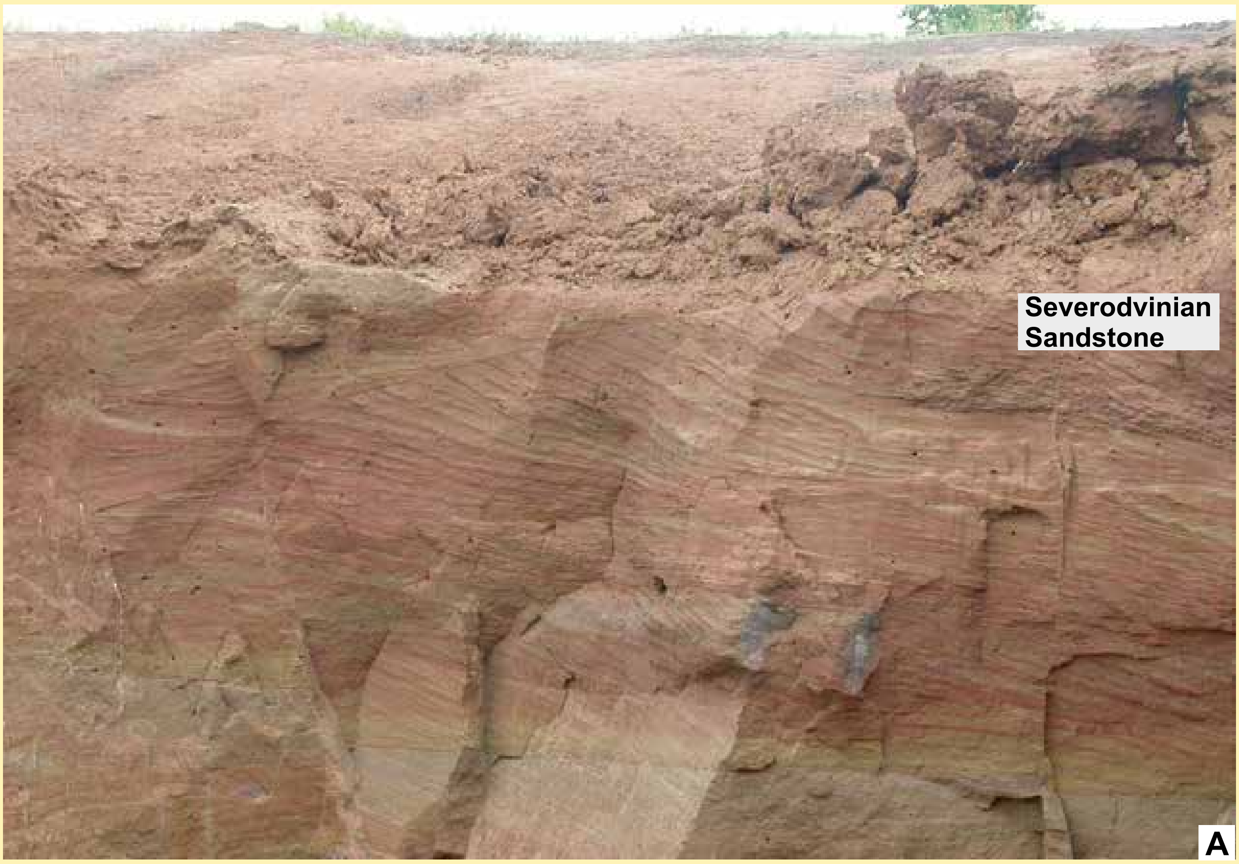
Severodvinian Regional Stage

Packages P13/148 Interval 81.60–82.10 m Thickness (visible) 0.50 m
Shale and sandstone. Shale: reddish-brown, indistinctly bedded with numerous slickensides. Sandstone: yellowish-grey, fine-grained, polymict with gently oblique bedding. The contact with the underlying bed is uneven.



Outcrop P12. General view of the middle part of the Krutoovrazhnaya (‘Steep Gullies’) Member (algal-microbial limestone, bed P11/141), (B) algal-microbial limestone (bed P11/141) riddled with numerous voids of plant roots *in situ*, (C) the Urzhumian / Severodvinian boundary in outcrop P13





Severodvinian Sandstone in the small quarry near the head of the Strela ('Arrow') Gully

BIOSTRATIGRAPHY

Non-marine ostracods

The rocks of the Sulitsa Formation contain too much magnesia to have many fossils. The first ostracods and bivalves appear only at the lower part of the Isheevo Formation, in the Green Shale Member. The species composition of the ostracod assemblage here is fairly poor.

The most diversified ostracod assemblage is associated with the middle part of the Isheevo Formation.

It comprises numerous and diverse species, very common in the Urzhumian deposits in different parts of the East-European Platform. These include *Palaeodarwinula fragiliformis* (Kash.), *P. elongata* (Lun.), *P. fragilis* var. *angusta* (Schned.), *P. chramovi* (Gleb.), *P. arida* (Molost.), *P. degitalis* (Mish.), *P. defluxa* (Mish.), *P. vicina* (Molost.), *P. torensis* (Kotsch.), *P. teodorovichi* (Bel.), *P. tuba* (Mish.), *P. obliva* (Molost.), *P. mera* (Starozh.), *P. inornatina* (Bel.), *P.* aff. *fainae* (Bel.), *Prasuchonella nasalis* (Sharap.), *Pr.* ex gr. *nasalis* (Sharap.), *Pr. libera* (Mish.), *Pr.* sp., *Kalisula garlanovi* (Molost.), and *K. plana* Molost. Their stratigraphic interval is confined to the Upper Urzhumian, to the *Palaeodarwinula fragiliformis*–*Prasuchonella nasalis* zone. The only exception is presented by *Palaeodarwinula mera, P. inornatina*, *P.* aff. *fainae* (Bel.) and *Prasuchonella nasalis,* which are fairly common in the continental strata of the Kazanian. The assemblage of dominated *Palaeodarwinula* and *Prasuchonella* co-occurs rather rarely with *Placidea* ex gr. *lutkevichi* (Spizh.), *Permiana elongata* (Posner), and *Sinusuella ignota* (Spizh.), all three having a broad stratigraphic interval.

The species *Suchonellina inornata* Spizh. (identified by V.A. Lukin and I.I. Molostovskaya) appears at the top of the Isheevo Formation, at the Krutoovrazhnaya (‘Steep Gullies’) Member, alongside the typically Urzhumian assemblage. It is one of the index species of the Severodvinian *Suchonellina inornata*–*Prasuchonella nasalis* zone.

The Russian General Stratigraphic Scale considers non-marine ostracods as a major faunistic group for estimation of the lower boundaries of the Middle and Upper Permian regional stages, which are predominantly or completely formed by continental speckled beds. Thus, the lower boundaries of the Urzhumian, Severodvinian, and Vyatkian are marked by the first occurrence of non-marine ostracod index species within continuous phylogenetic lineages (Kotlyar et al., 2013, 2014).

The base of the Urzhumian Stage is best represented in the Krasny Ovrag (‘Red Ravine’) section (Orenburg Region), which is proposed as the regional GSSP marked by the First Appearance Datum (FAD) of the non-marine ostracods *Paleodarwinula fragiliformis* and *Prasuchonella nasalis* (Molostovskaya, 2009).

The base of the Severodvinian Stage is best represented in the Monastery Ravine section (Kazan Region), which is proposed as the regional GSSP marked by the FAD of non-marine ostracods *Suchonellina inornata* (Minikh et al., 2009).

Evolutionary lineages of non-marine ostracods *Prasuchonella nasalis, Suchonella typica* and *Wjatkellina fragilloides* have been chosen for the definition of the substage boundaries within the Severodvinian and Vyatkian (Kotlyar et al., 2013, 2014).

The base of the Vyatkian Stage is best represented in the Mutovino Section on the Sukhona River (Vologda Region), which is proposed as the regional GSSP marked by the FAD of S*uchonella blomi* (Molostovskii, Minikh, 2001).

The terminal Upper Permian succession of the East-European platform (‘Vyazniki Horizon’) is marked by a complex ostracod zone *Suchonellina perelubica* – *Suchonella rykovi* – *Suchonella posttypica* (Kotlyar et al., 2013, 2014).

Non-marine bivalves

The section exposed in Cheremushka Gully was established as a stratotype of three non-marine bivalve range zones based on the species of *Palaeomutela* Amalitzky, 1892: *P. krotowi, P. wohrmani* and *P. numerosa* (Silantiev, 2014). The succession of these zones suggests Urzhumian (Wordian) Age.

A brief description of these zones is given below.

Palaeomutela krotowi Zone

Index species: *Palaeomutela krotowi* Netschajew, 1894. Stratotype of the zone is located on the right bank of the Volga River, 1.5 km west of the settlement of Pechishchi, Cheremushka Gully, outcrop Ch-2001, bed 19. The lower and upper boundaries of the zone correspond to the first appearance levels of *P. krotowi* Netsch. and *P. wohrmani* Netsch., respectively. Characteristic bivalve species are *P. vjatkensis* Gusev, *P. doratioformis (*Gus.), *Anadontella volgensis* (Gus.), *Prilukiella lata* (Netschajew). The *krotowi* Zone is registered in the Volga–Ural, North Caspian, and Dvina–Mezen basins. On the basis of the occurrence of the index species, this unit may be correlated with the *Palaeomutela visenda–Palaeomutela meraca* Zone established in the Tal'bei Formation of the Pechora Basin.

Palaeomutela wohrmani Zone

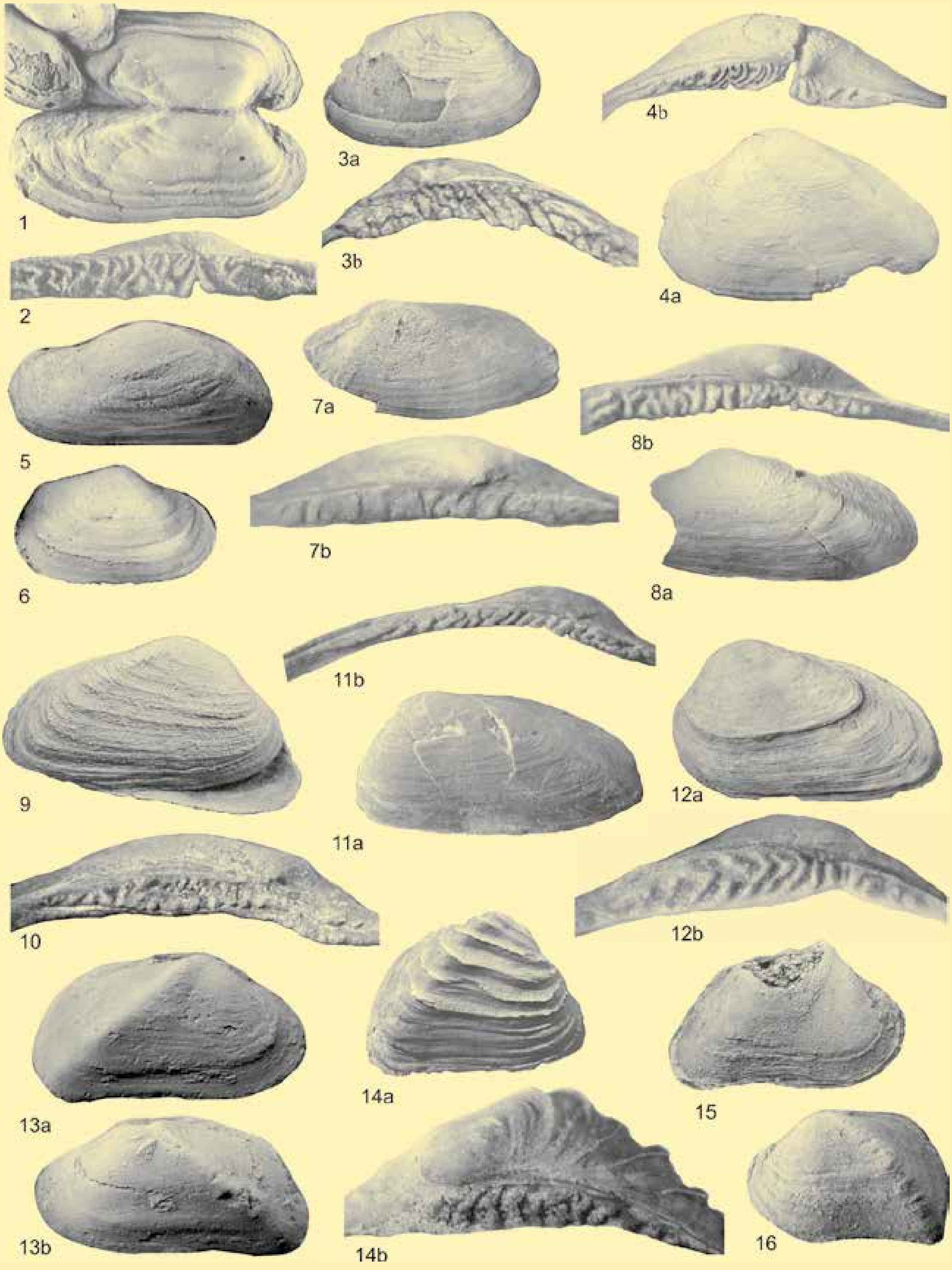
Index species: *Palaeomutela wohrmani* Netschajew, 1894. The stratotype of the zone is located on the right bank of the Volga River, 1.5 km west of the settlement of Pechishchi, Cheremushka Gully, Green Shale Member, bed 66. The lower and upper boundaries of the unit under consideration correspond to the first appearance levels of *P. wohrmani* Netsch. and *P. numerosa* (Gus.), respectively. Characteristic bivalve species: *P. krotowi* Netsch., *P. extensiva* (Gus.), *P. doratioformis* (Gus.), *Anadontella uslonensis* (Gus.), *A. volgensis* (Gus.), *A. tscherdinzewi* (Gus.), *Prilukiella janischewskyi* Plotnikov, *Pr. subovata* (Jones), *Pr. nitida* (Gus.), *Pr. mirabilis* (Gus.), *Pr. pugnatoria* (Gus.). The *wohrmani* Zone is established in the Volga–Ural and Dvina–Mezen basins. The *Anadontella* and *Prilukiella* species in common allow this unit to be correlated with the *Palaeomutela visenda–Palaeomutela meraca* Zone established in the Tal'bei Formation of the Pechora Basin (Kanev, 1985, 1994). The representatives of *Anadontellidae* and *Prilukielloidea* characteristic of the *wohrmani* Zone are close to morphotypes of these taxa from the *Anadontella supraphillipsii–Terciella certa* Zone corresponding to the Leninsk Horizon of the Kuznetsk Basin. This feature allows the stratigraphic units in question to be considered as conditionally synchronous.

Palaeomutela numerosa Zone

Index species: *Palaeomutela numerosa* Gus., 1990. The stratotype of the zone is located on the right bank of the Volga River,1.5 km west of the settlement of Pechishchi, Cheremushka Gully, Krutoovrazhnaya ('Steep Gullies') Member, bed 138. The lower and upper boundaries of the unit under consideration correspond to the first appearance levels of *P. numerosa* (Gus.) and *P. keyserlingi* Amalitzky, respectively. Characteristic bivalve species: *P. verneuili* Amal., *P. semilunulata* Amal., *P. solenoides* Amal., *P. subparallela* Amal., *P. marposadica* (Gus.), *P. rectodorsala* (Gus.), *P. tschuvashica* (Gus.). The zone is recorded in the Volga–Ural and Dvina–Mezen basins of the East European Platform.

Zonal species of non-marine bivalves from the *P. umbonata* group

All specimens are housed at the Geological Museum of Kazan Federal University (GM KFU). **(1, 2) *Palaeomutela stegocephalum* Netschajew**, **1894**: (1) GM KFU 36/996-1 (x2), open shell with the fragment of *Palaeomutela larae* Silantiev, 1995 in the left upper corner; (2) GM KFU 36/996-2 (x7), hinge; Solikamsk depression, Well 1542 (112 m), Ufimian Stage; **(3) *Palaeomutela ovatiformis* Gusev, 1990**, GM KFU 36/1014-2: (3a) right valve (x2), (3b) hinge (x7); Udmurt Republic, Balezino Settlement, Well 7 (240 m), Ufimian Stage; **(4) *Palaeomutela umbonata* (Fischer, 1840)**, GM KFU 36/3164: (4a) left valve (x2), (4b) hinge (x7); South Urals, Zhaksy-Kargala River, Kazanian Stage; **(5, 6) *Palaeomutela quadriangularis* Netschajew, 1894**: (5) lectotype, GM KFU 13/154 (x3), Sheshma River, settlement of Arkhangel'skoe, Kazanian Stage; (6) GM KFU 30/2094 (x4), Vyatka River Basin, Lubyanka River, the same stratigraphic position; **(7) *Palaeomutela krotowi* Netschajew, 1894**, lectotype, GM KFU 13/129: (7a) left valve (x2), (7b) hinge (x7); Vyatka River, settlement of Chirki, Urzhumian Stage; **(8) *Palaeomutela wohrmani* Netschajew, 1894**, lectotype, GM KFU 13/126-1: (8a) left valve (x3), (8b) hinge (x8); Volga River Basin, settlement of Sotnikovo, Urzhumian Stage; **(9, 10) *Palaeomutela numerosa* Gusev, 1990**: (9) holotype, GM KFU 30/3130 (x2); (10) GM KFU 30/1025-4 (x7), hinge of the left valve; Volga River, Monastery Ravine section, Urzhumian Stage; **(11) *Palaeomutela ulemensis* Gusev, 1990**, GM KFU 30/335: (11a) left valve (x3), (11b) hinge (x10); Volga River, Tetyushi, Urzhumian Stage, Severodvinian Stage; **(12) *Palaeomutela keyserlingi* Amalitzky, 1892**, GM KFU 30/171-23: (12a) left valve (x3.5), (12b) hinge (x12); Oka River, Nizhni Novgorod, Severodvinian Stage; **(13) *Palaeomutela curiosa* Amalitzky, 1892**, GM KFU 13/136-2 (x3.5), cast of the right (13a) and left (13b) valves, Vyatka River Basin, settlement of Kobra, Vyatkian Stage; **(14–16) *Palaeomutela golubevi* Silantiev, 2014**: (14) holotype, GM KFU 36/11-1107: (14a) right valve (x3), (14b) hinge (x9), Vetluga River, Well 10 (89 m); (15) GM KFU 36/11-1013-1 (x3), cast of the right valve, Klyaz'ma River, Gorokhovets, Zhukov Ravine section; (16) GM KFU 36/11-136-3 (x3) cast of the left valve, Oka River, village of Konstantinovo, Well 14 (54 m), Vyatkian Stage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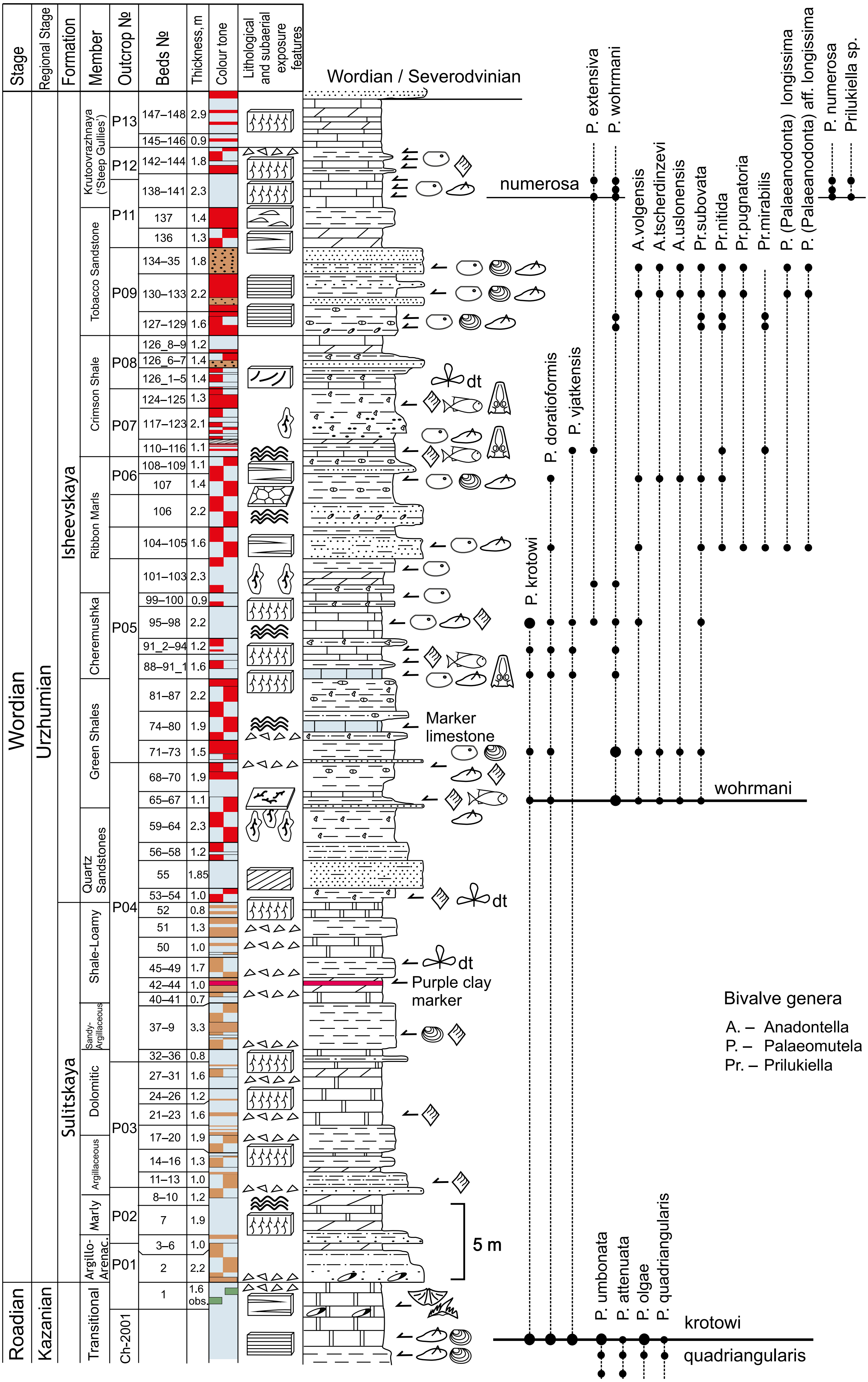
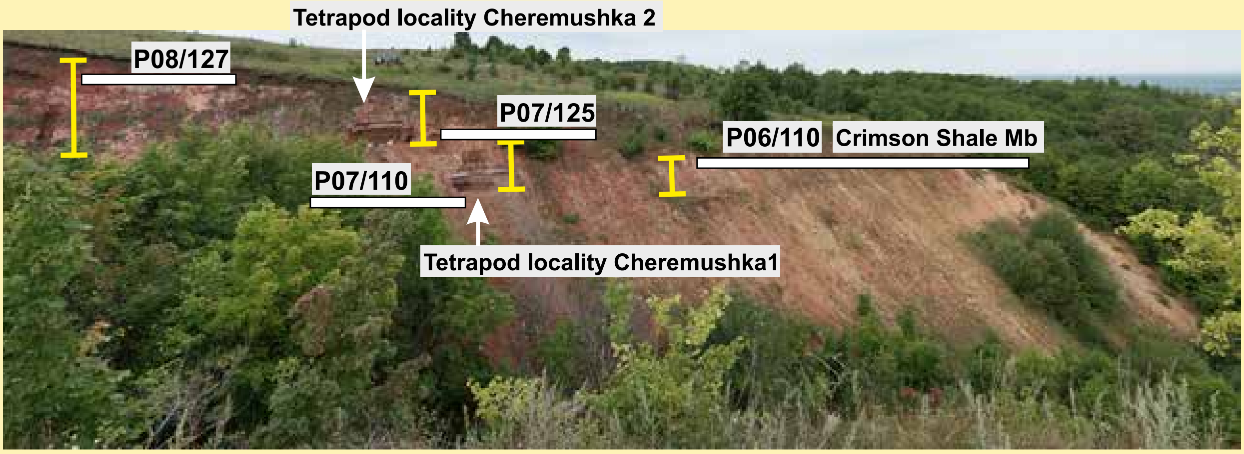
Cheremushka Gully: distribution of non-marine bivalves





Left slope of the Cheremushka Gully and location of outcrops P06, P07, P08 and tetrapod localities

Tetrapods

The Crimson Shale Member of the Isheevo Formation (outcrop P07) contains two localities of vertebrate fauna corresponding to the Late Urzhumian Age.

The Crimson Shale Member is represented by an alternation of bacterial-algal limestones and bright speckled shales of soil and basinal origin. The limestones are generally riddled with numerous voids left by *in situ* plant roots.

Tetrapod locality Cheremushka 1

Amphibians:

Leptoropha sp. (Leptorophinae, Kotlassiidae, Seymouriamorpha) – rare macerated skeletons of juvenile specimens;

Archegosauroidea fam. ind (Temnospondyli) – sporadic macerated skeletons of juvenile specimens (in the shales), rare large bones in the gritstone crust overlaying limestone P07/110.

Reptiles:

Dinocephalia fam. ind. – single teeth of carnivores in the gritstone crust overlaying bed P07/110.

The locality predominantly contains various lineages of juvenile amphibians, such as seymouriamorphs and temnospondyls, and is confined to the carbonate and shale facies. The locality could be attributed to the subautochthonous type due to the preservation of slightly deformed skulls and skeletons of juvenile amphibians. At the same time, the bones of adult animals are rare, and the percentage of reptilian taxa is minimal.

Tetrapod locality Cheremushka 2
(the upper bone-bed level – the lens)

Amphibians:

Archegosauroidea fam. ind (Temnospondyli) – sporadic bones of small and medium specimens;

Leptoropha sp. (Leptorophinae, Kotlassiidae, Seymouriamorpha) – individual cranial bones and teeth of specimens, already post-metamorphosis.

Reptiles:

Anomodontia fam. ind. (Venyukoviidae ?) – single bones and teeth of herbivores;

Dinocephalia fam. ind. – single teeth of carnivores;

Bolosauria gen. ind. (Captorhinomorpha) – single tooth bone.

The locality is confined to the shale gritstone, which forms the basement of the local alluvial lens. The locality contains a large number of individual bones of tetrapods and fish (Actinopterygii and Chondrichthyes) and represents typical allochthonous assemblage.

Tetrapod locality Gremyachka

The new locality for vertebrate fauna was discovered during the summer 2014 field work. It is situated 1 km south of the head of the Cheremushka Gully and is confined to the Crimson Shales Member of the Urzhumian regional stage (Bulanov et al., 2014).

In the new locality, the succession of the Crimson Shales Member has a more alluvial and lacustrine character. Intervals with palaeosoils are not clearly defined. The thin bed (0.3 m) of dark grey (coal-like) lacustrine shales lies at the top of the succession and clearly differentiates this section from the reference section. The tetrapod locality belongs to this shales bed, as well as in the thin (0.15 m) underlying band of greenish-grey sandstone that forms the ‘main amphibian bone bed’. Numerous separate bones are concentrated in the thin bed of sandstone close to the base of the ‘main amphibian bone bed’.

Amphibians:

Archegosauroidea fam. ind (Temnospondyli) – sporadic bones of small and medium specimens;

Leptoropha sp. (Leptorophinae, Kotlassiidae, Seymouriamorpha) – individual cranial bones and teeth of specimens, already post-metamorphosis.

Reptiles:

Anomodontia fam. ind. (Venyukoviidae ?) – single bones and teeth of herbivores;

Dinocephalia fam. ind. – single teeth of carnivores;

Bolosauria gen. ind. (Captorhinomorpha) – single tooth bone.

The new locality probably has an alluvial genesis. The bones of adult temnospondyls clearly predominate, but seymouriamorph and anthracoauromorph amphibians have not been found yet. Both carnivorous and herbivorous reptiles of different size compose the major part of the material collected. Most of the bones bear the clear traces of destruction that have preceded the burial, indicating the high energy of the water in the basin of sedimentation. Bones have been always found in disarticulated positions, so the new locality can be attributed to the allochthonous type. The lithological data also confirm the alluvial genesis of the “productive” sandstone. The black shales overlaying the ‘main amphibian bone bed’ of sandstone also contain bones of amphibians included in flat dark-beige nodules, sometimes occurring as aggregations. Nodules represent either coprolites filled with bones or skeletons of tetrapods buried *in situ*.

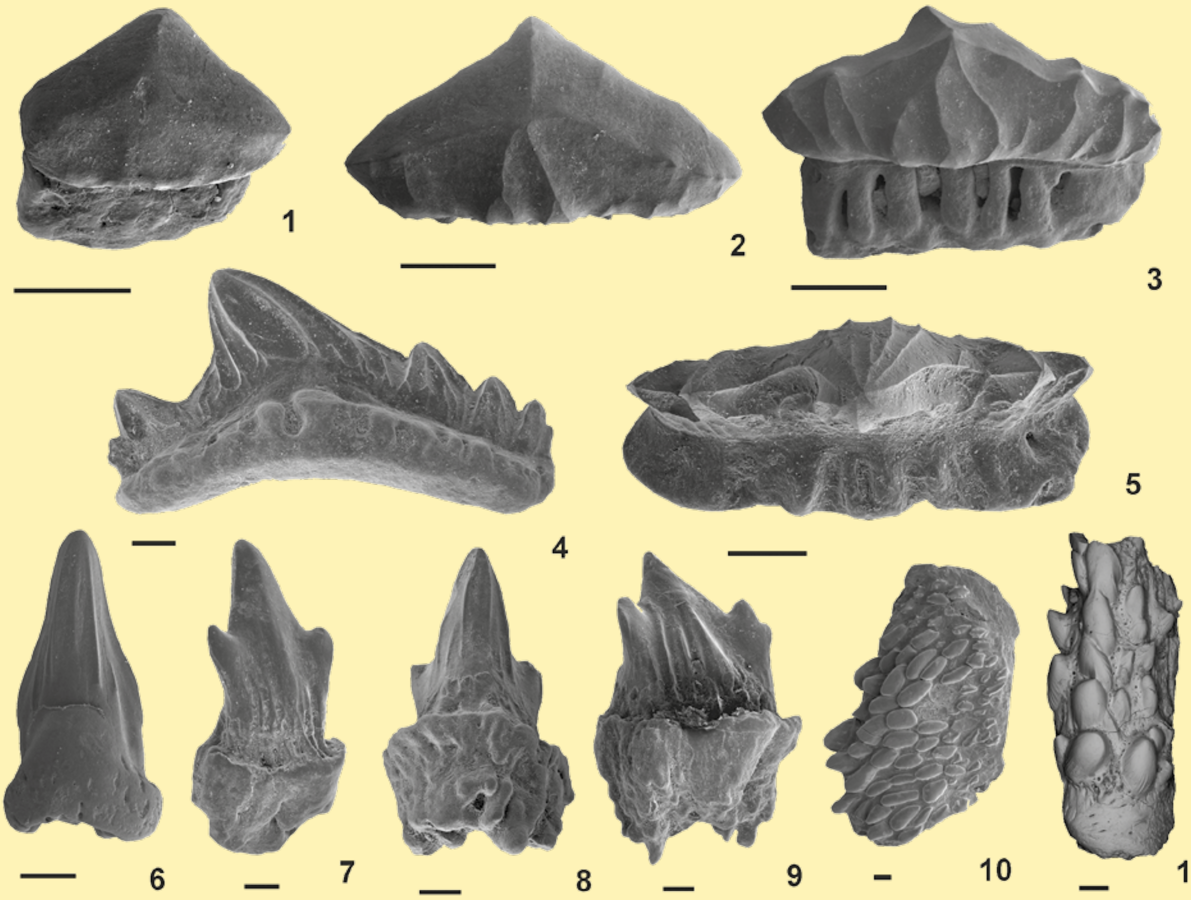
Tooth crown of carnivorous Dinocephalia; tetrapod locality Cheremushka 1

Fishes

The diverse fish assemblage occurs in the tetrapod locality Cheremushka 1. It contains isolated, well preserved chondrichthyan teeth, scales, fragments of spines and cartilage, as well as actinopterygian teeth, skull bones, scales. Chondrichthyans are represented by Sphenacanthidae gen. et sp. nov.; hybodontiforms "*Lissodus*" cf. *zideki* (Johnson) and "*Polyacrodus*" sp.; Neoselachii gen. et sp. nov., a possible ancestor of Galeomorphii. Actinopterygian fishes include *Discordichthys spinifer* A. Minikh, *Samarichthys* sp., *Varialepis* sp., ?*Kichkasia* sp.

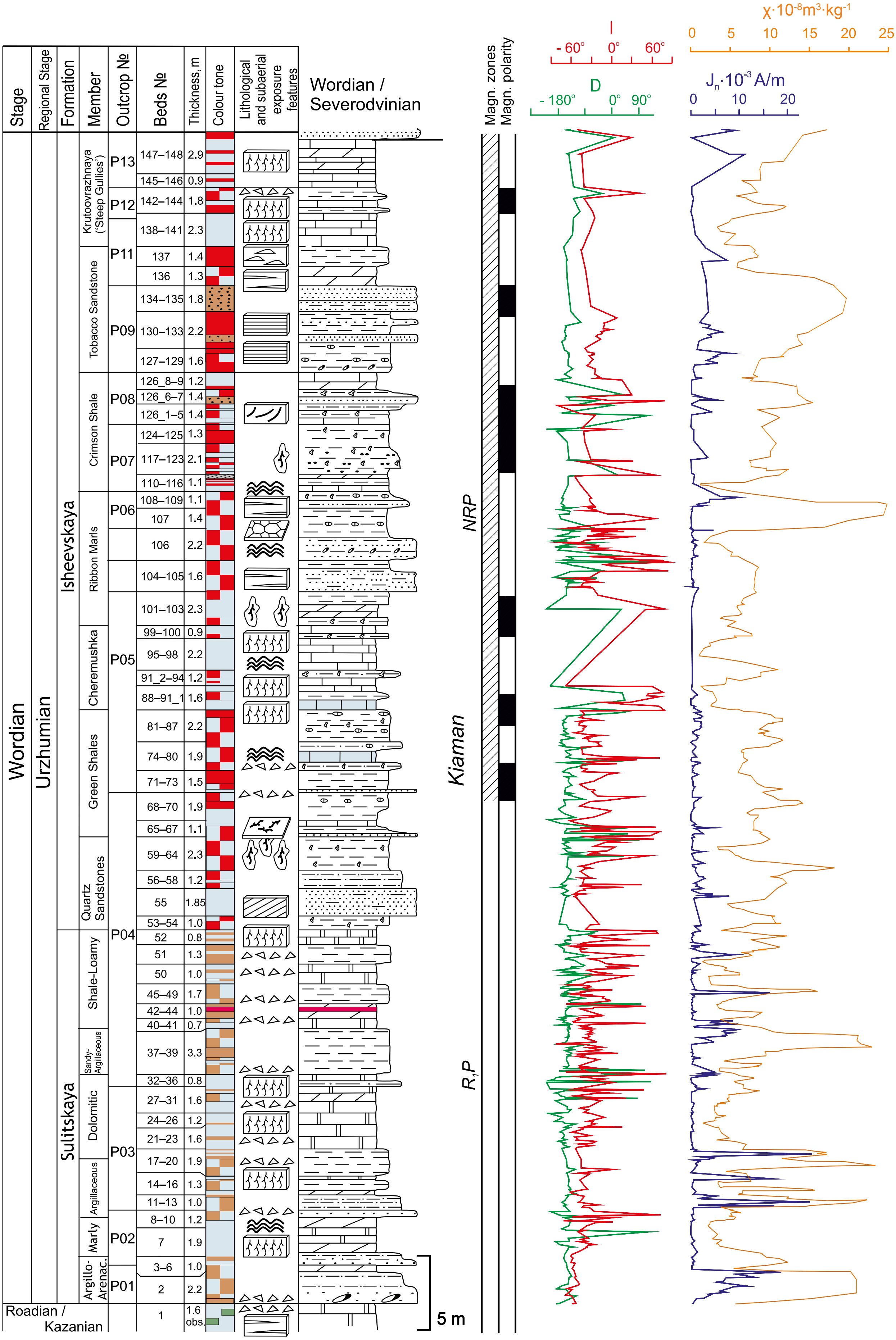
The diverse chondrichthyan and actinopterygian remains are recorded in the new locality of vertebrate, Gremyachka. Numerous teeth of new sphenacanthid; hybodontiforms "*Lissodus*" cf. *zideki* and "*Polyacrodus*" sp.; new neoselachian, hybodontiform scales and spines are found there. The actinopterygian scales and bones are attributed to *Discordichthys spinifer*, *Varialepis* cf. bergi A. Minikh, *Samarichthys* sp., *Kazanichthys* sp., *Kargalichthys* sp. Some teeth of "*Lissodus*" and "*Polyacrodus*" have the abraded their whole surface. Several such teeth and some scales of bony fishes bear the trace of living abrasion on the occlusal part of the crown arisen from the crushing type of shark feeding. The teeth of new sphenacanthid and neoselachian sharks and most of actinopterygian remains are well preserved and possess the tiny detailed ornamentation.

A new sphenacanthid shark earlier defined as *Xenosynechodus egloni* Glikman (Minikh, Minikh, 1996) has been found in the Late Kazanian – Severodvinian interval. *Discordichthys spinifer* and *Varialepis bergi* are known from the Urzhumian of European Russia (Minikh, Minikh, 2009).



Chondrichthyan teeth and actinopterygian scales from the localities Gremyachka (1–3, 6, 11) and Cheremushka 1 (4, 5, 7–10). (1, 2) **"***Lissodus***"** cf. *zideki* (Johnson); (3) **"***Polyacrodus***"** sp.; (4, 5) Sphenacanthidae gen. et sp. nov.; (6–9) Neoselachii gen. et sp. nov.; (10, 11) *Discordichthys spinifer* A. Minikh. Scale bars – 0.5 mm

Cheremushka Gully General Profile with Scalar Magnetic Parameters



MAGNETOSTRATIGRAPHY

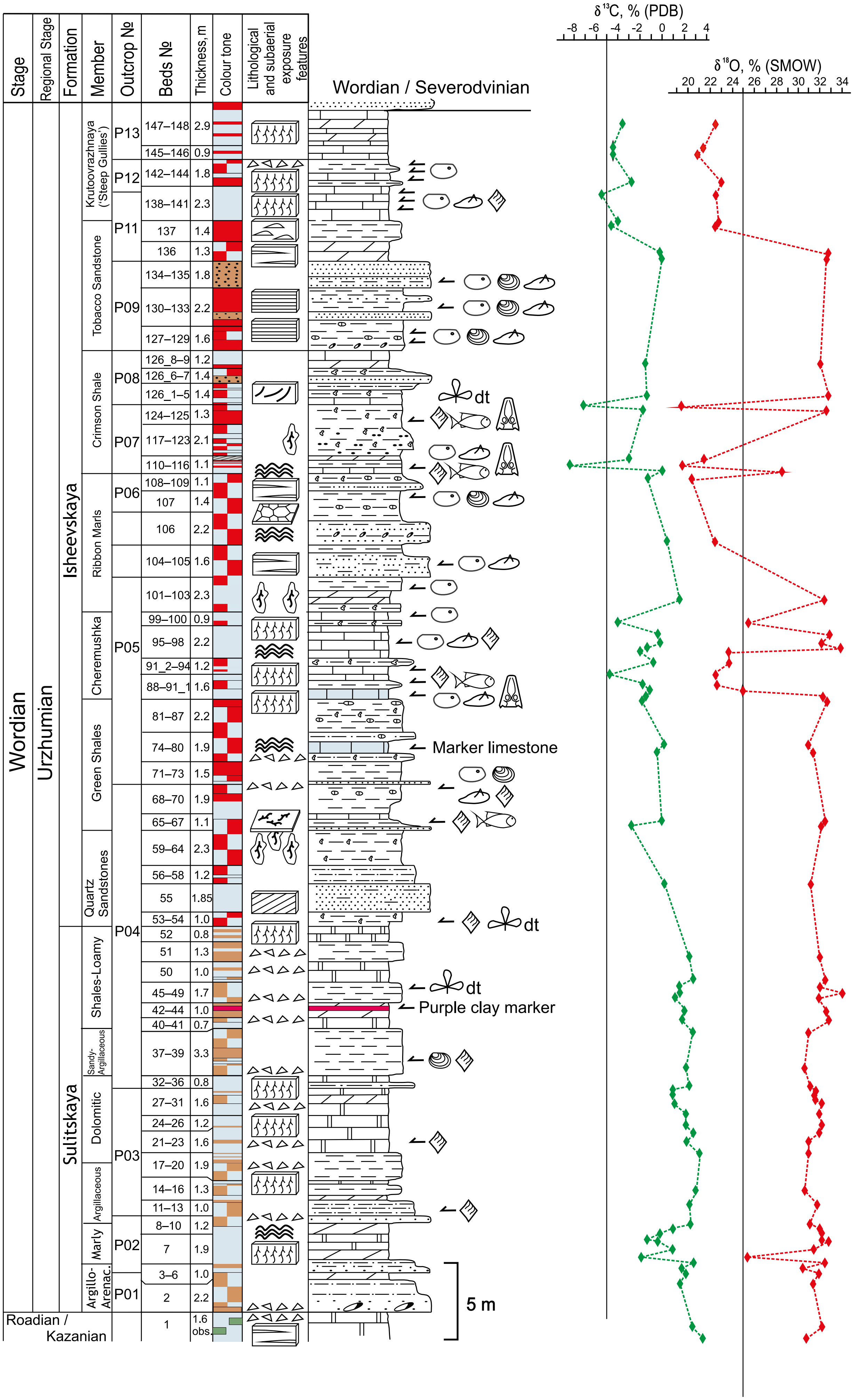
Paleomagnetic data of the Urzhumian Stage exposed in the Cheremushka Gully are based on 698 oriented specimens (Burov, Zharkov, Nurgaliev et al., 1998; Zharkov, 2007). Finely dispersed haematite, which is responsible for the predominately reddish colour of the rocks, is the main carrier of NRM. The magnetisation of the rocks of the Sulitsa Formation is weak, and many specimens, particularly after cleaning, are measured at the limits of accuracy, with high error. Rejection of weakly magnetised specimens leads to a compact distribution of the remaining 259 vectors around the direction of the reversed polarity. The Isheevo Formation, like the Sulitsa Formation, is characterised by substantial scatter of J_n^o directions remained after cleaning. When weakly magnetised, the specimens were rejected, and the remaining 95 vectors showed two compact groups of J_n^o directions, differing by 180° and corresponding to the normal and reversed polarity, with predominant reversed polarity. The characteristic feature of the Isheevo Formation rocks is their higher value of magnetic viscosity and a relatively low value for Q_n factor; this suggests a relatively low value of geomagnetic field strength. The upper part of the Isheevo Formation (about 20 m) points to the presence of normal and reversed polarity of J_n^o (NRP zone), scattered over the section as microzones, varying from 1 to 8 m in thickness. The lower part of the Isheevo Formation and entire Sulitsa Formation are magnetised by the reversed polarity field of the Kiaman Hyperzone (R_1P).

Formation / Age	N	Direction of J_n^o – ancient component of natural residual magnetisation		Precision of J_n^o vectors		Paleomagnetic pole in present geographic coordinates		Geomagnetic latitude, φ_m^o
		D	I	α_{95}	K	Φ	Λ	
Isheevo / Upper Urzhumian	56	219	– 39.9	2.9	41	46.6	172.7	22.7
Sulitsa / Lower Urzhumian	259	217	– 43.4	1.9	52	49.3	170.2	25.3

The nature of the NRP zone remains unclear in many aspects. Generally, the succession of the Sulitsa and Isheevo formations shows the dominance of reversed polarity of natural residual magnetisation of the rocks (J_n), with short episodes of normal polarity. The vectors in the intervals with normal polarity have the same sense of direction as Middle Permian vectors, although the modern direction also occurs. The intervals with normal polarity are usually represented by 1–2 samples, and only in the most representative interval there are samples from five levels. The intervals of normal polarity occur at the contacts of carbonates and sandy-argillaceous rocks. This allows the recognition of these intervals as episodes of methachronous magnetisation (Zharkov, 1998).

In sediments the carriers of magnetic signal is magnetic minerals which can be authigenic or allogenic. Authigenic can be presented by magnetotactic bacteria which are producing magnetite or greigite during their life. Mass specific magnetic susceptibility (χ) was measured on Bartington instrument with MS2B sensor for 580 samples. Magnetic susceptibility is in a good correlation with magnetization along the cross section. In the lower part of the section the most variable values of the χ are presented in Sulitskaya formation. The high values of χ are related to argillaceous sediments. The mean value of magnetic susceptibility is $10–15 * 10^{-8} m^3 \cdot kg^{-1}$.

