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PALAEONTOLOGY AND STRATIGRAPHY OF THE MIDDLE AND UPPER PERMIAN

(KAZAN AREA, VOLGA RIVER REGION)

Teaching manual

KAZAN
2024

КАЗАНСКИЙ ФЕДЕРАЛЬНЫЙ УНИВЕРСИТЕТ
ИНСТИТУТ ГЕОЛОГИИ И НЕФТЕГАЗОВЫХ ТЕХНОЛОГИЙ

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ПАЛЕОНТОЛОГИЯ И СТРАТИГРАФИЯ СРЕДНЕЙ И ВЕРХНЕЙ ПЕРМИ Приказанского района Поволжья

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S 60 **Palaeontology and Stratigraphy of the Middle and Upper Permian** (Kazan Area, Volga River Region): Teaching manual / V.V. Silantiev, D.N. Miftakhutdinova. – Kazan: Kazan University Press, 2024. – 114 p.

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 handbook is intended for students and teachers of fieldwork techniques.

Силантьев В.В., Мифтахутдинова Д.Н.

С60 **Палеонтология и стратиграфия средней и верхней перм**и Приказанского района Поволжья: учебное пособие / В.В. Силантьев, Мифтахутдинова Д.Н. – Казань: Издательство Казанского университета, 2024. – 114 с.

Представлены подробные описания и новые биостратиграфические, палеомагнитные, геохимические, хемостратиграфические и седиментологические данные по важнейшим типовым и опорным разрезам уфимского, казанского, уржумского и северодвинского ярусов. Пособие предназначено для студентов и преподавателей, изучающих и преподающих методику полевых работ.

CONTENTS

PREFACE

Welcome to the Republic of Tatarstan and Kazan Federal University. Next year, 2025, marks the 210th 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 methods used by Smith were soon applied in the vicinity of Kazan by the first geologists of the recently founded Kazan University. Founded in 1804, Kazan Federal University (KFU) 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 palaeontology at Kazan University.

To meet the challenges of the modern world, in 2010, KFU Faculty of Geology was transformed into the Institute of Geology and Petroleum Technologies. The experience of KFU geology over the past 220 years allows us to reflect on past geological exploration surveys and what we’ve learned. This teaching manual contains up to date information on Permian stratigraphy, sedimentology and palaeontology in the Kazan Area of the Volga River Region, 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). 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).

This teaching manual is based on the “A Field Guidebook of XVIII International Congress on Carboniferous and Permian. Kazan, August, 16–20, 2015” published in 2015 (Nurgaliev, Silantiev and Nikolaeva (eds.), 2015). Author would like to thank all the contributors for providing material for this guidebook and also the KFU Publication staff for their efficient high-quality work.

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 most highly placed official of the Republic of Tatarstan is the Head of the Republic, Rustam Minnikhanov. The Prime Minister of the Republic of Tatarstan 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 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.

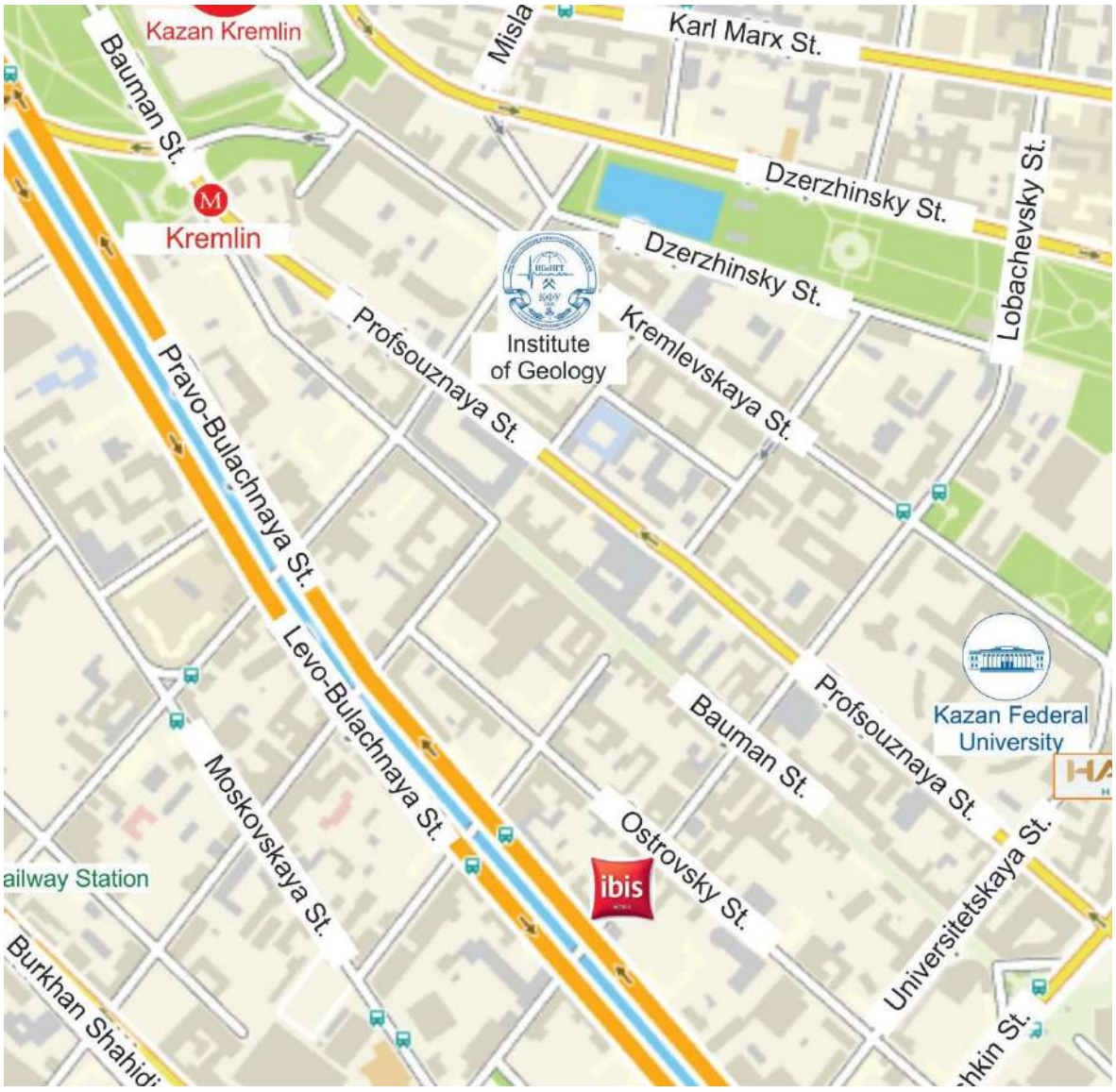
The name of the city ("kazan" means kettle in Turkic languages) fits the hot and bubbling rhythm of life in this remarkably beautiful city.

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!

Main building of the Kazan Federal University

Institute of Geology and Petroleum Technologies

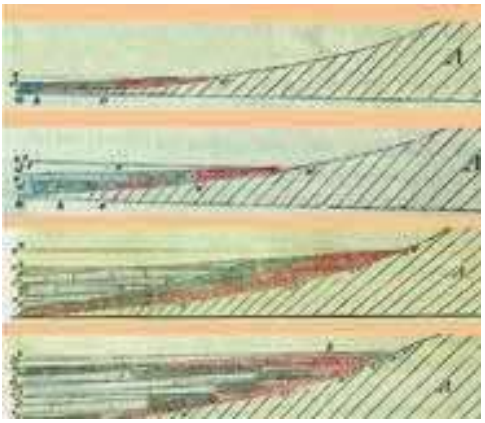
The Institute of Geology and Petroleum Technologies was established in 2011, based on the Geological Faculty of KFU. The Institute is the successor of the geological department.

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

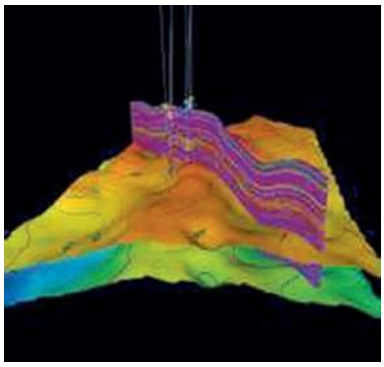
Institute of Geology and Petroleum Technologies is the leader of higher education in Russia in the fields of geological, geophysical, oil and gas technologies, engineering geology, hydrogeology and unconventional resources.

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"

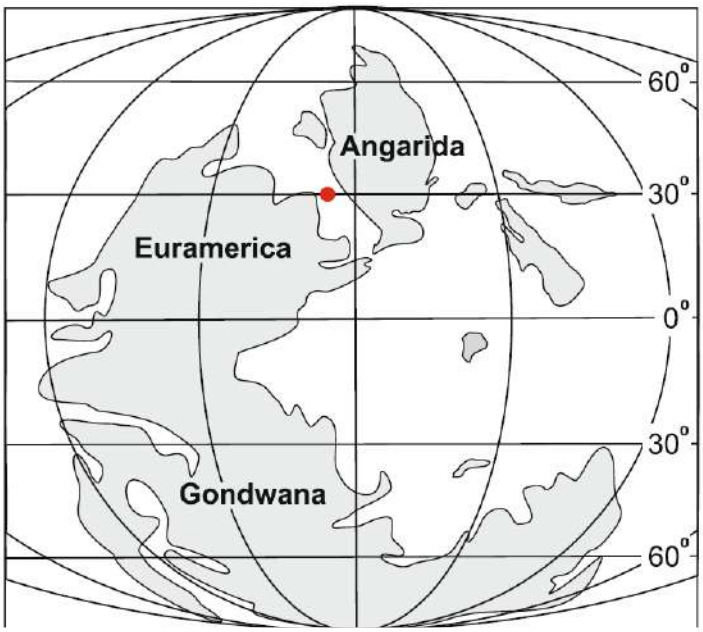
THE GEOLOGICAL SETTING AND PERMIAN STRATIGRAPHY OF THE AREA

Geographic settings

The area of the excursion is 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 (Volga and Kama rivers) to 364 m. The maximum altitudes are located in the south-east of the area, where the Bugulminsko-Belebeevskaya Uplift is located. The route will also include the city of Kazan, the towns of Tetyushi, Elabuga, Naberezhnye Chelny, Almetyevsk – the 'capital' of 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 part of the East European (Russian) Platform. The crystalline basement of the platform is composed of Archean and Proterozoic rocks and located at depths 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 in 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.