Cheremushka Gully General Profile: geochemical data



Sedimentological and geochemical data

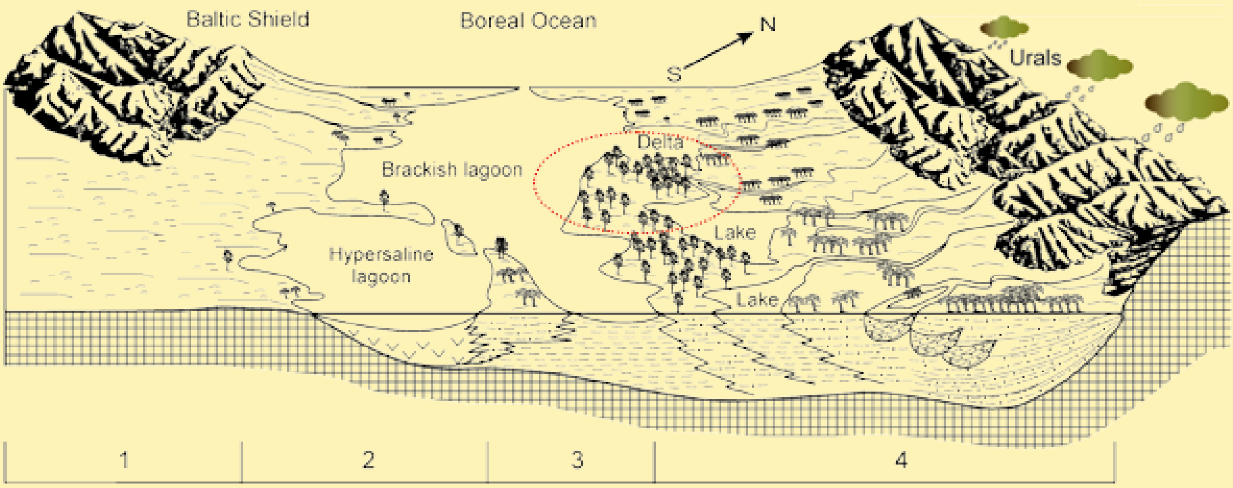
The lower part of the section contains numerous thin bands (average thickness 5 cm) of argillaceous breccias. These rocks consist of angular silty-argillaceous debris lying (‘floating’) in a argillaceous matrix. Gravel-sized lithoclasts are dispersed in the matrix and can be found together with shale coatings and occasional *in situ* roots. The coatings contrast with the matrix by their dark red, brown or green colour and divide the bed into many angular fragments, forming the reticular structure of the rock.

Along the strike of the beds, the argillaceous breccias form a regular succession: (1) breccias, (2) silty-shale rocks with broken and subhorizontal sloping lamination, (3) silty-shale rocks with irregular undulated lamination, and (4) silty-shale rocks with fine subhorizontal or horizontal lamination. Such a sequence indicates the subaerial transformation of the sediments without deep soil formation. The conditions may be interpreted as subaerial environments of plains resembling modern coastal or inland sabha.

In the upper part of the section, paleosols similar to cambisols are widespread. They are diagnosed by the presence of various *in situ* plant roots, by the greenish-grey colour with red spots (stains) of gleisation, by the numerous calcareous nodules (concretions), and by the slickensides. The soils are often represented only by the lower horizons of the paleosol profiles.

Erosional surfaces coincide with the upper boundaries of breccias and paleosols and are used as the main tool for detection of sedimentary cycles.

A sharp decrease in the δ13C is fixed in the sedimentary carbonates. In the lower 60 m of the section, the values of δ13C change from 3.7 ‰ PDB at the bottom to –4.8 ‰ PDB and –8.4 ‰ PDB in the Cheremushka Member and in the Crimson Shale Member, respectively. Upwords the section, a positive change in variations of δ13C is observed. Lower values of δ13C correlate with a very light isotopic composition of oxygen that is characterised by the decrease of the values of δ18O from 31–32 ‰ SMOW at the bottom of the section to 21.4 ‰ SMOW and 19.6 ‰ SMOW in the Cheremushka Member and in the Crimson Shale Member, respectively. Thereby, two negative excursions in the stable isotopic composition of carbon and oxygen in the Cheremushka Member and in the Crimson Shale Member are revealed. These excursions can be considered as global stratigraphic markers that suggest climate cooling and rising humidity.



Depositional model of the Urzhumian regional stage within the East-European Platform. The study area (Cheremushka Gully section) is marked by a red dotted line. (1) west bank of the Urzhumian sediment basin, (2) hypersaline protected lagoons, (3) brackish lagoons with predominant ‘basinal’ sedimentation, (4) deltas, lakes and alluvial-lacustrine plains with predominant paleosol accumulation

AUGUST 17

MONASTERY RAVINE SECTION

Tetyushi

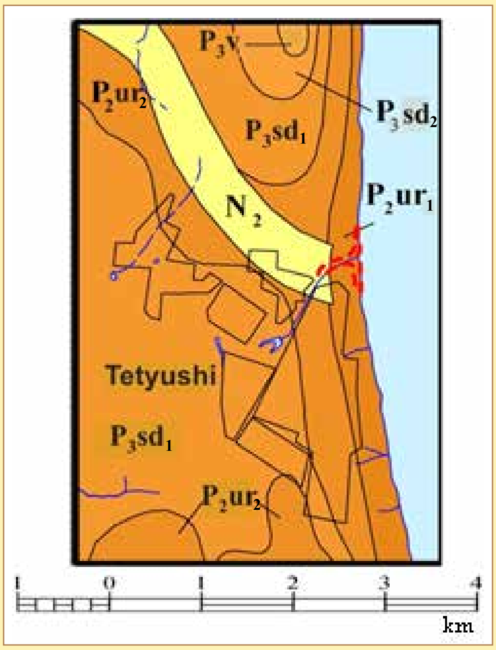
Coat of Arms of Tetyushi

Tetyushi is a town and the administrative centre of Tetyushsky District in the Republic of Tatarstan, Russia, located on the bank of the Kuybyshev Reservoir, 180 kilometres (110 mi) south of Kazan, the capital of the republic.

It was founded in the 16th century as Tetyushskaya zastava. It was granted town status in 1781.

The town was the site of a major battle during Stenka Razin's rebellion in 1668–1680.

Tetyushi pier



Geological map of Tetyushian folds region

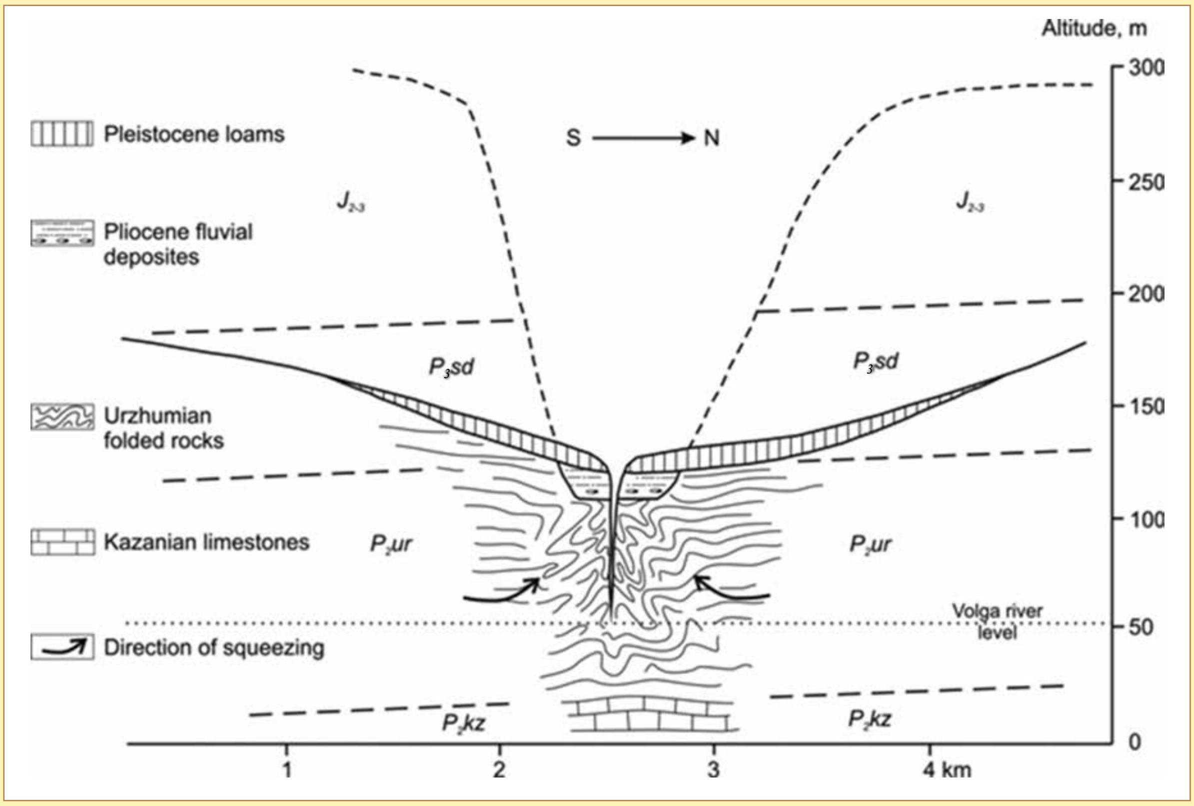
Tetyushian dislocations, view from the pier of Tetyushi

Tetyushian Folds

On the steep right bank of the Volga River, directly at the pier of Tetyushi, the pictorial folds of speckled Urzhumian rocks are exposed. The height of the folds is up to 30–50 m, the width is up to 100 m. The shape of the folds depends on the fold limbs morphology straight, and may by overturned or recumbent. A Pliocene paleovalley (500 m wide and 20 m depth of) stretches from the northern edge of Tetyushi Town, i. e. from the pier, to the northwest, and is filled with silty-sandy and pebble fluvial deposits. These deposits overlap the folded Permian rocks with angular unconformity. Fold dislocations can be traced for a distance of 1 km along the bank of the Volga River in both directions from the Pliocene paleovalley, further, the Permian beds become subhorizontal.

Several hypotheses have been proposed for the origin of these folds:
a) endotectonics, b) landslides, c) solifluction and others. A Professor of Kazan University, Alexey P. Dedkov (1967, 1999), proposed a possible model for the formation of these dislocations. According to his research, in the early Pliocene, topography here was strongly dissected, and the excess of the watersheds above the valleys reached 200–250 m. This resulted in “squeezing” of plastic, carbonate-argillaceous, Urzhumian rocks from under the hills to the bottom of the Pliocene valley. High relief is suggested by the presence of landslide bodies of Jurassic rocks buried on the slopes of Pliocene valleys. In addition, the pebbles from the fluvial deposits of Pliocene valleys, by the mineralogical composition, are identical to the pebbles from the Middle Jurassic conglomerates, which have been preserved to the south of Tetyushi.

Thus, Tetyushi folds are typical examples of exotectonics, which are widespread in the East European Platform in predominantly argillaceous rocks of different ages.



Geological profile along the right bank of the Volga River near Tetyushi

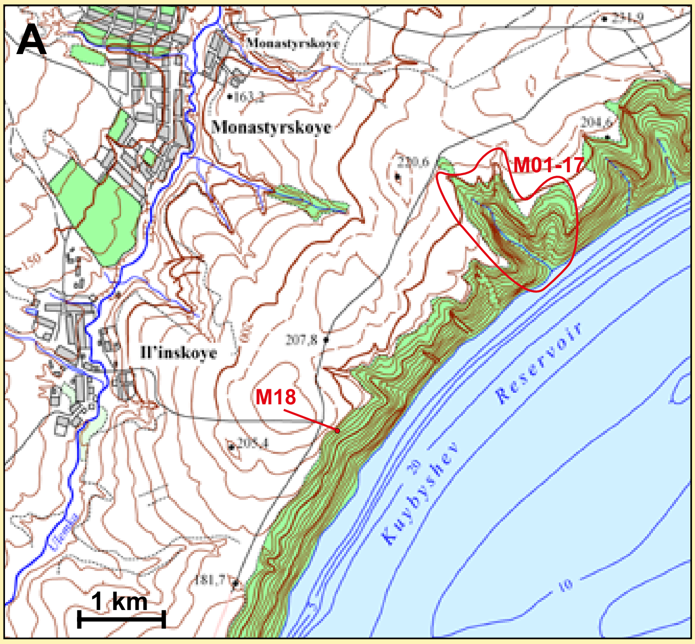
AUGUST 17 • STOP 1

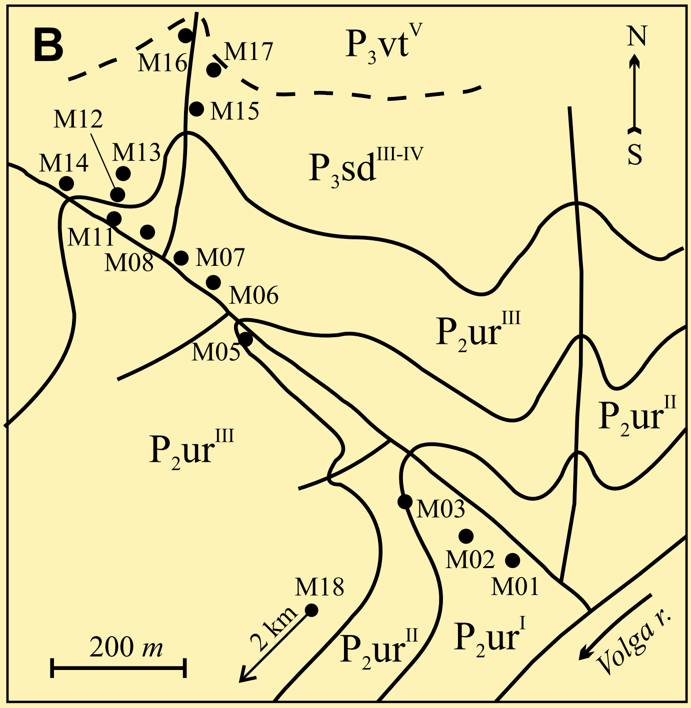
MONASTERY RAVINE SECTION. STRATOTYPE OF THE URZHUMIAN AND LIMITOTYPE OF THE SEVERODVINIAN STAGE

The Monastery Ravine is located on the right bank of the Volga River, in the vicinity of the village of Monastyrskoye, 12 km upstream of the town of Tetyushi. The Il'insky Gully lies 2 km southwest of the Monastery Ravine. The outcrops in the thalweg and slopes of these gullies represent one of the most complete and readily accessible sections of the Biarmian and Tatarian series in the region of the Kazan Povolzhye. The Monastery Ravine section was described first by Forsh N.N. during the geological mapping of the Volga region in 1938. He divided the section into 5 formations according to lithological criteria; these formations are used in the present guidebook. This section was repeatedly studied in the course of stratigraphic, lithological (Forsh, 1963, Sementovsky, 1973; Gusev, 1996b,1998b), paleomagnetic (Khramov, 1963, Burov and Boronin, 1977, Gialanella, 1997), and paleontological (Silantiev and Esin, 1993; Esaulova, 1998d, 1999; Esaulova et al., 1998; Larochkina and Silantiev, 2007) works. Recent studies, carried out on the section, revealed a new sedimentological and geochemical features (Arefiev and Silantiev, 2014), clarified the paleomagnetic data (Westfahl, 2005, Balabanov, 2014; Balabanov et al., 2009), allowed supplementing the data on tetrapods, fish and plants (Bulanov, 2014, Minikh and Minikh, 2009, Naugolnykh, 2007 and others), helped to identify and describe the paleosol profiles (Inozemtsev et al., 2011, Mouraviev et al., 2015).

According to the Resolution of Russian Interdepartmental Stratigraphic Committee (Reshenie…, 2006), the Monastery Ravine section is a stratotype of the Urzhumian and a limitotype of the Severodvinian. The section is represented there by all three stages – Urzhumian (~ Wordian), Severodvinian (~ Capitanian), Vyatkian (~ Wuchiapingian) – and five formations; and its thickness reaches 180 m. Four lower formations are more readily accessible in the Monastery Ravine, whereas the fifth one is better exposed in the Il'insky Gully.

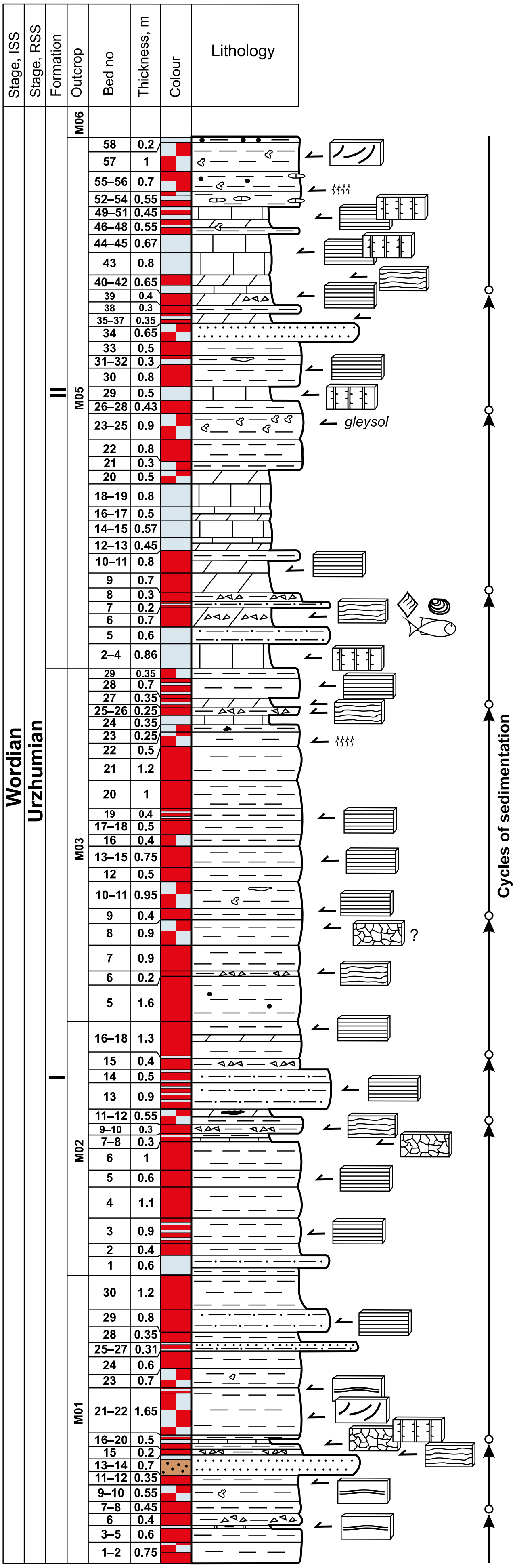
The general construction of the Monastery Ravine section can be seen in the 'Main Wall' on the left slope of this gully; the total height of the outcrop is 80 m.





Study area: (A) topographic map of the Monastery Ravine (rounded) and Il'inskii Gully (M18 station); (B) geological scheme of the Monastery Ravine with stations

Monastery Ravine, st. M01, M02, M03, M05



Monastery Ravine section, lower part, First and Second Formations

Urzhumian. The Urzhumian includes three formations: the First, the Second and the most part of the Third Formation.

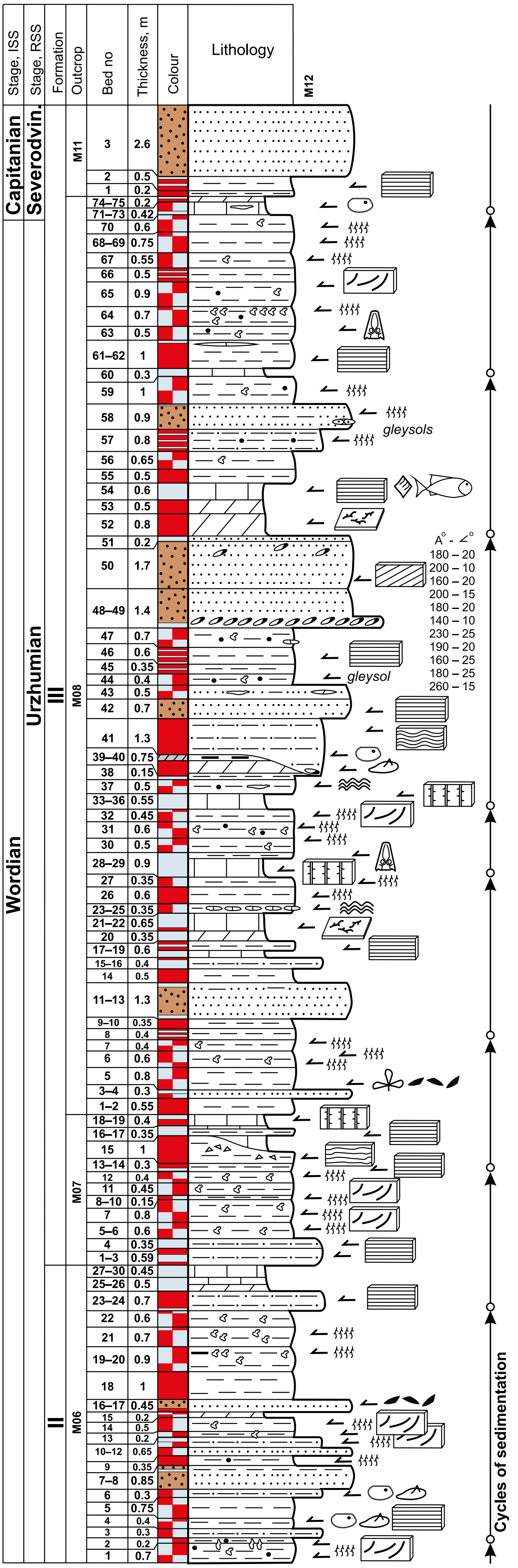
THE FIRST FORMATION. The lower part of the Formation is exposed near the mouth of the Monastery Ravine on the steep bank of the Volga River, while the upper part of the Formation is exposed in the right slope of the gully, where it forms a series of ledges. The thickness of the formation is ca. 45 m. The building of the water reservoir near the city of Samara in 1952 resulted in the waterline rising. So nowadays the Kazanian–Urzhumian boundary lies slightly below the water level of the Volga River. According to Forsch (unpublished Report to the Geological Survey, 1938), the Urzhumian starts with the dull-red siltstones with gypsum nodules. There is no distinct gap between the stages.

Generally, the First Formation is composed of red-bed shales and is distinctly subdivided into two parts. The shales of the lower part of the Formation are gypsiferous, containing many interbeds (3–20 cm thick) of grey and pink marls and argillaceous dolomites, more rarely of brown siltstones and sandstones. In the upper part of the Formation, shales are more homogenous and have a few interbeds of terrigenous and carbonate rocks. The shales often bear thin lenses of palygorskite.

Fossils occur rarely in the Formation and mostly in its upper part. The first bed with fossils lies 10 m below the top of the Formation and is composed of reddish-brown thinly bedded shales containing small (3–4 mm) distorted valves of conchostracans. Seven metres above this bed, dull-red unbedded shales, along with conchostracans, contain the isolated scales of the fishes *Platysomus biarmicus* Eichw., *Kargalichthys efremovi* Minich, *Amblypterina (Eurynotoides) costata* (Eichw.), *Acrolepis rhombifera* Eichw., *Palaeoniscum* cf. *kasanense* Gein. et Vetter, *Palaeoniscum* cf. *freislebeni* Bl., *Palaeoniscum kurtum* Krotov, *Varialepis orientalis* (Eichw.), *Varialepis bergi* A. Minich, *Elonichthys* sp., *Eurysomus* sp., and *Xenosynechodus* sp. The scales are 2–5 mm in size, black, not oriented and regularly distributed in the rock.

The First Formation in the right slope of the Monastery Ravine, M01–03 stations

Monastery Ravine, st. M06, M07, M08, M11



Monastery Ravine section, middle part, the Second and Third Formations

THE SECOND FORMATION is exposed in the second right tributary, and also in the thalweg and slopes of the Monastery Ravine. The thickness of the formation is ca. 35 m. Its lower boundary is drawn at the base of the 0.3 m thick bed of pinkish-grey, dolomitic, heterogeneous marl. In the bottom of the ravine, this bed forms a waterfall, first from the mouth.

The Second Formation is distinct in its cyclic structure and high content of carbonates. The section contains three argillaceous-carbonate members: at the bottom, in the middle, and at the top. These members are separated by two members of sandy-argillaceous rocks. The argillaceous-carbonate members are composed of greenish and pinkish-grey dolomites, argillaceous limestones and marls (0.2–1.5 m thick), containing thin (usually 10–30 cm) bands of red shales. The sandy-argillaceous members are composed of reddish-brown shales and siltstones with lenticular interbeds of brownish sandstones (up to 2 m).

Fossils are represented by non-marine ostracods, bivalves, fishes, amphibians, and plants.

The bed of the greenish-grey siltstone (5–20 cm), 6.5 m above the base of the formation, contains numerous scales of the fishes *Platysomus biarmicus* Eichw., *Amblypterina (Eurynotoides) costata* (Eichw.), *Amblypterina (Eurynotoides)* sp., *Palaeoniscum* cf. *kasanense* Gein. et Vetter, *Palaeoniscum* sp., *Varialepis bergi* A. Minich, *Elonichthys* sp., *Eurysomus* sp., and *Xenosynechodus* sp. The large (0.5–3.0 cm) reddish-brown scales occur parallel to the bedding planes and mainly concentrate in the thin (3–5 mm) bed, which also yields small amphibian bones.

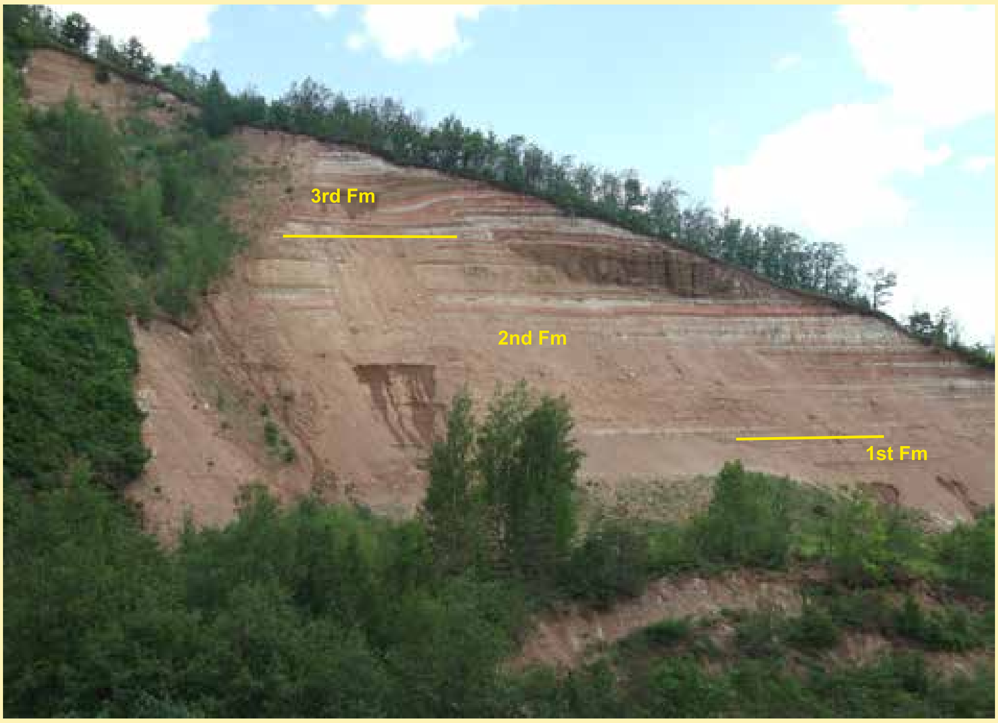
Eight metres below the top of the formation, the bed (0.1 m) of reddish-brown evenly and thinly laminated shales contains molds of the ostracods *Palaeodarwinula* cf. *fragiliformis* (Kash.), the bivalves *Palaeomutela castor* (Eichw.), *P. doratioformis* (Gus.), *Prilukiella subovata* (Jones), scales of the fishes *Varialepis* cf. *orientalis* (Eichw.), *Platysomus* sp., *Elonichthys* sp., fragments of the small-leafed plant *Phylladoderma tscheremushca* Esaul., and the remains of *Paracalamites frigidus* Neub. and *Stomochara diserta* Kis.

THE THIRD FORMATION is well exposed in the first right tributary and in the thalweg of the mainstream of the Monastery Ravine. The slopes of the ravine expose only the lower part of the formation; because of the slides, the primary structure of beds is distorted here by many small gliding planes. The thickness of the formation is ca. 45 m. Its lower boundary is drawn at the top of the upper dolomitic bed of the Second Formation. In the thalweg of the ravine, this bed forms the ledge, third from the mouth of the ravine. Beds M08/48-M08/54 form the biggest fourth ledge in the thalweg, its height is up to 5–6 m.

The Third Formation is distinct in the predominance of sandstones and siltstones in the succession. Carbonate beds are rare and thin. Reddish-brown shales and siltstones are most widespread and are usually intercalated by thick lenses of yellowish-brown, obliquely laminated sandstones. Carbonate rocks are represented by grey, nodular, and muddy limestones and marls. The cyclicity of the formation is distinct.

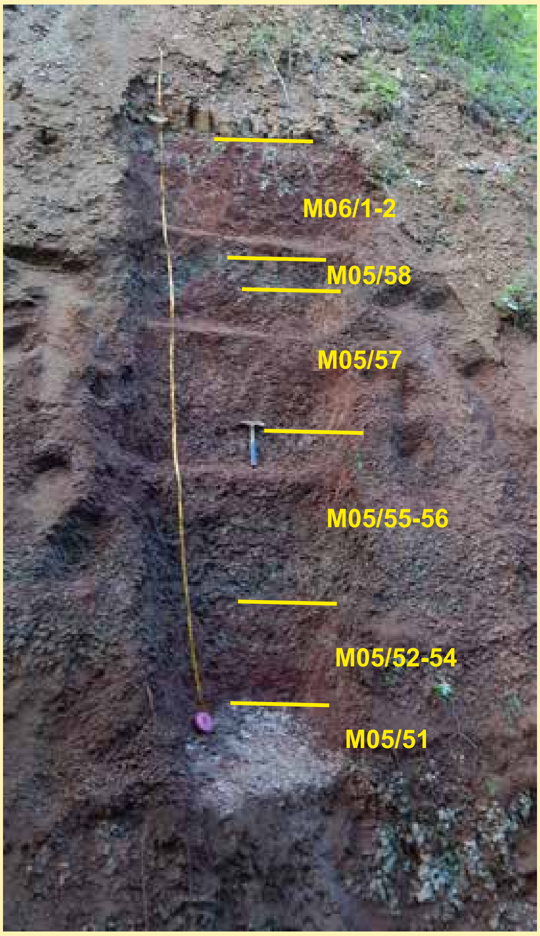
Different levels within the formation contain the remains of non-marine bivalves, ostracods, conchostracans, fishes, and tetrapods, and imprints and fragments of plants. Grey and brown siltstones 1–1.5 m above the base of the formation contain coaly remains of the trunks of *Sphenophyllum stouckenbergii* (Schm.) and *Paracalamites frigidus* Neub.

The bed of reddish-brown and greenish-grey siltstone eight metres higher than the previous one contains the ostracods *Palaeodarwinula elongata* (Lun.), *P. chramovi* (Gleb.), *P. teodorovichi* (Bel.), *P. fainae* (Bel.), *Prasuchonella nasalis* (Shar.), and *P* cf. *stelmachovi* (Spizh.), the bivalves *Palaeomutela ulemensis* (Gus.), *P. wöhrmani* Netsch., *P. numerosa* (Gus.), *P. marposadica* (Gus.) and *P. subparallela* Amal., rare scales of the fishes *Varialepis orientalis* (Eichw.) and *Amblypterina (Eurynotoides)* sp., and rare amphibian vertebrae. The argillaceous limestone, four metres above, contains the ostracods *Palaeodarwinula elongata* (Lun.), and *Prasuchonella nasalis* (Shar.), the remains of complete fishes *Platysomus biarmicus* Eichw., *Kargalichthys efremovi* Minich, *Varialepis bergi* A. Minich, *V. orientalis* (Eichw.), *Amblypterina (Eurynotoides) costata* (Eichw.), *Amblypterina (Eurynotoides)* sp., *Palaeoniscum curtum* Krotov, and *Xenosynechodus* sp., a few small bivalves of *Palaeomutela* sp. and conchostracans.



The 'Main Wall' of the Monastery Ravine with the First, Second, Third Formations

The base of the Second Formation in the first ledge of the thalweg



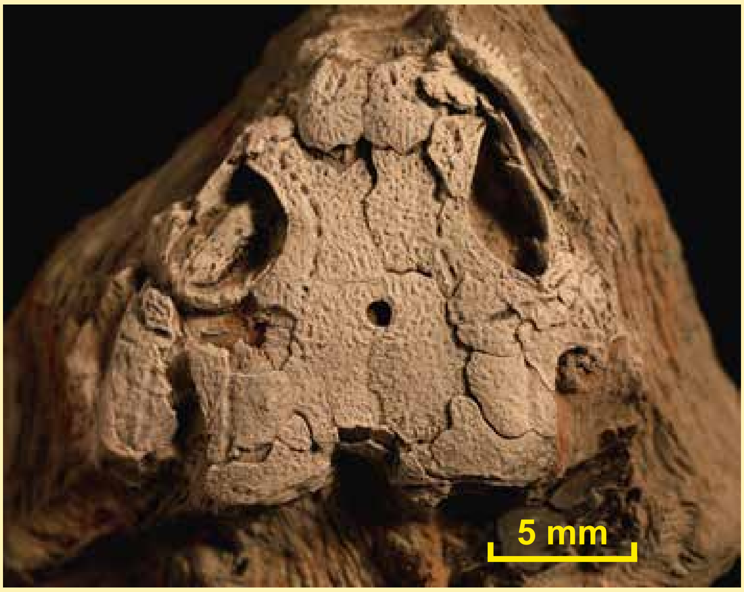
The paleosol profile, upper part of the Second Formation, above the second ledge of the thalweg

‘Fish bed’, limestone M08/54 (arrowed) in the right steep tributary of the ravine, Urzhumian Stage

Bivalves Palaeomutela from siltstone M08/41, Urzhumian Stage

***Paracalamites* sp.?,** trunks and leaves in shales M08/5, Urzhumian Stage

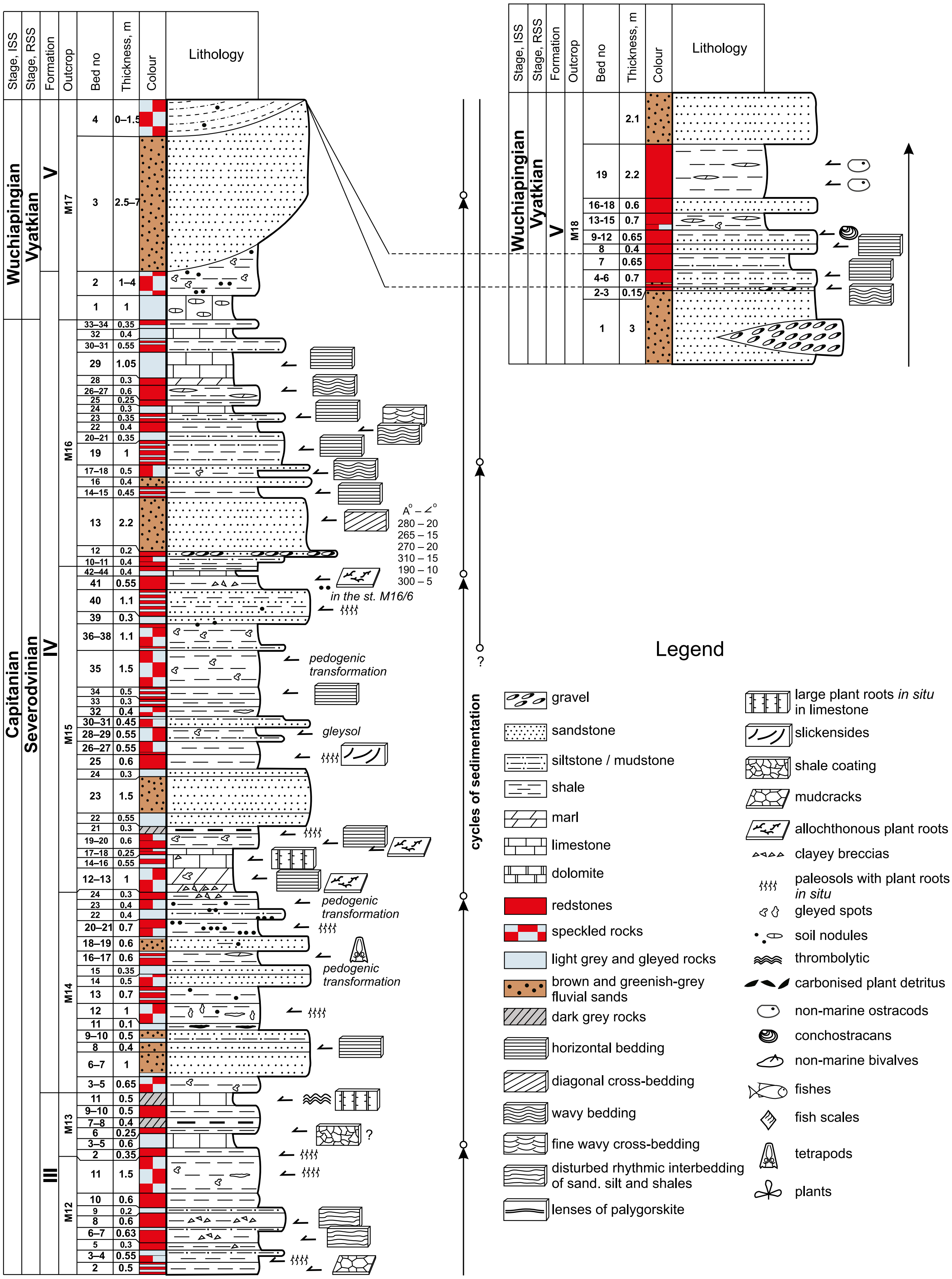
***Platysomus* remains** from limestone M08/54, Urzhumian Stage



***Karpinskiosaurus* sp.** skull in shales M08/38, Urzhumian Stage

Monastery Ravine, st. M12, M13, M14, M15, M16, M17

Key Gully, outcrop Pashino, st. M18



Monastery Ravine section, the upper part, the Third, Fourth and Fifth Formations

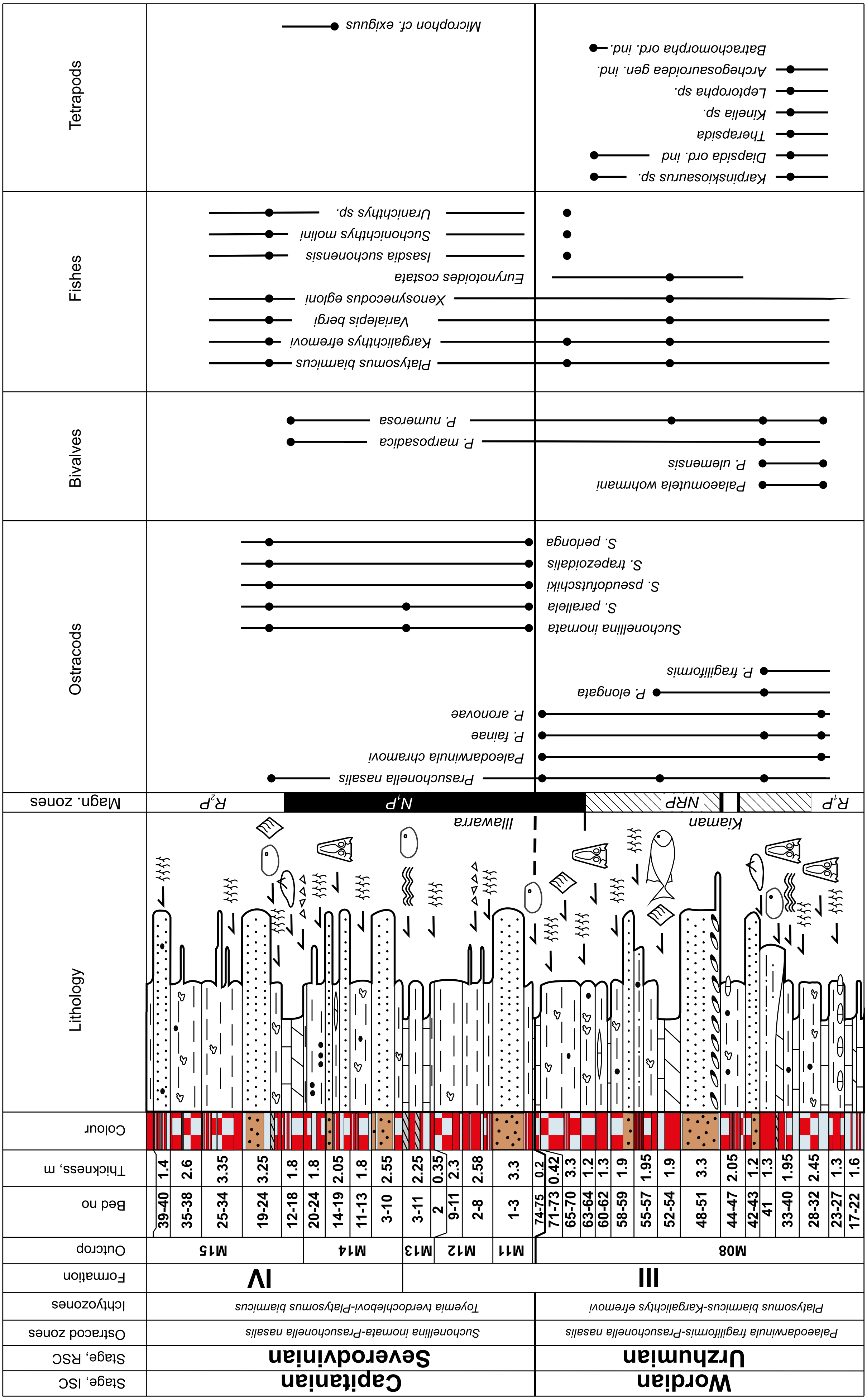
Severodvinian. The Severodvinian includes the upper 12 m of the Third Formation and almost the total Fourth Formation.

THE FOURTH FORMATION is exposed in the thalweg and the slopes of the first left tributary of the Monastery Ravine. It is represented by the alternation of siltstones, shales and sandstones with marls and limestones showing the distinct cyclicity. Sandstones are usually bluish or yellowish-grey, and recognised in three levels as lenses 2.50–8.0 m thick. Together with shales and siltstones, they form three argillaceous-sandstone members. Carbonate rocks concentrate mostly in the lower and upper parts of the formation, where they, together with shales, form separated argillaceous-carbonate members 4.5 m thick at the bottom and 7.8 m at the top of the Formation. The lower boundary of the Formation is drawn at the base of the bed of light-grey argillaceous limestone with a distinct vertical structure overlying the upper argillaceous-sandstone member of the Third Formation. The thickness of the Formation is ca. 33 m.

The Formation contains few fossils. At the base of the Formation, there are the ostracods *Suchonellina inornata* (Spizh.), *S. parallela* (Spizh.), *S*. ex. gr. *parvaeformis* (Kash.), *Prasuchonella nasalis* (Shar.), the charophytes *Cuneatochara vjatkensis* Kis. and *C. amara* (Said.). Upwards in the section, five metres below the top of the formation, the bed of bluish-grey marl, apart from the similar ostracod assemblage, contains large conchostracan shells, fragments of the bivalve *Palaeomutela* sp., scales of the fishes *Amblypterina (Eurynotoides) costata* (Eichw.), *Platysomus* sp., *Kargalichthys efremovi* Minich, and *Varialepis bergi* A. Minich. Ostracods occur in more calcareous part of the marl, whereas fish scales occur in more argillaceous part. The intermediate type of marl contains conchostracans and fragments of bivalve shells.

THE FIFTH FORMATION. The Fifth Formation and its boundary with the Fourth Formation is exposed 2 km southwest, in the upper reaches of the Il'insky Gully. In this gully, the section of the Formation is represented by the member (10–15 m) of yellowish-brown obliquely laminated sandstones, with conglomerate lenses, consisting of fragments of local rocks. Sandstones frequently contain silicified lenses and interbeds of red-bed siltstones, shales and marls. The apparent thickness of the Formation is 25 m.

The lower part of the Formation (shales and marls) contains ostracods and fragments of bivalves. Ostracods are characteristic of the boundary beds of the Vyatkian and Severodvinian Horizons and represented by *Palaeodarwinula fragilis* (Schn.), *Suchonellina parallela* (Spizh.), and *Volganella magna* (Spizh.), *V. laevigata* Schn. Sandstones contain bones of labyrinthodonts (*Dvinosaurus*), chroniosuchids (*Chroniosaurus*), leptorophids (*Raphanodon),* pareiasaurs (*Praelginia* and others) and numerous therapsids (Golubev, 1996).



Distribution of ostracods, bivalves, fishes, tetrapods in the Urzhumian-Severodvinian boundary beds

Urzhumian-Severodvinian boundary, biostratigraphical criteria

Severodvinian boundary is suggested at the base of bed M08/74 by the first appearance of the ostracod *Suchonellina* and index species *Suchonellina inornata* marked the basement of *Suchonellina inornata-Prasuchonella nasalis* zone (Minikh et al., 1999). Urzhumian ostracod species of *Palaeodarwinula* genus, on the contrary, occur just below this boundary. This level is close to *Platysomus biarmicus-Kargalichthys efremovi* and *Toyemia tverdochlebovi-Platysomus biarmicus* ichtyozones boundary (Minikh et al., 1999). Five metres below the Severodvinian boundary, in beds M08/64–66, there have been found the remains of the fishes *Isadia suchonensis*, *Suchonichthys molini* and *Uranichthys sp.* belonging to the *Toyemia tverdochlebovi-Platysomus biarmicus* ichtyozone. The same species as well as transitional *Platysomus biarmicus* and *Xenosynechodus* sp. have been identified in bed M14/16 and upper. Here, in this bed, isolated bones of the terrestrial amphibian *Microfon exiguus* have been found (Bulanov, 2014). Non-marine bivalves of Severodvinian complex appear in the section 20 m below the Urzhumian-Severodvinian boundary. The species such as *Paleomutela numerosa* and *P. marposadica* have been traced in Severodvinian deposits throughout the vast territory of the Volga-Ural Basin (Gusev, 1998b, Silantiev, 2014).