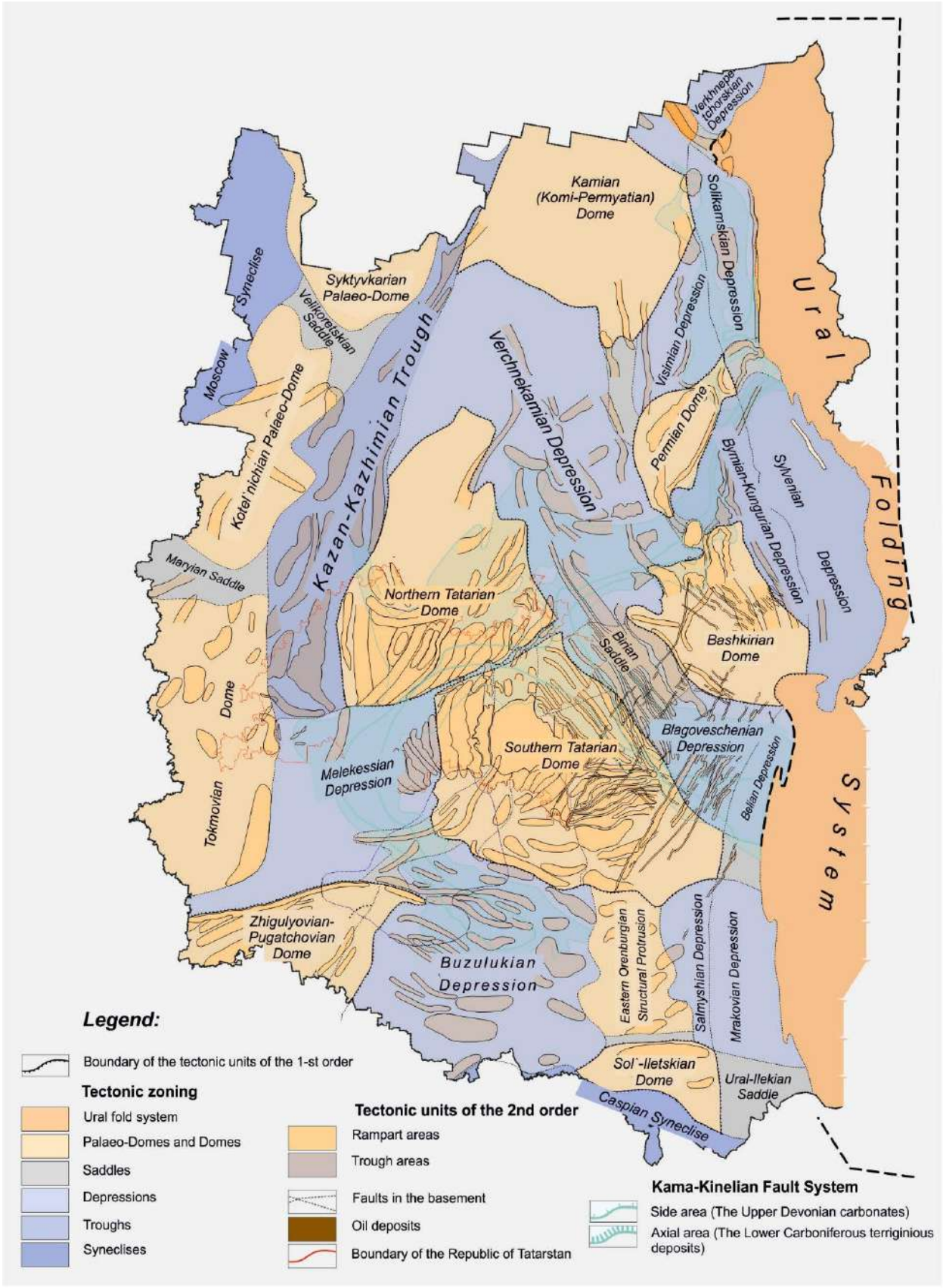


Paleogeography and position of the studied area. Paleogeography reconstruction of the Middle Permian modified after Ziegler et al. (1997)