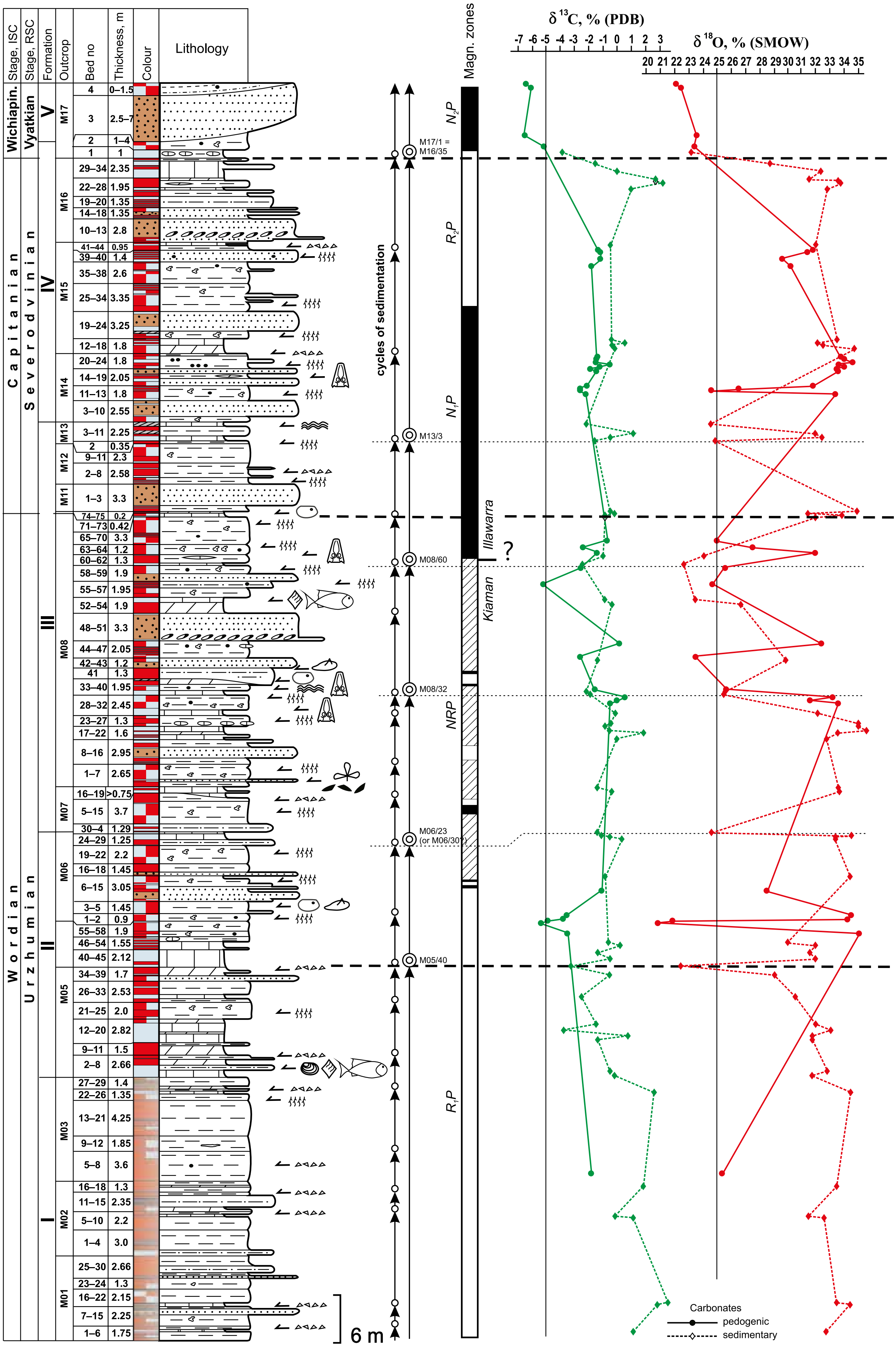
Kiaman-Illawarra reversal boundary lies 5–6 m below the Urzhumian–Severodvinian biostratigraphic boundary and practically coincides with *Toyemia tverdochlebovi-Platysomus biarmicus* ichtyozones boundary. The negative excursions of carbon and oxygen isotope values of sedimentary and pedogenic carbonates can be suggested as an additional marker of the Kiaman-Illawarra reversal boundary.

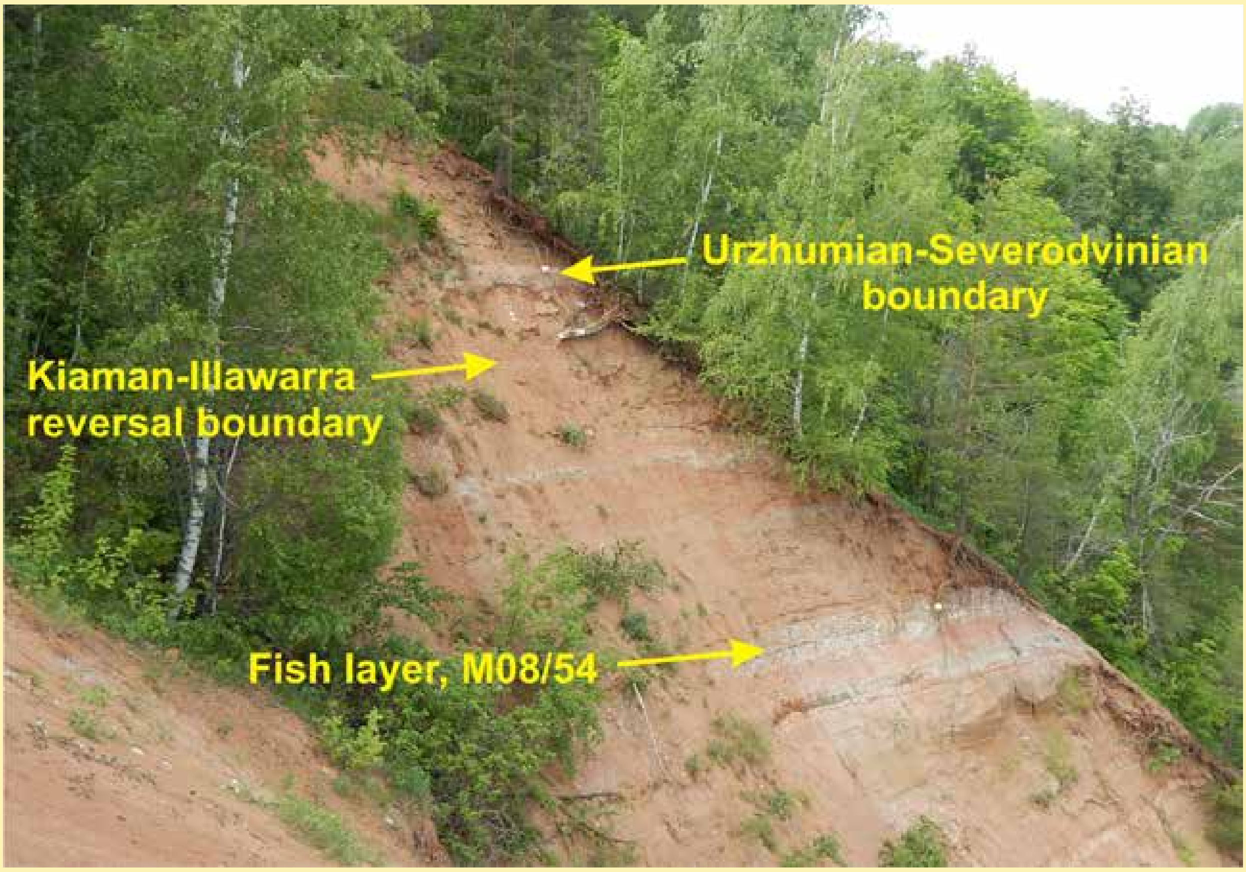
Paleodarwinula fragiliformis, index species of the Urzhumian ostracods

Suchonellina inornata, index species of the Severodvinian ostracods

Prasuchonella nasalis, transitional species of the Urzhumian and Severodvinian ostracods

Monastery Ravine General Profile





General view on the right steep tributary of the Monastery Ravine; June, 2015

Urzhumian/Severodvinian boundary in the right steep tributary of the Monastery Ravine; June, 2015

Chemostratigraphy

Stable isotope studies have been carried out on all stratigraphic levels in the Monastery Ravine section. 40 samples of pedogenic carbonates and 60 samples of sedimentary carbonates have been analysed on carbon and oxygen isotopic composition. The values of $\delta^{18}O$ vary from 22.3 to 35.5 ‰ SMOW. The minimum of $\delta^{18}O$ values corresponds to the boundaries of cycles established by sedimentological data. Five full cycles and two half-cycles of sedimentation can be distinguished on the base of the oxygen isotopic composition.

Variations of $\delta^{18}O$ values apparently reflect the evolution of local 'lacustrine' basins. Intervals with lightest oxygen structure may correspond to the spread of freshwater environments and to the active influx of meteoric water from the land during the humidisation and cooling (Leng, Marshall, 2004). Intervals with heaviest oxygen structure may correspond to the episodes of warming, when the basin waters were heavy due to evaporation. It is also possible that episodes of heavy oxygen composition may indicate the impact of marine ingression of the Boreal Sea. These events could be reflected in the flow of heavier water from the closed or semi-enclosed lagoon environments (Kuleshov et al., 2011). Decrease in $\delta^{18}O$ values in pedogenic carbonates is also associated with cooling, as is well demonstrated in the Quaternary soils (Levin et al., 2004; Kovda et al., 2014).

Significant facilitation of $\delta^{13}C$ values has been fixed in the lower part of the section up to mid-Urzhumian (Wordian) from 3.5 ‰ to -3.8 ‰ in sedimentary carbonates and from -1.8 ‰ to -5.2 ‰ in pedogenic ones. This negative excursions of carbon isotope values can reflect the global geochemical changes and, potentially, may be good stratigraphic markers. In the upper part of the section, a marked decrease of $\delta^{13}C$ values has been identified on the Severodvinian-Vyatkian (Capitanian-Wuchapingian) boundary. The same facilitation of carbon isotopic composition is typical for terrestrial deposits of central parts of East European Platform (Aref'ev et al., 2015).

Magnetostratigraphy

Paleomagnetic studies were repeatedly conducted in the Monastery Ravine (Burov, Boronin, 1977, Gialanella et al., 1997, Westfahl et al., 2005, Balabanov et al., 2009, Balabanov, 2014). Rocks of the First Formation and the lower part of the Second Formation are characterised by reversed polarity and belong to R_1P magnetic zone. The upper part of the Second Formation and the lower part of the Third Formation, with the total thickness of 35 m, have a strong metastable magnetism. Paleomagnetic metastability is usually a characteristic feature for weak-magnetic rocks. This metastability does not permit defining the component of initial natural magnetisation. The usage of gradual thermal cleaning of the samples makes it possible to specify the composition of the alternating-sign zone (NRP zone) and shows in most cases the reverse remanent magnetisation of rocks. Within the NRP zone, the intervals of normal and reversed polarity does not exceed 2–3 m of thickness.

Kiaman-Illawarra reversal boundary is located in the upper part of the Third Formation, at 5 m below the Urzhumian–Severodvinian biostratigraphic boundary. The upper part of the Third Formation and the lower part of the Fourth Formation belong to the N_1P magnetic zone of the Illawarra Hyperzone. The upper part of the Fourth Formation shows a reversed polarity. This interval of the section corresponds to the largest part of the R_2P magnetic zone. Paleomagnetic study of the Fifth Formation has been carried out at 18 levels within the Formation. By the direction of J_n vectors, the studied part of the Formation correlates with the N_2P zone. The available data do not allow us to calculate the coordinates of paleomagnetic pole, and geomagnetic latitudes for the rocks of the Fifth Formation.

Ages / formation	N	Direction of J_n^o – ancient component of natural residual magnetisation		Precision of J_n^o vectors		Paleomagnetic pole in present geographic coordinates		Geomagnetic latitude, φ_m^o
		D	I	α_{95}	K	Φ	Λ	
Urzhumian, First Fm	132	220.6	-33.4	2.4	26	42.4	172.3	18.3
Urzhumian, Second Fm	148	221.9	-34.9	2.5	22	42.5	170.1	19.2
Urzhumian / Severodvinian, Third Fm*	181	46.6	48.0	1.9	30	48.1	157.0	29.0
Severodvinian, Fourth Fm	54	220.0	– 37.2	4.7	16	44.8	171.1	20.8

* Paleomagnetic pole coordinates and geomagnetic latitude values are calculated for samples with normal polarity

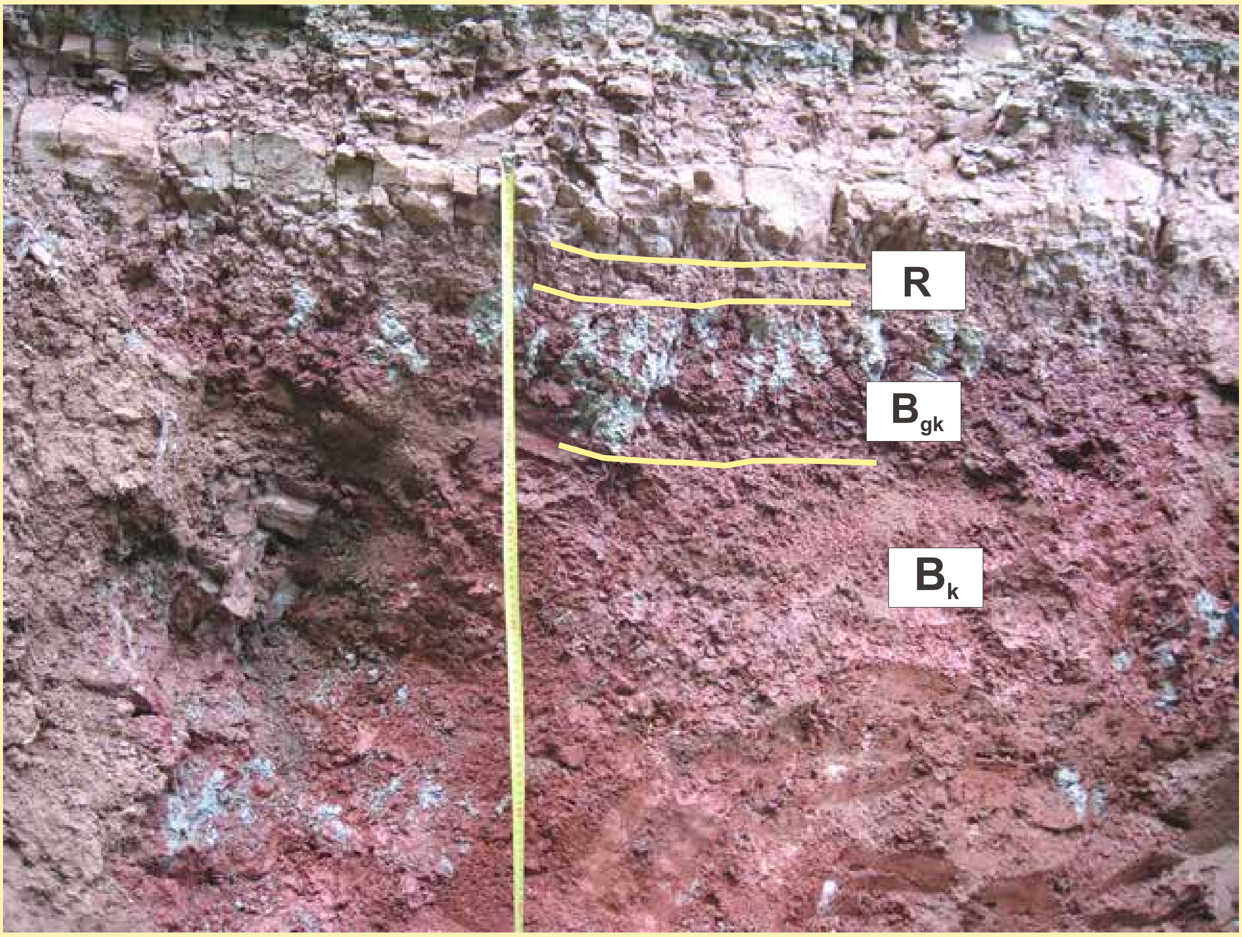
Cyclicity and paleosols

Recent study of the Monastery Ravine section allows us to recognise 21 full cycles and two incomplete cycles. The upper boundaries of argillaceous breccias as well as the upper boundaries of paleosols may be assumed as erosional surfaces. These erosional surfaces were chosen as the main criterion for the definition of sedimentary cycles (Arefiev, Silantiev, 2014). The thickness of these cycles vary from 2.5 to 16 m, the average thickness is 7 m. Considering the duration of mature paleosols formation for a few thousand years (Inozemtsev, Targulian, 2010), one can assume that the time of hiatuses in sedimentation is comparable to the duration of the sedimentation cycles.

Paleosols have been identified and described in more than twenty levels of these sections by the paleopedology features: *in situ* roots, slickensides, gleyed zones, carbonate nodules, blocky peds, etc. Paleosols are represented by eluvial-illuvial gleysols and paleoloesses (Naugolnykh, 2004), cambisols (Inozemtsev and Targulian, 2010), calcic gleysols and gleyed vertisols (Mack et al., 1993). It may be assumed that the parent rocks of paleosols shouid be presented by red-colour siltstones and shales. Both Urzhumian and Severodvinian paleosol macromorphology, especially the presence of carbonate nodules and gleysation, indicates a pronounced seasonality of climate associated with periodic moistening under the influence of monsoon rainfall.

The upper parts of the paleosol profiles (A horizon) are usually eroded, and now we can only observe B (B_k, B_g) and C horizons. Taking the thickness of A horizon for 0.1 m, we can estimate the mean annual precipitation, according to Retallack (2005), as 300 mm for the Urzhumian and 400–500 mm for the Severodvinian Age.

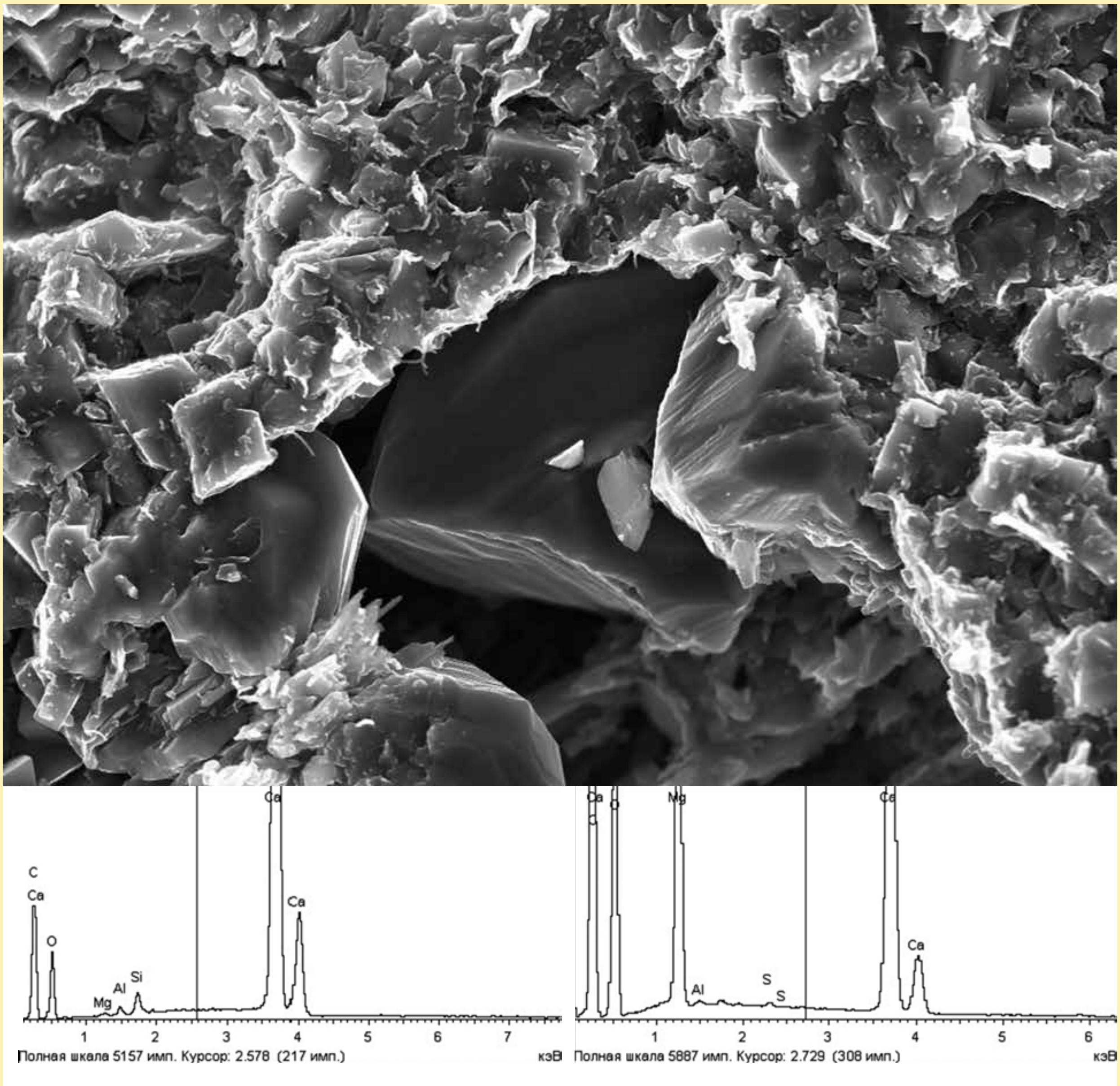
We have studied carbonate nodules from B_k horizons of paleosols located near the boundary of the Kiaman-Illawarra reversal. The samples have been analysed by an optical microscopy and scanning electron microscope (SEM), δ ^{13}C and δ ^{18}O isotopic analysis, X-ray diffraction and X-band Electron Paramagnetic Resonance (EPR). Pedonodules, occurring below the geomagnetic hyperzones Kiaman-Illawarra reversal, consist of dolomicrite, whereas those one overlying this boundary consist of calcimicrite (Mouraviev et al., 2015).



Paleosol with gleyed roots *in situ*, M06/1-2, the middle part of the Urzhumian Stage: R – reworked paleosol, B_{gk} – carbonate-gleyed horizon, B_k – carbonate horizon with nodules

SEM study allows us to detect a widespread presence of fossilised bacteriomorphic filaments on the surface and edges of carbonate and clastic mineral grains. Secondary carbonate grains from calcitic and dolomitic nodules are represented by diagenetic calcisparite. The last does not usually contain such filaments. The mineral composition of the filaments corresponds to the mineral composition of the substrate grains, i.e. calcite / dolomite / silica. Most of these filaments in carbonate nodules are fossilised remains of *Corynebacterium* or mycelium of *Actinomycetes*. It may be assumed that during wet seasons, these paleosol organisms could leach mineral substrate and grow up. During the dry seasons, carbonate minerals were precipitated and increased filaments were fossilised.

In carbonate nodules, $\delta^{13}C$ values vary from 0,6 to -5,2 ‰ (PDB), and $\delta^{18}O$ values vary from 21 to 35 ‰ (SMOW); in sedimentary carbonates $\delta^{13}C$ and $\delta^{18}O$ values vary from 2,6 to -3,2 ‰ (PDB) and from 22 до 35 ‰ (SMOW), respectively. There is a general regular facilitation of isotopic composition δ 13C in pedogenic carbonates compared with sedimentary ones. This confirms the formation of pedogenic carbonates with the participation of the lighter carbon of biogenic origin.



SEM micrograph with microprobe analysis spectra of dolomicrite pedonodule; Corynebacteria filaments cover the surface of dolomite grains: (1) secondary calcite grain, (2) dolomicrite, the bulk of the nodule. Monastery Ravine section, Middle Permian, Urzhumian (Wordian) Stage, bed M06/2

Thus, we have identified a transition from predominantly dolomite pedogenesis (where the dolomite is a primary mineral) to predominantly calcite pedogenesis just below the geomagnetic hyperzones Kiaman-Illawarra reversal. Near and above the same boundary, alluvial-deltaic cross-bedded sandstones are common in the section, and Severodvinian (Capitanian) species of non-marine ostracods, fishes, molluscs and tetrapods appear. This transition is accompanied by the facilitation in oxygen isotopic composition of pedogenic and sedimentary carbonates. The reason for such changes can be the fresh water influx from the land into the sedimentary basin.

Similar transitions from dolomite to calcite pedogenesis have been identified in Permian sediments of the world at different stratigraphic levels: in Central Spain, the end of Capitanian (De la Horra et al., 2012), in the Southern Urals, near the Permian-Triassic boundary (Kearsey et al., 2012). According to sedimentological markers, near the Wordian-Capitanian boundary in the tropical belt of Northern Pangaea, a “wetting phase” was revealed (Slowakiewicz et al., 2009), which corresponds well with the present data. These data may indicate a climatic change from arid conditions in the Urzhumian (Wordian) time to semi-arid conditions in the Severodvinian (Capitanian) one.

AUGUST 18–19

- **ELABUGA SECTION**
- **SENTYAK SECTION**

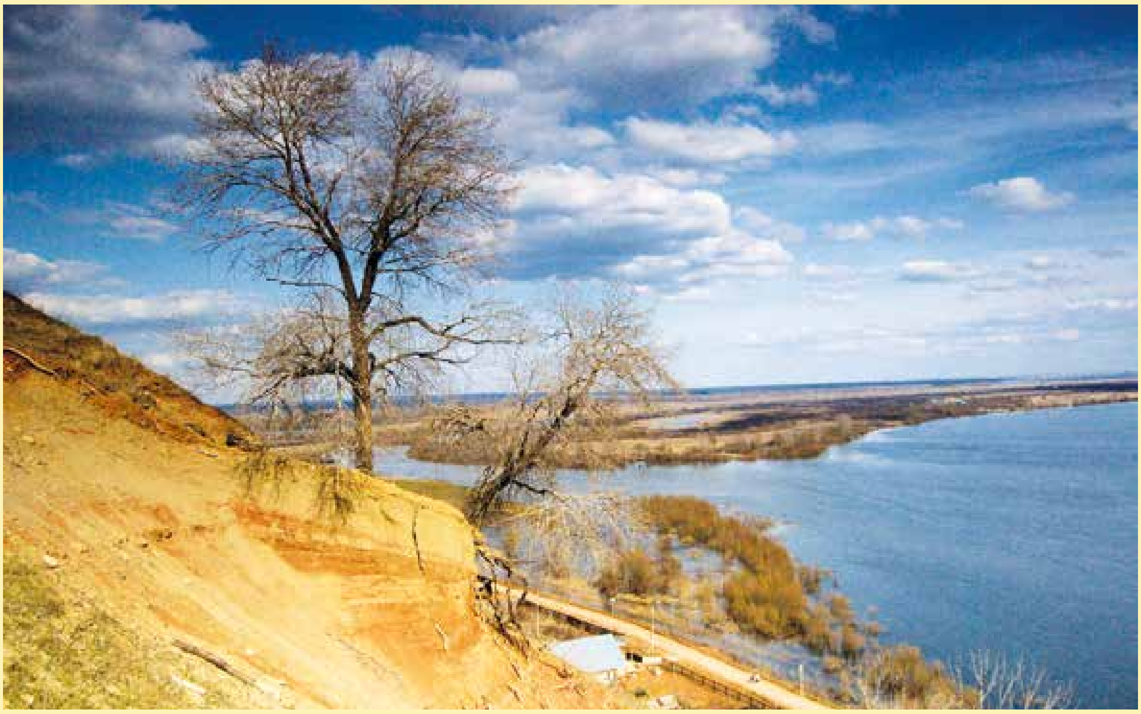
Elabuga

Coat of Arms of Elabuga

Elabuga is located 215 kilometres to the east of the capital of the Republic of Tatarstan – Kazan. It lies in the northeastern part of Tatarstan at the confluence of the Toima and Kama rivers. In the centre, a complex of provincial buildings (XIX century) is situated. Elabuga is often called “the town of museums”.

Square of the town – 41.1 sq. km
Population of the town – 70.000
Population of the area – greater than 100.000

Elabuga ancient settlement



Kama River near the town of Elabuga; view from Elabuga section

Elabuga State Museum-Reserve

The main purpose of the Elabuga State Museum-Reserve is to preserve historical and cultural heritage. It was founded in 1990. Nowadays, there are 184 historical monuments and objects of cultural heritage on the protected area of the museum that is about 491.5 hectares. Dominant concepts of the Museum-Reserve are the development of museums and various directions of tourism in Elabuga and Elabuga's district. In 2009, the Museum-Reserve became one of the thirty best European museums. In 2012, according to International festival "Intermuseum 2012", Elabuga State Museum-Reserve took Grand Prix and the status of "The best museum in Russia 2012".

Elabuga State Museum-Reserve includes such unique museums as Ivan I. Shishkin's Memorial House-Museum, Museum-Farmstead of Nadezhda A. Durova, The House of Memory of Marina Tsvetaeva, the Museum of District Medicine named after Vladimir M. Bekhterev, the Museum "Washhouse". Also the Museum-Reserve consists of The Local History Museum Complex, Interactive workshops, The Museum-Theatre "Tavern", The Exhibit Hall and Art Salon.

Historical Centre of Elabuga

Mail building of the Elabuga State Museum-Reserve

AUGUST 18

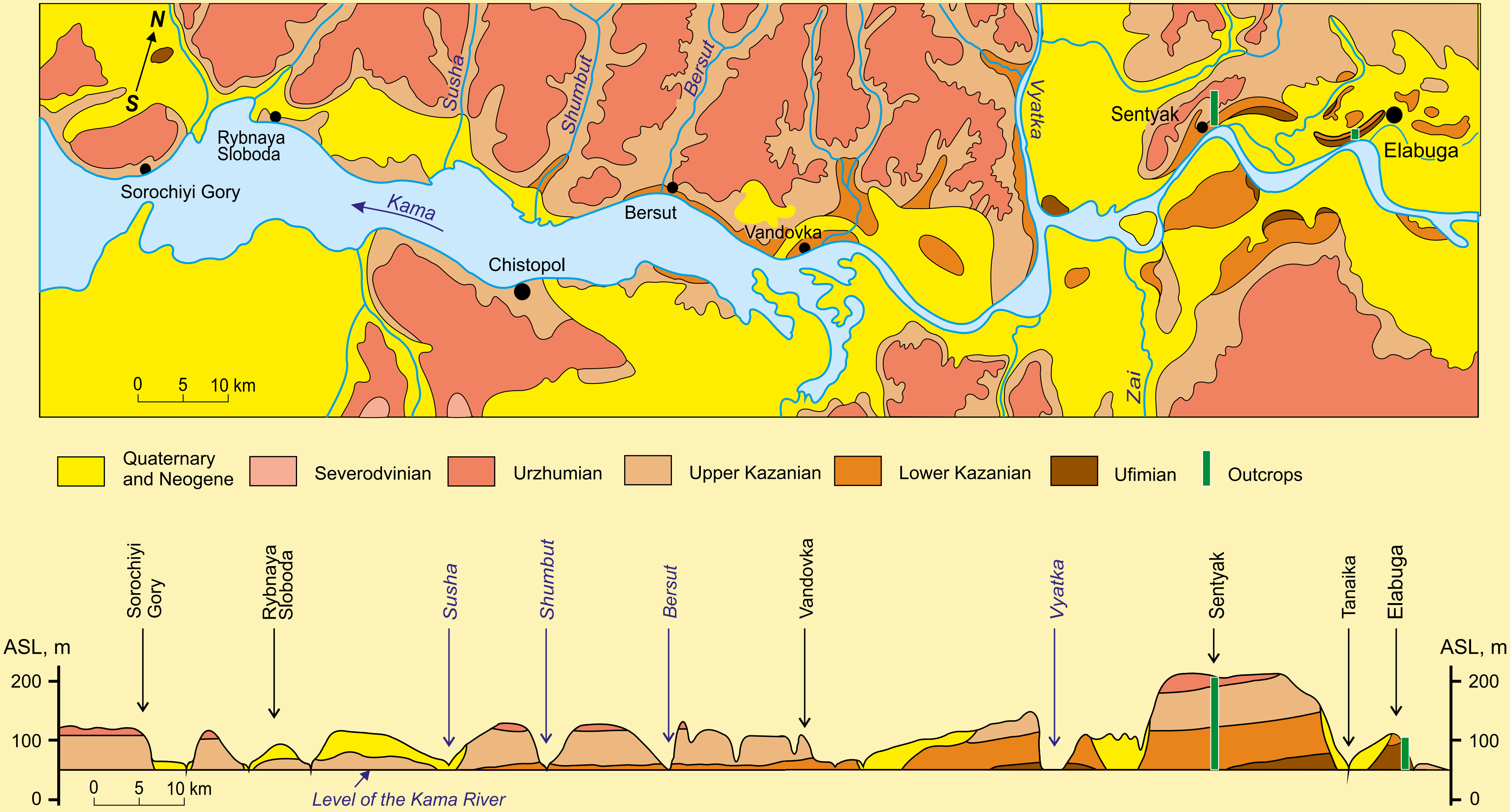
DESCRIPTION OF THE EXCURSION ROUTE IN THE LOWER REACHES OF THE KAMA RIVER (LOWER KAMA)

The territory of the Lower Kama includes the right and left banks of the Kama River from the village of Sorochiyi Gory to the town of Elabuga. Numerous outcrops of the Middle-Upper Permian non-deformed strata there provide an excellent opportunity to observe the facies transition of the Uralian foreland basin with the marine grey-bed rocks of the Kazanian Stage grading at short distances into non-marine red-bed rocks of the Belebey Formation. The Kama riverbank from the village of Sorochiyi Gory to the Bersut quay exposes horizontally bedded Upper Kazanian rocks grading eastward into less marine facies. Carbonate-argillaceous Urzhumian deposits preserved after the post-Permian erosion are exposed at the top of the riverbank slope and usually cover the watersheds. From Bersut to Elabuga, the Lower Kazanian and Ufimian rocks gradually appear above the waterline and show gently sloping anticlines.

In the outcrop near the town of Elabuga (August 18, Stop 1), one may observe the succession of Sheshma Formation of the historical Ufimian Stage, as well as the Ufimian–Kazanian boundary beds.

In the outcrop near the village of Sentyak (August 19, Stop 1), on the right bank of the Kama River, participants will be able to see the most complete section including the marine Lower Kazanian, the non-marine red-bed Belebey Formation (Upper Kazanian), and the basal beds of the continental Urzhumian succession. The Urzhumian red-bed rocks are superficially similar to red-bed series of the Kazanian. The base of the Urzhumian is marked by the first appearance of the non-marine ostracods *Paleodarwinula fragiliformis* and *Prasuchonella nasalis* (Molostovskaya, 2009).

Traditionally, Kazanian stratigraphic units recognised in marine and lagoonal-marine facies are used for detailed stratigraphy of the red-bed Kazanian rocks. Since it is not possible to draw biostratigraphic boundaries on criteria in this correlation in routine geological practice, it is essential to augment the correlation toolkit with cyclicity / sequence stratigraphy studies including observations on lateral facial changes of small stratigraphic units. In describing sections, we used the accepted stratigraphic scheme and terminology.



Generalised geological map and geological profile of the territory of the Lower Kama, Republic of Tatarstan

AUGUST 18 • STOP 1

ELABUGA SECTION. UFIMIAN/KAZANIAN BOUNDARY

The section is located on the right bank of the Kama River, 200 m downstream of the Elabuga Ancient Settlement (‘Elabuga Gorodishche‘). In this outcrop, the lower (Ufimian) red beds are readily distinguished from the upper (Kazanian) grey beds at remote observation. The section near Elabuga has been revisited many times for over 150 years by Nicolay A. Golovkinsky, Alexey M. Zaytsev, Feodossi N. Tschernyschew, Victor A. Tcherdyntsev, Mosey G. Solodukho, Eugenia I. Tichvinskaja, Yuriy V. Sementovsky, and many others. The data of these geologists are used in the description of the section.

Near the road leading to the quay of the Elabuga (road bed is at 64.0 m ASL), approx. 20 m above the waterline of the Kama River, the following beds are exposed (from bottom to top):

Outcrop E1

GPS: 55.74206 N 052.02694 E (WGS84). Datum: the lower half of right slope of the Kama River, vertical cutting for approx. 20 m, the bottom of the package E1/1 is 72 m ASL.

Ufimian Stage

Sheshmian Formation (Horizon)

Package E1/1 Interval 0.0–4.0 m Thickness (visible) 4.0 m

Sandstone: yellowish-brown, polymict, greywacke, calcareous-muddy, fine-grained and medium-grained, cross-bedded, solid. Clastic grains: quartz (15–35 %), local rocks (15–30 %), effusive rocks (15–30 %), and siliceous rocks (approx. 10 %). Sporadic components (1–5 %): potassium feldspar, biotite, plagioclase; clinochlore, muscovite, orthoclase. Most grains are coated with a film of iron hydroxides.

Package E1/2 Interval 4.0–20.0 m Thickness 16.0 m

Siltstone and shale: red, reddish-brown, pinkish-red, calcareous, with disorderly or massive structure and green spots of gleisation and calcareous concretions (1–50 mm) (paleosol horizons). Clastic grains: quartz (70 %), volcanic and chert rocks (25 %), feldspar (2 %), sporadic flakes of mica. The package contains thin (1–15 cm) laminae of bluish-grey calcareous siltstones and greenish-grey fine-grained sandstone.

Package E1/3 Interval 20.0–27.0 m Thickness 7.0 m

Sandstone: yellowish-grey, polymict, fine-grained, cross-bedded, partly calcareous and solid. In the lower part, the sandstone contains lenses and pebbles of reddish-brown shales and siltstone. Clastic grains: volcanic rocks (70 %), quartz (20 %), feldspar (5 %), biotite (5 %). Grain size ranges from 0.1 to 0.5 mm (predominantly 0.1–0.25 mm).

Package E1/4 Interval 27.0–32.0 m Thickness 5.0 m

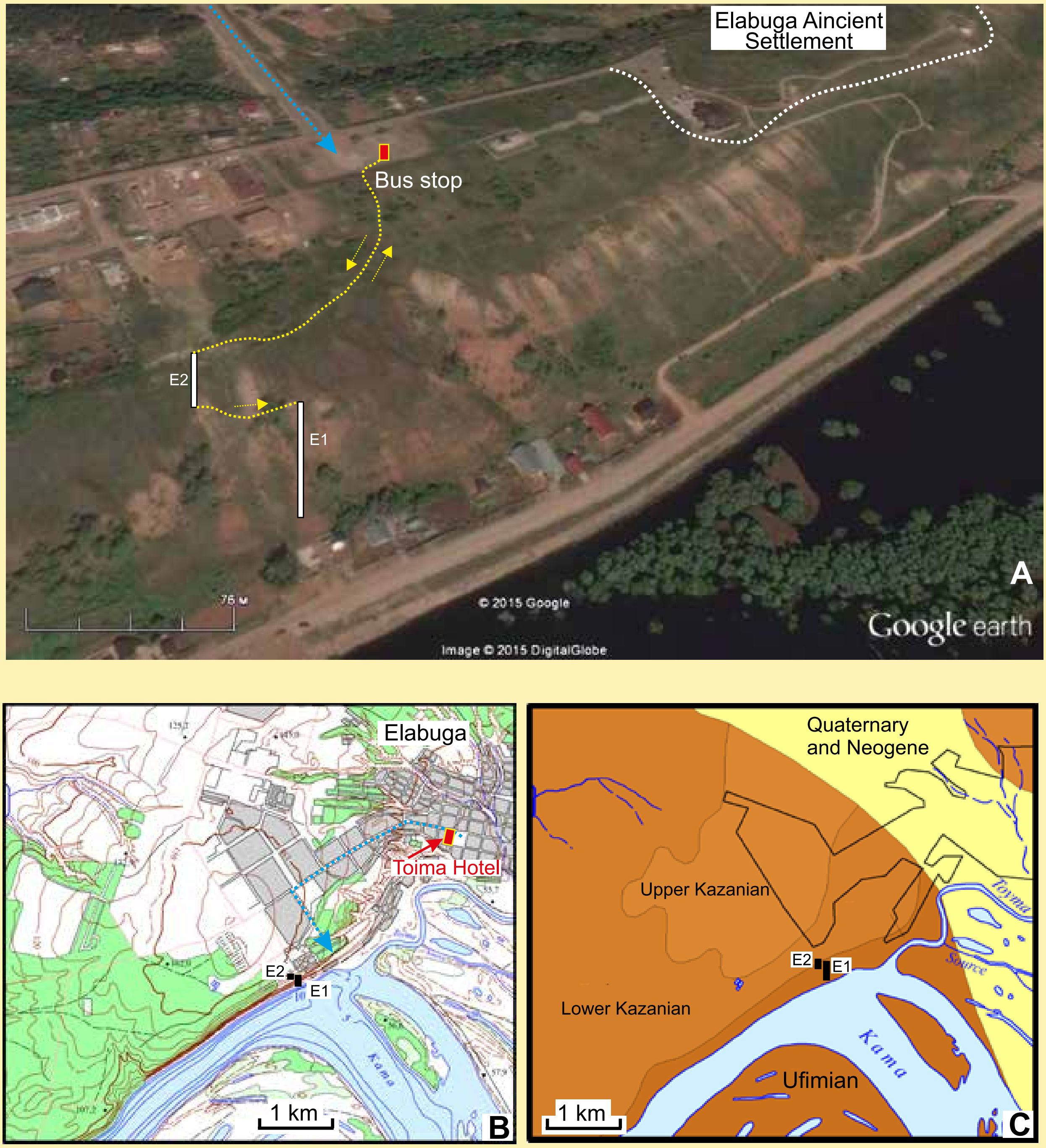
Siltstone and shale: reddish-brown, calcareous, with disorderly or massive structure and green spots of gleisation and calcareous concretions (1–30 mm) (paleosol horizons). The lower part of the bed contains rare non-marine ostracods *Palaeodarwinula* sp.

Package E1/5 Interval 32.0–34.5 m Thickness 2.5 m

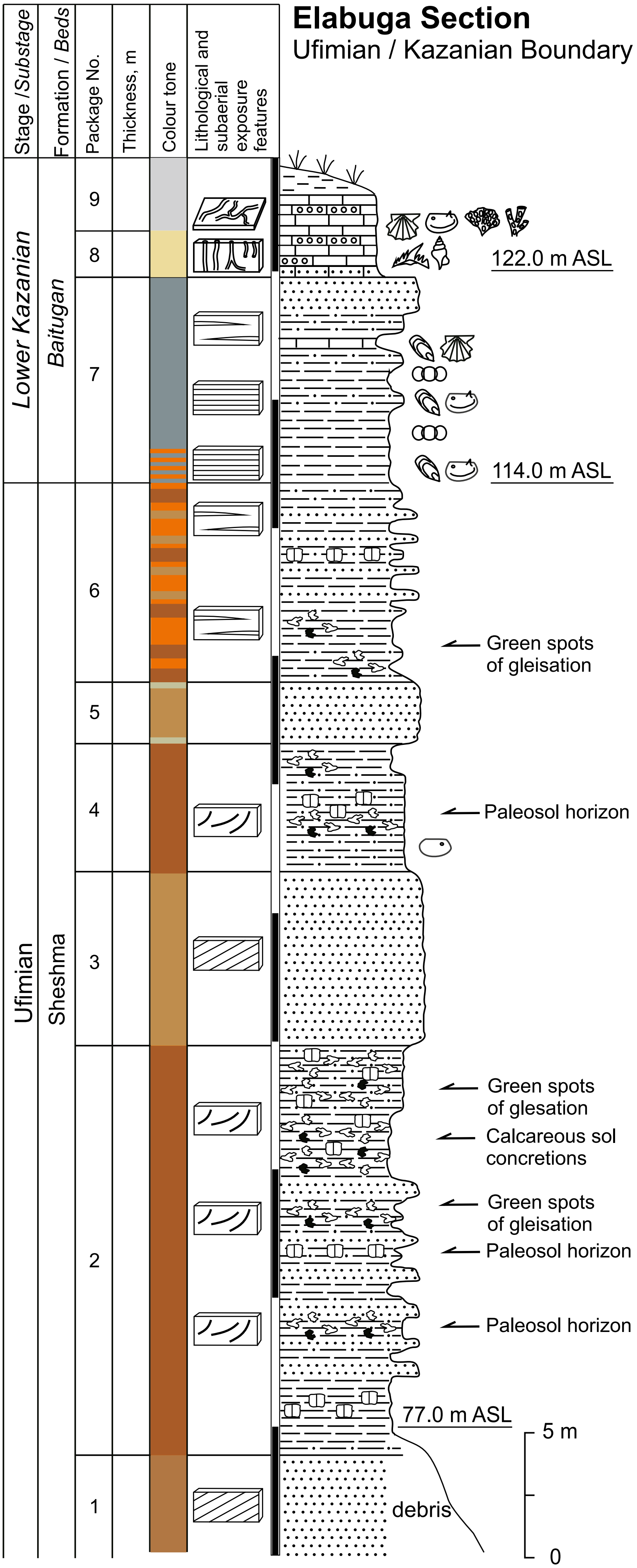
Sandstone: brownish-yellow, fine-grained, slightly argillaceous, greenish-grey at the top and at the bottom. Clastic grains: quartz (35 %), feldspar (35 %), effusive rocks (15 %), and siliceous rocks (approx. 10 %). Most grains are coated with a film of iron hydroxides.