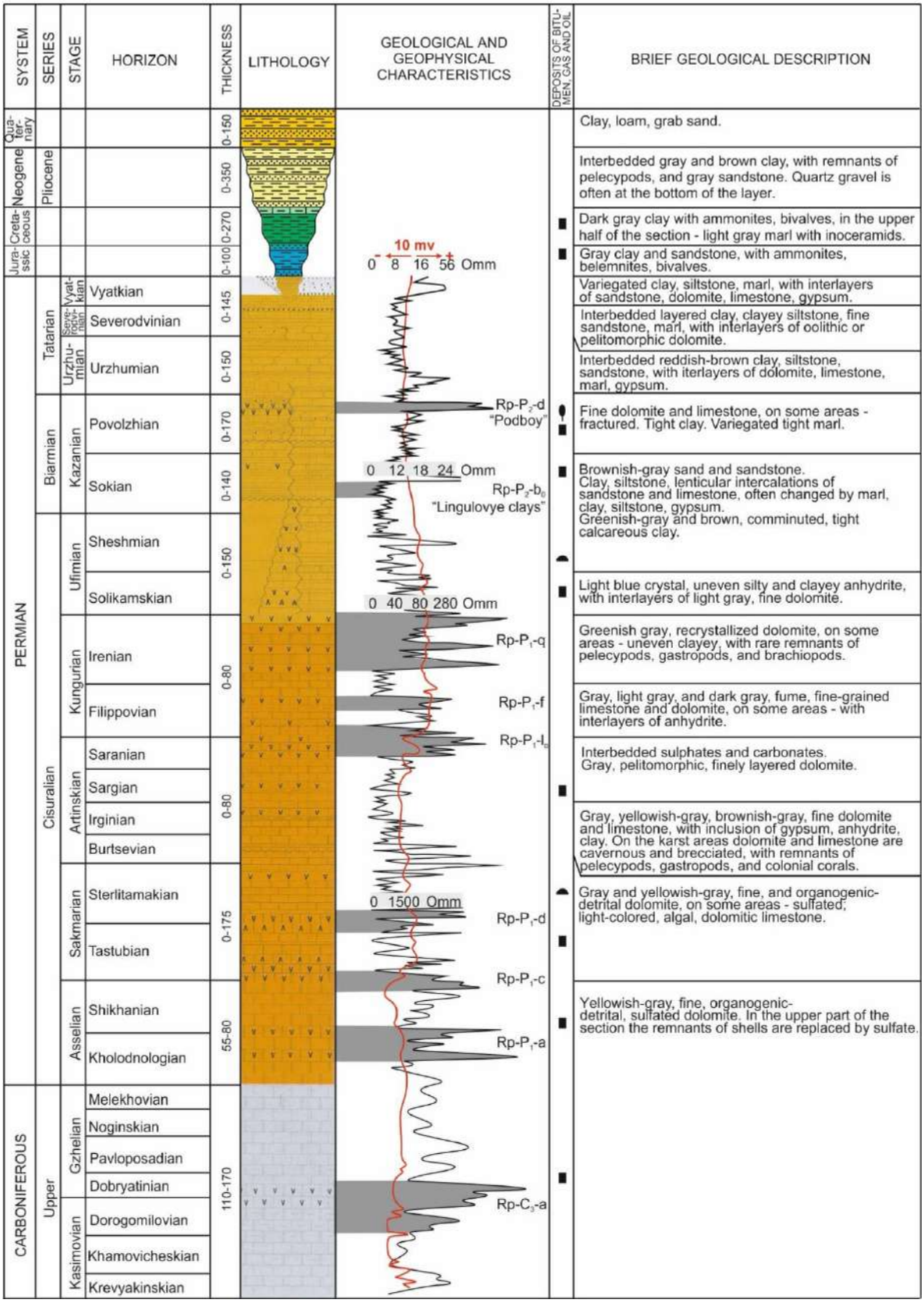
Middle and Upper Permian Stratigraphy

Historical overview

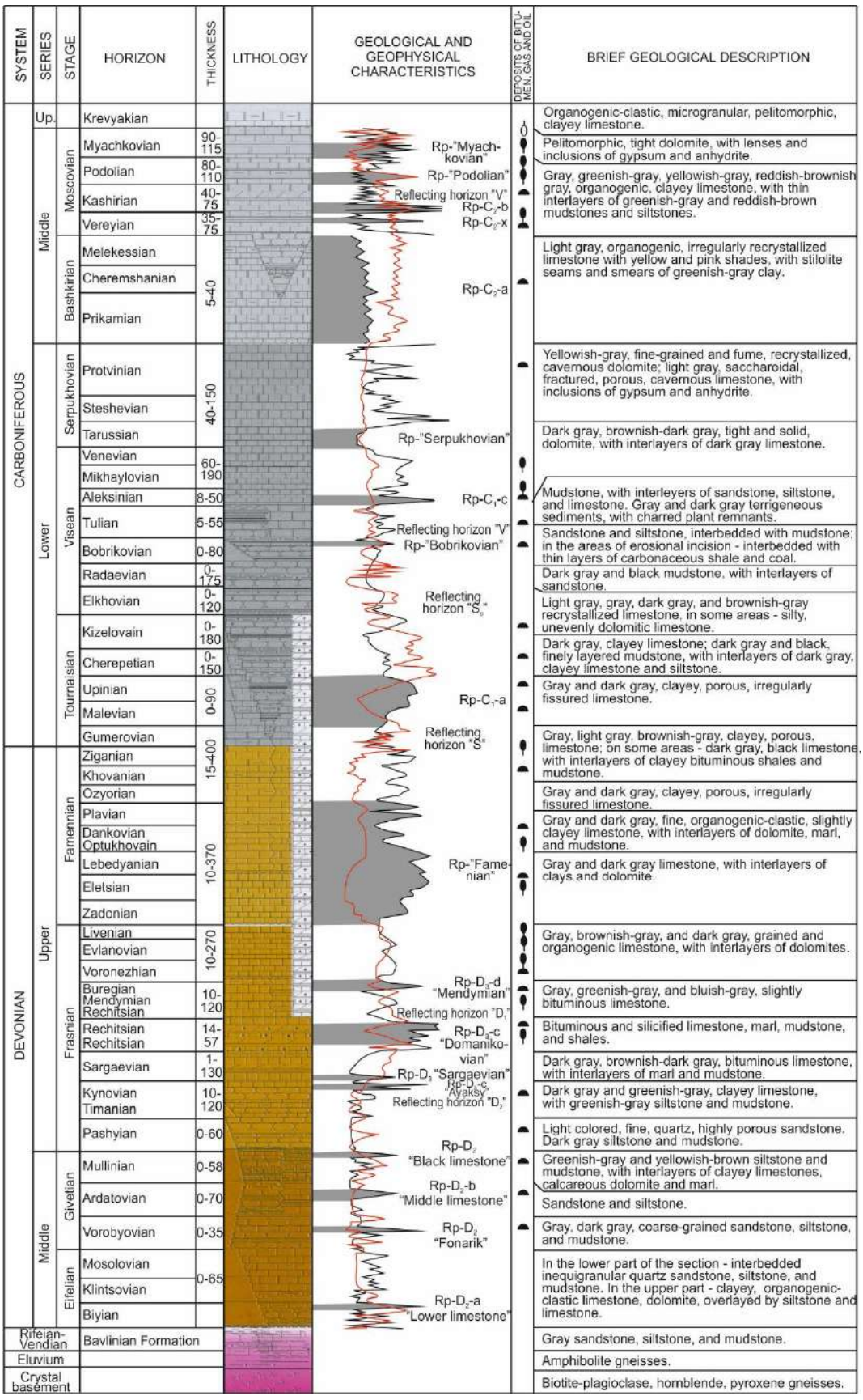
In Tatarstan and adjacent areas the Middle and Upper Permian rocks have been studied over a period of 175 years by many geologists and paleontologists. The outstanding Scottish geologist and scientist Roderick I. Murchison (1841, 1845) as well as the founders of the Kazan Geological School Professors Nicolay A. Golovkinsky (1868), Alexander A. Stuckenberg (1882), Petr I. Krotow (1885, 1888), Aleksey V. Netschajew (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 et al., 2005)



Generalized Geological and Geophisical Section of the Tatarstan area for the Upper Carboniferous – Quaternary deposits (modified after Shargorodsky et al., 2005)



Generalized Geological and Geophisical Section of the Tatarstan area for the Proterozoic – Upper Carboniferous deposits (modified after Shargorodsky et al., 2005)

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 'Russian' stages: Asselian, Sakmarian, Artinskian and Kungurian. The Guadalupian is subdivided by stages of North America, the Lopingian by stages of 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 ostracods species in continuous phylogenetic lines (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. At a regional scale of the East European Platform this boundary is defined on one stage below at the base of 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 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).

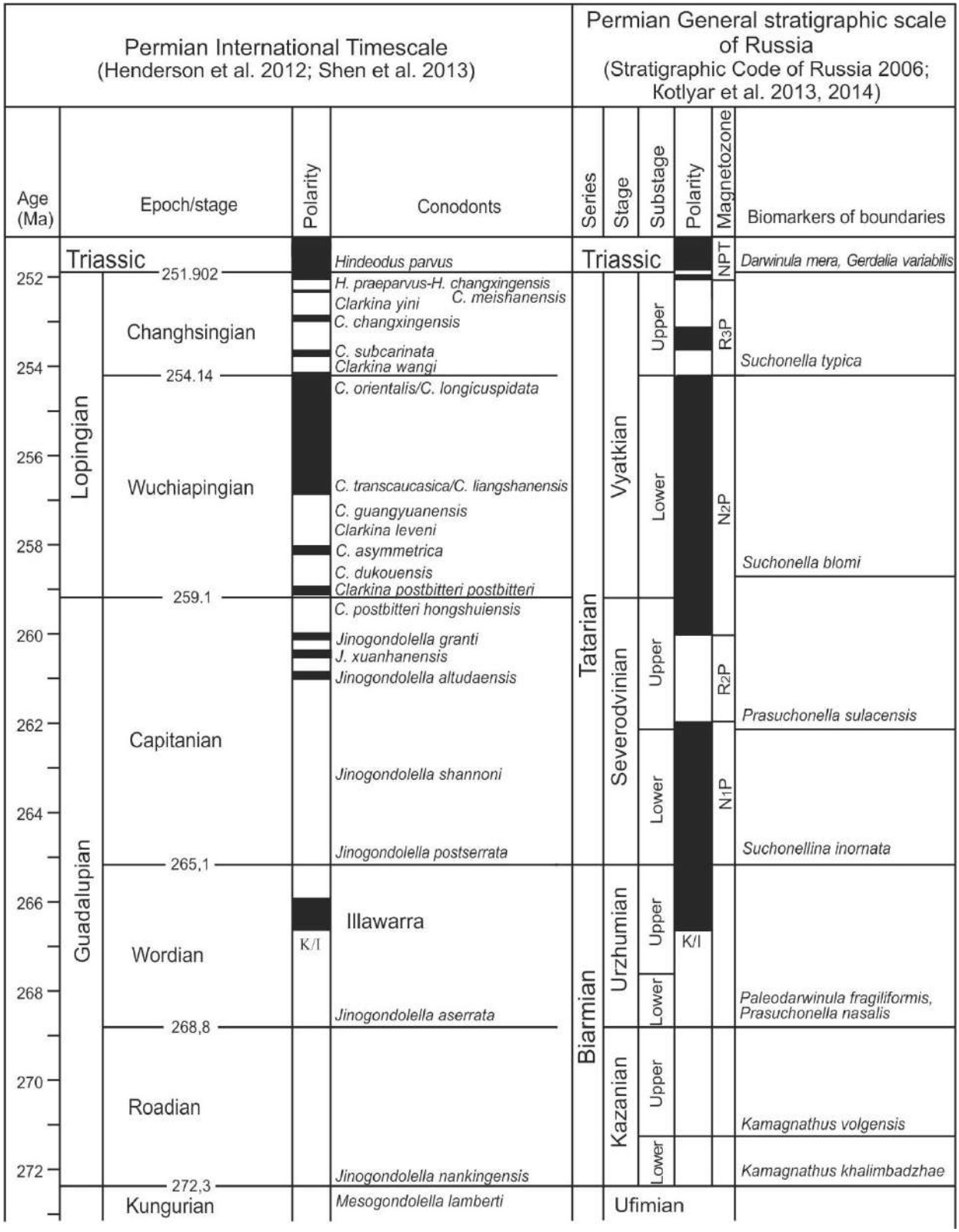
The lower boundaries of the stages which are formed by continental red beds (Urzhumian, Severodvinian, Vyatkian), marked by the first occurrence of non-marine ostracod species in continuous phylogenetic lineages.

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 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 lineage of non-marine ostracods *Prasuchonella nasalis – Suchonella typica* have been chosen for the definition of the stage boundaries within 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 interval of Permian-Triassic boundary (PTB) were extensively studied (Sennikov, Golubev, 2011, 2012; Golubev et al., 2012; Lozovsky et al., 2014). Continuity of PTB sequence was established due to these researches. There is no regional gap on PTB on East European Platform as traditionally believe.



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 field excursion, we will see predominantly 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 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.

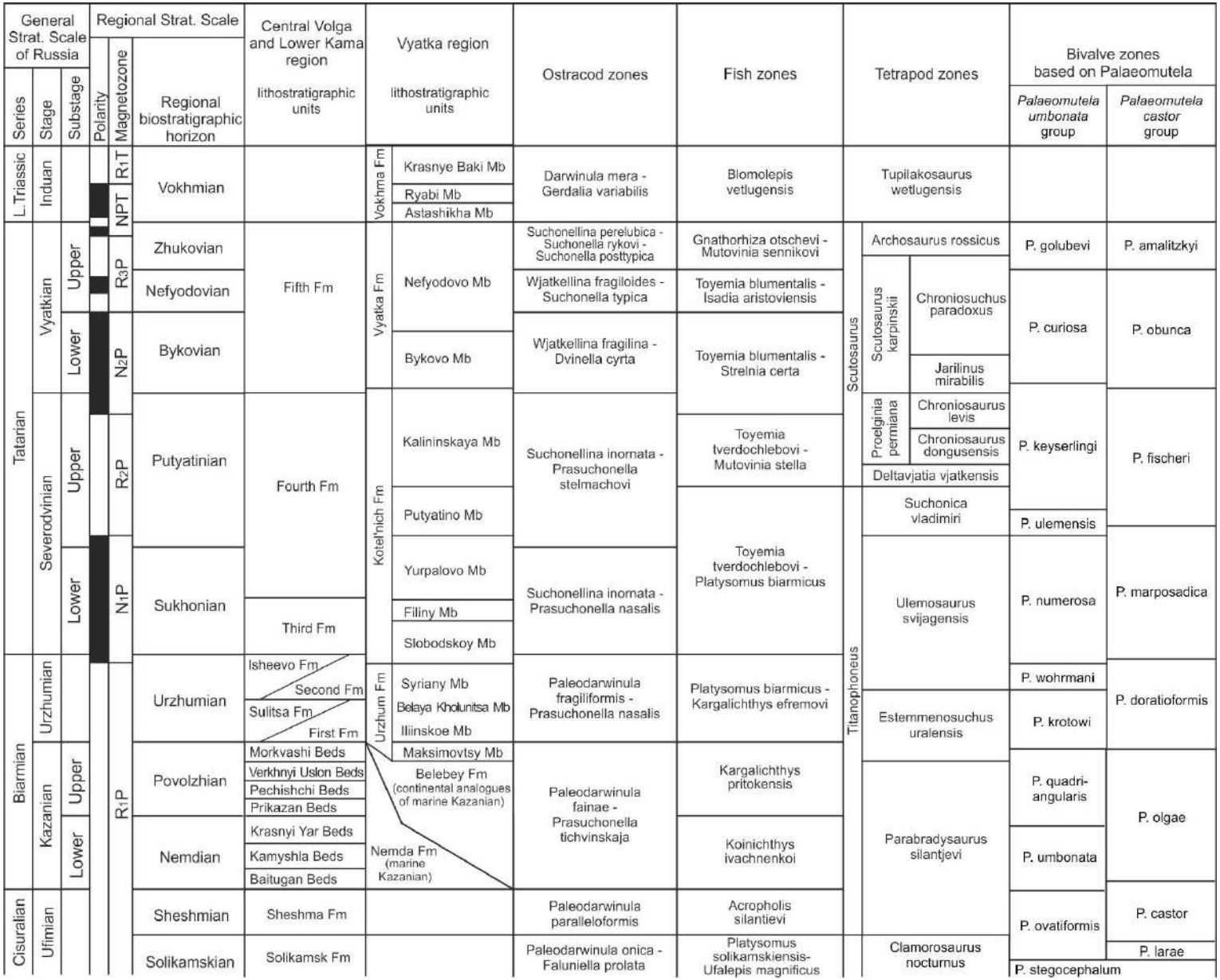
The Lower Solikamsk Subformation. This subformation does not outcrop and is studied in boreholes in the course of mapping and prospecting of the Verkhnekamsk Deposit of potash salts (Ivanov and Voronova, 1975; Kopnin, 1991, etc.). The subformation conformably overlies the saliferous Kungurian rocks of 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 clays 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 (Korrelyatsia..., 1981) and others. According to Silantiev (1996, 1998), in the section near the village of Tylkino, the Upper Subformation is composed of alternating clays, marl, and limestones with abundant non-marine fauna of ostracodes and bivalve (*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') continues uninterrupted further westward and is also traced in Tatarstan area. The western border of the area covered by the subformation (recognized as the Solikamsk Horizon) follows approximately 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 by grey marl and dolomite, with a total thickness of up to 10–15 m. The fauna occur very rarely and are 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 the territory of 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 Sheshma, Menzelya and Ik rivers. The full thickness of the horizon (170 m) is revealed by numerous boreholes. The horizon was best studied in the basin of the Sheshma River (Bogov, 1973, 1978; Esaulova, 1996, 1998a), from which it had received its name. The horizon is composed of red-bed sandstone, siltstone, and clays, 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 recognized as alluvial formations. Throughout all the succession, various paleosols are widespread. They are identified by spots of gleization, by the numerous calcareous nodules, and by the slickensides.



Middle and Upper Permian regional stratigraphic scale and zonation scheme of the area

Fossils in the Sheshmian are mainly represented by 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 spore occur rarely. During the excursion, the type section of the Sheshmian will be shown on the right bank of the of the Kama River, near the town of Elabuga (Day 3 Stop 1), and in the upper reaches of the Sheshma River, near the villages of Shugurovo and Karkali (Day 5 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. 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 (1996, 1998a) 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 (Day 3 Stop 1) and the village of Sentyak (Day 4 Stop 1) and in the upper reaches of the Sheshma River near the villages of Shugurovo and Karkali (Day 5 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 additional basal member of bitumen-sandstone known as 'Shugurovo Sandstones Member' (5–20 m). In the Kazan District, Baitugan Beds overlie the carbonate-sulfate Sakmarian rocks. The beds are mainly composed of grey calcareous clays 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 Clays Member. The Lingula Clays Member (5–15 m) is widespread over the entire territory of Tatarstan. It is readily recognizable 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 the Volga-Ural Anteclise. Sometimes, clays and siltstones contain interbeds of marl, limestone, and dolomite. Apart from lingulids (*Lingula orientalis* Gol. and *L. credneri* Gein.), all rock types, including clays, contain numerous articulate brachiopods, bivalves, bryozoans, crinoids, ostracodes, and foraminifers. The Lingula Clays Member are usually overlain by the member of bioclastic or oolitic limestone (3–8 m), from which multielement conodont apparatuses *Kamagnathus* had 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 clays, 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 a 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 are composed of (from bottom to top): 1) grey clays 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, including a reduced brachiopod fauna, whereas the diversity and number of bivalves is increased. The beds lack corals, crinoids, and *Globiella*; of spiriferids, the rare *Licharewia rugulata* (index species for the entire Lower Kazanian) persists (Solodukho, Tikhvinskaya, 1977).

Along the latitudinal line from Kazan to Elabuga, to the east of the town of Chistopol, grey-bed clayish 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 first to describe this section that has subsequently been 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 clay, 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 (1899, 1924) 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 in 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, ostracodes, molluscs, brachiopods, and conodonts. These beds are overlain by gypsiferous dolomites lacking fossils, and eventually by clayish-marly rocks with mostly non-marine fossils (bivalves and conchostracans) and terrestrial plant remains. Later, Solodukho and Tikhvinskaya (1977) recognized 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 the lithological cyclicity in the substage. Nowadays, these horizons are considered as the ‘Beds with geographical names’ (Gusev et al., 1993). The subdivision of the Upper Kazanian into four units is confirmed by the Decision of the Interdepartmental Stratigraphic Committee (Reshenie…, 1990) and was used during the mapping in Tatarstan. Toward 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 Belebeevskaya Formation. The eastern boundary of the beds containing marine Late Kazanian fauna is located approximately along the line Arsk–Kamskie Polyany.

BELEBEEVSKAYA 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 gleization, 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 ostracodes *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 (Day 1 Stop 1), continental facies, in the section near the village of Sentyak (Day 4 Stop 1) on the Kama River.

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

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.

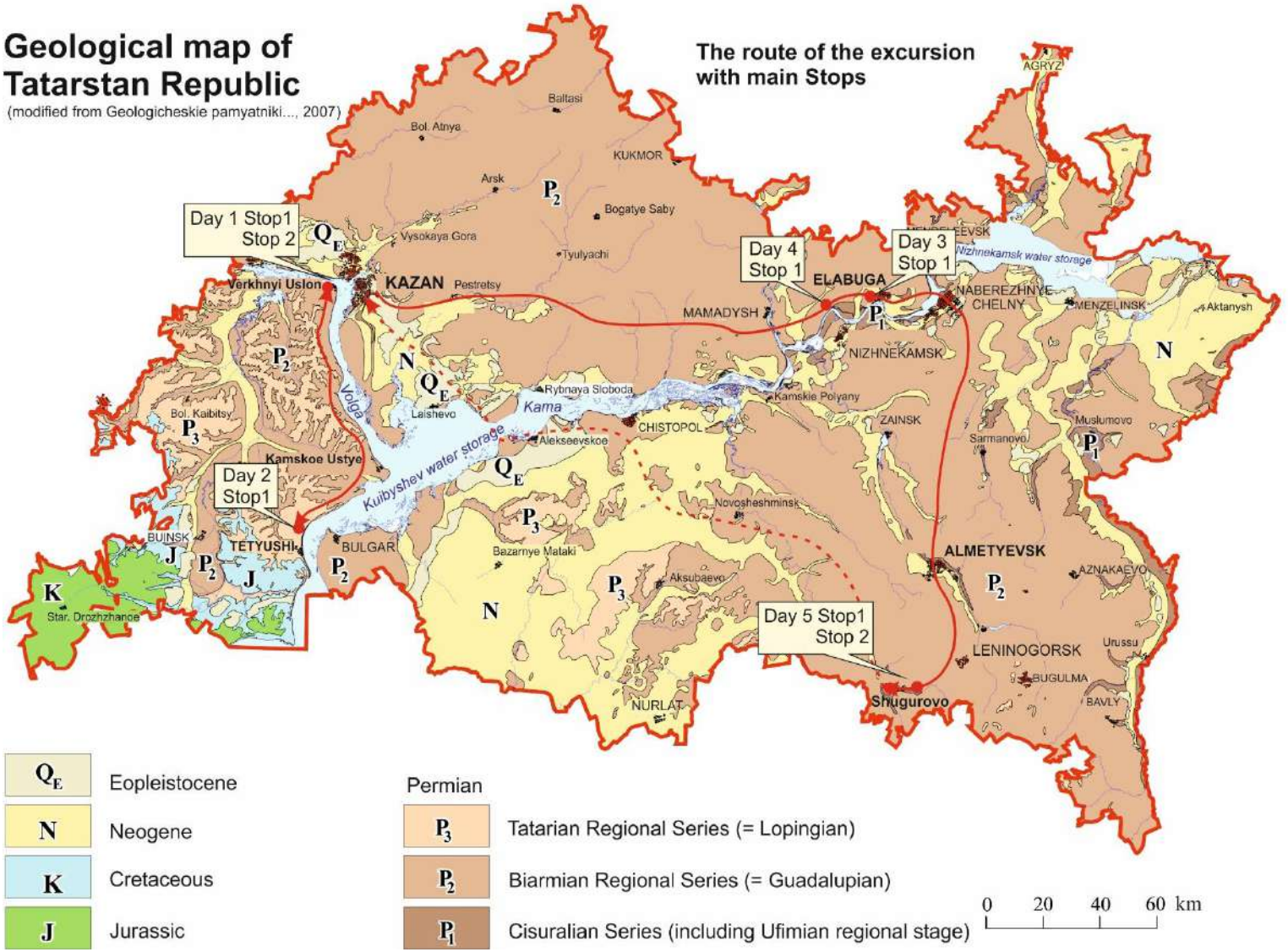
In Tatarstan, the reference sections of the Urzhumian are located in the Kazan District on the right bank of the Volga River: 1) 2 km upstream from the village of Pechishchi, in the Cheremushka Gully (Day 1 Stop 2) – parastratotype section, and 2) 12 km upstream from the town of Tetyushi, in the Monastery Ravine – stratotype section (Day 2 Stop 1). The section in the Monastery Ravine had 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., 2014, 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 clayish and terrigenous rocks with many marl and limestone intercalations. The Second Fm (or Isheevo Fm) is 50 m thick and characterized by well defined cyclic interbedding of terrigenous and clayish-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*. Clays with greenish-grey and red spots (stains) of gleization are usually overfilled with calcareous concretions (paleosol horizons). Clay with lenticular lamination contains 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* Gusev, *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 for the Urzhumian are *Archaeosyodon*, *Biarmosuchus*, Bolosauridae, Deuterosauridae, Dissorophidae, Estemmenosuchidae, Lanthanosuchidae, Phthinosaurus, Pristerognathidae, Titanophoneus, Tryphosuchinae, Ulemosauridae, Venyukovioidea.