Package E1/6 Interval 34.5–42.5 m Thickness 8.0 m

Alternation of reddish-brown and dull-brown unbedded mudrocks and siltstones with yellowish-brown sandstones. Shales are slightly calcareous, silty, with green spots of gleisation and calcareous concretions (1–30 mm) (paleosol horizons). Clastic components (10 %) are represented by subrounded, isometric and elongated grains of quartz (0.01–0.05 mm). Siltstones are calcareous-argillaceous, sometimes with numerous calcareous nodules 0.5–1.0 cm in diameter (paleosol horizons). Clastic components (0.05–0.2 mm) contain angular, less subrounded grains of quartz (95 %), rock fragments (3 %), grains of feldspar and mica flakes. Sandstones are calcareous-argillaceous, polymict, fine-grained. Clastic components (75–80 %) are represented mainly by the debris of shale rocks; rarely by modified grains of volcanic rocks, quartz, and plagioclase.



Study area: (A) space image of Elabuga Section (Image © 2015 DigitalGlobe) showing the locations of the outcrops (E1 and E2); (B) geographical map, and (C) generalised geological map of the area


Elabuga Section
Ufimian / Kazanian Boundary
Stage /Substage
Formation / Beds
Package No.
Thickness, m
Colour tone
Lithological and subaerial exposure features
Lower Kazanian
Baitugan
Ufimian
Sheshma
9
8
7
6
5
4
3
2
1
122.0 m ASL
114.0 m ASL
Green spots of gleisation
Paleosol horizon
Green spots of glesation
Calcareous sol concretions
Green spots of gleisation
Paleosol horizon
Paleosol horizon
77.0 m ASL
debris
5 m
0

Lower Kazanian Substage

Baitugan Beds

Lingula Shales Member

Package E1/7 Interval 42.5–50.5 m Thickness 8.0 m

The transition between the Ufimian and Kazanian is gradual. The lower part of the bed (ca. 1 m) shows the thin alternation of grey and bright-red shales. These shales are overlain by grey, bluish-grey, thinly laminated, platy shales. Upwards in the section, these shales are overlain by grey, calcareous, regularly bedded siltstones and sandstones with thin (0.1 m) lamina of limestone. The rock contains foraminifers *Nodosaria netchajevi* Tscherd., *N. krotovi* Tscherd., *Orthovertella protea* Gush. et Wat., *Geinitzina spandeli* Tscherd., *G. angusta* Tscherd., numerous inarticulate brachiopods *Lingula orientalis* Gol. and the more rare *L. credneri* Gein., and also the ostracods *Amphissites tscherdynzevi* Posn., *Falalicypris crepidalis* Kotsch., *Pseudoparaparchites formidabilis* Schneid., *Fascianella notabilis* Schneid., *Moorea facilis* Schneid., *Cavellina edmistonae* (Harr. et Lal.), *C. unica* Kotsch., *C. grandis* Schneid., *C. ellipticalis* Hamilton, *Healdia postcornuta* Schneid., *H. simplex* Round., *H. oblonga* Kotsch., *H. pseudosimplex* Kotsch., *H. subtriangula* Kotsch., *Healdianella vulgata* Kotsch., *Bairdia beedei* Ulr. et Bassl., *B ponderosa* Chen., *Acratia baschkirica* Kotsch., *A. ingeniosa* Schum., *Actuaria diffusa* Schneid., *A. deplanata* Shum., *Kirkbya* aff. *ingeniosa* Kotsch., *Sulcoindivisia kazanica* Schum., *Basslerella quasicrassa* Shum., the bivalves *Pseudobakewellia ceratophagaeformis* Noin., *Schizodus subobscurus* Lich., and *Alula* (?) *kutorgi* (Vern.), fish scales *Platysomus* sp., *Acentrophorus varians* Kirkby.

The spore-pollen assemblage contains a few (0.3–11.0 %) spores *Granulatisporites parviverrucosus* (Waltz), *Acanthotriletes rectispinus* (Lub.), *Cirratriradites procumbens* (Lub.), *Calamospora plicata* (Waltz), *Leiotriletes* sp. and *Punctatisporites* sp., the pollen of the *Striatiti* (17.8–56.3 %), *Costati* (18.0–32.3 %), and *Dissaciatrileti* (6.0–20.1 %), *Dissaciamonoletes* (1.3–24 %), *Diplosacciti* (0.5–6.8 %), and *Azonoletes* (1.3 %). Among the numerous pollen species, *Protohaploxypinus perfectus* (Naumova) is dominant.

Because of the presence of many *Lingula* shells this interval of the section is called the Lingula Shale Member. The Ufimian / Kazanian boundary is 114 m ASL.

Outcrop E2

GPS: 55.74250 N 052.02637 E (WGS84). Datum: the upper part of the right slope of the Kama River, rocky exposures of thick plates of the limestones armouring the edge of the slope; the basemen of package E1/8 Spiny Limestone Member is 122 m ASL.

Spiny Limestone Member

Package E2/8 Interval 50.5–52.5 m Thickness 2.0 m

Limestone: yellowish-grey, thickly platy, oolitic, bioclastic, sandy. Bioclasts compose 80 % of the rock and are presented by foraminifers, bivalves, brachiopods, bryozoans, and fragments of crinoids. The bioclastic interbeds contain the small foraminifers *Pseudoammodiscus megasphaericus* (Gerke), *Ps. microphaericus* (K. M.-Maclay), *Nodosaria netschajewi* Tscherd., *N. krotovi* Tscherd., the gastropods *Loxonema* sp., the bivalves *Lithophaga consobrina* (Eichw.), *Pseudobakewellia antiquaeformis* Noin., *Schizodus rossicus* Vern., and *Permophorus simplex* (Keys.), the brachiopods *Cancrinella cancrini* (Vern.), *Beecheria netschajewi* Grig., *Cleiothyridina pectinifera* (Sow.)., and *Licharewia rugulata* (Kut.), the bryozoans *Geinitzella* sp., and conodont index species *Kamagnathus khalimbadzhae* Chern., etc. The trace fossils are represented by large (5–10 mm in diameter) horizontal, branching burrows filled with shell debris.

Packages E2/9 Interval 52.5–54.5 m Thickness (visible) 2.0 m

Limestone: light-grey, compact, oolitic, massive, sometimes thinly bedded, containing the small foraminifers *Pseudoammodiscus megasphaericus* (Gerke), *Ps. microsphaericus* (K. M.-Maclay), and *Ichtyolaria inflata* (Gerke), the gastropods *Goniasma subangulata* (Vern.), the bivalves *Lithophaga consobrina* (Eichw.), *Parallelodon kingi* (Vern.), *Pseudobakewellia antiquaeformis* Noin., *Schizodus subobscurus* Lich., *Pseudomonotis speluncaria* Schl., *Allorisma elegans* (King), *Netschajewia pallasi* (Vern.), and *N. globosa* (Netsch.), the brachiopods *Cancrinella cancrini* (Vern.), *Beecheria netschajewi* Grig., and *Licharewia rugulata* (Kut.), the rare bryozoans *Geinitzella* sp., the conodonts *Kamagnathus khalimbadzhae* Chern.. This bed armours the edge of the slope and is overlain by the soil.

Outcrop E1. General view of the outcrop from the road to Elabuga pier (A), (B) middle part of outcrop E1, the Sheshma Formation succession

Geochemical data

The geochemical analysis showed that the lower part of the Ufimian succession (packages 1 and 2) containes increased concentrations of manganese, while the upper (packages 5 and 6) contains increased concentrations of zinc, barium, lithium, and molybdenum. The lower horizons of the Kazanian (package 7 — the Lingula Shale Member) contain interbeds with increased concentrations of copper, silver, and mercury. These increased concentrations indicate a geochemical reduction environment in the transition from the Ufimian red-bed rocks to the Lower Kazanian grey-bed rocks. The Lower Kazanian carbonates (packages 8 and 9) show increased concentrations of strontium, manganese, and barium. Generally, the Ufimian rocks contain abundant siderophile elements, whereas the Kazanian rocks contain abundant chalcophiles, indicating the transition from continental to marine sedimentary environments, respectively (Silantiev et al., 1998).

Outcrop E2. Limestone of the Spiny Limestone Member armouring the edge of the slope (A), (B) weathered surface of the Spiny Limestone showing wavy lamination; the karst cavities on the background

Paleomagnetic data of the Ufimian Stage exposed on the right bank of the Kama River near Elabuga Town are based on 46 oriented specimens (Burov, Zharkov, Nurgaliev et al., 1998). The Ufimian red-beds contain some rhythmically alternating units of argillaceous and sandy rocks. Along the strike, some sandstone lenses increase in thickness or thin out, being replaced by argillaceous succession represented by alternation of shale and siltstone. Oriented samples were taken unevenly. The argillaceous part of the section was sampled vertically at 0.5 m intervals, and the sandy part, at 0.5–4 m intervals. The shales of the Sheshma Formation are cryptolaminated, poorly sorted; they contain some amounts of silty and arenaceous material. Magnetite, hematite and maghemite are carriers of magnetisation. The ancient component of natural residual magnetisation is mainly related to hematite-bearing argillaceous rock types. The sandstones have porous and porous-basal argillaceous cement. They occur in the zone of active water exchange and are affected by derivative geochemical alterations. Hence, the paleomagnetic stability of the sandstones is relatively low. The distribution of natural residual magnetisation (J_n) directions over the sphere is planar. Magnetic cleaning reveals the direction of reversed polarity.

Formation / age	N	Direction of J_n^o – ancient component of natural residual magnetisation		Precision of J_n^o vectors		Paleomagnetic pole in present geographic coordinates	
		D	I	α_{95}	K	Φ	Λ
Lingula Shale Member / Lower Kazanian	56	232	– 34	6	46	50	169
Sheshma / Ufimian Stage	46	228	–34	6	81	39	170

Generally, the uppermost part (5–10 m) of the Sheshma Formation is characterised by relatively high values of magnetic properties, exceeding those of the underlying Ufimian red beds by an order of magnitude, and some orders higher than the overlying Lower Kazanian marine rocks.

The Lingula Shale Member (Lower Kazanian) also shows reversed polarity (Burov, Zharkov, Nurgaliev et al., 1998).

So, the Sheshma Formation (Ufimian) and the Lower Kazanian are magnetised by the reversed polarity field of the Kiaman Hyperzone (R_1P).

Paleontological data

Ufimian Stage ***Sheshma Formation***

Non-marine bivalves

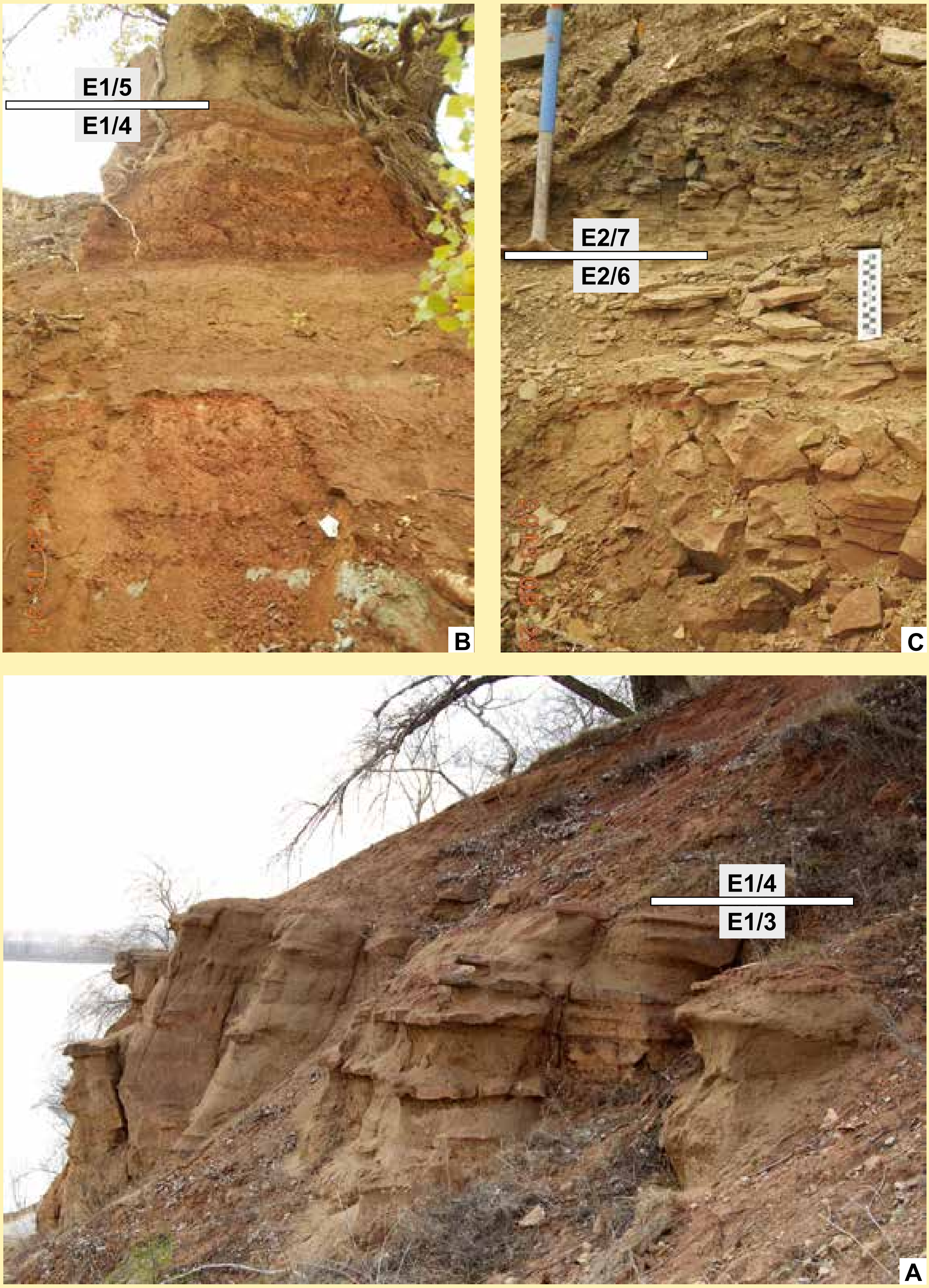
The section exposed on the right bank of the Kama River near the town of Elabuga was established as a stratotype of non-marine bivalve range zone *Palaeomutela umbonata* (Silantiev, 2014). The stratotype of the zone is located on the right bank of the Kama River near Elabuga, Elabuga Outcrop, package no. 6, lower member of argillaceous siltstones; Sheshma Formation, Ufimian Stage (Silantiev et al., 1998). Index species: *Palaeomutela umbonata* (Fischer, 1840). The lower boundary of the unit is marked by the first appearances of *P. umbonata* (Fischer). The upper boundary is marked by the first appearances of *P. quadriangularis* (Gus.). Characteristic bivalve species: *P. pseudoumbonata* (Gus.), *P. (Palaeanodonta) longissima* (Netsch.), *P. (Palaeanodonta) rhomboidea* (Netsch.), *P. olgae* (Gus.), *P. attenuata* (Gus.), P. aff. *attenuata* (Gus.).

The umbonata Zone is observable through the Volga–Ural and North Caspian basins of the East European Platform.

Kazanian Stage ***Lower Kazanian Substage***

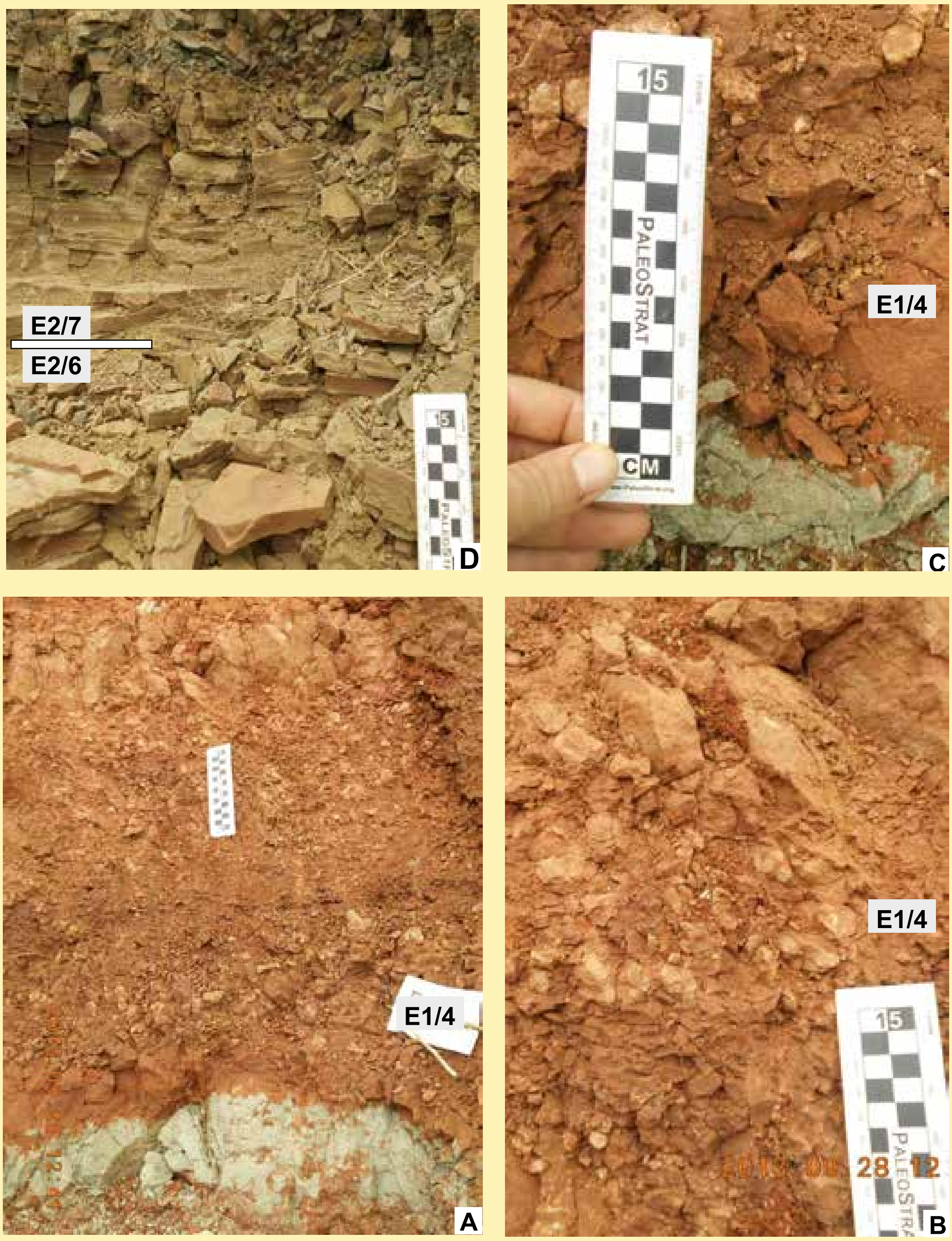
Baitugan Beds

Baitugan Beds are composed of grey-coloured siltstones, shales, marls, and limestones. Fossils of marine assemblage include ostracods, bivalves, brachiopods, rarely small foraminifers, gastropods, bryozoans, crinoids, and fish scales; sometimes the remains of plants are found. Rich miospore assemblages we extracted. The list of fossils is given below.



Outcrop E1. Cross-bedded, partly calcareous and solid sandstone of package E1/3 (A), (B) reddish-brown siltstone and shale of package E1/4, with green spots of gleisation and calcareous concretions (paleosol horizons), and (C) outcrop E2: the Ufimian / Kazanian boundary defined between E2/6 and E2/7 packages

Small foraminifers: *Nodosaria netchajevi* Tscherd., *N. krotovi* Tscherd., *N. elabugae* Tscherd., *Lingulonodosaria inflata* (Tscherd.), *Orthovertella protea* Gush. et Wat., *Geinitzina spandeli* Tscherd., *G. angusta* Tscherd.; *Pseudoammodiscus megasphaericus* (Gerke), *Ps. microsphaericus* (K.M.-Maclay), *Ichtyolaria inflata* (Gerke). The assemblage of small foraminifers, represented mainly by calcareous forms, is comparable with the *Nodosaria hexagona-Ichtyolaria subtilus* Beds assemblage. These beds were established for the east area of the East European Platform (Pronina, 1996). The beds with *Nodosaria hexagona-Ichtyolaria subtilus* correspond to the lower part of the Lower Kazanian (Baitugan Beds) of stratotype area. The species *Pseudoammodiscus microsphaericus* is particularly interesting because it occurs at the upper part of Gnishiksky regional stage of the Murgabian (Pronina, 1999).



Outcrop E1. General view of reddish-brown siltstone and shale of package E1/4, with green sandstone at the bottom and calcareous concretions (paleosol horizons) (A), (B, C) details of the same shale overfilled with calcareous concretions, (D) **Outcrop E2:** details of the Ufimian / Kazanian boundary defined between E2/6 and E2/7 packages

<u>Ostracods</u>: *Amphissites tscherdynzevi* Posn., *Falalicypris crepidalis* Kotsch., *Pseudoparaparchites formidabilis* Schneid., *Fascianella notabilis* Schneid., *Moorea facilis* Schneid., *Cavellina edmistonae* (Harr. et Lal.), *C. unica* Kotsch., *C. grandis* Schneid., *C. ellipticalis* Hamilton, *Healdia postcornuta* Schneid., *H. simplex* Round., *H. oblonga* Kotsch., *H. pseudosimplex* Kotsch., *H. subtriangula* Kotsch., *Healdianella vulgata* Kotsch., *Bairdia beedei* Ulr. et Bassl., *B. ponderosa* Chen., *Acratia baschkirica* Kotsch., *A. ingeniosa* Schum., *Actuaria diffusa* Schneid., *A. deplanata* Shum., *Kirkbya* aff. *ingeniosa* Kotsch, *Sulcoindivisia kazanica* Shum., *Basslerella quasicrassa* Shum.

Marine ostracods are characterised by diverse taxonomic composition, which is generally typical for the Lower Kazanian of the East European Platform. The assemblage contains *Amphissites tscherdynzevi* which is considered as the index-species of the Lower Kazanian Substage.

Similar ostracod assemblages are traced in the marine Lower Kazanian of Kirov and Orenburg regions (Belousova, 1956; Kochetkova, 1970), and South Urals (Kochetkova, 1970).

The ostracod assemblage from the section of Elabuga bears some resemblance to the ostracod assemblage known from the Lower Zechstein of Western Europe. There are some similar species: *Moorea facilis* Schneid., *Actuaria diffusa* Schneid., *Cavellina edmistonae* (Harr. et Lal.), *Healdia subtriangula* Kotsch., *Acratia baschkirica* Kotsch. (Malzahn, 1957; Krömmelbein, 1958).

Some ostracod species from Elabuga section are identical (e.g. *Cavellina ellipticalis* Hamilton), or show the morphological similarity with the species of the Middle Permian of North America (Kellet, 1933; Hamilton, 1942; Kochetkova, 1970). For example, the European species *Pseudoparaparchites formidabilis* Schneid. and *Healdia pseudosimplex* Kotsch. resemble (respectively) Pseudoparaparchites *kansasensis* Kellet and *Healdia unispinosa* Ham., which are widespread in the Middle Permian of Kansas and Texas.

It should be noted Elabuga ostracod assemblage includes a number of species typical for older stratigraphic units. For example, *Healdia postcornuta* Schneid. closely resembles *Healdia cornuta* Posn., widespread in the Lower Carboniferous deposits of the East European Platform. Species *Healdia simplex* Round. and *Bairdia beedei* Ulr. et Bassl. are known from the Pennsylvanian of Kansas (Kochetkova, 1970).

<u>Gastropods:</u> *Loxonema* sp., *Goniasma subangulata* (Vern.).

<u>Bivalves</u>: *Lithophaga consobrina* (Eichw.), *Parallelodon kingi* (Vern.), *Pseudobakewellia ceratophagaeformis* Noin., *Ps. antiquaeformis* Noin., *Schizodus rossicus* Vern., *Schizodus subobscurus* Lich., *Permophorus simplex* (Keys.), *Pseudomonotis speluncaria* Schl., *Allorisma elegans* King, *Netschajewia pallasi* (Vern.), *N. globosa* (Netsch.), *Alula* (?) *kutorgi* (Vern.).

<u>Brachiopods</u>: *Lingula orientalis* Gol., *L. credneri* Gein., *L. lawrskyi* Netsch., *Cancrinella cancrini* (Vern.), *Aulosteges horrescens* Vern., *Licharewia rugulata* (Kut.), *Odontospirifer subcristatus* (Netsch.), *Cleiothyridina pectinifera* (Sow.), *Beecheria netschajewi* Grig., *B. angusta* (Netsch.).

<u>Bryozoans</u>: *Geinitzella* sp., Trepostomida gen. indet., Fenestrida gen. indet.

<u>Conodonts</u>: *Kamagnathus khalimbadzhae* Chern., *Kamagnathus sp.*

<u>Fish scales</u>: *Platysomus* sp., *Acentrophorus varians* Kirkby.

<u>Miospores.</u> The spore-pollen assemblage contains a few spores (0.3–11.0 %), the pollen of the *Striatiti* (17.8–56.3 %), *Costati* (18.0–32.3 %), and *Dissaciatrileti* (6.0–20.1 %), *Dissaciamonoletes* (1.3–24 %), *Diplosacciti* (0.5–6.8 %), and *Azonoletes* (1.3 %).

The following species were defined: *Granulatisporites parviverrucosus* (Waltz), *Acanthotriletes rectispinus* (Lub.), *Cirratriradites procumbens* (Lub.), *Calamospora plicata* (Waltz), *Dictyotriletes* sp., *Leiotriletes* sp., *Scheuringipollenites* sp., *Lophotriletes parryensis* Utting, *Cyclogranisporites franklini* Utting, *Convolutispora* sp., *Punctatisporites* sp., *Apiculatisporis* sp., *Limitisporites monstruosus* (Luber et Waltz) Hart, *Krauselisporites papulatus* Virbitskas, *Alisporites plicatus* Jizba, *Pityosporites* sp., *Vitreisporites pallidus* (Reiss.) Nilson, *Raistrickia* sp., *Piceapollenites* sp., *Cordaitina uralensis* (Luber) Samoil., *C. subrotata* Luber var. *isopolaris* Varyukhina, *Florinites luberae* Samoil., *Protohaploxypinus perfectus* (Naumova), *Hamiapollenites tractiferinus* (Samoilovich), *H. bulaeformis* (Samoil.), *H. erebi* Utting, *Striatoabieites striatus* (Luber), *Vittatina subsaccata* Samoil. ex Wil., *V. costabilis* Wil., *V. connectivalis* (Zauer) Varyukhina ex Utting, *V. vittifera* (Luber) Samoil., *Lueckisporites virkkiae* Potonie et Klaus, *Entylissa caperata* (Luber) Varyukhina, *Crucisaccites ornatus* (Samoil.) Dibner, *Pakhapites rotundus* (Koloda), *Neoraistrickia delicata* Utting, *Weylandites striatus* (Luber) Utting, *Alisporites sublevis* (Lub.).

The miospore assemblage is typical for marine Lower Kazanian deposits and corresponds to the lower part of the *Lueckisporites virkkiae Zone* (Utting et al., 1997).

<u>Ihnofossils</u>. Large (5–10 mm in diameter) horizontal branching borrows, filled with shell bioclasts, are usually confined to the bottom of the massive limestone (package E2/8). The weathering draws prominent branching honeycomb pattern on the lower surface of limestone.

These trace fossils are traced over a large territory of the Lower Kama region (Bersut, Vandovka, Kotlovka, Sentyak, Tanaika, etc.) and are confined to the basement of the Spiny Limestone Member of Baitugan Beds (Lower Kazanian). The basement of the Spiny Limestone Member with branching trace fossils can be considered as local marker.

This list indicates that all fossil groups are characterised by rather poor species composition. This is a common feature of the considered facial zone, which is often interpreted as a ‘zone of shallow coastal lagoon’ (Solodukho, 1963). Biostratigraphic analysis reveals that the majority of encountered species are typical for the whole Kazanian Stage. Only the brachiopods *Licharewia rugulata* and the conodonts *Kamagnathus khalimbadzhae* are the index fossils of the Lower Kazanian. Abundant accumulations of brachiopods, bryozoans, and crinoids are common in the Lower Kazanian.

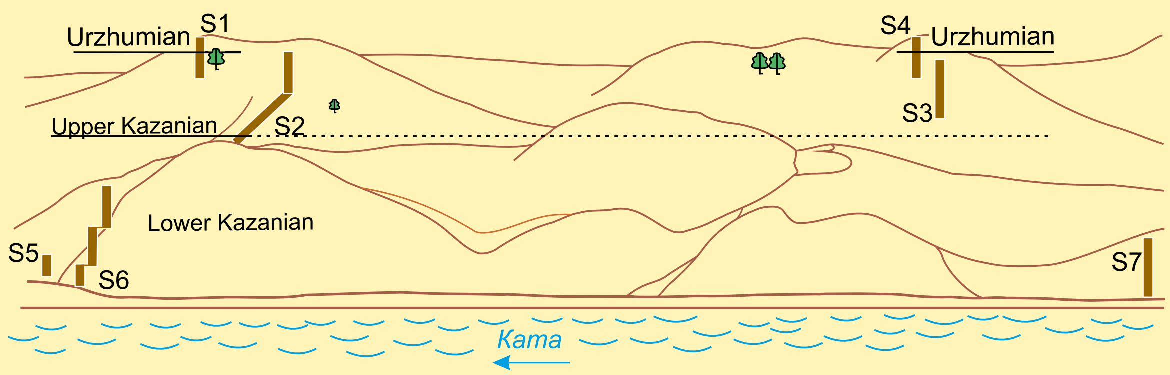
AUGUST 19 • STOP 1

SENTYAK SECTION. UPPER KAZANIAN IN CONTINENTAL FACIES

The section of the Kazanian near the village of Sentyak is the reference section for the Lower Kama region. The Kazanian in this area is composed mainly of red-bed rocks containing non-marine fossils. The beds with non-marine fauna occur in the lower part of the Kamyshla Beds. Here, the 4 m-thick member represents the alternation of the non-marine and marine beds. Marine fossils do not occur above the Kamyshla Beds.

The sections of the Kazanian near the village of Sentyak were studied by many workers, including Victor A. Tcherdyntsev (1914), Mosey G. Solodukho and Eugenia I. Tikhvinskaya (Tikhvinskaya, 1946), Nicolay N. Forsch (1955), Alexander P. Bludorov (1964), Yuriy V. Sementovsky (1973), etc. Their data were used for the description below.

The section is composed of seven outcrops, located on the right slope of the valley of the Kama River 0.5–2.0 km upstream of the village of Sentyak, 5 km downstream of the quay in the town of Nizhnekamsk. The lower beds of the Kazanian (packages 1–3, and the lowermost part of package 4) occur below the waterline of the Kama River. They were studied in borehole 1 drilled in 1995 (Sungatullin et al., 1996), 3 km northeast of the village of Sentyak.



Location of the outcrops 0.5–2.0 km upstream from the village of Sentyak

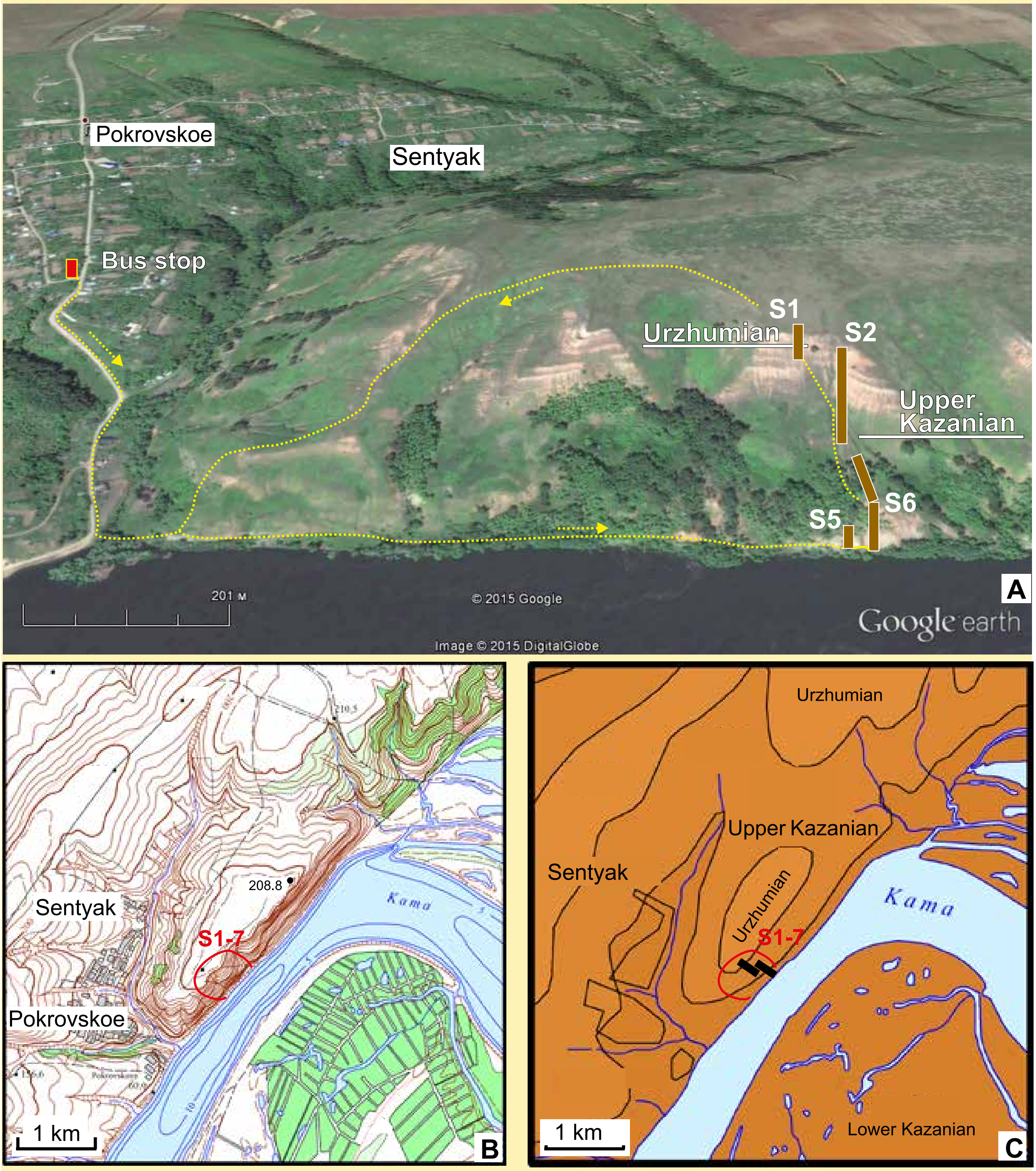
The composite section near the village of Sentyak is described below (from bottom to top). Intervals in bed-by-bed description are measured from the base of package 1 in each station.

Ufimian Stage

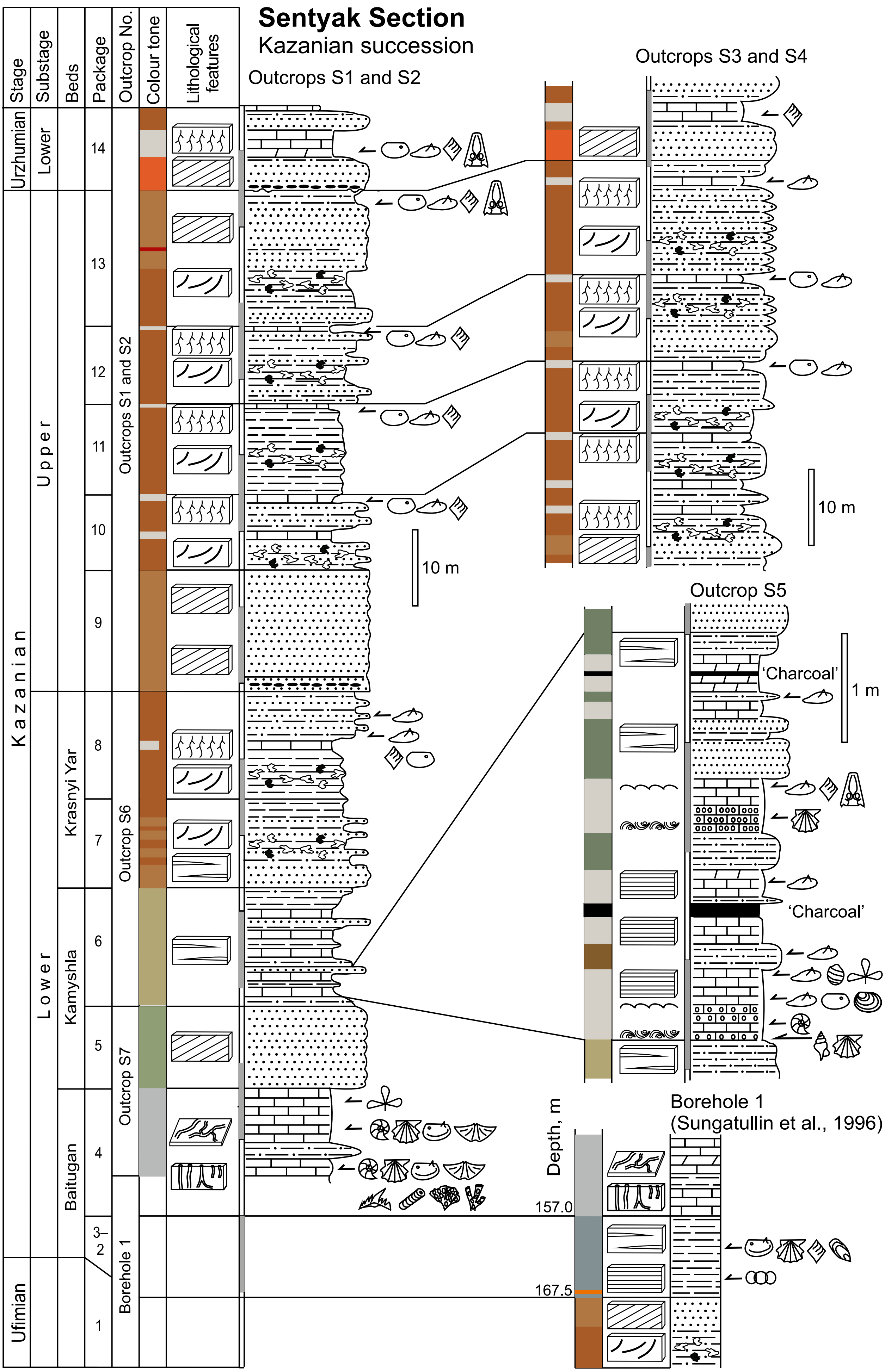
Sheshmian Formation (Horizon)

Package 1 Interval 0.0–10.0 m Thickness 10.0 m

Reddish-brown, calcareous, irregularly bedded siltstones and shales with interbeds of yellowish-brown polymict sandstones.



Study area: (A) space image of Sentyak Section (Image © 2015 DigitalGlobe) showing the locations of the outcrops (S1, S2, S5, and S6); (B) geographical map, and (C) generalised geological map of the area


Sentyak Section
Kazanian succession
Outcrops S1 and S2
Outcrops S3 and S4
Outcrop S5
Borehole 1
(Sungatullin et al., 1996)
Stage
Substage
Beds
Package
Outcrop No.
Colour tone
Lithological features
Urzhumian
Lower
Kazanian
Upper
Lower
Ufimian
Krasnyi Yar
Kamyshla
Baitugan
14
13
12
11
10
9
8
7
6
5
4
3–2
1
Outcrops S1 and S2
Outcrop S6
Outcrop S7
Borehole 1
10 m
10 m
1 m
'Charcoal'
'Charcoal'
Depth, m
157.0
167.5

Lower Kazanian Substage

Baitugan Beds

Lingula Shale Member

Package 2 Interval 10.0–10.5 m Thickness 0.5 m
Thin alternation of grey and red shales.
Package 3 Interval 10.5–21.0 m Thickness 10.5 m
Bluish-grey, thinly bedded, platy shales with numerous remains of the inarticulate brachiopod *Lingula orientalis* Gol., and ostracods *Healdianella*, *Cavellina*, etc., The rock contains the bivalves *Pseudobakewellia ceratophagaeformis* Noin., *Schizodus rossicus* Vern., and fish scales. Among miospores, the Striatiti and Costati are dominant. The most widespread miospores are *Protohaploxypinus perfectus* (Naumova), *Hamiapollenites bullaeformis* (Samoil.), *Striatoabieites striatus* (Luber), and *Weylandites striatus* (Luber) Utting (Utting et al., 1997).
Beds 1, 2, and 3 are studied in borehole 1 in the interval of 157–178 m.

Outcrop S7

GPS: 55.71165 N 051.75389 E (WGS84). Datum: the right bank of the Kama River, river water level at 53.0±3 m ASL. The rocks of package 4 are exposed in 1.0 m above the river level and 54.0 m ASL.

Package S7/4 Interval 21.0–40.0 m The total thickness 19.0 m
Grey, thinly bedded limestones and marls with interbeds of greenish-grey shales. The lower part of the bed is composed of bioclastic limestones containing small foraminifers, ostracods of the genera *Healdinella*, *Cavellina*, etc., and also the mass accumulations of distorted shells of the brachiopod *Cancrinella cancrini* (Vern.). Along with *Cancrinella*, the rock contains the more rarely occurring brachiopod *Licharewia rugulata* Kut., fragments of branched and reticulate bryozoans, crinoids, and the conodonts *Kamagnathus khalimbadzhae* Chern., etc. The base of the bioclastic limestone bed have the feeding burrows (10–15 mm in diameter) branched in the horizontal plane and filled with shell debris. The upper part of the bed contains thin alternations (0.1–0.2 m) of limestones, marls, and shales with well-developed platy structures. The rock contains the foraminifers *Pseudoammodiscus kamae* (Tscherd.), *Ps. microsphaericus* (K.M.-Macl.), *Ps. megasphaericus* (Gerke), *Syzrania samarensis* (Raus.), *Nodosaria suchonensis* K.M.- Maclay, rare marine bivalves, brachiopods, and ostracods. Some beds contain numerous remains of the plants *Annularia stelloides* Neub., *Paracalamites frigidus* Neub., and *Phylladoderma sentjakensis* Esual., etc.
In borehole 1, this bed occurs in the interval of 138.0–157.0 m. The section in outcrop S7 contains only the upper part of the package with an visible thickness of 12 m.

Kamyshla Beds

Package S7/5 Interval 40.0–52.0 m Thickness 12.0 m
Greenish-grey, polymict, obliquely bedded, calcareous sandstone with pebbles of argillaceous rock (photos 12 and 13). The sandstone contains the imprints of plants and silicified tree trunks.
The overlying beds are accessible in outcrop S6.

Outcrop S6

GPS: 55.70381 N, 051.74177 E (WGS84). Datum: the right bank of the Kama River, river water level at 53.0±3 m ASL. The rocks of package 6 are exposed in 5 m above the river level and 58.0 m ASL.
Package S6/6 Interval 52.0–67.5 m Thickness 15.5 m
Alternation of grey sandstones, siltstones, shales, marls, and limestone with marine and non-marine fauna. The lower part of the section contains a member (4 m thick) of alternating grey sandstones, siltstones, shales, and limestones with two interbeds of black coaly rock (‘charcoal’). This member was studied in adjacent outcrop 5 (GPS: 55.70381 N, 051.74177 E (WGS84); the base of limestone (S5/6-1) is 59.0 m ASL) in which the following successions were observed:

(S5/6-1) Grey limestones with the foraminifers *Glomospirella* aff. *umbilicata* Cush. et Wat., *Lingulonodosaria kamaensis* K.M.-Maclay, *L.* aff. *clavata* Paalz., *Pseudoammodiscus kamae* (Tscherd.), *Pseudonodosaria nodosariaeformis* (K.M.-Maclay), *Nodosaria farcimen* Sold., and *Geinitzina kazanica* K.M.-Maclay, marine gastropod *Goniasma* sp., and the bivalves *Lithophaga consobrina* (Eichw.), *Schizodus rossicus* Vern., *Pseudomonotis speluncaria* (Schloth.), and *Permophorus simplex* (Keys.). The upper part of the limestones is characterised by very fine 'sheet' lamination and contains conchostracans, non-marine bivalves *Palaeomutela umbonata* (Fisch.), *P. attenuata* (Gus.), and *P. olgae* (Gus.), mass accumulations of the charophytes *Stellatochara gracilis* (Esaul. et Said.) Kis., the leaves and stems of *Annularia stellatoides* Neub., *Brongniartites salicifolius* (Fisch.) Zal., *Paracalamites frigidus* Neub., *Phylladoderma sentjakensis* Esaul., *Radicites sentjakensis* Esual., *Cardiolepis sentjakensis* Esaul., and *Permotheca vesicasporoides* S. Meyen, Esaul. et Gom. with the miospores *Vesicaspora* ex gr. *magnalis* (Andreeva) Hart., etc. The thickness is 0.8 m.
(S5/6-2) Siltstone: greenish-grey, with *Palaeomutela* sp. The thickness is 0.15.
(S5/6-3) Limestone: grey, 'sheet' laminated, with *Palaeomutela umbonata* (Fisch.) and *P. attenuata* (Gus.). The thickness is 0.15 m.
(S5/6-4) Coaly rock ('charcoal'). The thickness is 0.13 m.
(S5/6-5) Siltstone: greenish-grey. The thickness is 0.06 m.
(S5/6-6) Limestones and marls with *Palaeomutela umbonata* (Fisch.). The thickness is 0.2 m.
(S5/6-7) Siltstone: greenish-grey. The thickness is 0.4 m.
(S5/6-8) Limestone: grey, compact, with marine bivalves *Schizodus rossicus* (Vern.), and *Permophorus simplex* (Keys.) in the lower part. The upper part contains the bivalves Liebea (?) sp., many fish scales of *Platysomus striatus* Ag., *Koinichthys ivachnenkoi* Esin, *Kasanichthys golyushermensis* Esin., *Acropholis stensioi* Ald., *Palaeoniscum kasanense* Gein. et Vett., *P. frieselebeni* Blainv., and *Acentrophorus varians* (Kirkby), and fragments of amphibian bones. The thickness is 0.6 m.
(S5/6-9)Sandstone: greenish-grey, with a shale seam in the upper part. The thickness is 0.5 m.
(S5/6-10) Limestone: grey, compact. The thickness is 0.2 m.
(S5/6-11) Siltstone: greenish-grey, with Palaeomutela umbonata (Fisch.). The thickness is 0.1 m.
(S5/6-12) Marl and limestone: grey, with a thin lamina of coaly rock and with *Pseudomonotis permianus* (Masl.). The thickness is 0.35 m. (S5/6-13) Siltstone: greenish-grey. The thickness is 0.2 m.