Severodvinian regional stage was established by Permian Commission of the Russian Interdepartmental Stratigraphic Committee in 2004 on the base of Severodvinian biostratigraphic Horizon (Tikhvinskaya, 1946; Stratigraphicheskie Skhemy…, 1962) as the lower regional stage of Tatarian Series (Upper Permian) (Reshenie…, 2004). Stratotype sections are located along the Sukhona River in the north-eastern part of Vologda Region. The Severodvinian is composed of red-bed clayish 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*. Clays with greenish-grey and red spots (stains) of gleization are usually overfilled with calcareous concretions (paleosol horizons). Clay with lenticular lamination contains 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 Geologicheskie pamyatniki..., 2007)
The route of the excursion with main Stops
Day 1 Stop1 Stop 2
Day 2 Stop1
Day 3 Stop 1
Day 4 Stop 1
Day 5 Stop1 Stop 2
KAZAN
ELABUGA
ALMETYEVSK
LENINOGORSK
Shugurovo
NIZHNEKAMSK
NABEREZHNYE CHELNY
CHISTOPOL
MAMADYSH
BUINSK
TETYUSHI
BULGAR
NURLAT
Volga
Kama
Kuibyshev water storage
Nizhnekamsk water storage
Eopleistocene
Neogene
Cretaceous
Jurassic
Permian
Tatarian Regional Series (= Lopingian)
Biarmian Regional Series (= Guadalupian)
Cisuralian Series (including Ufimian regional stage)
0 20 40 60 km

The basement of the Severodvinian is best represented in the Monastery Ravine section (Kazan Region) (Day 2 Stop 1), which is proposed as the regional GSSP marked by the FAD of non-marine ostracods *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 paleomagnetic zone 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 representatives of Bradysauridae, Burnetiidae, Cryptodontidae, Dicynodontidae, Dvinosauridae, Galeopidae, Gorgonopidae, Ictidorhinidae, Karpinskiosauridae, Moschowhaitsiidae, Nycteroleteridae, Scaloposauria.

Vyatkian regional stage was established by Permian Commission of the Russian Interdepartmental Stratigraphic Committee in 2004 on the base of Vyatkian biostratigraphic Horizon (Ignatiev, 1962; Stratigraphicheskie Skhemy…, 1962) as the upper regional stage of Tatarian Series (Upper Permian) (Reshenie…, 2004). Stratotype sections are located along upper reach of the Vyatka River in the Kirov Region. The Vyatkian is composed of basal sandstone and conglomerate overlaying by red-bed (speckled) clayish and terrigenous rocks with marl and limestone intercalations. Algal-microbial limestones are usually riddled with numerous voids of plant roots *in situ*. Clays with greenish-grey and red spots (stains) of gleization are usually overfilled with calcareous concretions (paleosol horizons). Clay with lenticular lamination contains 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 (N2P and R3P). 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 the 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 Tetyushskiy District of Tatarstan (Day 2 Stop 1).

THE UPPER KAZANIAN STRATOTYPE NEAR THE VILLAGE OF PECHISHCHI

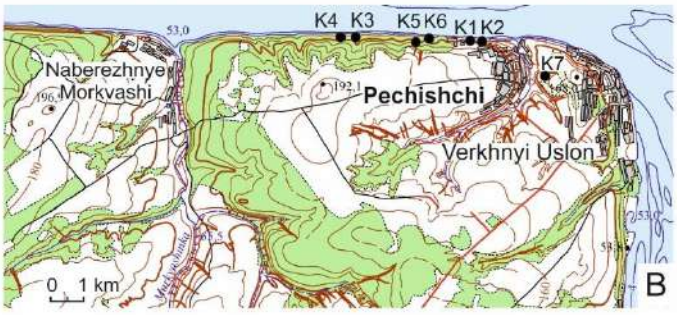
The region of the Volga River near Kazan (Kazan Povolzhye) includes the area along the bank of the Volga River from the village of Pechishchi to the town of Tetyushi. The Middle and Upper Permian rocks form the right bank of the river valley and are accessible for studies in the slope of the bank and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

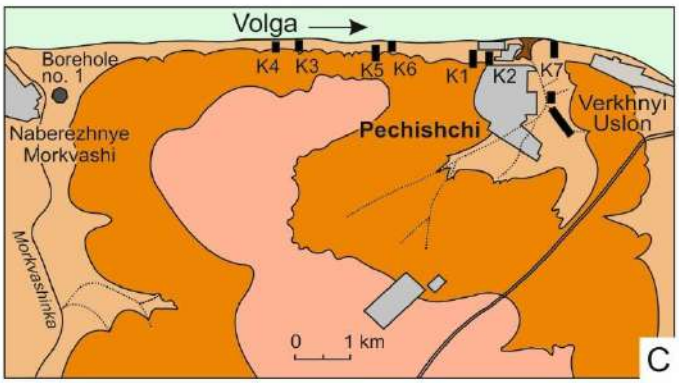
The geological excursion starts in the vicinity of the village of Pechishchi where two sections will be shown for the participants. These are the stratotype of the Upper Kazanian, exposed in the steep bank of the Volga River and in the slopes of the Telegraphnyi ('Telegraph') Gully and Kamennyi ('Rocky')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

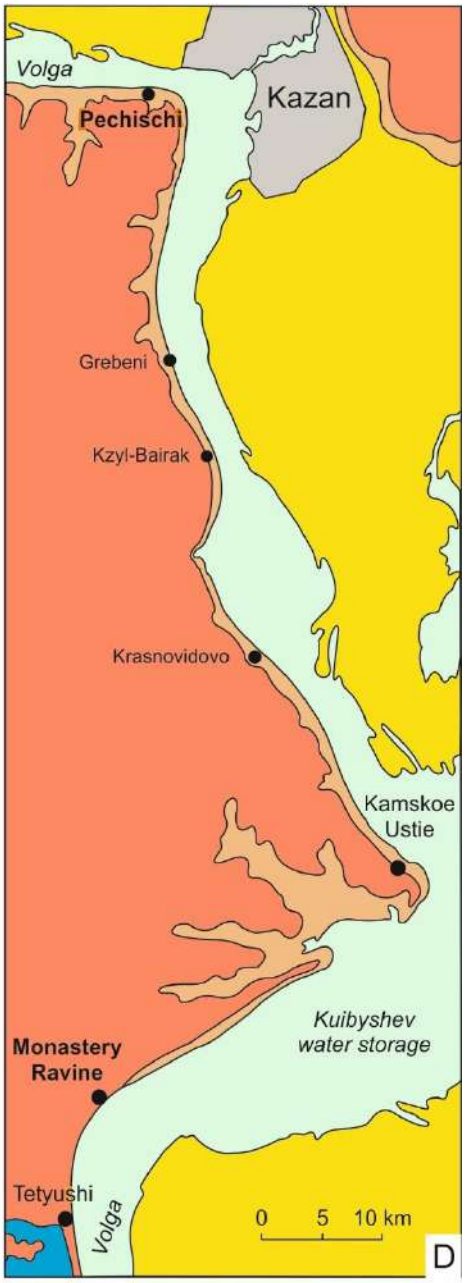
After visiting these sections, the excursion will go by regular or special high-speed boat down the Volga River toward the town of Tetyushi. Along this route one can observe from the boat continuous outcrops of the Kazanian and the Urzhumian showing syncline and anticline structures with gently sloping wings. The participants will see the stratotype of the Urzhumian exposed in the slopes of the Monastery and Ilyinsky Ravines slightly upstream of the town of Tetyushi.

The stratotype outcrops are exposed on the right bank of the Volga River opposite the city of Kazan. The boundary between Lower and Upper Kazanian and lower part of the succession (units 1–7) are 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 best accessible in the Cheremushka ('Bird Cherry') Gully.

Noinsky (1899, 1924) was first to describe the section, which he subdivided into eight series (Members in modern terminology), united in three complexes. Solodukho and Tikhvinskaya (1977) gave a detailed paleontological description of Noinsky's complexes, recognized 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, Golubev, Goetz, 2014; Silantiev et al., 2014; Goetz, Silantiev, 2015).

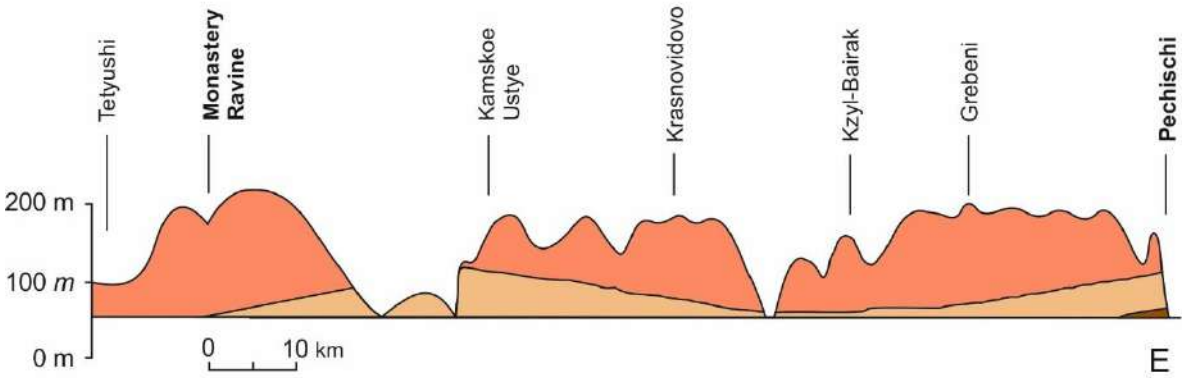


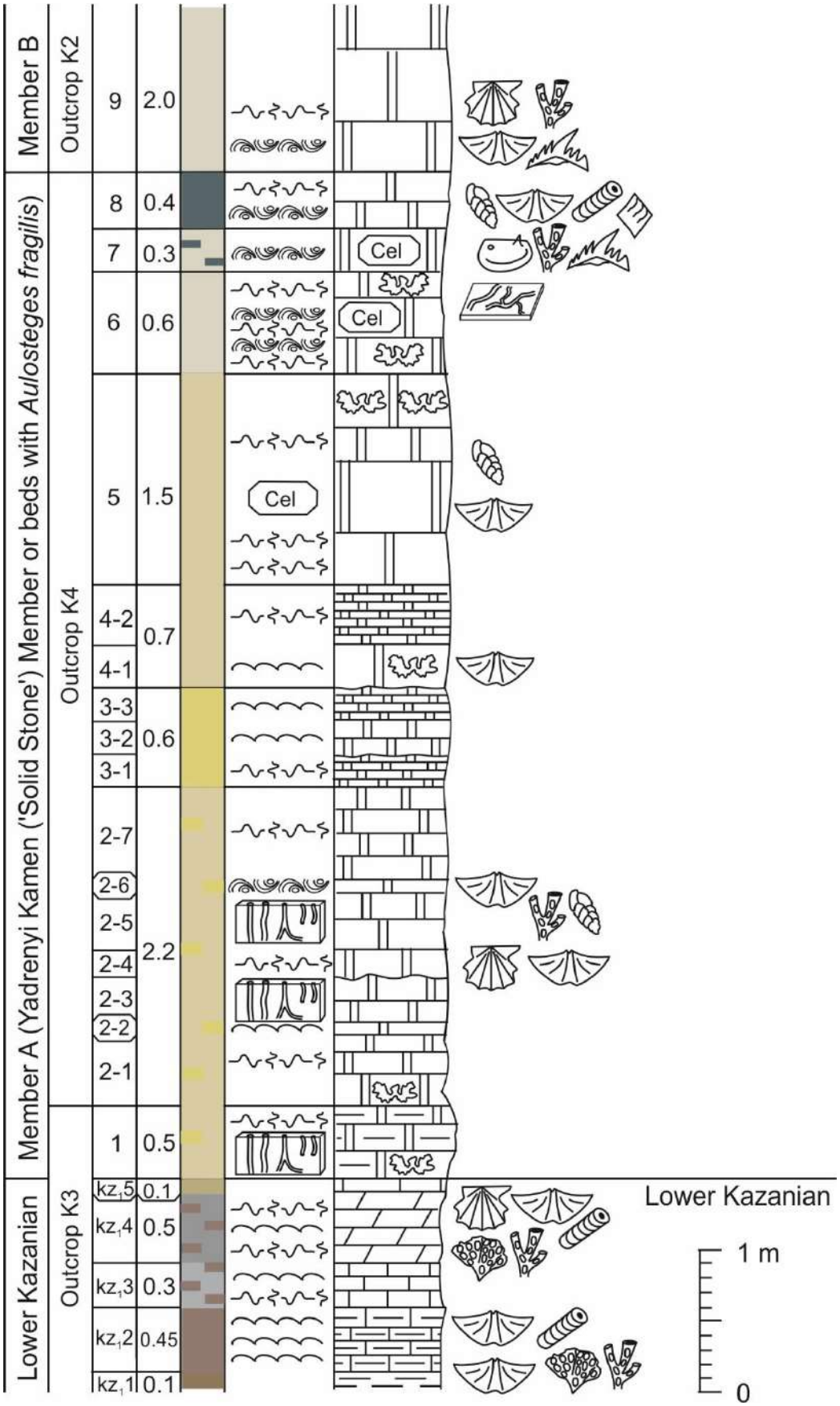




Stratigraphy

- Quaternary and Neogene
- Jurassic
- Severodvinian
- Severodvinian and Urzhumian
- Urzhumian
- Upper Kazanian
- Lower Kazanian




Member B
Member A (Yadrenyi Kamen ('Solid Stone') Member or beds with Aulosteges fragilis)
Lower Kazanian
Outcrop K2
Outcrop K4
Outcrop K3
9
2.0
8
0.4
7
0.3
6
0.6
5
1.5
4-2
4-1
0.7
3-3
3-2
3-1
0.6
2-7
2-6
2-5
2-4
2-3
2-2
2-1
2.2
1
0.5
kz1 5
0.1
kz1 4
0.5
kz1 3
0.3
kz1 2
0.45
kz1 1
0.1
Cel
Cel
Cel
Lower Kazanian
1 m
0

The description of the Kazanian 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. The right bank of Volga River in 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 number of samples indicate its position in meters from the base of each unit (e.g. sample K3/2 (0,22) was sampled 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 gray, with numerous collapsed brachiopods *Cancrinella cancrini* (Vern.), *Licharewia rugulata* (Kut.), *L. stuckenbergi* (Netsch.), *Blasispirifer multiplicostatus* (Netsch.), *Odontospirifer subcristatus* (Netsch.), and numerous fragments of bryozoans and crinoids. Shell structure is well preserved.

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

Limestone: pale gray, argillaceous, fine-grained, bedded, with disrupted subparallel sedimentary lamination. The lamination is also expressed on polished slabs as preferential 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: gray, weathers brownish, micritic (bioclastic wackestone to mudstone), weakly fissile, probably weakly argillaceous, with mass *Cancrinella cancrini* (Vern.) on 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 gray, 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 gray, dolomitic, fine-grained, thin-bedded. Base conformable and gradational. This unit may be part of the "Chervotochina" Bed sensu Noinsky (1899, 1924). This unit can be described as a transition from the fissile marl K03/$kz_1$4 to the thick-bedded dolostone K3/1 marking the 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. General section of Upper Kazanian was made on the base of Unit K4/2 exposed in the outcrop K4; more detailed sampling was conducted in outcrop K03]

LEGEND


Sands and sandstones
Silts and siltstones
Siltstones and sandstones
Clays and clayey silts
a Limestones (a),
b dolomites (b)
a Marls (a),
b 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
g g
Gypsum lenses, gypsiferous rocks
Ca Ca
Calcareous concretions and calcareous recrystallization
Si Si
Ciliceous concretions and quartz druses
Cel
Celestine
Silty-clay 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
Gray-colored rocks, rock with colors of gley spots, white and yellow sands
Variegated rocks
Dark gray rocks (shade of a pencil to black)
Brown and grayish-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
Scales and fish bones
Tetrapods
Leaves of higher plants
Girogonites of charophytes
Miospores

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 gray, 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 dissolved anhydrite nodules. Sedimentary texture: calcimudstone with rare horizontally oriented bioclasts (sample K03/2 (0,00)); vaguely granular, ooid-like dolostone texture (sample K03/2 (0,22)). Bedding planes show numerous moulds of 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. Overlying section is described in 70 m upstream walk (N 55,78265; E 048,90576, 53.0 m ASL, 125 m upstream of Trekhglavyi Ravine]

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 gray, yellowish, tight, massive, of medium hardness. Sample K03/3 (0,33) shows the boundary of two lithologies: the light colored dolostone (calcimudstone tecture) with *Cancrinella* pavement in upper part, overlain by yellowish gray dolostone with vague disrupted horizontal lamination and rip-up intraclasts. Sample K03/3 (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 gray, tight, hard, massive, locally vuggy, with rare brachiopods *Cancrinella cancrini* (Vern.). The sample K03/4 (0,06) shows mudstone texture with gently undulating lamination defined by horizontally oriented bioclasts and voids after brachiopod spines.

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

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

Dolostone: pale gray, 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.), *Cleiothyridina pectinifera* (Sow.).

The overlying layers are poorly accessible in outcrop K3.


K4/2-4
K4/2-3
2013 09 11 12:51
B


2013 09 18 11:27
K4/2-3
A


K4/8
C

Outcrop K4

GPS: 55,78261 N; 048,90420 E (WGS84). Datum: river water level at 53.0±3 m ASL. The right bank of 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. Upward in the section, above the dolostone with vermiform voids (Chervotochina ('Worm-hole') 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-hole') 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 gray, weathers yellowish, calcareous, thick-bedded, tight and hard. Samples show bioclastic mudstone texture with preferentially horizontal to random orientation of bioclasts. Thin (< 1 mm) curved channels 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 read of the top of K04/2 is 56.0 m ASL.

Unit K4/2 is detailized in 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 gray, 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 penetrating from top thin (< 5 mm in diameter) upright channels showing spongy internal structure and bleached haloes. The top of this subunit is undulating, erosional, with pockets up to 3 cm deep (Fig…. DSCN0551– DSCN0556).

Bed K4/2-4 [0.90–1.10] Interval 2.85-3.05 m Thickness 0.20 m

Dolostone: gray, 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 gray, 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 the Unit K4/2.

Bed K4/2-6 [1.50–1.60] Interval 3.45–3.55 m Thickness 0.10 m

Dolostone: pale gray, 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 gray, 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 gray, 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. Preferential 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. Preferential 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 gray, hard and tight, locally vuggy, with rare *Cancrinella cancrini* (Vern.). The unit can be divided in 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 crude lenticular lamination with shell pavements (including fragments and whole valves of *Aulosteges fragilis* (Netsch.). Base likely 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 crude 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-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.). In 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 gray, fissile to thin-bedded, with finely to microcrystalline fabric (5-50 μm), microporous, locally vuggy, relatively soft. Moderately bioturbated to laminated bioclastic packstone and wackestones. Bedding/fissility planes show lamine enriched in charophyte stalks and laminae dominated by brachiopod fragments. Some brachiopods are 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 colored 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 argillcarous,yellowish gray with bluish mottles, fine-grained, rich in void-filling bluish large celestine crystals. Laterally grades into gray colored recessive fissile calcareous marl. The marl facies contains cm-thick resistant limestone beds and lensis with shell coquinas and erosional surfaces indicative of tempestite rhythmicity . Macrofossils: bivalves, brachiopods of genera *Cancrinella*, *Aulosteges*, *Stenoscisma*, *Crurithyris*, and branching bryozoans.