Belebey Formation

Krasnyi Yar Beds

Package S6/7 Interval 67.5–79.5 m Thickness 12.0 m
Sandstones interbedded with yellowish-grey and reddish-brown siltstones and shales.
Package S6/8 Interval 79.5–93.5 m Thickness 14.0 m
Reddish-brown mudstone and siltstone with laminae of limestones. The upper part of the bed contains the non-marine ostracods *Palaeodarwinula verella* (Bel.), *P. varsanofievae* (Bel.), and *Prasuchonella belebeica* (Bel.), the bivalves *Palaeomutela umbonata* (Fisch.), *P. attenuata* (Gus.), and *P. olgae* (Gus.), *Concinella* sp., fish scales *Platysomus* sp. and *Paramblypterus* sp.

Packages 2–4 of this section are tentatively put in correspondence with the Baitugan Beds, beds 5 and 6 with the Kamyshla Beds, beds 7 and 8 with the Krasnyi Yar Beds of the stratotype section of the Lower Kazanian.

The overlying rocks are observed in outcrops S1–S4, in the upper part of the slope of the valley.

Outcrop S7. General view of marine Kamyshla Sandstone (A), (B) general view of the right bank of the Kama River near the village of Sentyak, and (C) basal Urzhumian sandstone in outcrop S1

Outcrop S2

GPS: 55.70486 N, 051.74011 E (WGS84). Datum: right bank of the Kama River, the upper rockslide terrace 53.0±3 m ASL. The basement of package 9 is exposed in 118.0 m ASL.

Upper Kazanian Substage

Belebey Formation (continuation)

Package S2/9 Interval 93.5–109.5 m Thickness 16.0 m

Sandstone: brownish-grey, obliquely laminated, with lenses of basal conglomerates overlying the eroded surface of the Lower Kazanian rocks. Solid calcareous sandstones form rocky ledges that are well traced along the slope. Horizontally, sandstone is replaced with sandy-muddy succession, and its thickness ranges from 2 to 15 m.

Package S2/10 Interval 109.5–119.5 m Thickness 10.0 m

Siltstone and shale with one-two laminae (0.3–0.5 m) of limestone. Siltstone and shale: red, reddish-brown, pinkish-red, calcareous, with green spots of gleisation and calcareous concretions (paleosol horizons). Limestone: dark- and light-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. Shales underlying the upper limestones bed contain the non-marine bivalves *Palaeomutela olgae* (Gus.) and *P. umbonata* (Fisch.), the ostracods *Palaeodarwinula varsanofievae* (Bel.), *P. aronovi* (Bel.), *P. sokolovi* (Bel.), *P. tuimasensis* (Kotsch.), *Prasuchonella tichvinskaja* (Bel.), *P. belebeica* (Bel.), and fish scales.

Package S2/11 Interval 109.5–131.5 m Thickness 12.0 m

Shales and siltstones with thin (up to 0.3 m) rare marl and limestone laminae. Siltstone and shale: red, reddish-brown, calcareous, with green spots of gleisation and calcareous concretions (paleosol horizons). Marls: grey, greenish-grey, cream-coloured, massive, silty and sandy. Limestone: dark-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. In the top, the shale overlying the upper limestone contain non-marine ostracods, the bivalves *Palaeomutela olgae* (Gus.), *P. umbonata* (Fisch.), and *P. krotowi* (Netsch.), and fish scales.

Package S2/12 Interval 131.5.5–141.5 m Thickness 10.0 m

Shales, siltstones and sandstones. Siltstone and shale: red, reddish-brown, calcareous, with green spots of gleisation and calcareous concretions (paleosol horizons). Sandstone: brownish-red, wavy laminated. At the top, the package contains a bed (0.2–0.6 m) of light-grey algal-microbial limestone riddled with numerous voids of plant roots *in situ*. Shales subjacent to limestone surfaces contain non-marine ostracods, the bivalves *Palaeomutela olgae* (Gus.), *P. pseudoumbonata* (Gus.), and *Palaeomutela (Palaeanodonta) longissima* (Netsch.), fish scales of *Platysomus* sp., and *Palaeoniscum kasanense* Gein. et Vett.

Package S2/13 Interval 141.5–159.0 m Thickness 17.5 m

Sandstones and siltstones with rare thin (0.2–0.3 m) laminae of marl. Sandstones and siltstones: reddish-brown, calcareous, with green spots of gleisation and calcareous concretions (paleosol horizons). Marls: grey, greenish-grey with red spots of gleisation. At the top of the package, the succession contains a lens of a brownish-red siltstone (0.5 m) with the non-marine bivalves *Palaeomutela olgae* (Gus.) and *Palaeomutela (Palaeanodonta) longissima* (Netsch.), ostracods, fishes and tetrapods.

Packages 9 and 10 are tentatively assigned to the Prikazan Beds, package 11 to the Pechishchi Beds, package 12 to the Verkhnyi Uslon Beds, and package 13 to the Morkvashi Beds of the stratotype section of the Upper Kazanian near the village of Pechishchi.

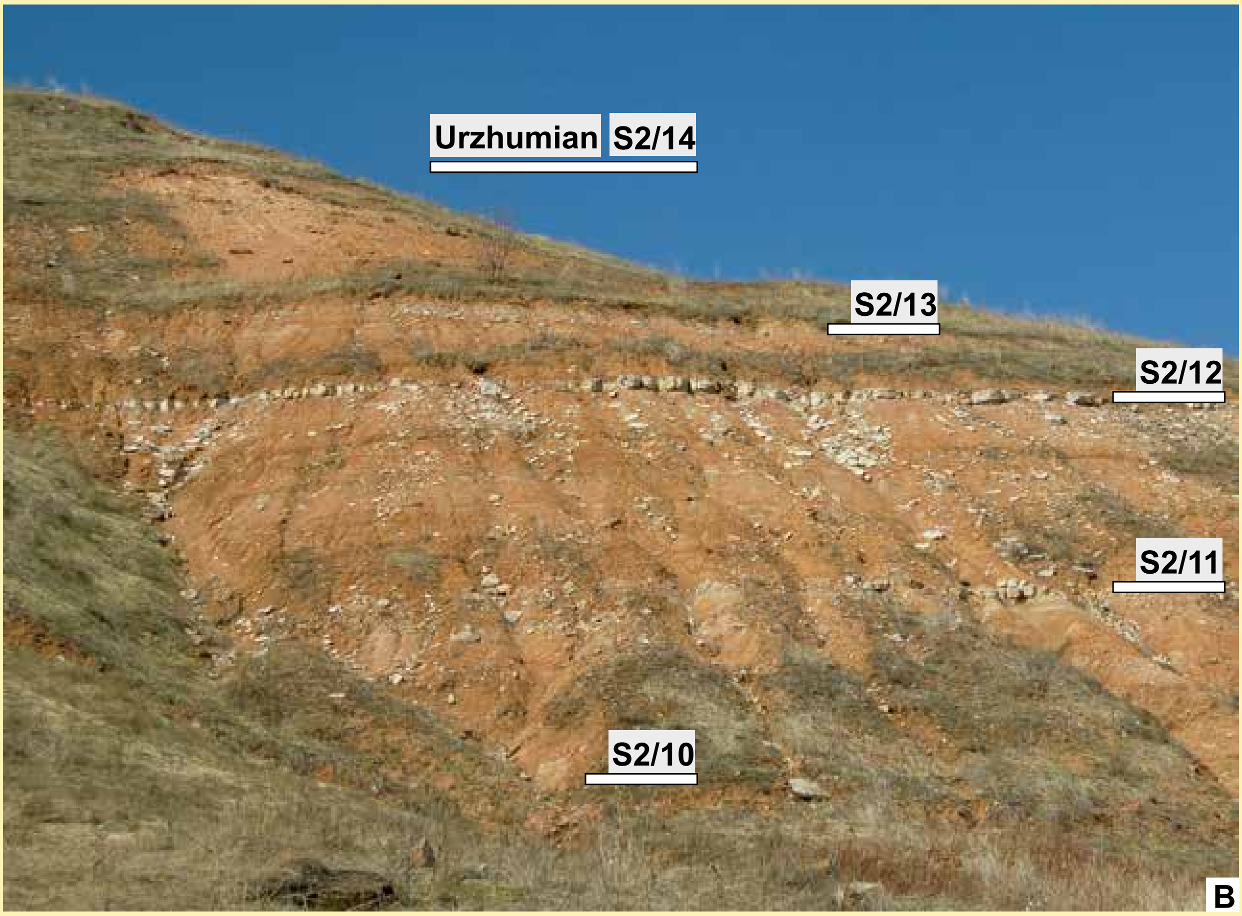
Outcrop S1

GPS: 55.70552 N, 051.773852 E (WGS84). Datum: the right bank of the Kama River, the upper part of the slope, the edge of the slope is 195.0±3 m ASL. The basement of package S1/14 is exposed in 185.0 m ASL.

Urzhumian Stage

Package S1/14 Interval 159.5–169.0 m Thickness 10.0 m

Sandstone (5 m-thick): reddish-brown, medium-grained, obliquely laminated, with thick pillar fractures. The surface of the red-bed Kazanian succession is eroded and slightly undulated.



Outcrop S2. Basal Upper Kazanian cross-bedded sandstone (package S2/9) (A), and (B) general view of outcrop S2

The sandstone is overlain by the alternation (thickness is approx. 5 m) of red, violet, and pink siltstones and shales with bluish-grey marl and limestones. Marl and shale: grey, dark-grey, muddy, compact, solid, algal-microbial, sometimes very hard and finely wavy laminated, riddled with numerous voids of plant roots *in situ*. Shale adjacent to limestone contains the non-marine bivalves *Palaeomutela krotowi* Netsch., *P. vjatkensis* (Gus.), *P. doratioformis* (Gus.), *Anadontella volgensis* (Gus.), the ostracods *Palaeodarwinula fragiliformis* (Kash.), *P. teodorovichi* (Bel.), *P. torensis* (Kotsch.), *P. defluxa* (Misch.), *P. elongata* (Lun.), *P. elegantella* (Bel.), *P. chramovi* (Gleb.), and *Prasuchonella nasalis* (Shar.), etc., fish scales, and rare fragments of amphibian bones.

The package is overlain by the soil (194 m ASL) of the slope edge.

Geochemical data

The geochemical analysis of the Ufimian / Kazanian boundary based on the succession in the borehole 1 (Sungatullin et al., 1996) shows that the boundary beds contain increased concentrations of silver and mercury, which is similar to the geochemical data from the outcrop near the town of Elabuga. The boundary of the Baitugan and Kamyshla Beds contains increased contents of tin and lead.

The charcoal seams in the Kamyshla Beds show increased concentrations of silver, gold, copper, germanium, and platinum-group elements. The Urzhumian rocks show increased concentrations of manganese.

Generally, the section near the village of Sentyak shows three groups of elements that occur in increased concentrations. These are:

(1) The elements connected with carbonates — Sr, Mn, Ba.

(2) The elements of the terrigenous red-bed complex of the Belebey Formation — Cr., Ni, V, Ti, Ga, Y, Li (siderophile elements).

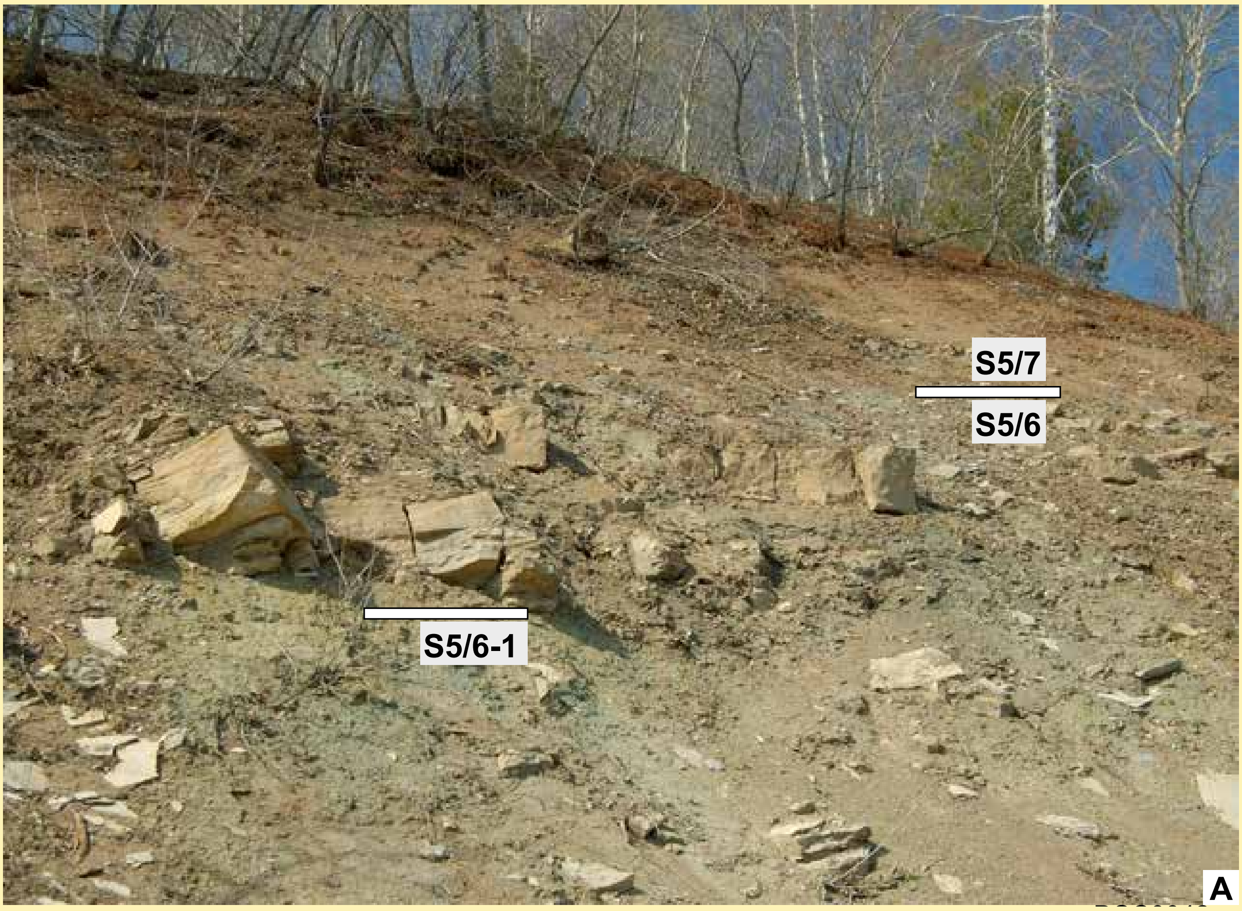
(3) The elements indicating the geochemical barriers in 'continent-sea' transition (Ufimian / Kazanian boundary) and 'sea-continent' transition: Cu, Ag, Hg, Au, Pl, platinum-group elements (chalcophiles and noble metals).

Paleomagnetic data

Detailed paleomagnetic studies were conducted in the Kotlovka section, located 4 km downstream from the village of Sentyak (Burov, Zharkov, Nurgaliev et al., 1998) and in borehole 1 drilled 3 km northeast of the village of Sentyak (Sungatullin et al., 1996).

Oriented samples were taken at 0.5–1.0 m. The distribution of the values of magnetic properties is consistent in pattern; it is connected with lithology and determined by the depositional environment. The sandstones of basal beds are the most intensely magnetised rocks. Marls and limestones, making up, as a rule, the upper parts of rhythmic cycles, are relatively low magnetic rocks. Shale-siltstone-sandy rocks in the middle part of the cycle, composing its main body, give intermediate values of magnetic properties. The magnetic parameters of the rocks are determined by a hematite-maghemite-magnetite association of ferromagnetic minerals. The distribution of natural residual magnetisation (J_n) directions before and after cleaning suggests the presence of a stable reversed polarity geomagnetic field throughout the Kazanian. Primary J_n directions indicate that J_n in the rocks of Belebey Formation is dominated by the primary (ancient) component (J_n°) of natural residual magnetisation. Thermal cleaning leads to compact grouping of vectors around the ancient direction of reversed polarity geomagnetic field. The scatter in declination of ancient component of J_n is within 200° to 240°, whereas the scatter in inclination of ancient component of J_n is within –20° to –60°.

Thus, the Kazanian and Ufimian geomagnetic field exhibits a stable reverse polarity belonging to the Kiaman Hyperzone. The composite Ufimian and Kazanian section, based on many outcrops, levels of sampling, and a wide variety of facies rock types, contains almost no strictly proven evidence of normal polarity of the paleogeomagnetic field. Apparent sporadic normal polarity variations or throws of J_n directions are caused by a higher role of the present component of chemical nature (Burov, Zharkov, Nurgaliev et al., 1998).



Outcrop S5 and S6. General view of outcrop S5 (A), and (B) general view of outcrop S6

Paleontological data

Lower Kazanian Substage

Baitugan Beds

Baitugan Beds are mainly composed of grey-coloured siltstone, shale, marl and limestone. Fossils are represented by marine organisms: ostracods, bivalves, brachiopods, rarely by small foraminifers, gastropods, bryozoans, crinoids, and fish scales; sometimes the remains of plants are found. The list of fossils follows below.

Small foraminifers: *Pseudoammodiscus kamae* (Tscherd.), *Ps. microsphaericus* (K.-M. Macl.), *Ps. megasphaericus* (Gerke), *Syzrania samarensis* (Raus.), *Nodosaria cf. suchonensis* K.M.-Macl.

Ostracods: *Healdianella vulgaris* Kotsch., *Cavellina unica* Kotsch., *C. grandis* Schneid., *C. edmistonae* (Harris et Lalicher), *Falalicypris crepidalis* Kotsch., *Healdia simplex* Roundy, *Bairdia beedei* Ulrich et Bassler, *Monoceratina cymbula* Shum., *Sulcoindivisia kazanica* Shum., *Acratia kazanica* Shum.

Gastropods: *Goniasma subangulata* (Vern.), *Loxonema volgensis* (Gol.), *Loxonema* sp. *Straparollus* sp.

Bivalves: *Nuculopsis wymensis* (Keys.), *Nuculana kasanensis* (Vern.), *Nuculana* sp., *Pseudobakewellia ceratophagaeformis* Noin., *Ps. antiquaeformis* Noin., *Pseudomonotis* sp., *Schizodus rossicus* Vern., *Astartella permocarbonica* (Tschern.), *Permophorus simplex* (Keys.), *Liebea ex gr. squamosa* (Sow.).

Brachiopods: *Lingula orientalis* Gol., *L. credneri* Gein., *L. lawrskyi* Netsch., *Cancrinella cancrini* (Vern.), *Licharewia rugulata* (Kut.), *Odontospirifer subcristatus* (Netsch.), *Cleiothyridina pectinifera* (Sow.), *Beecheria netschajewi* Grig., *B. angusta* (Netsch.).

Bryozoans: *Trepostomida* gen. indet., *Fenestrida* gen. indet.

Fish scales: *Acentrophorus varians* Kirkby, *Palaeostrugia rhombifera* (Eichw.), *Kasanichthys golyushermensis* Esin, *Palaeoniscum kasanense* (Gein.).

Conodonts: *Kamagnathus khalimbadzhae* Chern., *Kamagnathus* sp.

Macroflora: the stems of *Paracalamites frigidus* Neub.; *Annularia stellatoides* Neub., phytoleims *Phylladoderma meridionalis S.* Meyen, *Ph. sentjakensis* Esaul., dispersed cuticles *Carpolithes*, fragments of leafy mosses and algae, dispersed cuticle, charred wood.

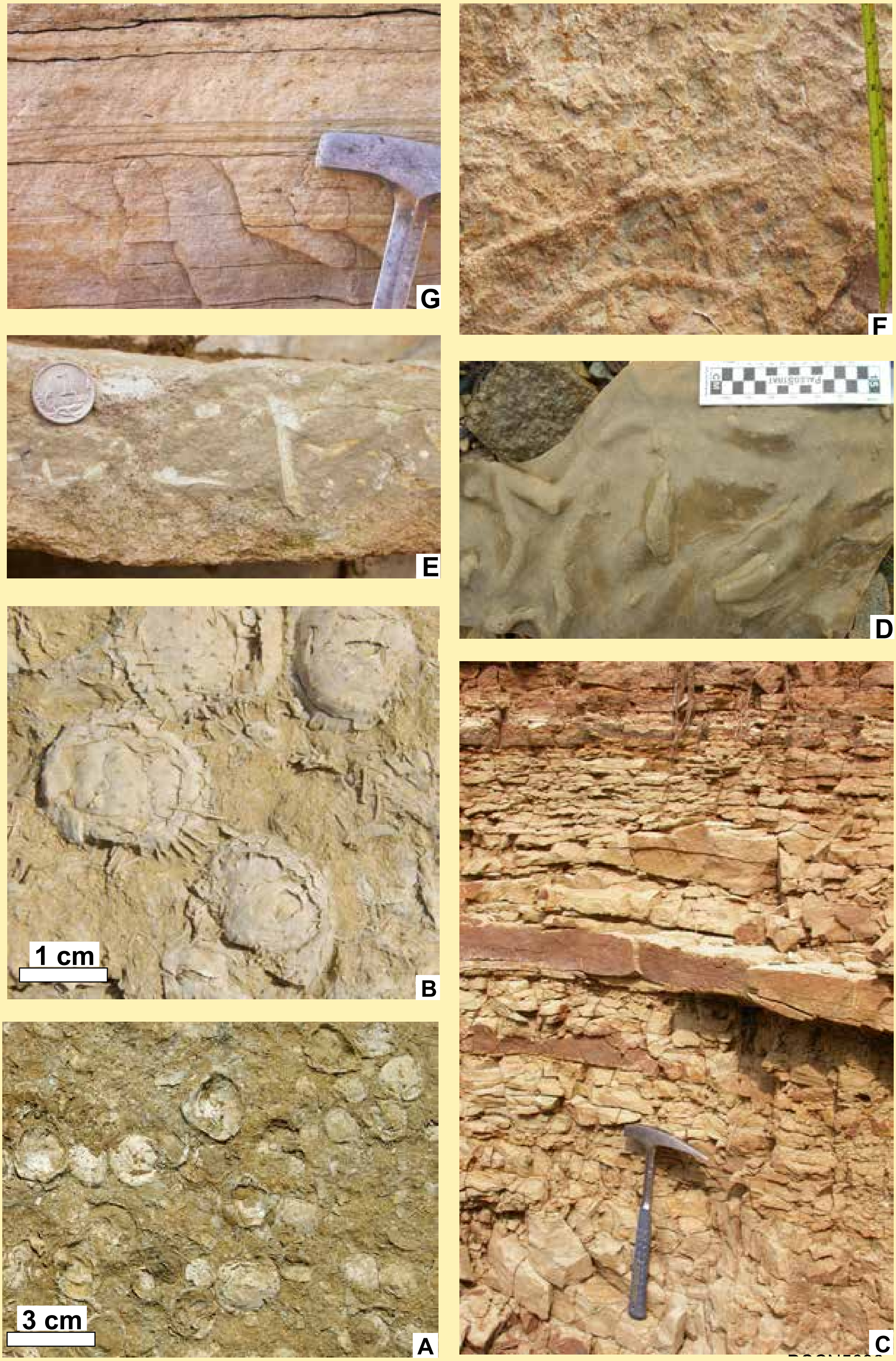
Miospores: *Striatiti* and *Costati* (dominants); *Granulatisporites parviverrucosus* (Waltz), *Acanthotriletes rectispinus* (Lub.), *Cirratriradites procumbens* (Lub.), *Calamospora plicata* (Waltz), *Leiotriletes* sp. and *Punctatisporites* sp., *Protohaploxypinus perfectus* (Naumova), *Hamiapollenites bullaeformis* (Samoil.), *Striatoabieites striatus* (Luber) and *Weylandites striatus* (Luber) *Utting.*

This list indicates that all faunistic groups are characterised by rather poor species composition. This is a common feature of the facial zone under consideration, which is often interpreted as a 'zone of shallow coastal lagoon' (Solodukho, 1963). Biostratigraphic analysis reveals that the majority of the species encountered are typical for the whole Kazanian Stage. Only the brachiopod *Licharewia rugulata* and the conodonts *Kamagnathus khalimbadzhae* are the index fossils of the Lower Kazanian. Abundant accumulations of brachiopods, bryozoans, and crinoids are common in the Lower Kazanian. Paleoecological analysis allows the establishment of two markers in the Baitugan Beds.

1) *Lingula Shale Marker* (packages 2 and 3) – bluish-grey, thinly bedded, platy shales, some of which contain interbeds with abundant or scattered accumulations of small phosphate valves belonging to the inarticulate brachiopod *Lingula orientalis* Gol. and others. Separate bedding planes contain small foraminifers, ostracods, gastropods, bivalves, fish scales, and plant detritus. Interbeds with *Lingula* lie at different stratigraphic levels in the lower part of the Baitugan Beds and differ from each other by concomitant fossils.

The *Lingula Shale Marker* is traced over the entire territory of the Republic of Tatarstan and outside (north of the Samara Region, etc.). According to many researchers, this is the most reliable marker in the Kazanian.

2) *Spiny Limestone Marker* (lowermost part of package 4) – in the Sentyak section, this bioclastic coquina limestone overlies the *Lingula Shale Member* and has a thickness of approx. 1.0 m. The *Spiny Limestone* comprises up to 90 % deformed shells of the brachiopod *Cancrinella cancrini*; their fragments and needles (spines), hence the name 'Kolyuchiy Izvestnyak' – '*Spiny Limestone*'). *Cancrinella cancrini* occurs together with *Beecheria netschajewi*, *Aulosteges horrescens* Vern., *Odontospirifer subcristatus* (Netsch.), *Cleiothyridina pectinifera* (Sow.), and the Lower Kazanian index-species *Licharewia rugulata*.



The details of the Lower Kazanian rocks. The Spiny Limestone with the pavement of brachiopod *shells Cancrinella cancrini* (A, B), (C) thinly bedded platy limestone, package S7/4 (Baitugan Beds), (D, E, F) the same platy limestones with various trace fossils, package S7/4 (Baitugan Beds), (G) non-marine limestone with fine ‘sheet’ lamination, the upper part of unit S5/6-1

Some bedding planes contain ostracods, fragments of branched and reticulate bryozoans, crinoids, the multielement conodonts *Kamagnathus khalimbadzhae* Chern. The base of the bioclastic limestone bed has feeding burrows (10–15 mm in diameter) branched in the horizontal plane and filled with shell debris.

Spiny Limestone Marker is quite confidently distinguished within the area of Lower Reaches of the Kama River, as well as in the Kazan area and in the southeast of Tatarstan.

Kamyshla Beds

In the Sentyak section, the Kamyshla Beds (thickness is approx. 20 m) are composed of grey and brownish-grey sandstone, siltstone and shale with subordinate interlayers of limestone and marl. The Kamyshla Beds contain marine and non-marine fossils (outcrops S6 and S7, packages 5 and 6).

The list of marine fossils follows below.

Small foraminifers: *Glomospirella* aff. *umbilicata* Cusch. et Wat., *Lingulonodosaria* cf. *clavata* Paalz., *Pseudoammodiscus kamae* (Tscherd.), *Pseudonodosaria nodosariaeformis* (K.M.-Maclay), *Nodosaria farcimeni* Sold., *Lingulonodosaria kamaensis* K.M.-Maclay, *Geinitzina kazanica* K.M.-Maclay.

Gastropods: *Loxonema* sp. *Straparollus* sp.

Bivalves: *Nuculopsis wymensis* (Keys.), *Nuculana* sp., *Lithophaga consobrina* (Eichw.), *Liebea squamosa* (Sow.), *Pseudobakewellia antiquaeformis* Noin., *Ps. ceratophagaeformis* Noin., *Pseudomonotis speluncaria* (Schloth.), *Ps. permianus* Masl., *Schizodus rossicus* Vern., *Permophorus simplex* (Keys.), *Netschajewia globosa* (Netsch.), *N. alata* (Netsch.).

Marine fossil assemblage of the Kamyshla Beds is more impoverished than in the underlying Baitugan Beds. This indicates deterioration of marine environments that caused a migration from this area of a number of stenohaline animals: brachiopods (*Licharewia, Odontospirifer*, and *Beecheria*), bryozoans, crinoids, and conodonts. All marine species of the Kamyshla Beds are typical of the whole Kazanian Stage.

The non-marine fauna is represented by conchostracans, ostracods, bivalves, and plant remains. A list of non-marine fossils is given below.

Ostracods: *Palaeodarwinula varsanofievae* (Bel.), *Prasuchonella belebeica* (Bel.).

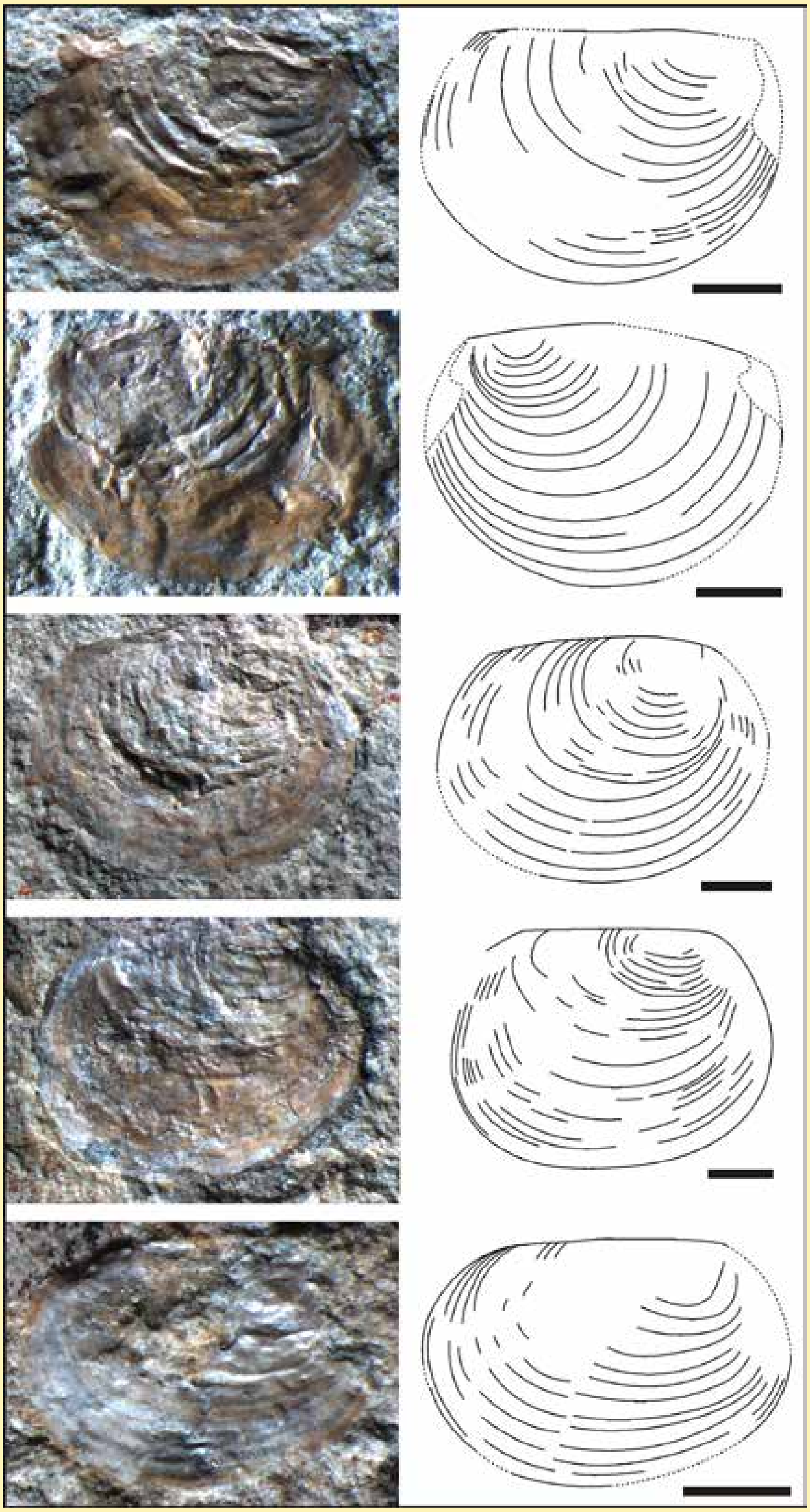
Conchostracans: A monospecific conchostracan fauna occurs in a 1 m thick, grey coloured, non-marine limestone (unit S6/6-2). The conchostracan valves are preserved as yellowish brown substance. The morphology (using the terminology of Scholze and Schneider, 2015) strongly resemble *Estheriina (Estheriina)* sp. 1 figured by Tasch (1987: Pl. 33, Fig. 7), which was described from the Late Permian of the Lower Rio do Rasto Formation in Brazil. The holotype of this species has been taxonomically revised by Goretzki (2003) and defined as a younger synonym of *Cyzicus (Lioestheria) bigarellai* Tasch, 1987, which occurs in the Middle Permian of the Estrada Nova Formation in Brazil.

Non-marine bivalves. Muddy grey limestones with fine obliquely wavy lamination (unit S6/6-2) as well as overlying limestones and marls containing assemblages of the *Palaeomutela umbonata* Zone. Index species: *Palaeomutela umbonata* (Fischer, 1840). Characteristic bivalve species: *P. pseudoumbonata* (Gus.), *P. (Palaeanodonta) longissima* (Netsch.), *P. (Palaeanodonta) rhomboidea* (Netsch.), *P. olgae* (Gus.), *P. attenuata* (Gus.), *P*. aff. *attenuata* (Gus.).

Fishes. Fish remains have been studied from the Kotlovka section located 4 km west of the Sentyak section. Samples were taken from the analogues of unit S6-8 (middle part of the Kamyshla Beds). The fish assemblage contains isolated, well preserved chondrichthyan teeth of *Sphenacanthus* sp., Sphenacanthidae gen. et sp. nov. and ‘*Polyacrodus’* sp., and hybodontiform scales, as well as actinopterygian teeth and scales of *Varialepis* sp. The teeth of a new sphenacanthid shark earlier described as *Xenosynechodus egloni* Glikman (Minikh and Minikh, 1998, 1999) occur in the Kazanian–Severodvinian interval of the East European Platform.

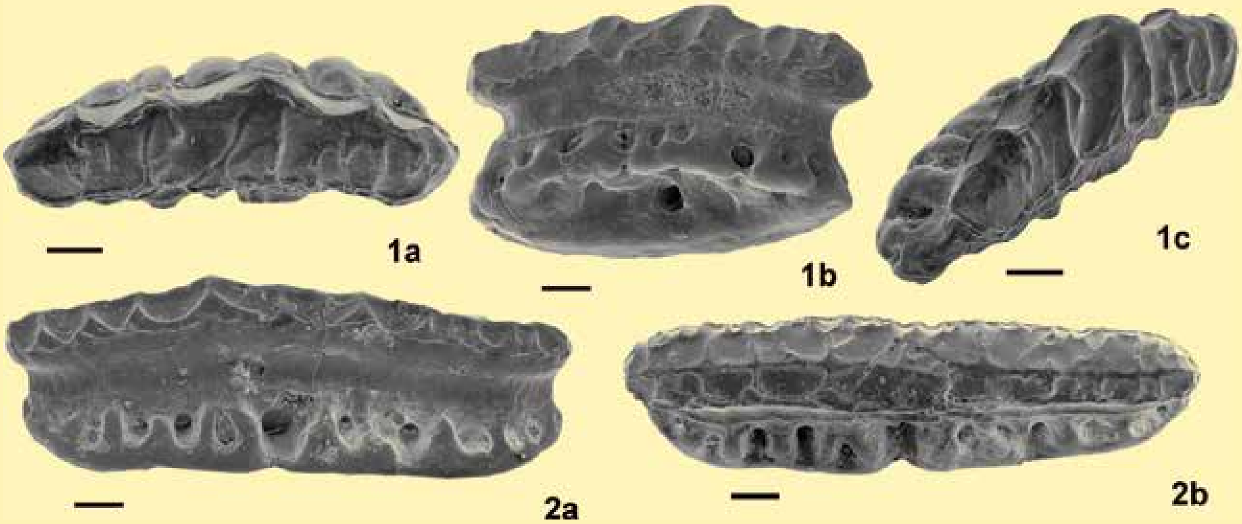
Tetrapods. Deformed scull of a temnospondyl amphibian Dissorophidae gen. indet. (unit S6–8).

Charophytes: *Stellatochara gracilis* (Esaul. et Saidak.) Kis. (unit S6/6-2).



Conchostracans of the Sentyak section, outcrop S6 resembling *Estheriina (Estheriina)* sp. 1 Tasch, 1987. Scale bars 1 mm.
Description of the morphology of the valve (using the terminology of Scholze & Schneider, 2015): size large to very large (3.4–5.1 mm); oval shape; short to long dorsal margin; umbo in submedian and marginal to supramarginal position; growth lines 13–24; larval valve very small; anterior and posterior margins sharply curved to very sharply curved; points of maximal curvature of the anterior margin median-dorsal, at the posterior margin median to median dorsal, and at the ventral margin median-anterior to median-posterior

Macroflora: muddy grey limestones with fine obliquely wavy lamination (unit S6/6-2) contain *Phylladoderma sentjakensis* Esaul. with abundant seeds of *Nucicarpus sentjakensis* Esaul., reproductive organs of *Permotheca vesicasporoides* S. Meyen, Esaul. et Gom. and *Cardiolepis sentjakensis* Esaul., as well as root remains *Radicites sentjakensis* Esaul. This assemblage possibly belonged to a single plant and was buried close to its place of growth, which can be inferred from its good preservation. The pollen Vesicaspora ex gr. magnalis (Andreeva) Hart was extracted from the reproductive organs of *Permotheca vesicasporoides* and *Cardiolepis sentjakensis.* Moving further west, into the axial part of the basin, one can only encounter dispersed fragments of *Phylladoderma sentjakensis* Esaul., which show signs of a longer transport (Esaulova, 1998d).



Chondrichthyan teeth from the locality Kotlovka. 1 – *Sphenacanthus* sp., a – occlusal, b – labial and c – lateral views. 2 – **'***Polyacrodus'* sp., a – lingual and b – occlusal views. Scale bars 0.1 mm

Generally, the faunal assemblage of the Kamyshla Beds is characterised by the following main features:
1) section consists of an alternation of marine and non-marine beds;
2) upwards in the sequence, beds with marine organisms are reduced in number and the taxonomic diversity of marine fossils becomes poorer;
3) marine fauna is mainly represented by diminished bivalve assemblages confined to thin beds of oolitic limestones;
4) non-marine fauna is usually represented by ostracods and bivalves that usually occur together with plant remains and are confined to carbonate rocks (limestones and marls).

Krasnyi Yar Beds

The Krasnyi Yar Beds are composed of reddish-brown siltstone and shale interbedded by thin beds of marl, limestone and sandstone (thickness 26 m). The beds contain only few non-marine fossils. The fossils are confined to thin grey-coloured shale interbeds, rarely occurring in the top of the beds succession. These shales contain carbonised plant remains, rare shells of bivalves and conchostracans, and fish scales. A list of fossils is below.

<u>Ostracods</u>: *Palaeodarwinula verella* (Bel.), *P. varsanofievae* (Bel.), *Prasuchonella belebeica* (Bel.).

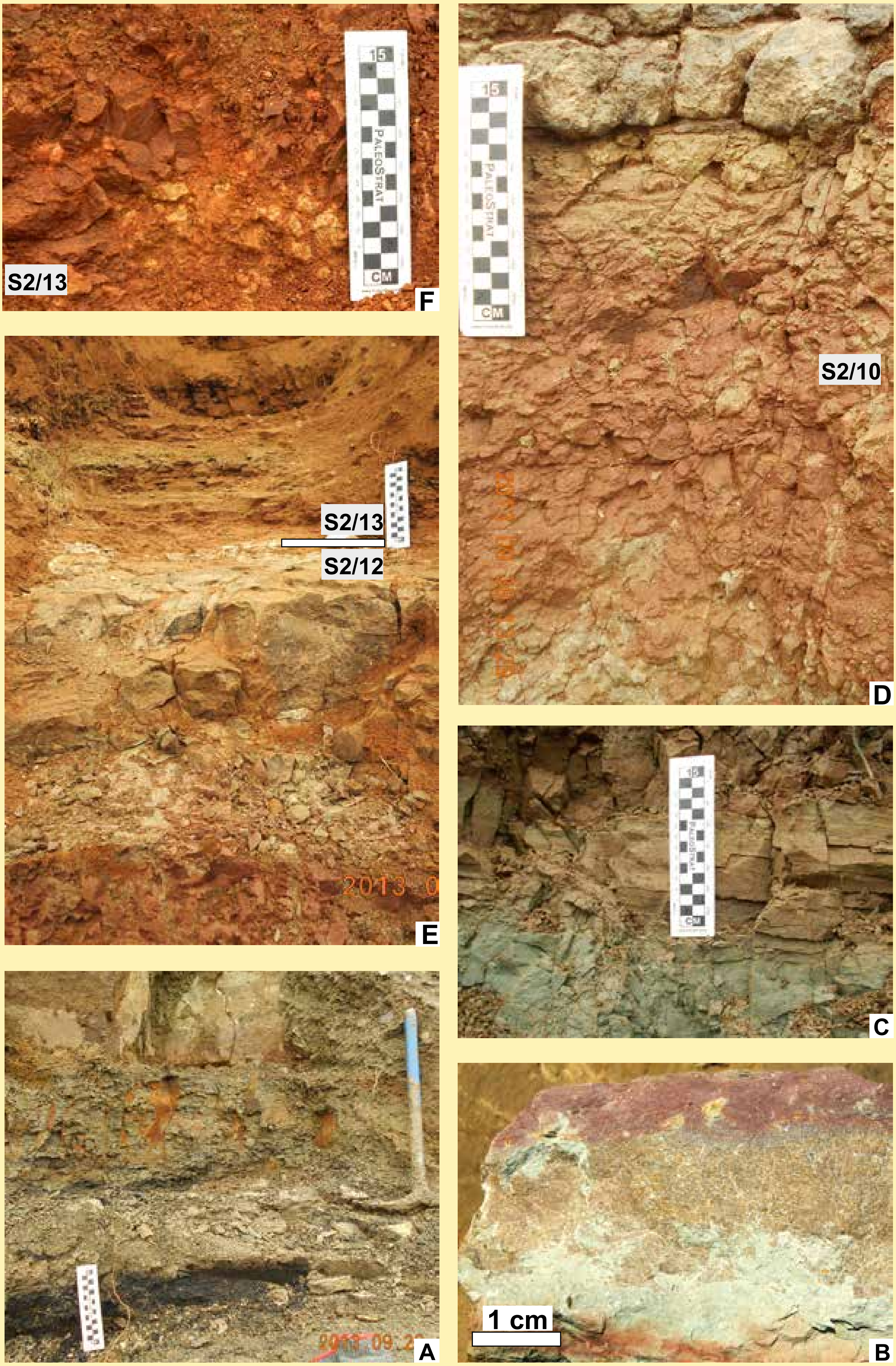
<u>Non-marine bivalves:</u> The Sentyak section has been established as a stratotype of the non-marine bivalve range zone Palaeomutela quadriangularis, which lower boundary is confined to the upper part of the Krasnyi Yar Beds (Silantiev, 2014). *Palaeomutela quadriangularis* Zone. Index species: *Palaeomutela quadriangularis* Netschajew, 1894. The stratotype of the zone is located on the right bank of the Kama River, near Nizhnekamsk, Sentyak section, outcrop S6, package 8, bed 33 (Silantiev, 2014). The lower boundary of the zone is placed at the level of first appearance of *P. quadriangularis* (Netsch.). Characteristic bivalve species: *P. kamae* (Gus.), *P. umbonata* (Gus.), *P. olgae* Gus., *P. (Palaeanodonta) longissima* (Netsch.), *P. (Palaeanodonta) rhomboidea* (Netsch.). The unit is recorded in the Volga–Ural and North Caspian basins of the East European Platform.

<u>Fish scales:</u> *Platysomus* sp., *Paramblypteris* sp., *Palaeonisci gen indet.*

<u>Macroflora</u>: *Pecopteris cf. varsanofievae Fef. Paracalamites frigidus* Neub. fragments of *Phylladoderma*.

<u>Conchostracans</u>: *Curvacornutus* sp.

All species of the Krasnyi Yar Beds assemblage are common in non-marine facies (Belebey Formation) of the Kazanian Stage.



The details of the Kazanian rocks. The charcoal (unit S5/6-4) in the Kamyshla Beds (A), (B) variegated limestone containing non-marine bivalves, package S6/8, Krasnyi Yar Beds, (C) green and brown shales of the uppermost part of the Kamyshla Beds, (D, E, F) the details of the Upper Kazanian succession: shales with calcareous concretions (paleosol horizons) and algal-microbial limestones

Upper Kazanian Substage

The continental deposits of the Upper Kazanian Belebey Formation are composed of reddish-brown mottled sandstones, siltstones, shales, and minor thin carbonate interbeds. The Sentyak section contains four stratigraphic levels with fossils. These are thin carbonate-shale interbedding units containing similar to each other impoverished assemblages of non-marine fossils, as listed below. All species found in the Sentyak section are common for the non-marine facies (Belebey Formation) of the Kazanian Stage.

Ostracods: the assemblage of *Palaeodarwinula fainae-Prasuchonella tichvinskaja* Zone (continental Kazanian). the assemblage includes *Palaeodarwinula fainae* (Bel.), *P. belebeica* (Bel.), *P. aronovi* (Bel.), *P. sokolovi* (Bel.), *P. irenae* (Bel.), *P. varsanofievae* (Bel.), *P. tuimasensis* (Kotsch.), *Prasuchonella tichvinskaja* (Bel.), *P. varsanofievae* (Bel.), *P. chramovella* (Bel.), *Prasuchonella tichvinskaja* (Bel.), *Pr. onega* (Bel.), *Darwinuloides sentjakensis* (Sharap.).
Non-marine bivalves: The assemblage of the *Palaeomutela quadriangularis* Zone (Upper Kazanian).
Fish scales: *Platysomus* sp., *Palaeoniscum kasanense* Gein. et Vett.
Macroflora: stems of *Paracalamites* sp. and *Cordaitales* sp.

Urzhumian Stage
The Urzhumian is the red-bed succession composed of sandstones, siltstones, shales, marls, and limestones. The shales and siltstones contain non-marine bivalves, as well as numerous conchostracans, ostracods, fish scales and fragments of macrofossils. Fossils are restricted to the lower part of the Urzhumian succession, as listed below. This assemblage is very representative for the Urzhumian Stage.
Conchostracans: *Limnadia khovorkilica* Nov., *L. elliptica* Mol., *L. labra* (Mitchell), *L. erresecta* Nov., *Eulimnadia sueta* Nov., *Pseudestheria (Sphaesopsis) mackini* Mol., *Ps. kashirtzevi* Nov., *Lioestheria simplex* Mol., *Rossoestheria angulata* (Lutk.), *Curvacornutus vladimirovi* Nov.
Ostracods: the assemblage of *Palaeodarwinula fragiliformis-Prasuchonella nasalis* Zone (Urzhumian). The assemblage includes *Palaeodarwinula fragiliformis* (Kash.), *P. teodorovichi* (Bel.), *P. torensis* (Kotsch.), *P. defluxa* (Misch.), *P. elongata* (Lun.), *P. elegantella* (Bel.), *P. chramovi* (Gleb.), *Prasuchonella nasalis* (Shar.), *Darwinuloides edmistonus* Bel., *D. sentjakensis* Shar.

Non-marine bivalves: the assemblage of *Palaeomutela krotowi Zone* (lower part of the Urzhumian) (Silantiev, 2014). The assemblage includes *Palaeomutela krotowi* Netsch., *P. doratioformis* (Gus.), *P. vjatkensis* (Gus.), *Prilukiella lata* (Netschajew), *Anadontella volgensis* (Gus.).
Fish scales: *Platysomus* sp., *Kasanichthys vjatkensis* Esin.
Macroflora: *Sphenophyllum (Tichvinskia) stuckenbergi* (Schmalch.) Esaul., *Paracalamites frigidus* Neub.

AUGUST 20

- **KARKALI SECTION**
- **SHUGUROVO SECTION**

Coat of Arms of Almetyevsk

Almetyevsk

Almetyevsk is located on the left bank of the Zay River (a tributary of the Kama), 265 kilometres (165 mi) southeast of Kazan.

Almetyevsk is an important centre for Russia's oil industry. The Druzhba pipeline starts in Almetyevsk. Pipelines to Nizhny Novgorod, Samara, and Subkhankulovo also start in this city. The city houses several oil equipment plants producing pipes, pumps and other oil-related tools.

Lenin Avenue in Almetyevsk

Monument to oil industry workers in Almetyevsk

Coat of Arms of Leninogorsk

Leninogorsk and Shugurovo

Leninogorsk is a town in the Republic of Tatarstan, Russia, located 322 kilometres (200 mi) southeast of Kazan.

Shugurovo is a village in Leninogorsky District of the Republic of Tatarstan, Russia, located 30 kilometres (19 mi) south-west of Leninogorsk, the administrative centre of the district, on the Lesnaya Sheshma River (a tributary of the Sheshma). Shugurovo was founded in the 19th century. It was granted the status of urban-type settlement in 1950 but was demoted to a rural locality on October 25, 2004.

Leninogorsk is one of the greenest cities in Russia

Stela dedicated to well №1 in Shugurovo

AUGUST 20 • STOP 1

DESCRIPTION OF THE EXCURSION ROUTE IN THE UPPER REACHES OF THE SHESHMA RIVER (SOUTH-EASTERN TATARSTAN)

A one-day bus excursion to show the participants the geology of South-eastern Tatarstan will be organised. The most interesting Permian sections in this region are exposed in the upper reaches of the Sheshma River, near the villages of Shugurovo and Karkali. From the bus window, numerous outcrops of marine carbonate-terrigenous Lower Kazanian rocks can be seen. The Upper Kazanian, represented by non-marine red-bed rocks and thin Urzhumian succession, constitutes the upper parts of the watersheds, usually exposed only in the road cuts. The Ufimian succession is exposed in a small area on the right bank of the Sheshma River, near the village of Shugurovo, where it overlies the Sakmarian reef limestones. These limestones form an isolated exposure in the valley of the Sheshma River, close to the western outskirts of the village of Karkali.

The Ufimian–Kazanian succession near the villages of Shugurovo and Karkali is well-known to Russian geologists and was studied for over 200 years by Lepekhin (1795), Netschaev and Zamyatin (1913), Noinsky (1932), Raspopov (1932), etc. From the mid-20th century, the section near the villages of Shugurovo and Karkali became the subject of specialised stratigraphic, paleomagnetic and paleontological studies (Forsch, 1955, Boronin and Burov, 1977; Ignatiev, 1976; Burov et al., 1998; Utting et al., 1997; Silantiev et al., 1998).

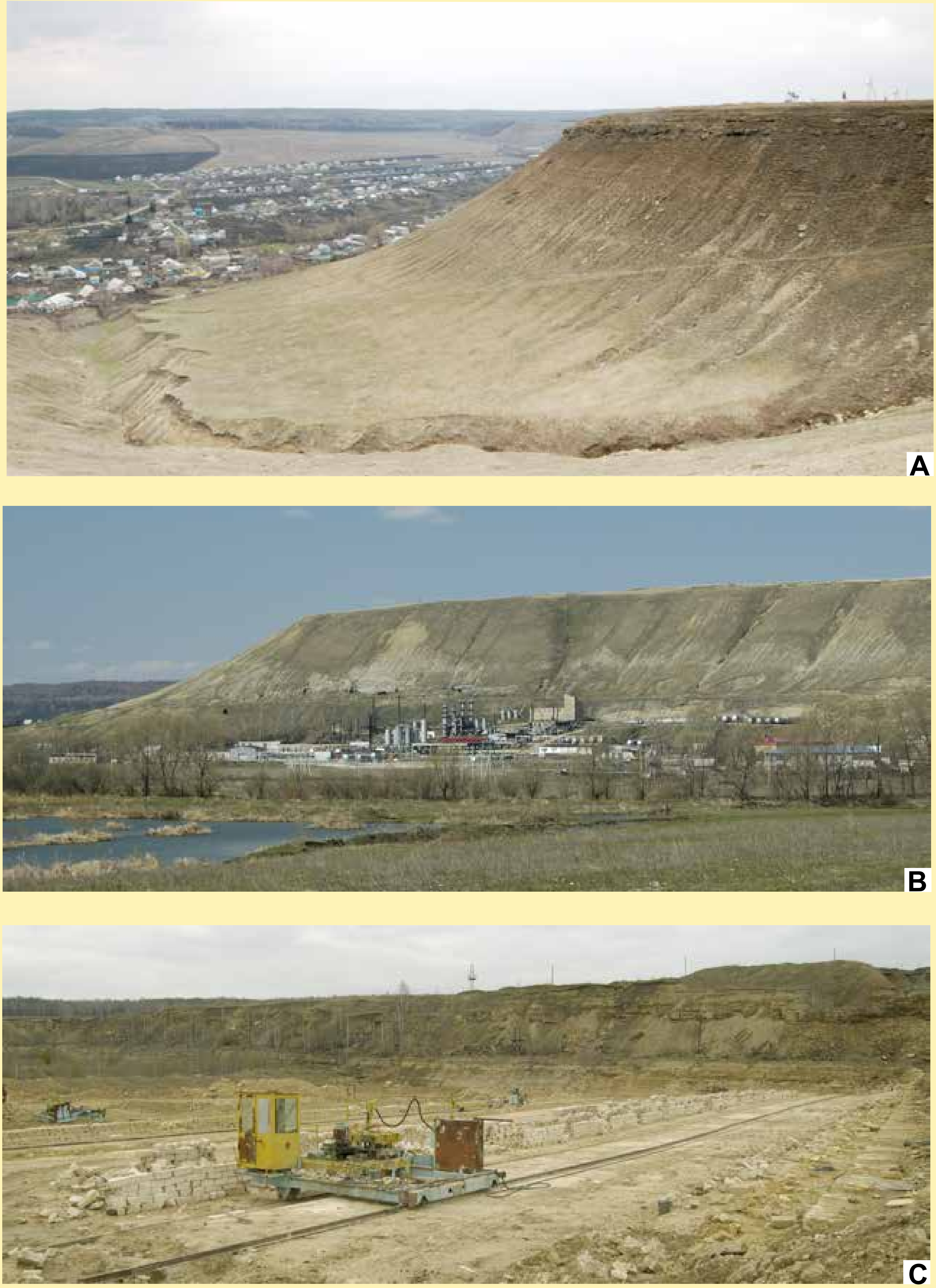
Originally, the section attracted attention due to common occurrences of bitumen on the surface in the basin of the Sheshma River. At the very beginning of the 18th century, the newspaper “Vedomosti” published a report on “oil seeps” on the surface of the rocks in the upper reaches of the Sok and Sheshma rivers. This was the first published reports of oil occurrences in Russia.

From the mid-19th century, Mining Department, Mineralogical Society and later the Russian Geological Committee periodically sent recognised geologists and mining engineers to this region to evaluate its oil potential. The history of the tar sand production and the search for liquid oil in the Shugurovo District was discussed by Noinsky (1932).

In the north-eastern vicinity of the village of Shugurovo, outcrops of tar sandstone form a large field of heavy and viscous oil. This field was well-known since the 19th century and until recently was utilised by the Shugurovo Tar Plant. In 2015, the Shugurovo Tar Plant was transformed into the Memorial Park of Geological Heritage.

The bioclastic-oolitic limestone of the Kamyshla Beds of the Lower Kazanian Substage is exposed in the Karkali building and facing stone quarry. The embankment of the Kazanka River in Kazan as well as the streets of Sviyazhsk and the ancient town of Bolgar were faced with this building stone in 2010–2015.

The observation of the sections near the villages of Shugurovo and Karkali indicates that the Lower Kazanian marine rocks are strikingly different in their facies. However, abundant fossils (foraminifers, ostracods, gastropods, bivalves, brachiopods, bryozoans, crinoids, and conodonts) allow positive correlation of these two successions.



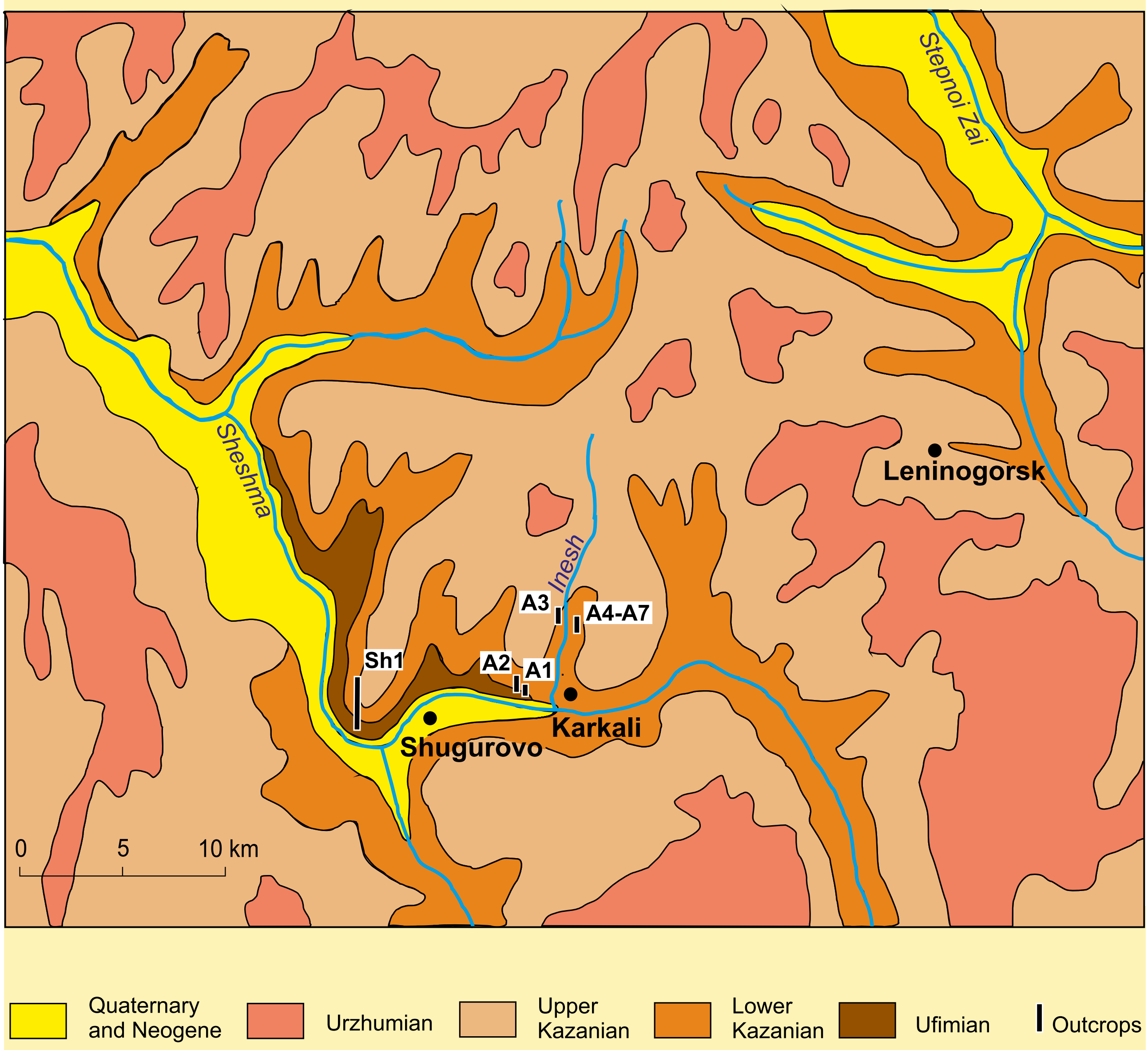
General view of the Sheshma River Valley and Shugurovo Village from the watershed of the right slope (A), (B) Shugurovo Petroleum Tar Plant, mining the field of heavy and viscous oil since 1906 (now — Memorial Park of Geological Heritage), and (C) the Karkali Limestone Quarry utilising the Lower Kazanian limestone as a building and facing stone since 1957. The first apartment buildings of Leningorsk and Almetyevsk were constructed of this limestone. Reserves of productive limestone are approx. 2,500,000 tonnes

KARKALI SECTION. UFIMIAN / KAZANIAN BOUNDARY AND THE LOWER KAZANIAN IN SHALLOW MARINE FACIES

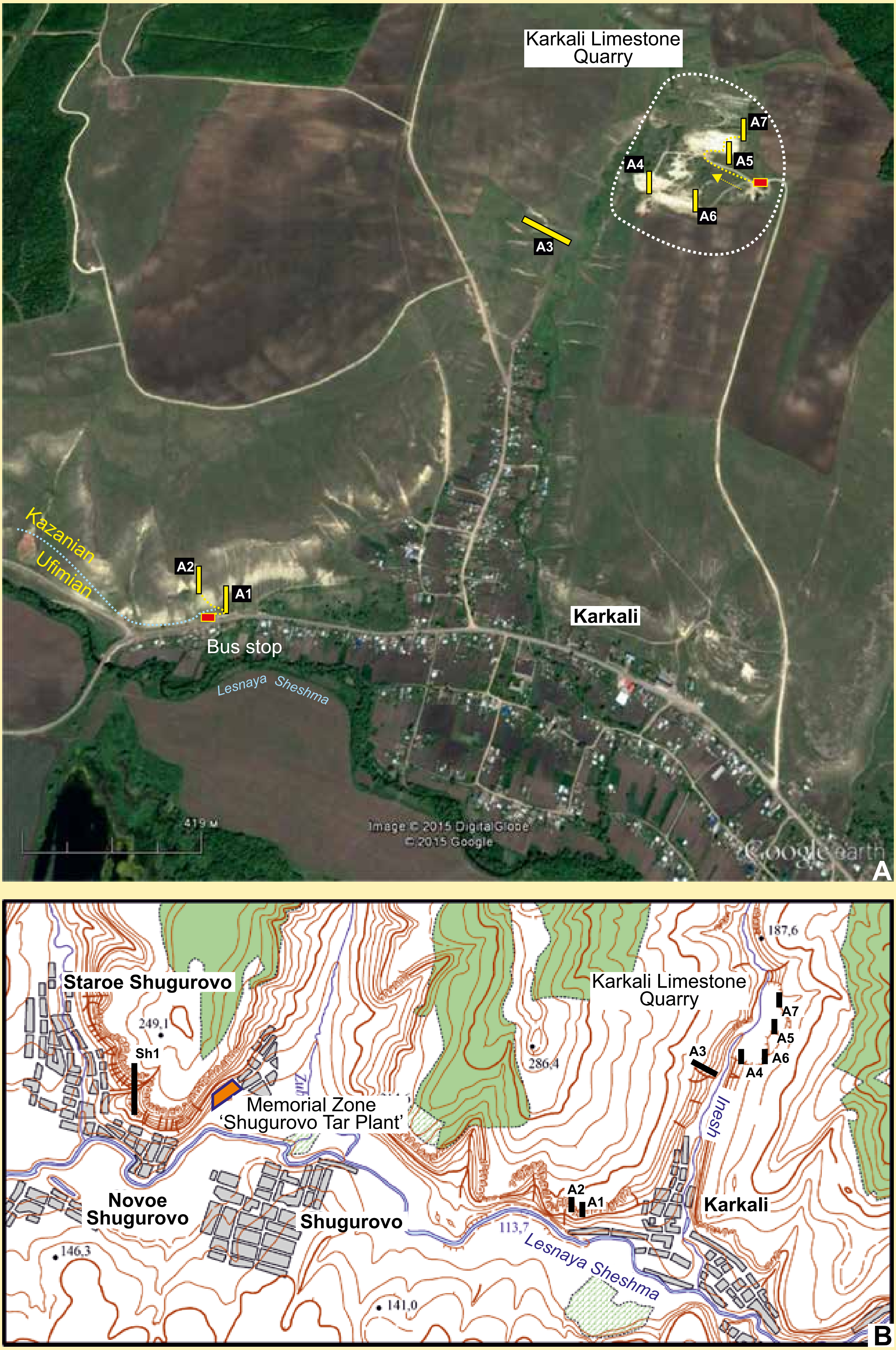
On the right slope of the valley of the Sheshma River, between the villages of Shugurovo and Karkali, the Ufimian red-bed rocks are overlain by the lowermost Kazanian beds composed of dark-grey, bituminous sandstones. Over several decades, these bituminous rocks were explored by the Shugurovo Tar Plant. Laterally, these bituminous sandstones are split by dark-grey shales and siltstones containing coaly plant fragments and mass accumulations of marine ostracods and bivalves.

The Lower Kazanian succession in this area is similar to the stratotype Kazanian sections in the Samara region, in the basin of the Sok River. These two sections complement each other and their comparison shows quite sharp facies changes in the Ufimian and especially the Kazanian rocks over a short distance.

Several outcrops (A1–A8) were used to compile general profile of the section. Upwards in the section, the sequence in the right slope of the Sheshma River shows the following beds (from bottom to top).



Generalised geological map of the upper reaches of the Sheshma River, Republic of Tatarstan



Study area: (A) satellite image of the outskirts of Karkali Village (Image © 2015 DigitalGlobe) showing the locations of the outcrops (A1–A7); (B) geographical map of the area

Outcrop A1

GPS: 54,50756 N 052,17834 E (WGS84). Datum: the lower half of the right slope of the Sheshma River, 9 m above the road bed; rain canals and vertical cutting for approx. 20 m; the bottom of package A1/1 is 129 m ASL. Outcrop extends from this point to about the middle of the valley slope, and then is closed by thin talus upwards to the slope edge.

Ufimian Stage

Sheshmian Formation (Horizon)

Package A1/1 Interval 0.0–5.0 m Thickness (visible) 5.0 m

Sandstone: brownish-red, polymict, calcareous-muddy, fine-grained and medium-grained, cross-bedded or with disorderly structure, solid. Clastic grains: effusive rocks (50 %), quartz (35 %), feldspar (10 %), and sporadic flakes of biotite. Most grains are coated with a film of iron hydroxides. The upper surface of the package is eroded and slightly undulated.

Horizontally, 300 m west of this station, the sandstone is replaced with variegated silty-argillaceous succession containing subordinate interbeds of light-grey, algal-microbial limestones. Laminated brownish-red shales contain rare non-marine bivalves *Palaeomutela* ex gr. *attenuata* Gus., *P. (Palaeanodonta) castor* (Eichw.), and ostracods *Paleodarwinula* sp.

Shugurovo Sandstone (Shugurovo Beds)

Package A1/2 Interval 0.5–7.0 m Thickness 2.0 m

Sandstone: from brownish greenish-grey in the lower part to light greenish-grey in the upper part; fine-grained (0.1–0.25 mm), polymictic, cross-bedded, solid. Clastic grains: quartz (50 %), effusive rocks (35 %), feldspar (10 %), and sporadic flakes of biotite. Quartz grains are slightly corroded, isometric, angular and subrounded. Uppermost part of the package (0.1 m) is represented by light-grey calcareous solid sandstone textured by branching fissures of desiccation.

Horizontally, 4 km west of this station, near the village of Shugurovo, the Shugurovo Sandstone becomes thicker (up to 15 m) and bituminous forming a large field of heavy and viscous oil. This field was well-known since the 19th century and until recently was explored by the Shugurovo Tar Plant. In 2015, the Shugurovo Tar Plant was transformed into Memorial Park of Geological Heritage.

Package A1/3 Interval 7.0–7.10 m Thickness 0.1 m

Limestone: pinkish-grey, grey, fine-grained, solid, with numerous small branched columns resembled micro-stromatolites. The columns are filled by sessile foraminifers *Tolypammina* sp. The bed top is uneven (due to the rounded upper surfaces of the columns) and contains rare marine bivalves *Netschajewia* sp. Horizontally, the quantity of branched columns is changed from abundant to sparse.

The Kazanian age of Shugurovo Sandstone is determined by conventions of the Interdepartmental Stratigraphic Committee of Russia basing on lithological and sequence-stratigraphical data. In the Karkali section, biostratigraphic boundary of the Kazanian is located above at the base of package A1/4 and defined by the first occurrence of the age-diagnostic conodont *Kamagnathus* (Kotlyar et al., 2007).

Kazanian Stage

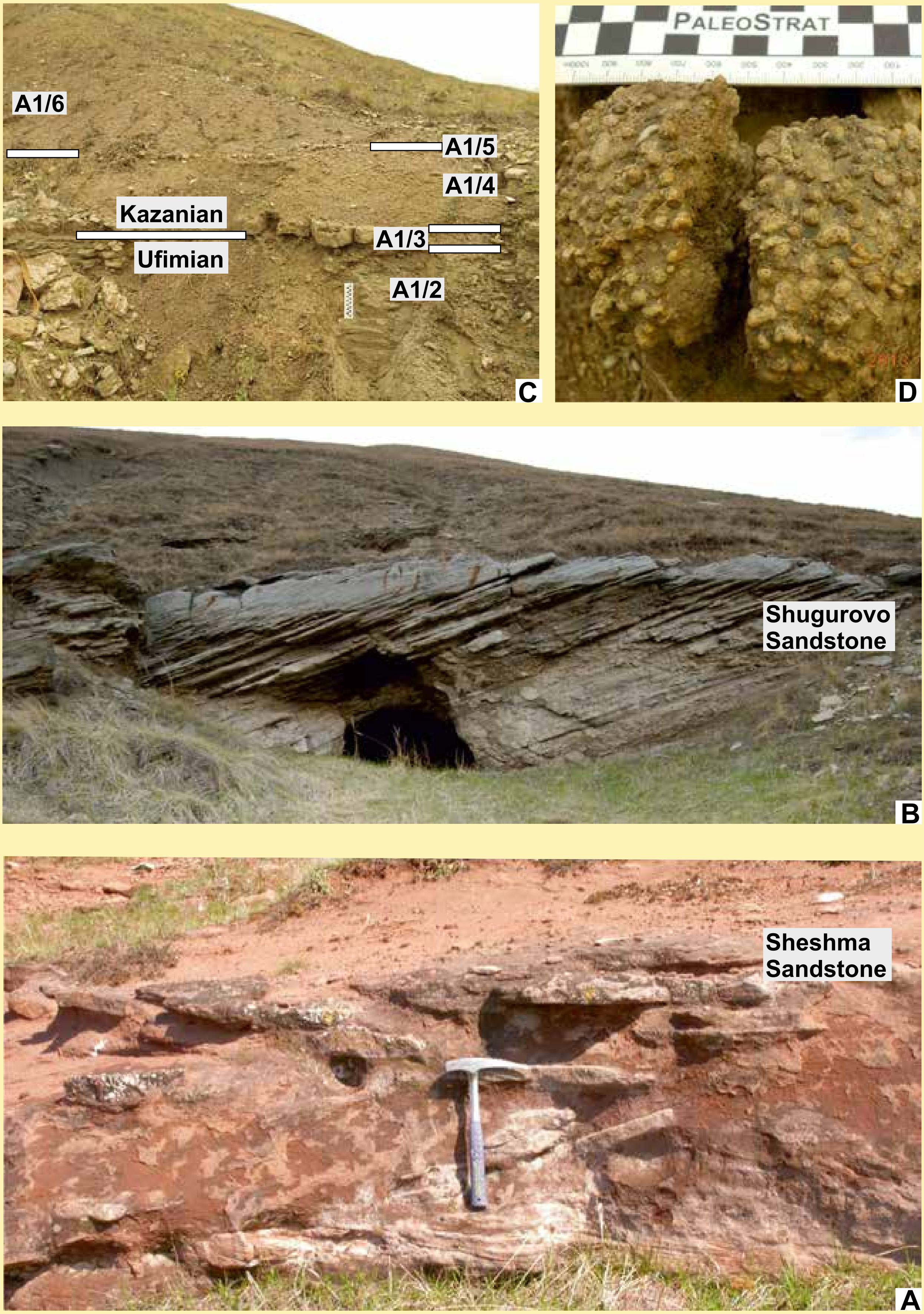
Lower Kazanian Substage

Baitugan Beds

Lingula Shale Member

Package A1/4 Interval 7.10–7.45 m Thickness 0.35 m

Shale: greenish-grey, calcareous, soft, flexible, with numerous (up to 40 % of bulk rock) well preserved shells of brachiopods *Dielasma netschajewi* Grig., *Campbellelasma variiforme* Smirn., *Campbellelasma vulgaris* Smirn., and fragments of branched bryozoans.



Brownish-red sandstone of the Sheshma Formation (Ufimian) at the Shugurovo section (A), (B) cross-bedded bituminous Shugurovo Sandstone near the north-west border of Shugurovo Tar Plant, (C) general view of outcrop A1 and the Ufimian / Kazanian biostratigraphic boundary, and (D) limestone with numerous small columns resembling micro-stromatolites (package A1/3)

Package A1/5 Interval 7.45–7.50 m Thickness 0.05 m

Limestone: grey and dark-grey with slight reddish and greenish tints, fine-grained, solid. The top surface is uneven which is caused by the shells of Dielasmatidae *in situ* (hence the name 'Dielasmovyi izvestnyak' – 'Dielasma Limestone') and small algal-microbial mounds.

Foraminiferal assemblage: *Tolypammina* sp. (sessile forms), *Pseudoammodiscus megasphaericus* (Gerke), *Nodosaria* sp. Ostracods: *Healdia* sp., *Healdianella* sp., *Cavellina* sp., etc. Gastropods: *Goniasma* sp., *Loxonema* sp. Brachiopods: *Cleiothyridina pectinifera* (Sow.), *Dielasma netschajewi* Grig., *Campbellelasma variiforme* Smirn., *Campbellelasma vulgaris* Smirn., and fragments of branched bryozoans. The number of bioclasts significantly decreases from the base to the bed top.

Package A1/6 Interval 7.5–20.5 m Thickness 13.0 m

Shale: grey and dark-grey with slight greenish and yellowish tints, thinly bedded, platy. Thin interbeds (5 cm) of concretionary limestones and marls occur at the different levels. From the bottom to top, the lamination changes from thinly to medium and thick bedded. Some bedding planes contain assemblages of marine ostracods, inarticulate the brachiopods *Lingula orientalis* Gol., the bivalves *Pseudobakewellia ceratophagaeformis* Noin., *Netschajewia* sp., branched and fenestrated bryozoans, and charred plant debris. The lowermost part of the package contains the brachiopods *Licharewia rugulata* (Kut.) and the conodonts *Kamagnathus khalimbadzhae* Chern., the index-species defining the biostratigraphic boundary of the Kazanian Stage.

The overlying succession is more conveniently observed in outcrop A2.

Outcrop A2

GPS: 54,50775 N 052,17633 E (WGS84). Datum: the middle part of the right slope of the Sheshma River, vertical cutting for approx. 15 m; the basement of package A1/7 Spiny Limestone Member is 149 m ASL. Thick plates of this limestone armour the slope.

Spiny Limestone Member

Package A2/7 Interval 20.5–21.5 m Thickness 1.0 m

Limestone: yellowish-grey, bioclastic, coquina, medium-bedded, with numerous small foraminifers, ostracods, gastropods, brachiopods *Cancrinella cancrini* (Vern.), *Dielasma netschajewi* Grig., *Licharewia rugulata* (Kut.), In some places the rock is overwhelmed by brachiopod spines (hence the name 'Spiny Limestone').

The base of the bioclastic limestone bed has the feeding burrows (10–15 mm in diameter) branched in the horizontal plane and filled with shell debris.

Package A2/8 Interval 21.5–33.2 m Thickness 11.7 m

Alternation of yellowish-grey, medium-bedded marls, limestones and mudstones. Several bedding planes contain pavements of the brachiopods *Cancrinella cancrini* (Vern.). The rock also contains ostracods, bivalves of *Nuculana*, *Lithophaga, Pseudobakewellia, Palaeolima*, the brachiopods *Licharewia rugulata* (Kut.), and *Dielasma netschajewi* Grig. Some bedding planes contain only charred plant fragments with rare *Lingula*, as well as other ones contain only subhorizontal trace fossils and plant debris.

Outcrop A3

GPS: 54,51876 N 052,19355 E (WGS84). Datum: the right slope of the Inesh River, the mouth of two gullies; vertical cutting for approx. 15 m; the basement of the outcrop is 149 m ASL.

Spiny Limestone Member

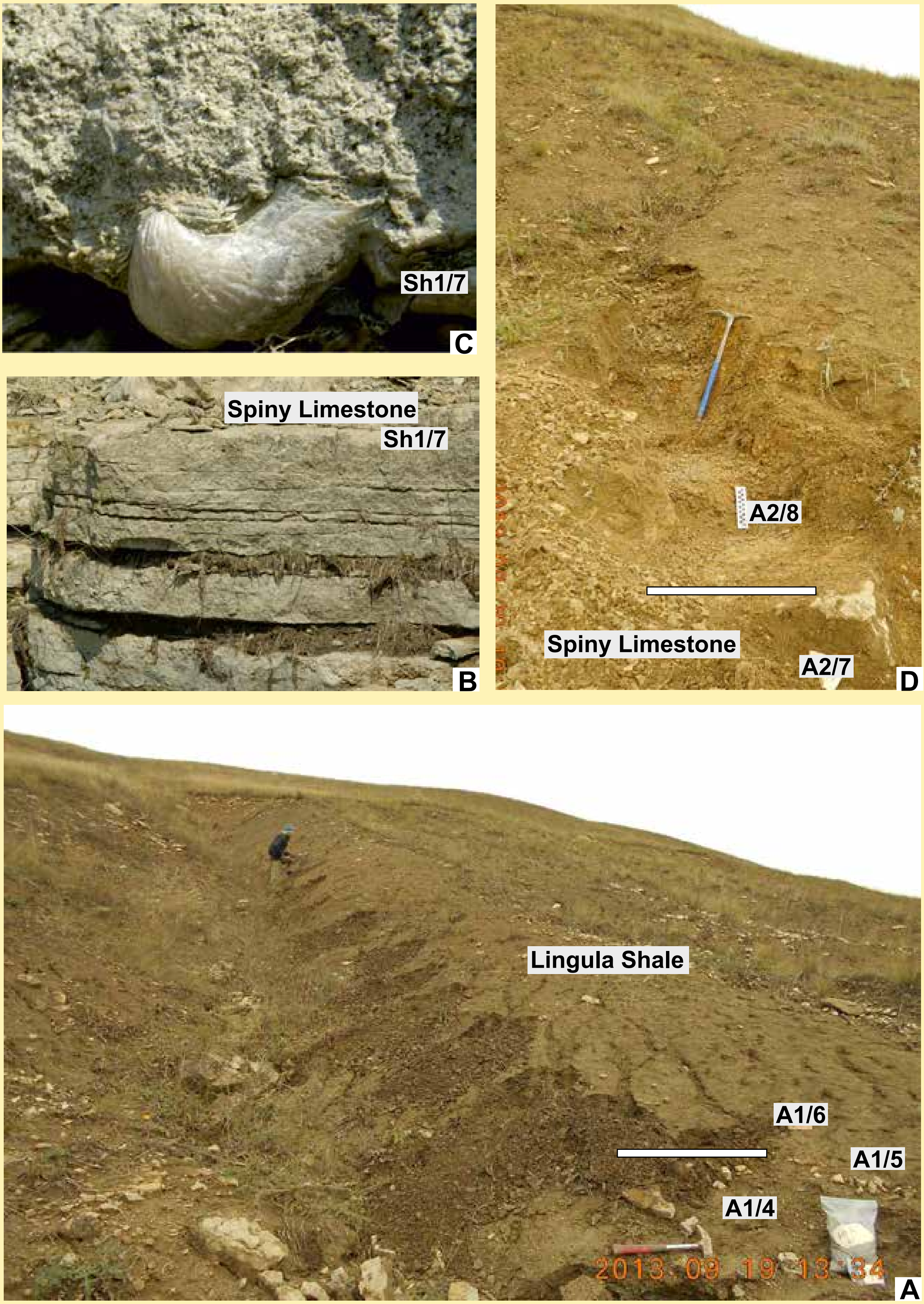
Package A3/8 Interval 23.2–33.2 m Thickness (visible) 10.0 m

Alternation of yellowish-grey marls, limestones and mudstones; analogue of package A2/8.

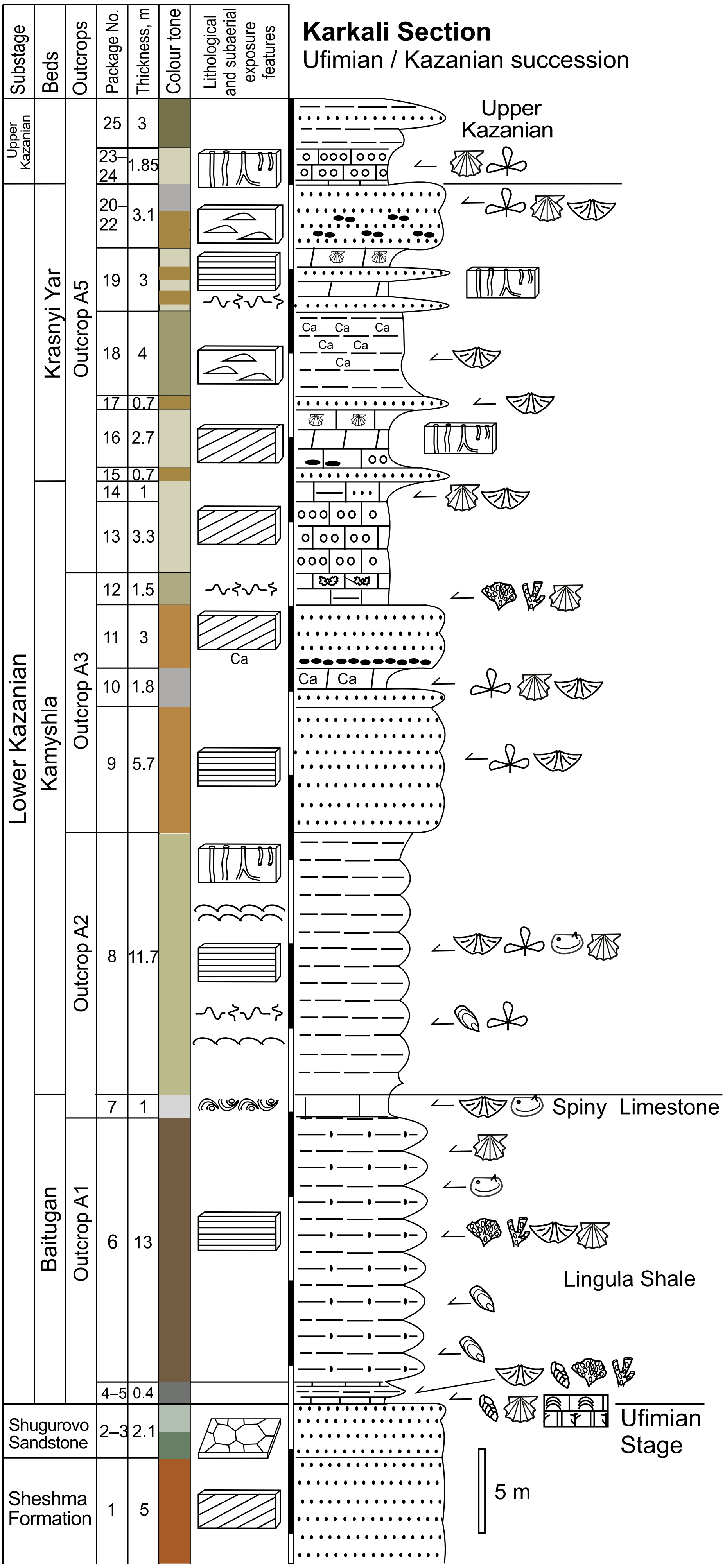
Kamyshla Beds

Package A3/9 Interval 33.2–38.9 m Thickness 5.7 m

Sandstone: alternation of soft argillaceous and solid calcareous beds. Both types of sandstones are brownish and yellowish-grey, platy (1–20 cm), fine grained. Argillaceous sandstone contains charred plant debris that marks thin lamination. Some bedding planes contain the pavements of *Cancrinella cancrini* (Vern.). Usually rocks lack fossils.



Upper part of outcrop A1 and exposure of the *Lingula* Shale (A), (B) the marker Spiny Limestone at the Shugurovo section, package Sh1/7, (C) the fragment of the brachiopod index-species *Licharewia rugulata* (Kut.) in the Spiny Limestone, and (D) general view of the outcrop A2


Karkali Section
Ufimian / Kazanian succession
Substage
Beds
Outcrops
Package No.
Thickness, m
Colour tone
Lithological and subaerial exposure features
Upper Kazanian
Lower Kazanian
Krasnyi Yar
Kamyshla
Baitugan
Outcrop A5
Outcrop A3
Outcrop A2
Outcrop A1
Shugurovo Sandstone
Sheshma Formation
25 3
23–24 1.85
20–22 3.1
19 3
18 4
17 0.7
16 2.7
15 0.7
14 1
13 3.3
12 1.5
11 3
10 1.8
9 5.7
8 11.7
7 1
6 13
4–5 0.4
2–3 2.1
1 5
Ca
Upper Kazanian
Spiny Limestone
Lingula Shale
Ufimian Stage
5 m

Package A3/10 Interval 38.9–40.7 m Thickness 1.8 m

Rhythmic alternation of sandstones and marls. Sandstone: grey, calcareous, solid, with fragments of brachiopod shells. Marl: light-grey, soft; some interbeds with abundant plant remains (including algae ?) and charred plant debris; some interbeds contain numerous juvenile brachiopods and bivalves. The bedding planes of sandstones are textured by ripples.

Package A3/11 Interval 40.7–43.7 m Thickness 3.0 m

Sandstone: grey, yellowish-grey and brownish-grey, fine-grained, solid, with lenticular and cross-bedded lamination, and flat pebbles of carbonate rocks at the base. Five levels with thin (2–10 cm) lenses of bioclastic and pelloidal limestone occur at the lower part of the package. Rocks contain fragments and debris of brachiopod shells. Thick solid plates of sandstone form rocky exposures on the slope. The lower surface of the package is eroded and slightly undulated.

Package A3/12 Interval 43.7–45.2 m Thickness 1.5 m

Alternation of soft sandstone and limestone. Sandstone: yellowish-grey, calcareous, relatively soft. Limestone: light-grey and yellowish-grey; argillaceous and arenaceous, soft, pelloidal and oolitic, bioclastic (brachiopods) and bioturbated, cavernous. Rocks contain fragments and debris of brachiopod shells and bryozoans.

Package A3/13 Interval 45.2–46.7 m Thickness (visible) 1.5 m

Limestone: light-grey and yellowish-grey, oolitic, with bioclastic (brachiopods) lenses, with cross-bedded lamination in the upper part. Package forms the rocky exposures in the heads of the gullies. The full thickness of package 13 and overlying succession are observed in outcrop A5.

Outcrop A5

GPS: 54,52169 N 052,20494 E (WGS84). Datum: the left slope of the Inesh River, Karkali Limestone Quarry, 'main' old quarry area. Bed of the quarry coincides with the top surface of package A3/12 and is 155 m ASL.

Package A5/13 Interval 45.2–48.5 m Thickness 3.3 m

Limestone: light-grey and yellowish-grey, oolitic, massive, solid, with lenticular and cross-bedded lamination in the upper part. The lenses of bioclastic limestone contain internal moulds of bivalves and define lamination.

Package A5/13 represents first productive interval of the Karkali Limestone Quarry.

Package A5/14 Interval 48.5–49.5 m Thickness 1.0 m

Limestone: light-grey and yellowish-grey, arenaceous or argillaceous, bioturbated, platy, with thin lenses of oolitic and bioclastic limestone. The latter contains the bivalves *Nuculana kasanensis* (Vern.), *Schizodus rossicus* Vern., *Permophorus simplex* (Keys.), *Pseudomonotis (Trematiconcha) noinskyi* (Lich.), the brachiopods *Cancrinella cancrini* (Vern.), *Dielasma netschajewi* Grig., fragments of bryozoans and crinoids.

The overlying succession is observed in the east wall of the Karkali Limestone Quarry.

Krasnyi Yar Beds

Package A5/15 Interval 49.5–50.2 m Thickness 0.7 m

Sandstone: greenish-grey and brownish-grey ('tobacco'), fine-grained, polymictic, calcareous and solid in the lower part (0.4 m), argillaceous, thin laminated and soft in the upper part (0.3 m). Thin plates (approx. 0.5–1 cm) define lenticular lamination. The bedding planes contain rare fragments of brachiopod shells and charred plant debris.

Package A5/16 Interval 50.2–52.9 m Thickness 2.7 m

Limestone: light-grey, grey, grey with slight brownish tint, oolitic, pelloidal, arenaceous, massive, with subordinate lenses of yellowish-grey marls. Several intervals of limestone are riddled with numerous upright channels (10–15 mm in diameter and up to 20 cm in height).
The package can be divided into four parts, from base to top:

Bed A5/16-1 [0.00–0.25] Interval 50.2–50.45 m Thickness 0.25 m
Succession of yellowish-grey sandstone, limestone and marl. Thin interbed of calcareous sandstone with the pebbles and shell debris forms the basement of the bed. Overlying soft marl contains only charred plant debris. The upper part of the bed includes the plates of pelloidal and arenaceous limestone with abundant small shells of molluscs and brachiopods. Randomly oriented bioclasts indicate bioturbation. Bioclastic pavements are locally preserved in the upper part of the bed.