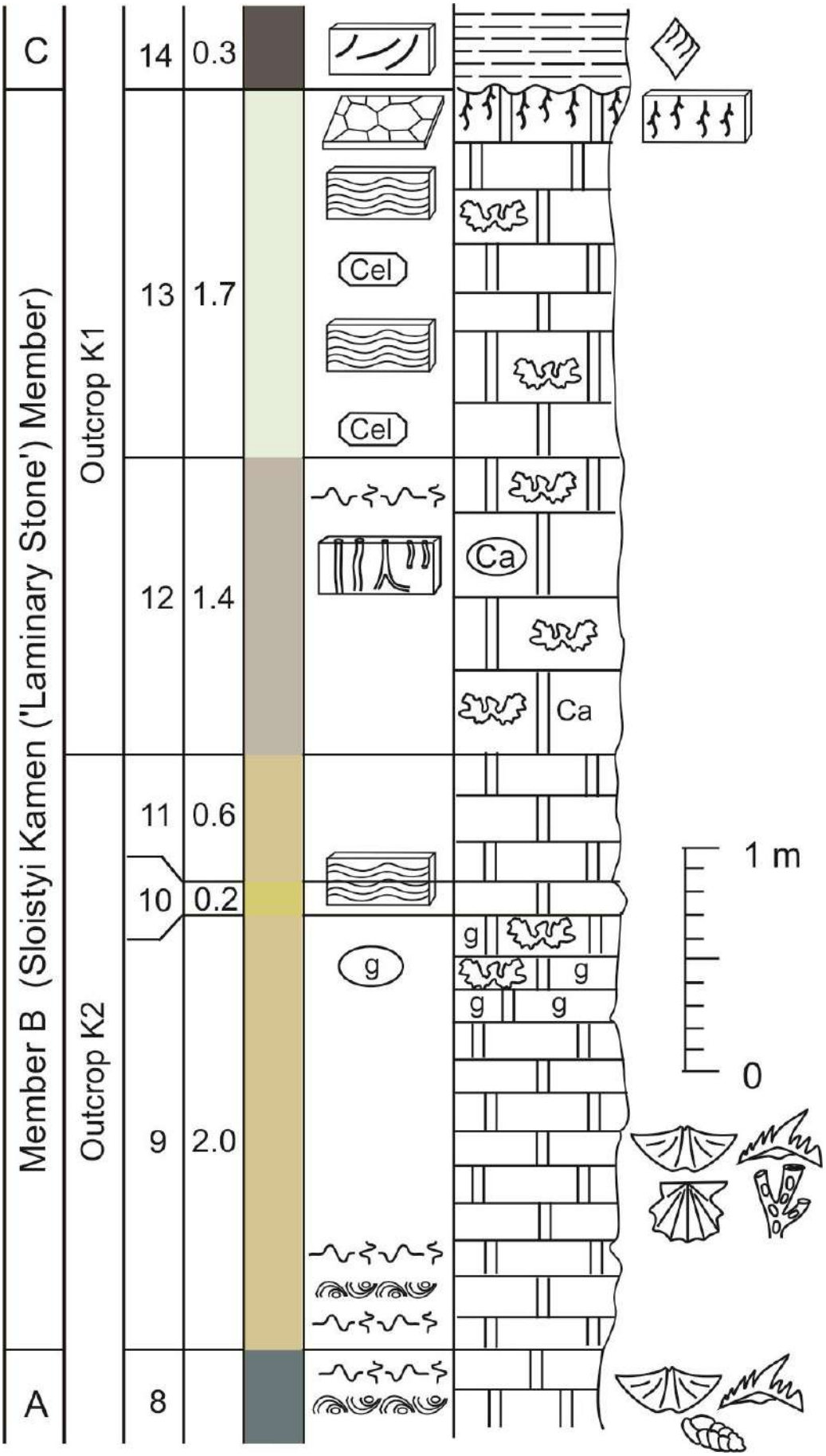
Unit K4/8 Interval 7.90-8.30 m Thickness 0.40 m

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

Dolostone to limestone: bluish gray (hence the historic name Sinyaya plita), fine-grained, weathering rusty. The lower part is hard and monolithic, locally composed of weakly fissile bluish gray 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 mejeni* Kozur.

The overlying succession is more conveniently observed in outcrop K2.

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


C
Member B (Sloistyi Kamen ('Laminary Stone') Member)
A
Outcrop K1
Outcrop K2
14
0.3
13
1.7
12
1.4
11
0.6
10
0.2
9
2.0
8
Cel
Cel
Ca
Ca
g
g
g
g
1 m
0

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 Podluzhnik Member ('Stone lying under the meadow' Member). The top of the Podluzhnik forms a terrace of 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 gray, 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 caverns after 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 mey*eni Kozur et Movsch.

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 gray, hard and tight, breaking along smooth to gently conchoid surfaces, locally showing thin undulating bedding. No fossils.

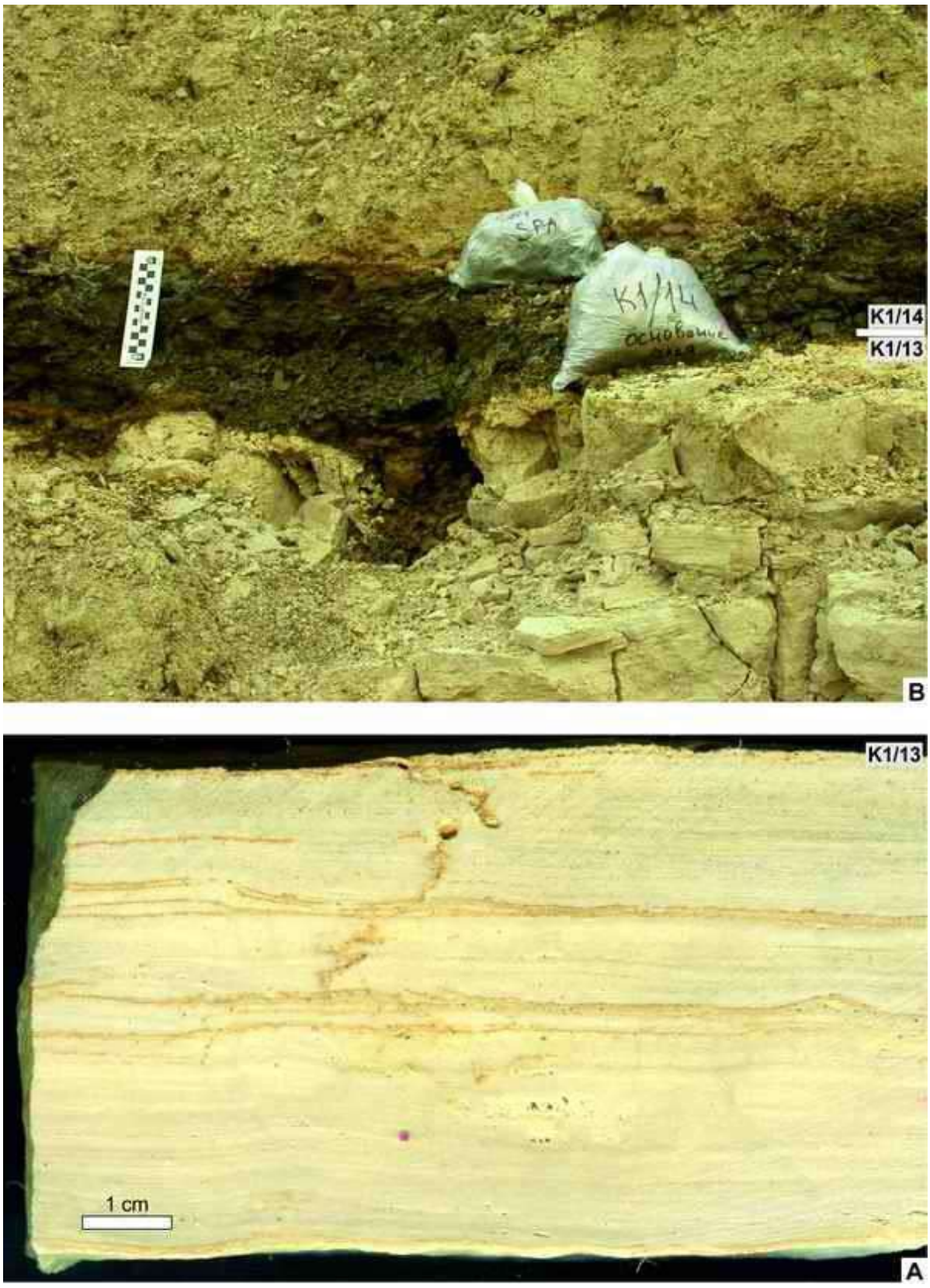
Unit K2/11 Interval 10.50-11.10 m Thickness 0.60 m

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

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

The overlying succession is described in outcrop K1.

Outcrop K2. General view of the outcrop



Outcrop K1. Unit K1/13, dolostone with “teepee” structure (A), (B) general view on 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 to the back (western) yard of the Flour milling plant; 40 m west of outcrop K2 (up the stream). The base of the package K1/12 occurs at 61.0±3 m ASL.

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

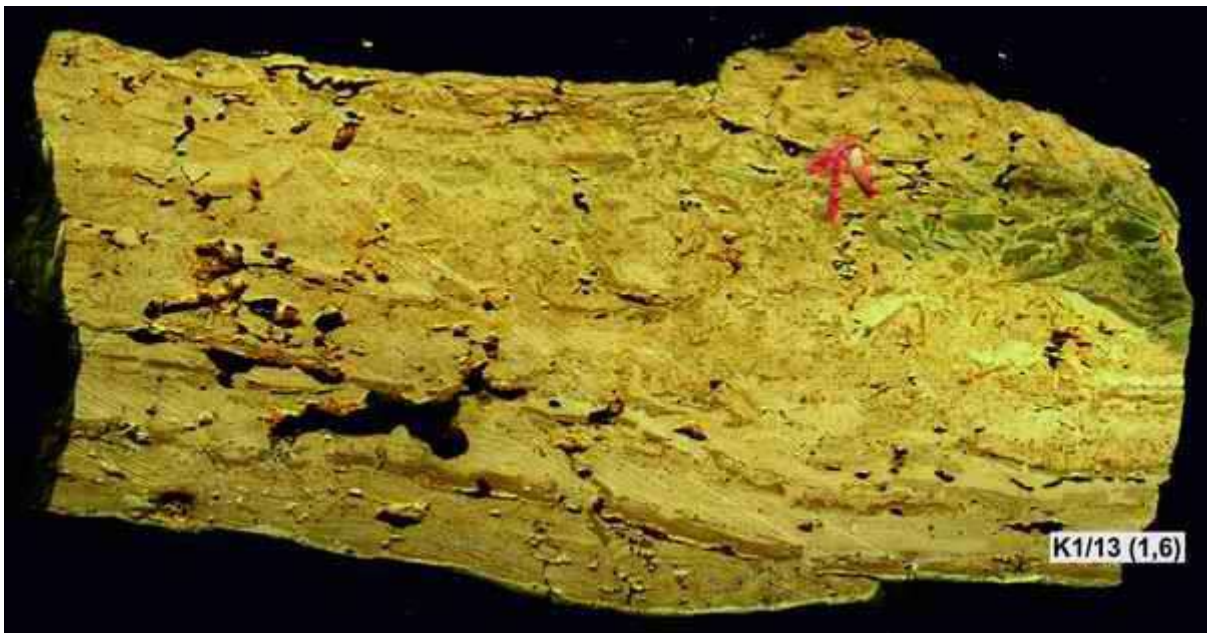
Bed no. 12 Rakovistyi Rubets ('Hollowed Seam') of Noinsky (1899, 1924).