Bed A5/16-2 [0.25–1.55] Interval 50.45–51.75 m Thickness 1.3 m
Limestone: light-grey with slight brownish tint, oolitic, with numerous bivalves *Netschajewia* dispersed over the entire interval. The top of this subunit is slightly undulating, erosional. The top surface is penetrated with numerous upright channels (10–15 mm in diameter and up to 20 cm in height) resembling *Thallassinoides*.

Bed A5/16-3 [1.55–2.50] Interval 51.75–52.70 m Thickness 0.95 m
Limestone: light-grey, arenaceous, with the pebbles of carbonate rocks in the bottom and abundant upright channels over the entire interval. The upper part of the limestone becomes more arenaceous and contains the shell (bivalves) pavements.

Bed A5/16-4 [2.50–2.70] Interval 52.70–52.90 m Thickness 0.20 m
Shell coquina: light-grey and yellowish-grey, formed by internal moulds of the large schizodont bivalves *Oriocrassatella plana* Golowk. The top of the bed is slightly undulating, erosional.

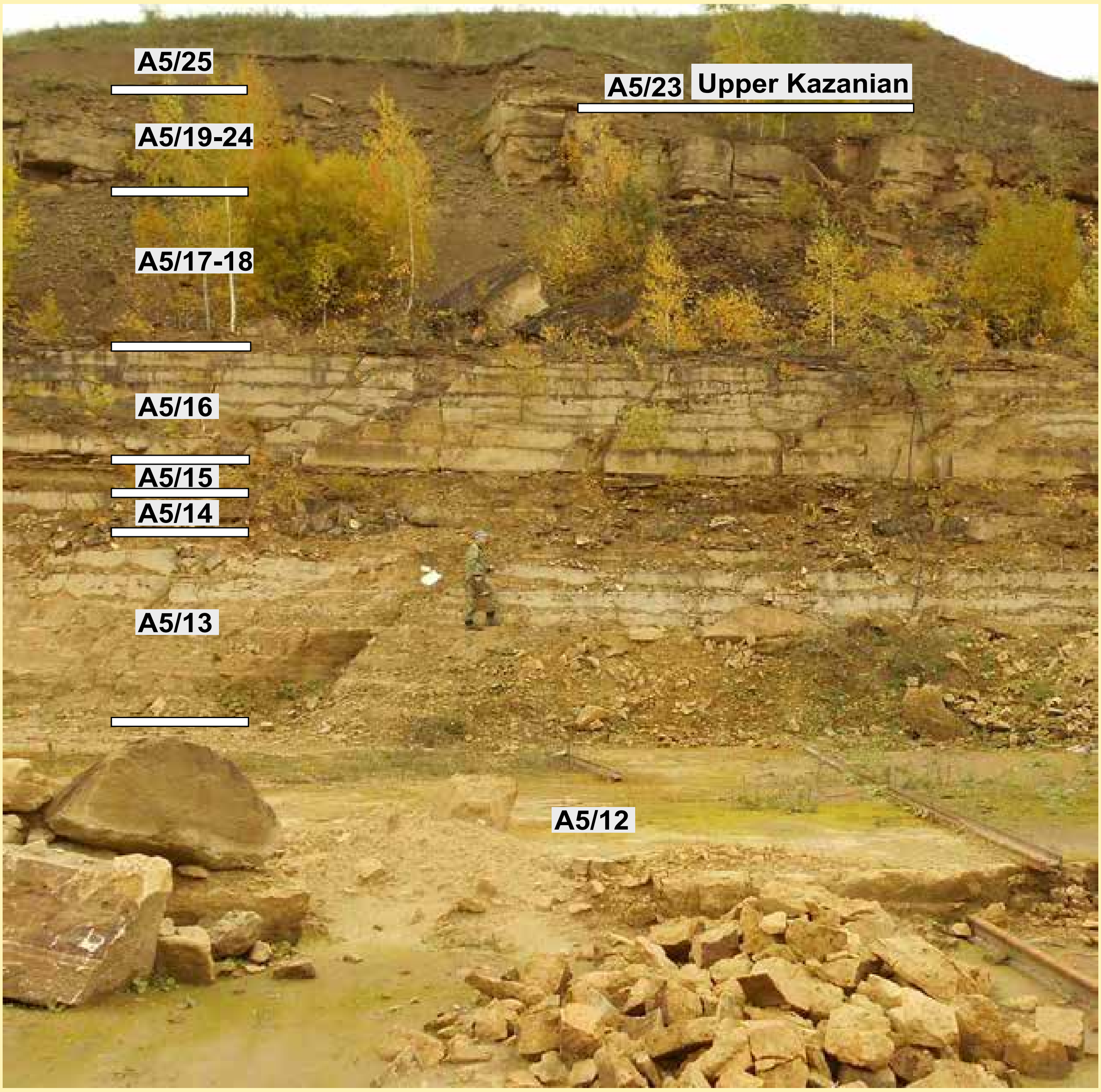
Horizontally, 10–30 m west of this station, bed A5/16-4 cuts off the underlying limestones up to the bottom of package A5/16. At this place, coquina is replaced with arenaceous cross-bedded limestone. Further to the west, arenaceous cross-bedded limestone is replaced again with oolitic limestone with '*Thallassinoides'.*

Package A5/17 Interval 52.9–53.6 m Thickness 0.7 m
Sandstone: grey-brown, in the upper part yellowish-brown, polymictic with mudstone beds (to 1 cm). The lower part of the package (10 cm) is more argillaceous and contains abundant subhorizontal branched trace fossils (approx. 5–8 mm in diameter) and the numerous brachiopod shells *Cancrinella cancrini* Vern*.* The upper part contains the pavements of *Cancrinella* and rare shells of the Kazanian index-fossil *Licharewia rugulata* (Kut.).

Package A5/18 Interval 53.6–57.6 m Thickness 4.0 m
Alternation of marls and subordinate interbeds of shale and sandstone. Marls: greenish-grey, soft, fine laminated, with the scyphozoan cnidarians *Conularia hollebeni* Gein., the bivalves *Lithophaga consobrina* (Eichw.), the brachiopods *Dielasma netschajewi* Grig., and *Cancrinella cancrini* (Vern.). Shale: dark-grey with greenish-grey tint, calcareous, fine lenticular laminated, platy, with charred plant debris and rare trace fossils.

Package A5/19 Interval 57.6–60.6 m Thickness 3.0 m
Alternation of sandstone and marl. Sandstone: brownish-yellow, polymictic, fine-grained, with subhorizontal lenticular lamination. Marl: yellowish-grey, silty, with numerous pavements of bivalve shells and upright borrows resembling *Scolithos.* The pavements and trace fossils define the boundaries with adjacent sandstone beds. The shells of *Cancrinella* normally oriented to the bedding planes of marl indicate bioturbation.

Package A5/20 Interval 60.6–60.85 m Thickness 0.25 m
Sandstone: greenish-grey, greenish-brown, fine-grained, polymictic.



Outcrop A5. The Karkali Limestone Quarry, east wall of the 'main' old quarry area

Package A5/21 Interval 60.85–61.45 m Thickness 0.60 m

Deepening-upward succession of yellowish-grey calcareous sandstone containing the lenses of marl and limestone. Large (up to 15 cm) pebbles of light-grey limestones with marine Kazanian bivalves in the lower part.

Package A5/22 Interval 61.45–63.70 m Thickness 2.25 m

Sandstone: grey, fine grained, polymictic, lenticular laminated. Two equal beds of sandstone are divided by thin (0.15 m) interbed of calcareous mudstone. Mudstone contains brachiopods *Cancrinella,* bivalves and charred plant debris.

Upper Kazanian Substage

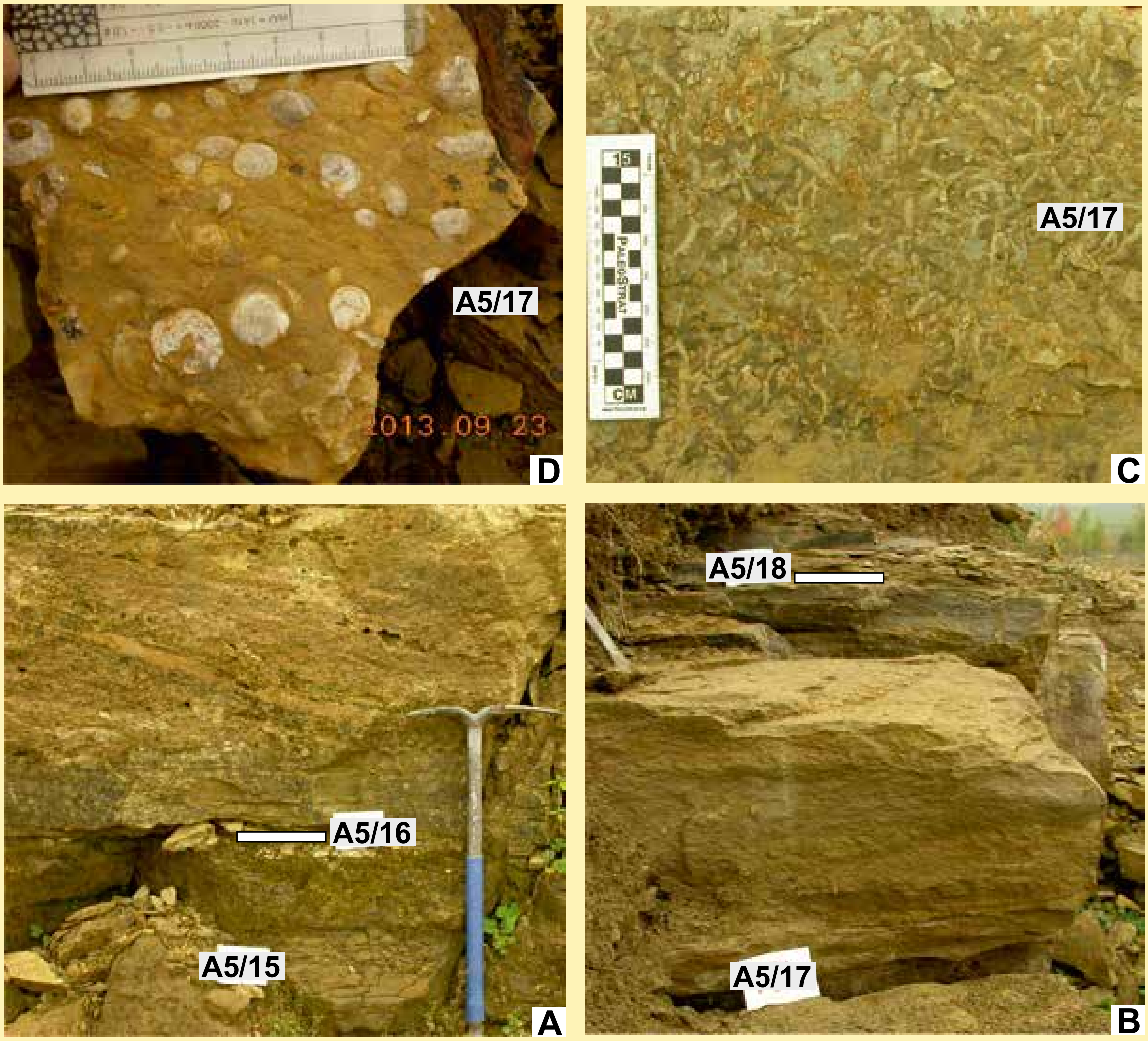
Package A5/23 Interval 63.70–63.90 m Thickness 0.20 m

Limestone: light-grey, fine-grained, arenaceous, locally preserving subhorizontal wavy lamination. Horizontally, 200 m north of this station, in outcrop A7, the package is replaced with alternation of platy limestones and sandstones which thickness is increased to 1.5 m.

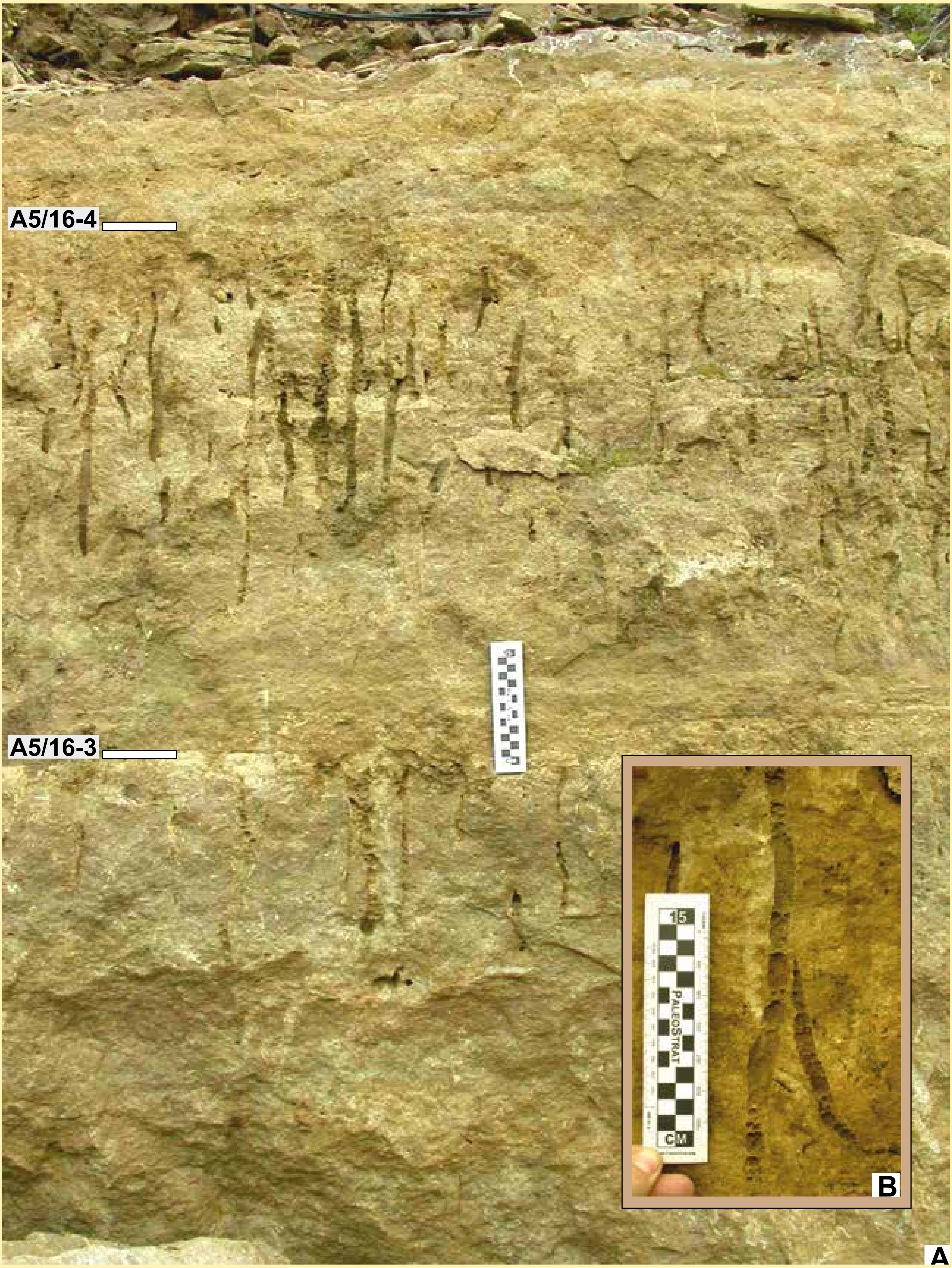
Package A5/24 Interval 63.90–65.55 m Thickness 1.65 m
Limestone: light-grey, yellowish-grey, with oolitic and bioclastic interbeds.
The package can be divided into four parts, from base to top:

Bed A5/24-1 [0.00–0.60] Interval 63.90–64.50 m Thickness 0.60 m
Limestone: porous, oolitic and bioclastic, with solid laminated interbed in the bottom and abundant upright channels (two intervals, in 0.05–0.15 and 0.40–0.60 m from the base). Some channels are branched in their lower end. The rock contains dispersed internal moulds of gastropods and the large schizodont bivalves *Oriocrassatella plana* Golowk. The top of the bed is undulating, erosional.
Bed A5/24-2 [0.60–0.90] Interval 64.50–64.80 m Thickness 0.30 m
Limestone: porous, bioclastic and riddled by upright channels in the lower part (0.0–0.2 m); arenaceous and horizontally laminated in the upper part (0.2-0.3 m).
Bed A5/24-3 [0.90–1.20] Interval 64.80–64.95 m Thickness 0.15 m
Limestone: bioclastic, platy, solid; bioclasts and plant debris define the fine horizontal lamination.
Bed A5/24-4 [1.20–0.90] Interval 64.95–65.55 m Thickness 0.60 m
Limestone: bioclastic, oolitic, bioturbated, with several types of upright slightly curved channels resembling *Scolithos*. Small bivalves *Schizodus* and *Netschajewia* are preserved probably *in situ*.

Package A5/25 Interval 65.55–68.55 m Thickness 3.0 m
Alternation of sandstone, siltstone and mudstone: dark greenish-grey in the lower part and brownish-grey in the upper part. No fossils.



Outcrop A5. Cross-bedded limestone (package A5/16) overlays 'tobacco' platy sandstone (package A5/15) (A), (B) the boundary between package A5/17 (sandstone) and A5/18 (argillaceous package), (C) bottom surface of package A5/17 with subhorizontal branched trace fossils, and (D) the bedding plane of the middle part of package A5/17 with a pavement of the brachiopods *Dielasma* and *Cancrinella*



Outcrop A5. Upper part of package A5/16, limestone with abundant upright channels (A), and (B) details of branched upright channel

Geochemistry data

Geochemical data were obtained by electron spin resonance (ESR) and X-ray fluorescence (XRF) methods. The distribution of the characteristic paramagnetic labels and most important chemical parameters along the summary section and within sedimentary environmental groups is shown in the table and on the summary section (below).

The calcite mineralisation was fixed at the lower part of the section (packages 4–9) on Mn^{2+} labels. The dolomite mineralisation (on α label) was observed at the upper part of the section (packages 10–13, 16, 18, 21–24). The bottom of bed 10 was revealed as the low level of dolomite mineralisation zone.

The paramagnetic labels SO_3^-, PO_2^-, C_{600} point on unaltered carbonates, especially, in packages 10, 12, 16, 18. The labels of E'-centres and R-centres reflect events of terrestrial flux, especially, during Krasnyi Yar time. Packages 23–24 (the Upper Kazanian) are composed of significantly altered carbonates (on the absence of labels SO_3^-).

On XRF data, three components are revealed as the most important. There are silicon (quartz), calcium (carbonate minerals) and aluminium (argillaceous minerals) in the composition of investigated rocks. On the summary section, one can see that the sum of these elements is greater than 70 %. The significance of these components is highlighted by the triangular diagram and plots Al vs. Si and K vs. Al. A marine paleobioproductivity and paleoredox-conditions can be interpreted in Cu, Ni, Zn and Mo variations, respectively.

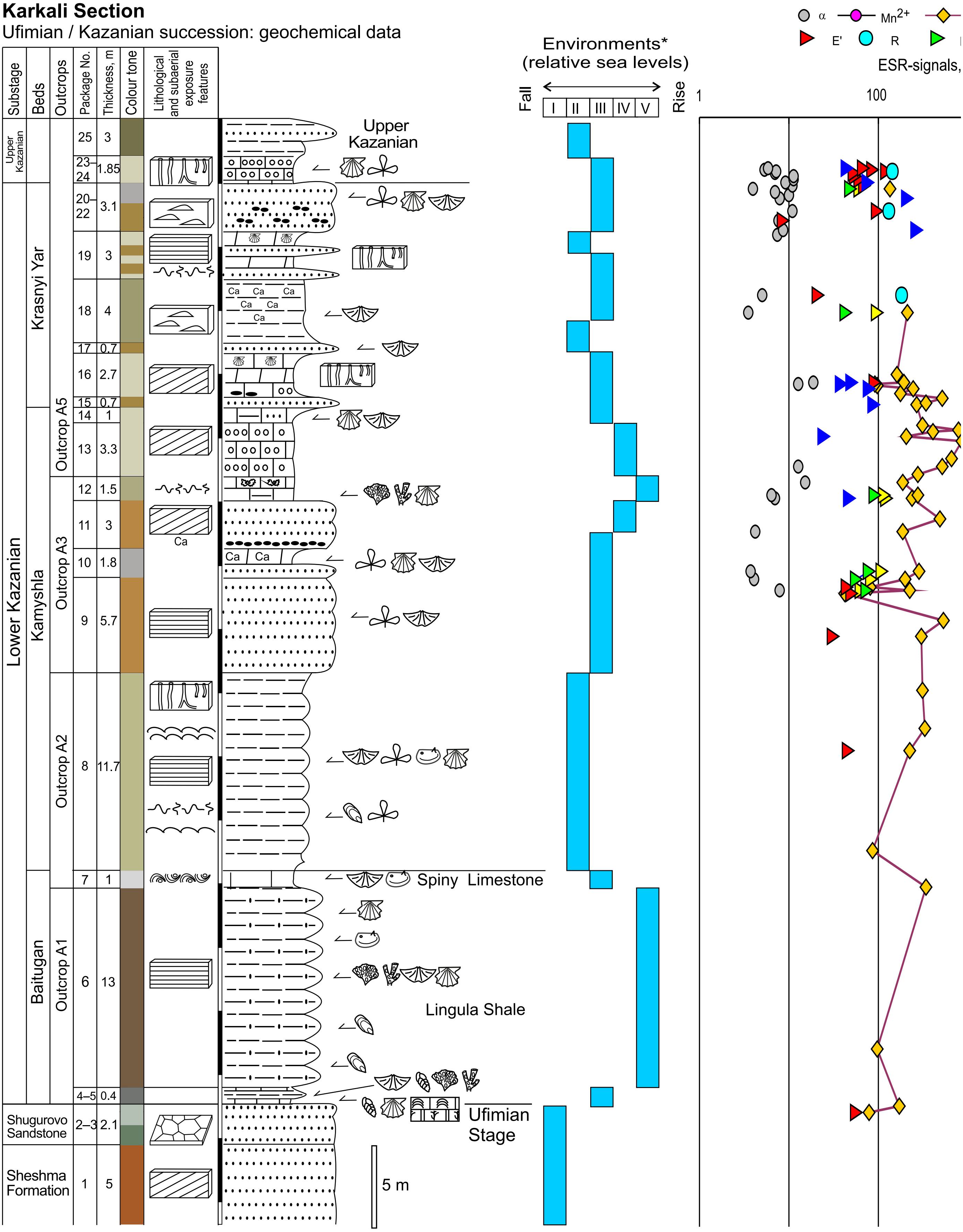
The geochemical variations specifically reflect the lithostratigraphic and the facial alternation within the Lower Kazanian succession; therefore they can be used as the reconstructive criteria in the stratigraphic and facial framework of the Kazanian in the Volga-Kama region.

Outcrop A5. Coquina-limestone of bed A5/16-4 with flat angulated fragment of carbonate rock

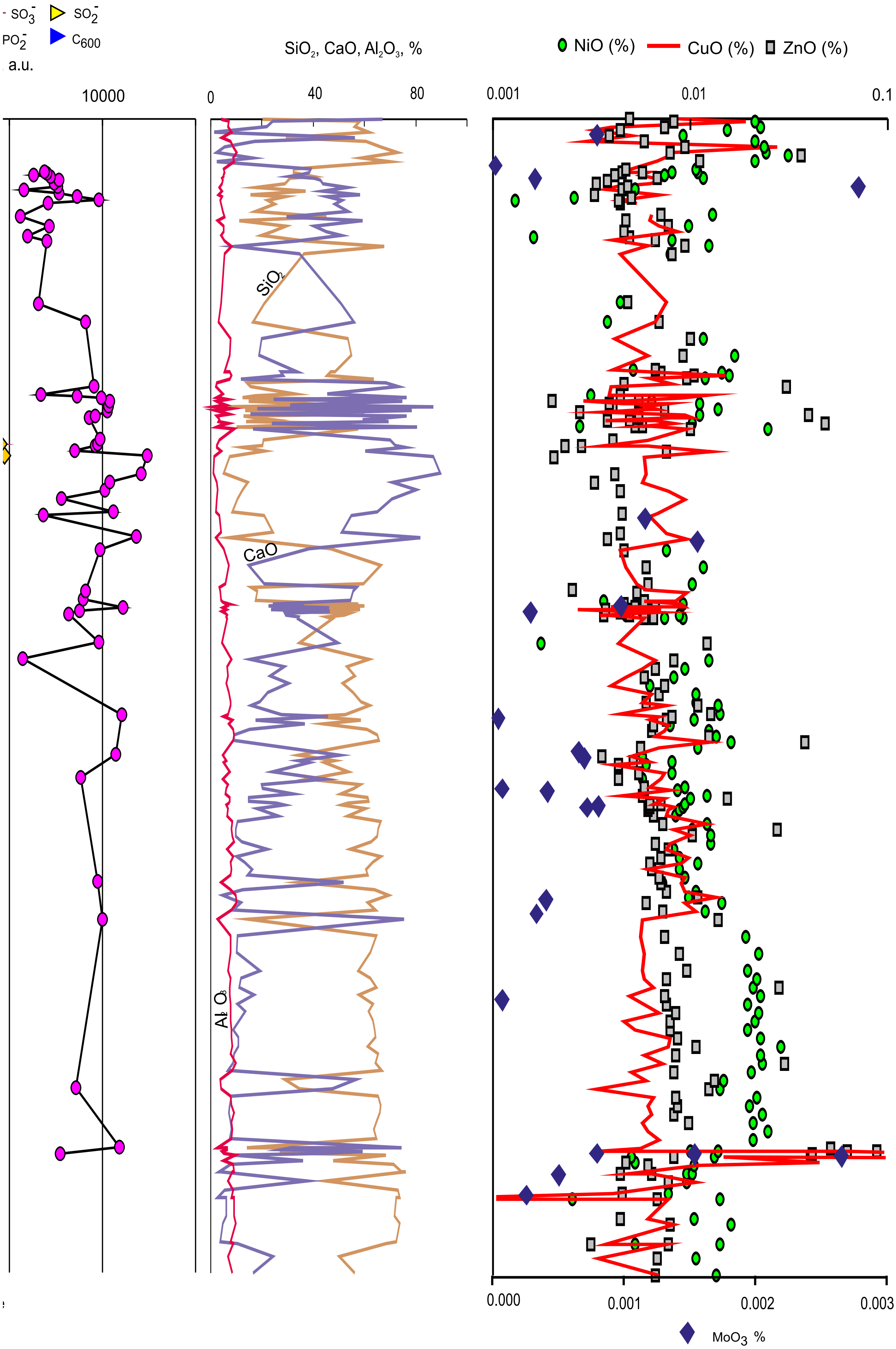
Stratigraphic unit	Packages No.	Sedimentary environments	Sea level, a.u.	Paramagnetic labels	XRF labels
Ufimian stage	1–3	Delta	I		Redox-potential is not high
Baitugan	4–5	Littoral	III	Mn^{2+}, SO_3^-, E'	Redox-potential is low
	6	Transgression. Sublittoral. Below base of waves	V	Mn^{2+}, SO_3^-	Bioproductivity is high
	7	Shallow water. Littoral	III	Mn^{2+}, SO_3^-	Redox-potential is low
Kamyshla	8	Regression. Shallow water. Littoral	II	Mn^{2+}, SO_3^-	Bioproductivity is not high, redox-potential is not high
	9–11	Passive shallow water. Channels and ichnofossils	II–III	Mn^{2+}, SO_3^-, E'	Bioproductivity is high, redox-potential is not high
	12	Local transgression. Littoral.	V	Mn^{2+},SO_3^-, SO_2^-, C_{600}, PO_2^-	Redox-potential is low. Bioproductivity is decreasing
	13	Ooiltes. Littoral	IV	Mn^{2+},SO_3^-, C_{600}	Bioproductivity is high
	14	Oolites and ichnofossils. Littoral	III	Mn^{2+},SO_3^-, C_{600}	Bioproductivity is high, redox-potential is not high
Krasnyi Yar	15	Active littoral	III	Mn^{2+}, E', R, PO_2^-	Redox-potential is high
	16	Local lagoons	II	Mn^{2+}, SO_3^-, C_{600}	Bioproductivity is high, redox-potential is high
	17	Channels	II		
	18	Active littoral	II-III	Mn^{2+}, E', R, PO_2^-, SO_3^-, SO_2^-	Redox-potential is high
	19	Littoral	III-II		Redox-potential is high
	20–22	Littoral with channels	III	Mn^{2+}, E', R, C_{600}	Bioproductivity is high, redox-potential is high
The Upper Kazanian substage	23–24	Oolites and ichnofossils. Littoral	III	Mn^{2+},SO_3^-, SO_2^-, PO_2^-, C_{600}, C_{350}, E', R	Bioproductivity is high
	25	Littoral with channels and fans	II		Redox-potential is not high. Bioproductivity is high

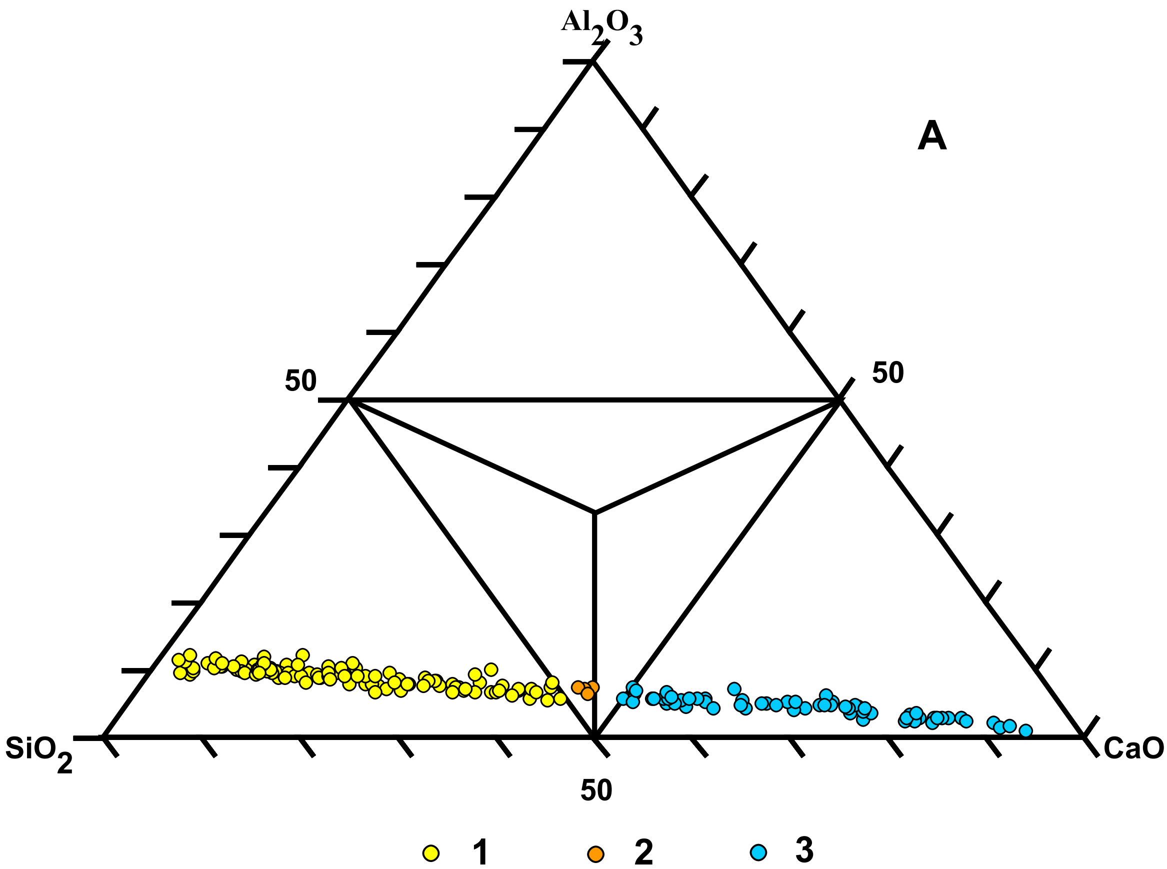
Karkali Section

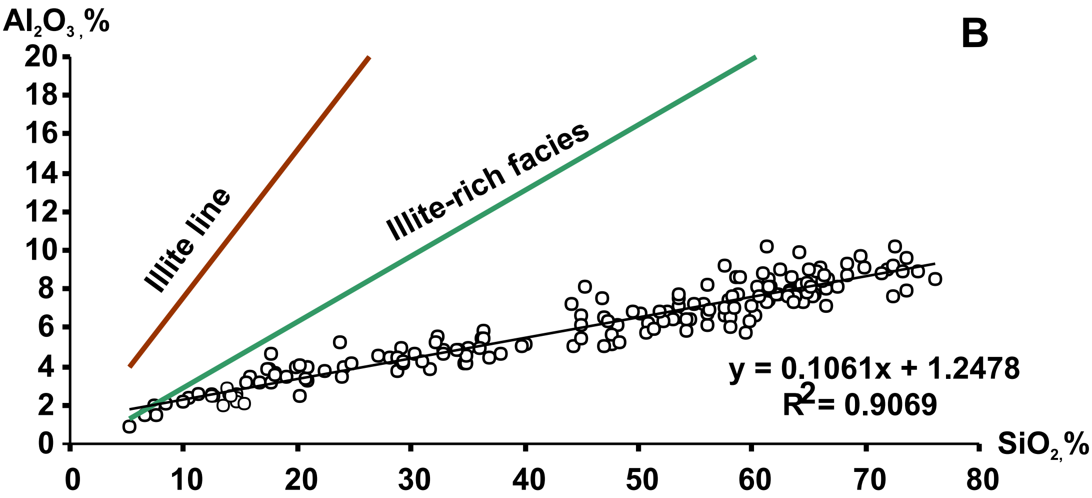
Ufimian / Kazanian succession: geochemical data

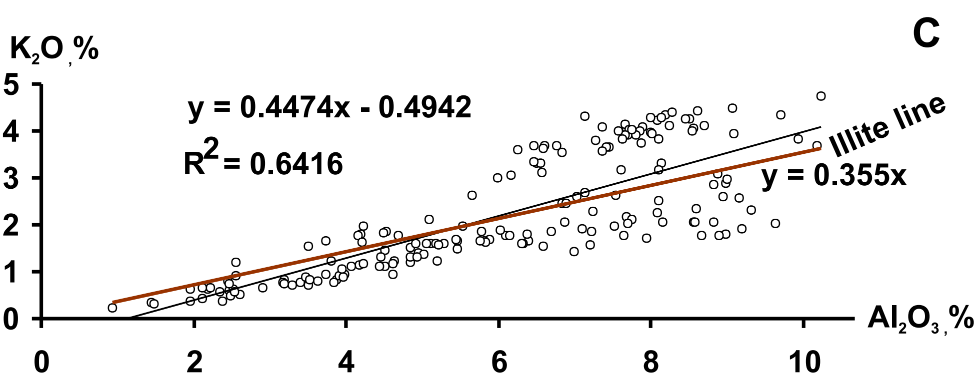


*Sedimentary environments I–V are presented in the table


SO3
SO2
PO2
C600
a.u.
10000
SiO2, CaO, Al2O3, %
0
40
80
SiO2
CaO
Al2O3
NiO (%)
CuO (%)
ZnO (%)
0.001
0.01
0.1
0.000
0.001
0.002
0.003
MoO3 %







Geochemical plots. Diagram of the main components Si (quartz), Al (shale minerals), Ca (carbonate minerals): 1 – sandstones, siltstones and mudstones; 2 – mixed rocks; 3 – carbonate rocks (A); and (B, C) approximation of argillaceous component as predominantly illite

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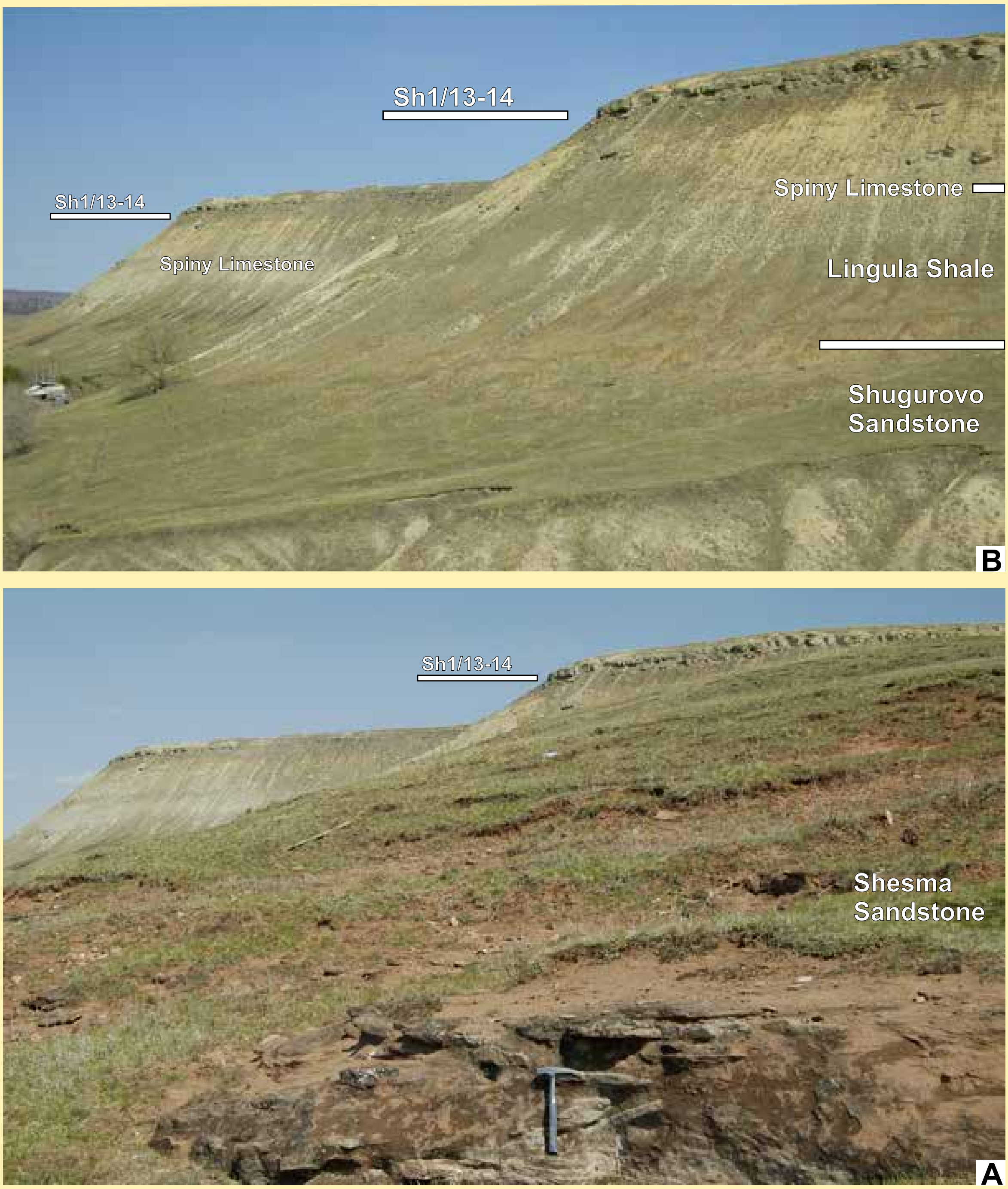
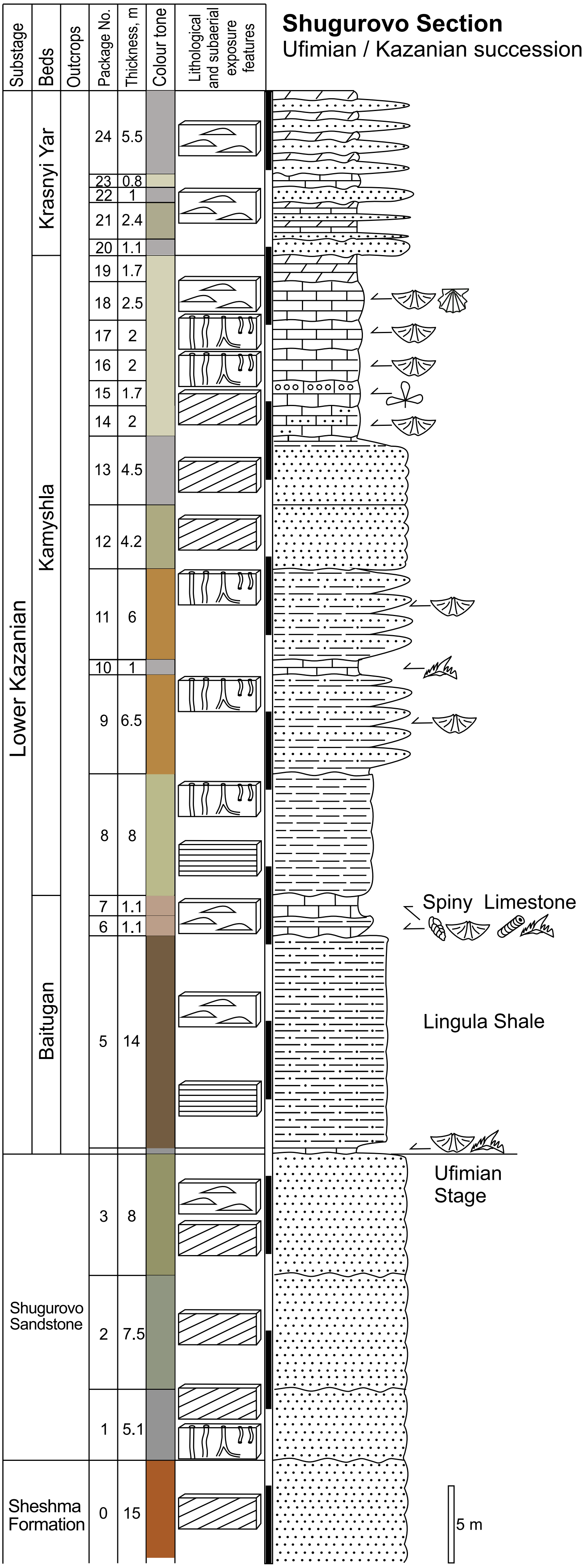
SHUGUROVO SECTION. BITUMINOUS DELTAIC SANDSTONES OF THE SHESHMA FORMATION (UFIMIAN) AND SHALLOW MARINE LOWER KAZANIAN

The last stop of the excursion includes viewing the outcrops of the Ufimian / Kazanian succession exposed near the village of Shugurovo and in the vicinity of the Shugurovo Tar Plant. The section here is similar to that described near the village of Karkali. Changes in the thicknesses of the packages are characteristic of the lower part of the section composed of sandy series. The summary section (based on Kotlyar et al., 2007) includes all packages recognised in the Karkali section.



Outcrop Sh1. General view of the outcrop from the base of Sheshma Sandstone (A), and from the top of Shugurovo Sandstone (B)

Shugurovo Section
Ufimian / Kazanian succession



Paleomagnetic data

Paleomagnetologists repeatedly studied the Ufimian / Kazanian succession exposed near the villages of Shugurovo and Karkali (Boronin, Burov, 1977; Burov et al., 1998). Oriented samples were taken vertically at approx. 1.0 m intervals. The Sheshma Formation (Ufimian) and the Kazanian are magnetised by the reversed polarity field of the Kiaman Hyperzone (R_1P).

Formation / age	N	Direction of J_n^o – ancient component of natural residual magnetisation		Precision of Jn_o vectors		Paleomagnetic pole in present geographic coordinates	
		D	I	α_{95}	K	Φ	Λ
Lower Kazanian	126	226	–38	8	10.1	50	169
Sheshma / Ufimian Stage	20	228	–29	6			

Paleontological data

Lower Permian

Sakmarian Stage

Light-grey solid limestone of the Sakmarian Stage contains fusulinids, colonial corals, ostracods, the crinoids *Columnaria stuckenbergi* Ger., the gastropods *Bellerophon* sp., the bivalves *Schizodus* sp. and *Cyrtodontarca bakewellioides* Jakow. The Lower Permian Age is confirmed by *Cyrtodontarca bakewellioides* Jakowlew which is an index-fossil for the Sakmarian of the Volga-Urals and the Donets Basin.

Ufimian Stage

Sheshma Formation

Non-marine bivalves

Reddish-brown shales exposed near the western outskirts of the village of Karkali contain rare non-marine bivalves *Palaeomutela* ex gr. *attenuata* Gus., and *P.* (*Palaeanodonta*) *castor* (Eichw.). This impoverished assemblage coincides with the non-marine bivalve range zone *Palaeomutela castor* (Silantiev, 2014) of the Ufimian age.
The variegated sandstone of the Sheshma Formation does not contain fossils.

Shugurovo Sandstone (Shugurovo Beds)

Cross-bedded greenish-grey bituminous sandstones forming the basal transgressive part of the Lower Kazanian succession contain no marine fossils. The interbeds of sheet-laminated algal-microbial limestones which are sparsely occurred in the sandstone succession contain non-marine ostracods, bivalves, fish scales and plant remains. Particularly, analogous sheet-laminated limestone, exposed 45 km south in the section near Kamyshla Village (type region of the Lower Kazanian), contains abundant plant assemblage (Fefilova, *in* Korellyatsiya… 1981) including mosses *Musci* sp., ground-pines *Lepidophlois* sp., Lycopodiales, *Tylodendron speciosum* Weis, *Signacularia noinskii* Zal., *Knorria* sp., *Viatscheslaviophyllum vorcutense* Neub., arthrophytes *Paracalamites frigidus* Neub., *P. decoratus* (Eichw.) Zal., *P. striatus* Schm., *P. robustus* Zal., *P. similis* Zal., *P. kutorgai* (Gein.) Zal., *Calamites gigas* Brogn. *Phyllotheca* cf. *biarmica* Zal., *Ph. deliquescens* (Goep.) Zal., *Ph. campanularis* Zal., *Ph. elaschewitschii* Radcz., *Sciadisca* sp., *Annularia* sp., *Sorocaulus czekanowskii* (Schm.), *Sphenophyllum* sp., pteridosperms *Paragondwanidium* cf. *sibiricum* (Zal.) S. Meyen, *Brongniartites salicifolius* (Fischer) Zal., *Comia* sp., *Compsopteris* sp., *Syniopteris* sp., *Iniopteris* sp., *Aphlebia* sp., *Isiolopteris serrata* Zal., *Odontopteris tatarica* Zal., *O. crenulata* Zal., *O. rossica* Zal., cordaites *Rufloria synensis* (Zal.) S. Meyen, *Cordaites* sp., ginkgophytes *Psygmophyllum* sp., conifers *Ullmannia biarmica* Zal., *U. bronii* Zal., *Phylladoderma meridionalis* S. Meyen, *Pseudovoltzia* sp., seeds *Carpolithes* sp., *Cordaicarpus* ex gr. *kovbassinae* Such., *C.* ex gr. *nanus* Such., *Samaropsis* ex gr. *siberiana* Zal., *S.* ex gr. *khalfinii* Such., *S.* aff. *elegans* Neub., *Cardiolepis* sp., *Sylvella* sp., *Nucicarpus* sp., reproductive organs *Permotheca* sp., *Peltaspermum* sp., *Cordiacarpus* sp., Paracalamostachys sp., and charophytes.

Kazanian Stage

Lower Kazanian Substage

Baitugan Beds

Baitugan beds are mainly composed of grey-collared siltstone, shale, marl and limestone. Fossils are represented by marine organisms: small foraminifers, ostracods, bivalves, brachiopods, gastropods, bryozoans, crinoids, conodonts, and fish scales; sometimes the remains of plants are found. Rich miospore assemblages are obtained.

In general, the paleontological characterisation of the Baitugan beds is similar to that of the sections near Sentyak and Elabuga in the lower reaches of the Kama River.

The first appearance of the conodont *Kamagnathus khalimbadzhae* defines the biostratigraphic boundary of the Kazanian in the base of 'Dielasma Limestone' (package A1/5 in the Karkali section, and lowermost limestone of package 5 in the Shugurovo section).

The assemblage of small foraminifers represented mainly by calcareous forms is comparable with the *Nodosaria hexagona-Ichtyolaria subtilus* beds assemblage established in the Lower Kazanian of the East European Platform (Pronina, 1996).

Marine ostracods are characterised by diverse taxonomic composition, which is generally typical of the Lower Kazanian of the East European Platform. The assemblage contains *Amphissites tscherdynzevi* which is considered as the index-species of the Lower Kazanian Substage.

The miospore assemblage is typical of marine Lower Kazanian deposits and corresponds to the lower part of the *Lueckisporites virkkiae* Zone (Utting et al., 1997).

Two markers which we have already seen in the sections of the lower reaches of the Kama River are distinguished in the section.

1) *Lingula Shale Marker* (package A1/6 in the Karkali section and package 5 in the Shugurovo section) — bluish-grey, thinly bedded, platy shales with *Lingula orientalis* Gol.

2) *Spiny Limestone Marker* (package A1/6 in the Karkali section and packages 6 and 7 in the Shugurovo section) — the bioclastic limestone with numerous brachiopods *Cancrinella cancrini* (Vern.), *Dielasma netschajewi* Grig., *Licharewia rugulata* (Kut.), In some places the rock is overwhelmed by brachiopod spines, hence the name 'Koluchiy Izvestnyak' – '*Spiny Limestone'*.

Kamyshla Beds

In the sections near the villages of Shugurovo and Karkali, the Kamyshla Beds (thickness approx. 35 m) consist of grey and brownish-grey sandstone, shale and limestone, and contain only marine fossils including small foraminifers, ostracods, gastropods, bivalves, brachiopods, bryozoans, crinoids, conodonts, and fish scales.

The list of fossils follows below.

<u>Small foraminifers</u>: *Ammodiscus* sp., *Palaeonubecularia* sp., *Orthovertella* sp., *Pseudonodosaria* sp., *Globivalvulina* ex gr. *bulloides* (Brady), *Pseudoammodiscus kamae* (Tscherd.), *Ps. megasphaericus* (Gerke), *Ps. microsphaericus* (K. M.-Macl.), *Nodosaria elabugae* Tscherd., *N. netschajewi* Tscherd., *N. hexagona* Tscherd., *N.* ex gr. *saggita* K. M.-Macl., *N.* ex gr. *krotowi* Tscherd., *N.* ex gr. *farcimeniformis* K. M.-Macl., *N.* ex gr. *noinskii* Tscherd., *N.* ex gr. *pseudoconcinna* K. M.-Macl., *Lingulonodosaria kamaensis* K. M.-Macl., *Geinitzina angusta* Tscherd., *G.* ex gr. *postcarbonica* Spand., *G. spandeli* Tscherd., *G. kazanica* K. M.-Macl., *Ichtyolaria ex gr. fallax* (K. M.-Macl.), *Tetrataxis lata* Spand., *Hemigordius* ex gr. *planispiralis* K. M.-Macl., *Glomospira* ex gr. *gordialis* (Park. et Jon.), *Prothonodosaria praecursor* (Rauser), *Ichtyolaria* ex gr. *fallax* (K. M.-Macl.), *Ichtyolaria* sp.

<u>Ostracods:</u> *Healdia postcornuta* Schn., *Healdianella vulgaris* Kotsch., *Cavellina unica* Kotsch.

<u>Gastropods</u>: *Goniasma* sp., *Loxonema* sp., *Straparollus* sp., *Bellerophon* sp.

<u>Bivalves</u>: *Nuculopsis wymensis* (Keys.), *N. trivialis* (Eichw.), *Nuculana kasanensis* (Vern.), *Parallelodon* sp., *Lithophaga consobrina* (Eichw.), *Schizodus rossicus* Vern., *Permophorus simplex* (Keys.),

Pseudomonotis permianus Masl.*, Ps. speluncaria* Schloth., *Ps. (Trematiconcha) noinskii* (Licharew), *Oriocrassatella plana* (Gol.).
Bryozoans: Trepostomida gen. indet., Fenestrida gen. indet.
Conodonts: *Kamagnathus khalimbadzhae* Chern.
Brachiopods: *Cancrinella cancrini* (Vern.), *Terrakea hemisphaeroidalis* (Netsch.), *Aulosteges* sp., *Licharewia rugulata* (Kut.), *L. stuckenbergi* (Netsch.), *L. schrenckii* (Keys.), *Licharewia* sp., *Beecheria netschajewi* Grig., *Pinegathyris royssiana* (Keys.), *Cleiothyridina pectinifera* (Sow.). The species of *Terrakea* and *Licharewia* are the index-fossils of the Lower Kazanian.

Distribution of brachiopods in the Kazanian of Karkali and Shugurovo Sections

	Lower Kazanian			Upper Kazanian
	Baitugan Beds	Kamyshla Beds	Krasnyi Yar Beds	
Lingula orientalis Gol.	X			
Cancrinella cancrini (Vern.)	X	X	X	X
Aulosteges sp.	X	X	X	X
Cleiothyridina pectinifera (Sow.),	X	X	X	X
Campbellelasma vulgaris Smirn.	X			
Campbellelasma variiforme Smirn.	X			
Dielasma netschajewi Grig.	X	X	X	X
Pinegathyris royssiana (Keys.)	X	X		X
Terrakea (?) hemisphaeroidalis (Netsch.)		X		
Licharewia stuckenbergi (Netsch.)		X		
Licharewia rugulata (Kutorga)	X	X	X	
Licharewia schrenkii (Keys.)		X		

The brachiopod assemblage allows the tracing of Kamyshla beds throughout the east of the East European Platform.

Krasnyi Yar Beds
The Krasnyi Yar beds consist of marine sandstone and bioclastic bioturbated limestone. Fossils are represented by impoverished assemblages of small foraminifers, scyphozoan cnidarians, ostracods.
Small foraminifers: Nodosaria sp.
Scyphozoan cnidarians: *Conularia hollebeni* Gein.
Bivalves: *Lithophaga consobrina* (Eichw.), *Schizodus rossicus* Vern., *Permophorus simplex* (Keys.), *Pseudomonotis permianus* Masl.*, Oriocrassatella plana* Golowk.
Brachiopods: *Cancrinella cancrini* (Vern.), *Aulosteges* sp., *Dielasma netschajewi* Grig., *Licharewia rugulata* (Kutorga).
Bryozoans: Trepostomida gen. indet.

The impoverished euryhaline invertebrate assemblage indicates contamination of marine environments probably associated with decreasing of basin salinity.

The Upper Kazanian age of the overlying succession is determined based on its lithology and sequence-stratigraphic analysis.

The stratotype and reference Middle and Upper Permian outcrop sections collected in this guide-book provide the insight into the facies pattern, sedimentary history, and biostratigraphic correlative potential of the historical Ufimian, Kazanian, and lower Tatarian stages. Intergradation of shallow-marine fossiliferous and continental beds would potentially enable a better understanding of the correlation of the Boreal and Tethyan successions of the Permian in the marine and continental facies.

REFERENCES

Arefiev MP, Silantiev VV (2014) Sedimentological and geochemical evidence for cyclicity recorded in Urzhumian and Severodvinian successions at the key section of Monastyrskii Ravine (Kazan Volga, East European Platform). CPC–2014 Field Meeting on Carboniferous and Permian Nonmarine – Marine Correlation, Freiberg, pp 4–5

Aref'ev MP, Kuleshov VN, Pokrovskii BG (2015) Carbon and oxygen isotope composition in Upper Permian–Lower Triassic terrestrial carbonates of the East European Platform: a global ecological crisis against the background of an unstable climate. Doklady Earth Sciences. 460(1):11–15

Balabanov YuP (2007) Paleomagnetic characteristics. In: Larochkina IA, Silantiev VV (eds) Geologicheskiye pamyatniki prirody Respubliki Tatarstan. Kazan, p 83 (in Russian)

Balabanov YuP (2014) Paleomagnetic characterization of the Middle and Upper Permian deposits based on the results from the key section in the Monastery Ravine. In: Proc. Kazan Golovkinsky Stratigraphic Meeting, Kazan, pp 14–17

Balabanov YuP, Minikh MG, Minikh AV (2009) Kiama–Illavarra reversal in reference section of Biarmian–Tatarian boundary deposits of Permian in Monastery Ravine. In: Upper Paleozoic of Russia: stratigraphy and facial analyses. Kazan, pp 168–169 (In Russian)

Balme BE (1979) Palynology of Permian–Triassic boundary beds at Kap Stosch, East Greenland. Meddelelser om Grønland, 200(6):1–46

Banner JL, Hanson GN (1990) Calculation of simultaneous isotopic and trace element variations during water–rock interaction with application to carbonate diagenesis. Geochim. Cosmochim. Acta, 54(3):1–23

Belousova ZD (1956) Ostracods from the Upper Permian. In: Voprosy stratigrafii, paleontologii i litologii paleozoya i mezozoya raionov Evropeiskoy chasti SSSR. Moscow, pp 73–117 (in Russian)

Betekhtina OA, Tokareva PA (1988) Nemorskie dvustvorki (Non-marine bivalves). In: Verkhniy Paleozoi Angaridy. Fauna i Flora. Novosibirsk, pp 59–71 (in Russian)

Bludorov AP (1964) A history of the Paleozoic coal accumulation in the southeast of the Russian Platform. Moscow, 305 p (In Russian)

Bogov AV (1971) Stratigraphical Implication of Spore-and-Pollen Complexes in Permian Sediments on the Territory of Tatar Republic. In: Geologiya Povolzh'ya i Prikam'ya (Geology of the Volga River Region and Kama River Region), Kazan, pp 157–164 (in Russian)

Bogov AV (1973) The Ufimian rocks in the Republic of Tatarstan studied by the structure boring. In: Materials on the geology of the east of the Russian Platform, Kazan, 5:185–191 (in Russian)

Bogov AV (1977) To the Paleontological Characteristic of Ufimian Sediments in the Tatar Republic. In: Materialy po Stratigrafii Verkhnei Permi na Territorii SSSR (Materials on Stratigraphy of the Upper Permian on the Territory of the Soviet Union), Kazan, pp 174–181 (in Russian)

Brand V, Veizer J (1981) Chemical diagenesis of a multicomponent carbonate system: 2, Stable isotopes, J. Sediment. Petrol. 51:987–997

Bulanov VV (2014) The character of changes in aquatic tetrapod communities of the East Europe in the Late Urzhumian – Early Severodvinian time. In: Proc. Kazan Golovkinsky Stratigraphic Meeting, Kazan, pp 25–26

Bulanov VV, Ivanov AO, Kuznetzova JV, Silantiev VV (2014) The new locality of the Late Urzhumian vertebrate fauna in Kazan Region (East European Platform, Russia) In: Proc. Kazan Golovkinsky Stratigraphic Meeting, Kazan, pp 27-28

Burov BV, Boronin VP (1977) Palaeomagnetic Illawara Zone in the Upper Permian and Lower Triassic deposits of the Middle Volga Region. In: Materialy po Stratigrafii Verkhnei Permi na Territorii SSSR (Materials on Stratigraphy of the Upper Permian on the Territory of the Soviet Union), Kazan, pp 25–52 (in Russian)

Burov BV, Nurgaliev DK, Yasonov PG (1986) Paleomagnitnyi analiz (Paleomagnetic analysis). Kazan, 168 p (in Russian)

Burov BV, Zharkov IYa, Nurgaliev DK, Balabanov YuP, Borisov AS, Yasonov PG (1998) Paleomagnetic Characteristics of Upper Permian Sections in the Volga and the Kama areas. In: Esaulova NK, Burov BV, Rozanov AYu (eds) Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 236–263

Burov BV, Esaulova NK, Gubareva VS (eds) (1999) Verkhnepermskiye stratotipy Povolzhiya (Upper Permian stratotypes of the Volga region). Proc. Intern. symposium, Moscow, 380 p

Chalimbadja VG, Silantiev VV (1997) Conodonts from the Upper Permian type strata of European Russia. Proceedings of the Royal Society of Victoria, 110(1/2):137–145

Chernykh VV, Chalimbadja VG, Silantiev VV (2001) Representatives of the *Kamagnathus* gen. nov. (conodonts) from Kazanian Stage of Volga region. Ekaterinburg: Institut Geologii i Geokhimii, Collected articles, 6:74–82 (in Russian)

Chuvashov BI, Dyupina GV (1973) Upper Palaeozoic terrigenous deposits of western slope of Middle Urals. Trudy Instituta Geologii i Geokhimii Sverdlovsk, 105:3–208 (in Russian)

Dedeev VA (eds.) (1981) Korrelyatsia raznofacialnykh otlozhenii verkhnei permi severa Evropeiskoi chasti SSSR (Correlation of different facies of the Permian of the north of the European part of the USSR). Leningrad, 160 p (in Russian)

De la Horra R, Galán–Abellán AB, López–Gómez J, Sheldon ND, Barrenechea JF, Luque FJ, Arche A, Benito MI (2012) Paleoecological and paleoenvironmental changes during the continental Middle–Late Permian transition at the SE Iberian Ranges, Spain. Global and Planetary Change, 94–95:46–61

Esaulova NK (1996a) The Stratotype of the Sokian Horizon near the village of Baitugan. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 70–78 (in Russian)

Esaulova NK (1996b) The Sheshmian Horizon in the basin of the Sheshma River. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 62–69 (in Russian)

Esaulova NK (1996c) Macroflora. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 303–333 (in Russian)

Esaulova NK (1998a) Sheshmian Horizon in the Basin of the Sheshma River. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 34–40

Esaulova NK (1998b) Stratotype of the Lower Kazanian Substage near the village of Baitugan (the Sok River). In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 40–46

Esaulova NK (1998c) Stratotype of the Povolzhyan Horyzon (Regional Stage) near the village of Pechishchi. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 46–52

Esaulova NK (1998d) Macroflora. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 193–209

Esaulova NK (1999) Zonal subdivision of Upper Permian of Volga–Ural region by charophytes. Upper Permian stratotypes of the Volga region. Proc. Internat. symposium. Moscow, pp 102–109

Esaulova NK, Lozovsky VR, Rozanov AYu (eds.) (1998) Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, 300 p

Esin DN, Mashin VL (1998) Ichthyolites. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 176–188

Faddeyeva IZ (1974) Palynological characteristics of the stratotypes of the Permian stages in the USSR. In: Palynology of the Proterophytic and the Paleophytic. Proc. 3rd Internat. Palynological Conference. Moscow, pp 135–139

Fischer P (1840) Nachtrag zur Hrn. Major von Qualen`s geognostischen Beitragen zur Kenntnis des westlichen Urals. Moscou, p 486

Forsch NN (1951) Stratigraphy and Facies of the Kazanian Stage in the Middle Volga River Region In: Tr. Vses. Nauchno-Issled. Geol.-Razved. Inst., Nov. Ser., 45:34–80 (in Russian)

Forsh NN (1955) The Permian Deposits. The Ufa Formation and the Kazanian Stage. Trudy Vsesoyuznogo nauchno–issledovatelskogo Instituta, Novaya Seria, 92, pp 1–156 (in Russian)

Forsh NN (1963) On the stratigraphic subdivision and correlation of Tatarian sections of east of the Russian platform by the complex of lithological-stratigraphic, paleomagnetic and paleontological data. In: Paleomagnetic stratigraphic research. Leningrad, pp 175–211 (In Russian)

Fredericks GN (1918) About the stratigraphy of the Permian deposits of the eastern European Russia. Izvestia Geologicheskogo Komiteta, 30(7–8):581–588 (in Russian)

Gayazova AK (1974) Spore–pollen assemblages of the Lower Kazanian deposits of the western part of the Orenburg oblast. In: Palynology of the Proterophytic and the Paleophytic. Proc. 3rd Internat. Palynological Conference. Moscow, pp 160–165

Gialanella PR, Heller F, Haag M, Nurgaliev D, Borisov A, Burov B, Jasonov P, Khasanov D, Ibragimov S, Zharkov I (1997) Late Permian magnetostratigraphy on the eastern Russian platform. Geologie en Mijnbouw, 76(1–2):145–154

Golubev VK (1996) Terrestrial vertebrates. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 381–389

Golubev VK (2000) The faunal assemblages of Permian terrestrial vertebrates from Eastern Europe. Paleontological Journal, 34(2):211–224

Golubev VK (2001) Event Stratigraphy and Correlation of Kazanian Marine Deposits in the Stratotype Area. Stratigraphy and Geological Correlation, 9(5):454–472

Golubev VK, Sennikov AG, Minih AV, Minih MG, Kuhtinov DA, Balabanov YuP, Silantev VV (2012) The Permian–Triassic boundary in the South–East of Moscow synclise. In: Problems of Paleoecology and Historical Geoecology. Saratov, pp 144–150 (in Russian)

Gomankov AV (1992) The interregional correlation of the Tatarian and the problem of the Permian upper boundary. International Geology Review, 34:1015–1020

Goretzki J (2003) Biostratigraphy of Conchostracans: A Key for the Interregional Correlations of the Continental Palaeozoic and Mesozoic – Computer–aided Pattern Analysis and Shape Statistics to Classify Groups Being Poor in Characteristics. PhD thesis, Bergakademie Freiberg, 2v

Götz AE, Ruckwied K (2014) Palynological records of the Early Permian postglacial climate amelioration (Karoo Basin, South Africa). Palaeobiodiversity and Palaeoenvironments, 94(2):229–235

Götz AE, Silantiev VV (2014) Palynology of the Kazanian stratotype section (Permian, Russia): palaeoenvironmental and palaeoclimatic implications. Palaeobiodiversity and Palaeoenvironments, 95(2):149–158

Götz AE, Ruckwied K, Barbacka M (2011) Reconstruction of Late Triassic (Rhaetian) and Early Jurassic (Hettangian) palaeoecology and palaeoenvironment of the Mecsek Coal Formation (S Hungary): implications from macro– and microfloral assemblages. Palaeobiodiversity and Palaeoenvironments, 91(2):75–88

Götz AE, Hancox J, Lloyd A (2013) Mozambique's coal deposits: unique palaeoclimate archives of the Permian period. Mozambique Coal Conference, Fossil Fuel Foundation, Johannesburg

Gradstein FM, Ogg JG, Smith AG (2004) A Geologic Time Scale. University, Cambridge, 589 p

Grigorieva AD (1962) Kazanian productids of the Russian Platform and their habitats. In: Tr. Paleontol. Inst. Moscow, 92:1–223 (in Russian)

Gusev AK (1990) Nemorskie dvustvorchatye mollyuski verkhnei permi Evropeiskoi chasti SSSR (Upper Permian Non-Marine Bivalves of the European Part of the USSR), Kazan, 293 p (in Russian)

Gusev AK (1996a) The reference section of the Urzhumian Stage in the Cheremushka ravine. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 113–122 (in Russian)

Gusev AK (1996b) The reference section of the Tatarian Stage near the Monastyrskoe village. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 123–141 (in Russian)

Gusev AK (1998a) Reference Section of the Urzhumian Horizon in the Cheremushka Gully. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 62–70

Gusev AK (1998b) Reference Section of the Tatarian Stage near the village of Monastyrskoe. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 70–79

Gusev AK, Burov BV, Esaulova NK et al. (1993) Biostratigraphy of the Upper Permian in Povolzhye and Prikamye. In: Bull. RMSK of the Central and Southern Russian Platform, 2: 77–80 (in Russian)

Hamilton JB (1942) Ostracodes from the Upper Permian of Texas. J. Paleontol, 16(6):712–718

Henderson CM, Davydov VI & Wardlaw BR (2012) The Permian Period. Chapter 24 in The Geologic Time Scale 2012 (vol. 2). Elsevier, pp 653–679

Ignatiev VI (1962) The Tatarian Stage in the Central and Eastern Regions of the Russian Platform. Facies and Paleogeography. Kazan, Part 2, 337 p (in Russian)

Ignatiev VI (1976) The formation of the Volga–Urals Anteclise in the Permian Period, Kazan, 256 p (in Russian)

Ignatiev VI (1996) Patterns of facies changes of the Upper Permian Rocks in the Urals and Povolzhye. In: Stratotypes and Reference Sections of the Upper Permian in the Regions of the Volga and Kama Rivers, Kazan, pp 70–78 (in Russian)

Ignatiev VI, Urasina EA (1973) Diversity of faunal assemblages in the Kazanian or the right banks of the Kama and Vyatka Rivers In: Materials about the geology of the east of the Russian Platform, vol. 5, Kazan, pp 39–94 (in Russian)

Inozemtsev SA, Naugolnykh SV, Yakimenko EY (2011) Upper Permian paleosols developed from limestone in the middle reaches of the Volga River: Morphology and genesis. Eurasian Soil Science, 44(6):604–617

Inozemtsev SA, Targulian VO (2010) Verkhnepermskiye paleopochvy: svoystva, processy, usloviya formirovaniya (Upper Permian Paleosols: Features, Processes, Environment), Moscow, 188 p

Ivanov AA, Voronova ML (1975) The Verkhnekamskoe Deposit of the Potassium Salt. Leningrad, 219 p (in Russian)

Ivanov AO (2011) Permian anachronistid sharks of the East European Platform and Urals. In: Palaeozoic and Mesozoic Vertebrates of Eurasia: Evolution, Assemblage Changes, Taphonomy and Palaeobiogeography, Proc. Intern. Conf., Moscow, pp 17–19 (in Russian)

Kanev GP (1985) Zonal division of Permian coal-bearing deposits of the Pechora Basin based on non-marine bivalves, Tr. Inst. Geol. AN SSSR, Komi Filial, 54:65–70 (in Russian)

Kanev GP (1994) Non-marine bivalve-based correlation of zonal stratigraphic scales of the Russian Platform and the Pechora Basin. Tr. Inst. Geol. AN SSSR, Komi Filial, 82:37–44 (in Russian)

Kellett B (1933) Ostracodes of the Upper Pennsylvanian and the Lower Permian strata of Kansas: I. The Aparchitidae, Beyrichiidae, Glyptopleuridae, Kloedenellidae, Kirkbyidae and Youngiellidae. J. Paleontol, 7–1:59–108

Kearsey T, Twitchett RJ, Newell AJ (2012) The origin and significance of pedogenic dolomite from the Upper Permian of the South Urals of Russia. Geol. Mag, 149(2):291–307

Khabarov EM, Ponomarchuk VA, Morozova IP (2000) Evolution of Isotopic Compositions of Strontium and Carbon from Carbonates of Riphean Basins on the Western Margin of the Siberian Craton, Novosibirsk, 1 pp

Khisamov RS, Gatiyatullin NS, Tarasov EA, Voitovich SE, Liberman VB, Shargorodsky IE, Voitovich ED, Ekimenko VA (2010) Geological exploration works in the regions with a high level of underground resources identification. Kazan, 274 p (in Russian)

Khramov AN (1963) Paleomagnitnoye izuchenie razrezov verkhney permi i nizhnego triasa severa i vostoka Russkoi platformy (Paleomagnetic study of Upper Permian and Lower Triassic sections of east and north of the Russian platform). In: Paleomagnetic stratigraphic research. Leningrad, pp 145–174 (In Russian)

Kochetkova NM (1970) Stratigrafiya i ostrakody verhnepermskih otlojenii juzhnyh rajonov Bashkirii (Stratigraphy and ostracods of Upper Permian deposits of South Bashkiria. Moscow, 117 p

Kopnin VI (1991) The Solikamsk Potassium–bearing Basin. International Congress 'Permian System of the World', Guidebook for geological excursions, Pt 3, no. 1, Sverdlovsk, pp 103–135

Koroloev ME, Sokolov MN and Nelidov NN (1974) Geological excursions in the Kazan Region, Kazan, 105 p (in Russian)

Kotlyar GV and Stepanov DV (eds) (1984) Osnovnye cherty stratigrafii permskoy sistemy SSSR (The main features of the stratigraphy of the Permian system of the USSR). Leningrad, 280 p

Kotlyar GV, Golubev VK, Silantiev VV (2014) General stratigraphic scale of the Permian marine–continental and continental formations of the East European Platform. In: Proc. Kazan Golovkinsky Stratigraphic Meeting Kazan, pp 49–51

Kotlyar GV, Golubev VK, Silantiev VV (2013) General stratigraphic scale of the Permian system: current state of affairs. In: General stratigraphic scale of Russia, Moscow, pp 171–179 (in Russian)

Kovda I, Morgun E, Gongalsky K (2014) Stable isotopic composition of carbonate pedofeatures in soils along a transect in the southern part of European Russia. Catena,112:56–64

Krotov P.I. (1894) Orohydrographical essay of the western part of the Vyatka Governorate in the limits of the 89th Sheet. Proceedings of the Geological Committee, 8(2):1–241 (in Russian)

Krotov P.I. (1900) Geological studies in the south-western part of the area of the 108th Sheet of the General Map of European Russia in the Vyatka Governorate. Publishing House of the Geological Committee, 19:161–200 (in Russian)

Krömmelbein K (1958) Ostracoden aus dem unteren Zechstein der Bohrung Leba in Pommern. Geologische Jahrbuch, 75:115–135

Kuleshov VN, Sedaeva KM, Stroganova YuYu (2011) Geochimiya izotopov ($\delta^{13}C$, $\delta^{18}O$) i usloviya obrazovaniya nizhne–srednepermskikh otlozhenii reki Soyany (Arkhangelskaya oblast') (Geochemistry of isotopes $\delta^{13}C$, $\delta^{18}O$ and conditions of formation of Lower–Middle Permian deposits of Soyana river (Arkhangelsk region)). Lithology and Natural resources.3:298–316 (In Russian)

Kump LR (1989) Alternative modeling approaches to the geochemical cycles of carbon, sulfur, and strontium isotopes. Am. J. Sci, 289:390–410

Kump LR (1991) Interpreting carbon–isotope excursions: Strangelove oceans. Geology, 19: 299–302

Kuznetsov A, Semikhatov M, Gorokhov I, Melnikov N, Konstantinova G and Kutyavin E (2003) Strontium Isotopic Composition of Carbonate Rocks of Karatavian Series of South Urals and Standard Curve of 87Sr/86Sr Ratio Variations in Late Riphean Ocean. Stratigraphy. Geological Correlation 11(5):415–449

Larochkina IA, Silantiev VV (eds) (2007) Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic). Kazan, 296 p (in Russian)

Leonova TB (2007) Correlation of the Kazanian of the Volga–Urals with the Roadian of the global Permian scale. Palaeoworld, 16:246–253

Leng MJ, Marshall JD (2004) Palaeoclimate interpretation of stable isotope data from lake sediment archives. Quaternary Science Reviews, 23:811–831

Levin NE, Quade J, Simpson SW, Semaw S, Rogers M (2004) Isotopic evidence for Plio–Pleistocene environmental change at Gona, Ethiopia. Earth and Planetary Science Letters, 219:93–110

Lozovsky VR, Balabanov YuP, Ponomarenko AC, Novikov IV, Buslovich AL, Morkovin BI, Yaroshenko OP (2014) Stratigraphy, paleomagnetism and petromagnetism of the Lower Triassic in Moscow syneclise. 1. Yug River basin. Bulletin of Moscow Society of Naturalists. Geological series. 89(2):61–72 (in Russian)

Mack GH, James WC, Monger HC (1993) Classification of paleosols. GSA Bulletin, 105:129–136

Makarova OV (2007) Miospores. In: Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic). Kazan, pp 82–83 (in Russian)

Malzahn E (1957) Neue Fossilfunde und vertikale Verbreitung der niederrheinischen Zechsteinfauna in den Bohrungen Kamp 4 und Friedrich Heinrich 57 bei Kamp Lintfort. Geol. Jb, 73:91–126

Mangerud G (1994) Palynostratigraphy of the Permian and lowermost Triassic succession, Finnmark Platform, Barents Sea. Review of Palaeobotany and Palynology, 82:317–349

McArthur JM, Howarth R and Bailey TR (2001) Strontium isotope stratigraphy: LOWESS Version 3, Best–fit line to the marine Sr–isotope curve for 0 to 509 Ma and accompanying look–up table for deriving numerical age. J. Geol, 109:155

Minikh MG, Minikh AV (1998) Fishes. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 258–269

Minikh MG, Minikh AV (1999) Stratigraphic significance of Late Permian fishes of the East European stratotype area. Fish assemblages and zonal scale. In: Upper Permian stratotypes of the Volga region. Proc. Intern. symposium. Moscow, pp 265–268 (In Russian)

Minikh AV, Minikh MG (2009) Ikhtiofauna Permi Evropeyskoy Rossii (Permian Ichthyofauna of European Russia), Saratov, 244 p (in Russian)

Minikh MG, Minikh AV, Molostovskaya II, Andrushkevich SO (2009) K voprosu o tochke stratigraphicheskoy granitsy severodvinskogo yarusa (On the question of the point of stratigraphic boundary of Severodvinian stage). Volga and Pricaspian Region Resources, 58:31–38 (In Russian)

Molin VA, Koloda NA (1972) Upper Permian spore and pollen assemblages of the north of the Russian platform. Leningrad, 76 p (in Russian)

Molostovskaya II (2009) The Urzhumian stage and its limitotype (boundary–stratotype). Volga and Pricaspian Region Resources, 59:40–45 (in Russian)

Molostovskaya II, Lukin VA (1998) The zonal subdivision of the Upper Permian based on different faunal and floral groups. Ostracods In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers. Moscow, pp 154–163

Molostovskii EA, Minikh AV (eds) (2001) Tatarian deposits of the Sukhona River. Saratov, 204 p (in Russian)

Morozova IP (1970) Late Permian bryozoans. Moscow, 203 p (in Russian)

Mouraviev FA, Arefiev MP, Silantiev VV, Khasanova NM, Nizamutdinov NM, Trifonov AA (2015) Red paleosols from reference sections of the Middle and Upper Permian of Kazan Volga region and their paleoclimatic significance. Paleont. Journal (in press)

Murchison R, Verneuil E, Keyserling A (1845) The geology of Russia in Europe and the Ural Mountains. London, Vol I: 652 p; Vol II: 512 p

Naugolnykh SV (2004) Permian and Early Triassic paleosols. In: Semikhatov MA, Chumakov NM (eds) Climate in the Epochs of Large Biospheric Rearrangements. Moscow, pp 194–220 (in Russian)

Naugolnykh SV (2007) Kazanian and Tatarian plants of Permian. In: Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic). Kazan, pp 236–254 (In Russian)

Netschaev AV (1894) Fauna from the Permian rocks of the east of the European Russia. In: Tr. O–va Estestvoispyt. pri Kazan. Univ, 1894, 27(4):1–503 (in Russian)

Netschaev AV and Zamyatin AN (1913) Geologicheskie issledovaniya severnoi chasti Samarskoi Gubernii (The geological study of northern part of Samara Gubernia). In: Trudy Geologicheskogo Komiteta, 84:1–208 (in Russian)

Noinsky ME (1899) The Permian sequence on the right slope of the Volga River near the village of Pechishchi opposite the city of Kazan. In: Tr. Kazan. O–va Estestvoispyt, Kazan, 13(6):34

Noinsky ME (1924) Some data on the structure and facies of the Kazanian in the Prikazansky District. Izv. Geol. Com, 43(6):565–622 (in Russian)

Noinsky ME (1932) Kratkiy ocherk istorii izucheniya nedr Tatrskoi Respubliki (Brief history of mineral investigation in the Tatar Republic). In: Mineral resources of Tatar Republic. Kazan, pp VII-LXXXV (in Russian)

Nurgalieva NG, Nurgaliev DK (2015) Cyclical composition of Permian rocks. ARPN JEAS, 10–1:279–290

Nurgalieva NG, Ponomarchuk VA, Nurgaliev DK (2007) Strontium Isotope Stratigraphy: Possible Applications for Age Estimation and Global Correlation of Late Permian Carbonates of the Pechischi Type Section (Volga River). Russian Journal of Earth Sciences, 9 (1):ES1002

Nurgalieva NG, Silantiev VV, Vetoshkina OS, Ponomarchuk VA, Nurgaliev DK, Urazaeva MN (2015). Some new data on isotope stratigraphy of the Permian rocks at the east of the Russian Platform. ARPN JEAS, 10(10):4436–4442

Paprocka A (2007) Stable carbon and oxygen isotopes in recent sediments of lake Wigry, NE Poland: implications for lake morphometry and environmental changes. In: Dawson TE, Siegwolf RTW (eds) Stable Isotopes as indicators of Ecological Change, pp 267–282

Poyato–Ariza, FJ, Talbot MR, Fregenal–Martinez MA, Melendez N and Wenz S (1998) First isotopic and multidisciplinary evidence for non–marine coelacanth and pycnodontiform fishes: palaeoenvironmental implications. Palaeogeogr. Palaeoclimatol. Palaeoecol, 144:65

Pronina GP (1996) Foraminifers. In: Esaulova NK, Lozovsky VR, Rozanov AYu (eds.) Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers, Kazan, pp 246–257 (in Russian)

Pronina GP (1999) The correlation of Upper Permian deposits of the Boreal region of small foraminifera. In: Upper Permian stratotypes of Volga region: Proc. Internatl. Symposium, Moscow, pp 182–191

Raspopov G (1932) Geological discovery in the Upper Reaches of the Sheshma River in Bugulma Canton of Tatar Republic. In: Mineral resources of Tatar Republic, Kazan, pp 3–27 (in Russian)

Reshenie (1965) Mezhvedomstvennogo Soveshchaniya po Razrabotke Unìfitsirovannykh Stratigraficheskikh Skhem Verkhnego Dokembriya i Paleozoya Russkoi Platformy, 1962 (Resolution of the Interdepartmental Conf. on Elaboration of Unified Stratigraphic Schemes for Precambrian and Paleozoic of the Russian Platform, 19) (in Russian)

Reshenie (1990) Mezhvedomstvennogo Regional'nogo Stratigraficheskogo Soveshchaniya Po Srednemu I Verkhnemu Paleozoyu Russkoi Platformy, Leningrad, 1988 (Resolution of the Interdepartmental Stratigraphic Conf. on the middle and Upper Paleozoic of the Russian Platform, Leningrad, 1988) (in Russian)

Reshenie (2006) Mezhvedomstvennogo Stratigraficheskogo Komiteta i ego postoyannykh komissiy. Permskaya komissiya Resolution on the modernization of the Upper Series of the System (Kazan, July 14–15, 2004). St. Petersburg, VSEGEI, 36:14–30 (in Russian)

Retallack GJ (2005) Pedogenic carbonate proxies for amount and seasonality of precipitation in paleosols. Geology, 33:333–336

Ruckwied K, Götz AE, Jones P (2014) Palynological records of the Permian Ecca Group (South Africa): Utilizing climatic icehouse-greenhouse signals for cross basin correlations. Palaeogeography, Palaeoclimatology, Palaeoecology, 413:167–172

Ruckwied K, Götz AE, Pálfy J, Török Á (2008) Palynology of a terrestrial coal–bearing series across the Triassic/Jurassic boundary (Mecsek Mts., Hungary). Central European Geology, 51(1):1–15

Scholze F, Schneider JW (2015) Improved methodology of ‘conchostracan’ (Crustacea: Branchiopoda) classification for biostratigraphy. Newsletters on Stratigraphy 48 (3):287–298

Schmitz B, Aberg G, Werdelin L, Bendix–Almgreen S and Forey P (1991), 87Sr/86Sr, Na, F, Sr and La in skeletal fish debris as a measure of the paleosalinity of fossil–fish habitats, Geophysical Society of America Bulletin, 103:786

Sennikov AG, Golubev VK (2011) Discovery of the Triassic in Nizhny Novgorod City. In: Permian System: Stratigraphy, Paleontology, Paleogeography, Geodynamics, and Mineral Resources, Perm, pp 307–312 (in Russian)

Sennikov AG, Golubev VK (2012) On the Faunal Verification of the Permo–Triassic Boundary in Continental Deposits of Eastern Europe: 1. Gorokhovets–Zhukov Ravine. Paleontological Journal 46(3):313–323

Sementovsky YuV (1973) Usloviya obrazovaniya mestorozhdenii mineral’nogo syr’ya v pozdnepermskuyu epokhu na vostoke Russkoi platformy (The conditions of the formation of the Deposit of Mineral Resources in the Late Permian in the East of the Russian Platform). Kazan, 256 p

Silantiev VV (1996a) The Solikamskian Horizon of the Permian in the Fore–Urals. In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 13–55 (in Russian)

Silantiev VV (1996b) Solikamskian and Sheshmian Horizons in the reference sections along the Belaya River (Bashkortostan), In: Stratotypy i oporniye razrezy verkhney permi Povolzhya i Prikamya (Upper Permian Stratotypes and Reference Sections in Volga and Kama River Basins). Kazan, pp 56–61

Silantiev VV (1998a) Solikamskian Horizon in of the Permian in the Fore. In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers, Moscow, pp 11–31

Silantiev VV (1998b) Solikamskian and Sheshmian Horizons in the reference sections along the Belaya River (Bashkortostan). In: Stratotypes and reference sections of the Upper Permian in the regions of the Volga and Kama Rivers, Moscow, pp 31–34

Silantiev VV (2001) The organic world of Kazan Ages on the East European platform. In: The Evolution of the Organic World. Evolution of Biota. Tomsk, pp 732–737 (in Russian)

Silantiev VV (2007) Sections of Kazanian Stage. Classical section of stratotype of the Upper Kazanian In: Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic), Kazan, pp 33–49

Silantiev VV (2014) Permian Non–marine Bivalve Zonation of the East European Platform. Stratigraphy and Geological Correlation 22 (1):1–27

Silantiev VV, Esin DN (1993) The reference section of the Tatarian in the Monastery Gully (Prikazanskoe Povolzhye). Vestnik Moskovskogo Universiteta 4(4):38–48

Silantiev VV, Zharkov IYa, Sungatullin RKh, Khassanov RR (1998) International Symposium —Upper Permian Stratotypes of the Volga Region. Guidebook of Geological Excursion, Kazan, 76 p

Silantiev VV, Kurkova SV and Mouraviev FA (2007) The ‘Perekhodnaya’ Member in the Cheremushka Gully. In: Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic), Kazan, pp 60-66 (in Russian)

Silantiev VV, Morozov VP, Krinari GA et al (2007) The reference section of the Urzhumian Stage in the Cheremushka Gully. In: Geologicheskiye pamyatniki prirody Respubliki Tatarstan (Geological Heritage of Tatarstan Republic), Kazan, pp 84–92 (in Russian).

Silantiev VV, Golubev VK, Götz AE (2014a) Depositional model of the East European Platform during Kazanian (Roadian) time. Proc. Kazan Golovkinsky Strat. Meeting, Kazan, pp 80–82

Silantiev VV, Arefiev MP, Balabanov YuP, Golubev VK, Götz AE, Davydov VI, Kabanov PB, Kotlyar GV, Mouraviev FA, Nurgalieva NG, Nurgaliev DK, Urazaeva MN (2014b) Multidisciplinary stratigraphic research of the Middle and Upper Permian of East European Platform (preliminary results of 2013–2014). Proc. Kazan Golovkinsky Strat. Meeting, Kazan, pp 83–84

Shargorodsky IE, Liberman VB, Kazakov ER, Zinatova MF, Girina IN and Ziganshin AA (2005) New tectonic scheme of the central regions of the Volga Federal District. Georesources, 9(1):10–13

Shen SZ, Schneider JW, Angiolini L, Henderson CM (2013) The International Permian Timescale: March 2013 update. In: The Carboniferous–Permian Transition. New Mexico Museum of Natural History and Science, Bulletin 60:411–416

Slowakiewicz M, Kiersnowski H, Wagner R (2009) Correlation of the Middle and Upper Permian marine and terrestrial sedimentary sequences in Polish, German, and USA Western Interior Basins with reference to global time markers. Paleoworld, 18:193–211

Slyusareva AD (1960) Kazanian Spiriferids of the Russian Platform and their habitats. Tr. Paleontol. Inst, Moscow, 80:1–132 (in Russian)

Solodukho MG (1963) Lower Kazanian deposits of the central and southern parts of the Mariisko–Vyatskih uplifts. Uchenye Zapiski Kazanskogo Universiteta, 123(5):6–25 (in Russian)

Solodukho MG,Tikhvinskaya EI (1977) The basis for the subdivision of the Kazanian Stage into horizons. In: Materialy po Stratigrafii Verkhnei Permi na Territorii SSSR (Materials on Stratigraphy of the Upper Permian on the Territory of the Soviet Union), Kazan, pp 187–219 (in Russian)

Stephens NP, Summer DY (2003) Late Devonian carbon isotope stratigraphy and sea level fluctuations, Canning Basin, Western Australia. Palaeogeogr., Palaeoclimat., Palaeoeco., 191:203–219

Stratigraphic Code of Russia (2006). The Third edition, VSEGEI Press, St. Petersburg, 96 p (in Russian)

Stratigraphicheskie Skhemy paleozoiskikh otlozheniy. Permskaya Systema (Stratigraphic Schemes of the Paleozoic. The Permian System). Moskva, Gostoptekhizdat, 1962 (in Russian)

Stuckenberg AA (1890) General Geological Map of Russia, Sheet 138. Proceedings of the Geological Committee, 4(2):1–78 (in Russian)

Sungatullin RKh, Umantsev VV and Silantiev VV (1996) New data on the stratigraphy and mineral resources of the Elabuzhsko–Bondyuzhsky Arch. In: Permian deposits in the Republic of Tatarstan, Kazan, pp 20–26 (in Russian)

Tasch P (1987). Fossil Conchostraca of the Southern Hemisphere and Continental Drift. The Geological Society of America Memoir 165:1–290

Tikhvinskaya EI (1946) Stratigraphy of the red–bed Permian rocks in the east of the Russian Platform, Vol. 1. Uchenye Zapiski Kazanskogo Universiteta, 106–4(16):1–354 (in Russian)

Tcherdyntsev VA (1914) On the foraminifera fauna of the Permian strata of the eastern zone of European Russia. Trudy Obshestva estestvoispytatelei, Kazan, 17(5):1–88 (in Russian)

Ulmishek GF(2001) Petroleum Geology and Resources of the North Caspian Basin, Kazakhstan and Russia. U.S. Geological Survey Bulletin, 2201–B, 25 p

Utting J, Esaulova NK, Silantiev VV and Makarova OV (1997) Palynological assemblages from Ufimian and Kazanian stratotype areas in Russia and comparison with Canadian Arctic. Canadian J. Earth Sci, 34:1–16

Varyukhina LM (1971) The spores and pollen of red–coloured and coal bearing deposits of the Permian and Triassic in the northeast part of Russia. Leningrad, 159 p (in Russian)

Varyukhina LM, Koloda NA, Molin VA, Fefilova LA, Chalyshev VI (1975) Biogeographical zonation of the European North of the USSR (Permian and Triassic). Leningrad, pp 100–229 (in Russian)

Veizer J, Ala D, Azmy K, et al (1999) 87Sr/86Sr, ^{13}C and d^{18} O evolution of Phanerozoic seawater, Chem. Geol., 161, 59

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