Dolostone: dull gray, finely crystalline, of medium hardness, cavernous, with rusty ferruginous crusts produced on weathered surfaces and geodes of ferruginized 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, in top more bioturbated with small curved burrows. Locally dolostones is grading into dark gray crystalline limestone likely representing dedolomite.

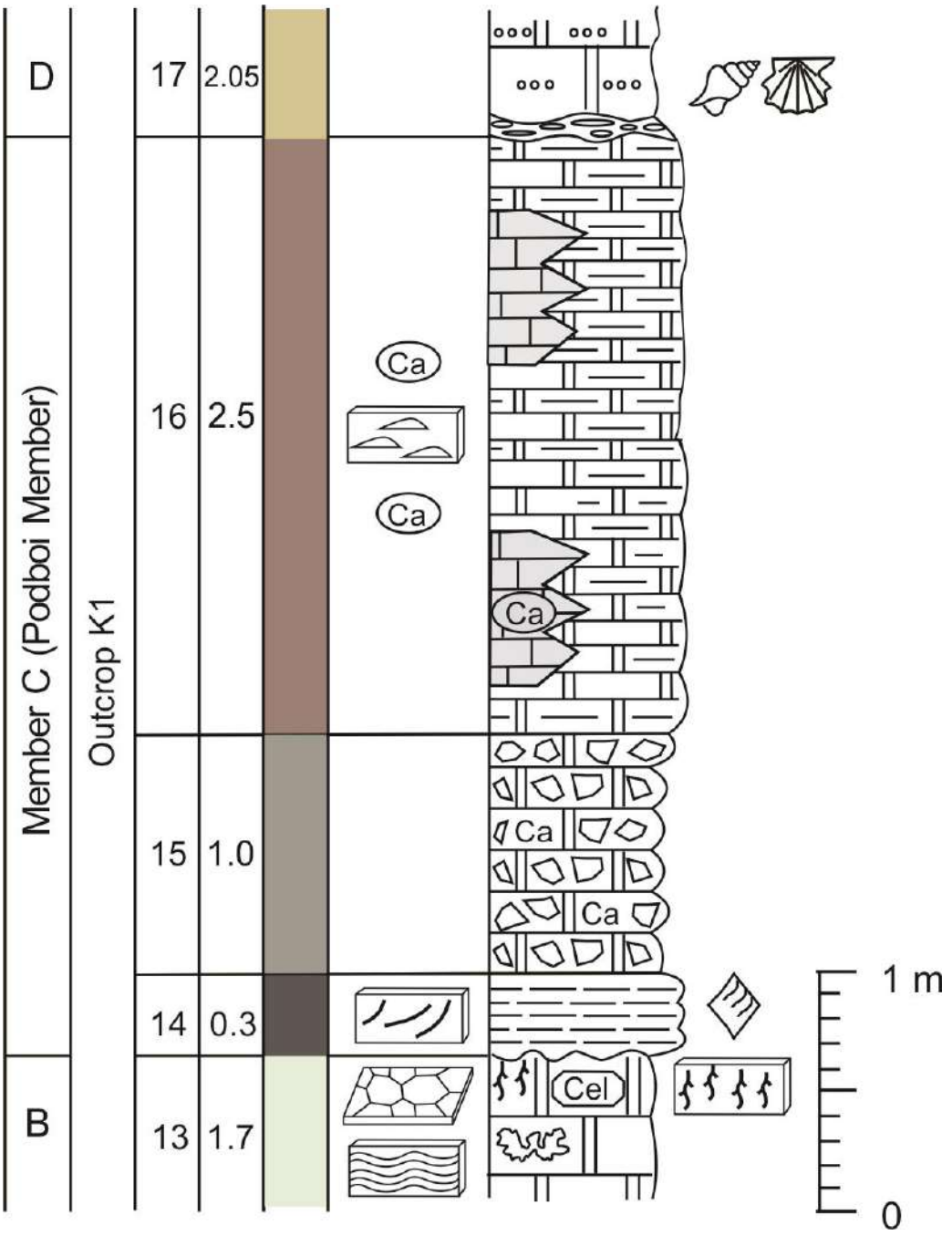
Unit K1/13 Interval 12.50-14.20 m Thickness 1.70 m

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

Dolostone: very pale gray (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 illuvial shale coatings or stringers in top despite the overlying shale (Package K1/14).



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


D
Member C (Podboi Member)
B
Outcrop K1
17
2.05
16
2.5
15
1.0
14
0.3
13
1.7
Ca
Ca
Ca
Ca
Ca
Cel
1 m
0

Pechishchi Beds

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 gray, 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 – grayish 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 gray shale with brownish partings; 0.15–0.30 m – dark brownish gray 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.

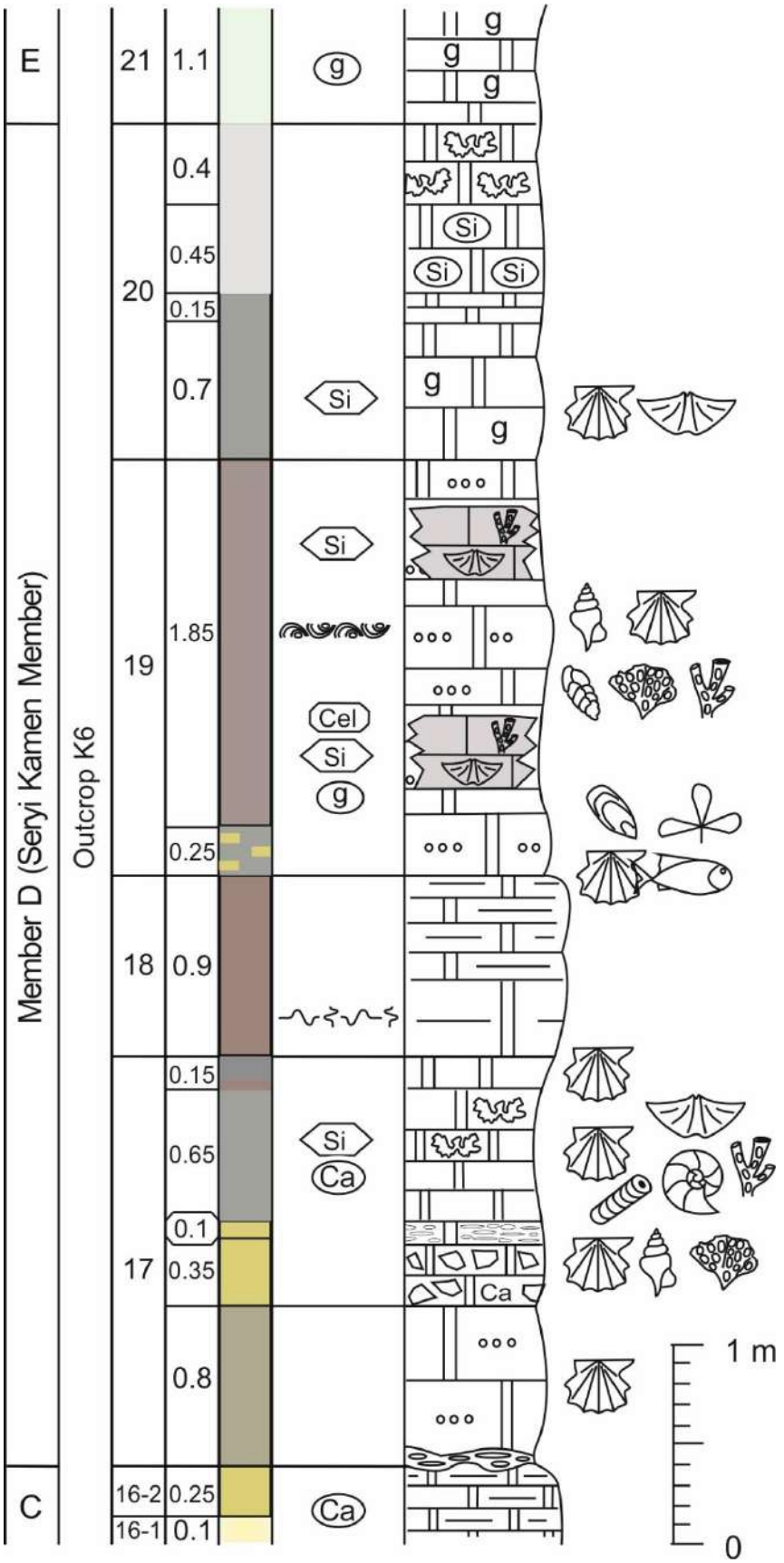
Unit K1/16 Interval 15.50-18.00 m Thickness 2.50 m

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 dedolomitized into dark gray secondary calcite. A cavernous coarsely crystalline secondary limestone (apparently dedolomite) was observed between outcrops K1 and K2.

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

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


E
Member D (Seryi Kamen Member)
C
Outcrop K6
21
20
19
18
17
16-2
16-1
1.1
0.4
0.45
0.15
0.7
1.85
0.25
0.9
0.15
0.65
0.1
0.35
0.8
0.25
0.1
g
Si
Cel
Ca
1 m
0

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 the unit K6/16 (Member C Podboi) is exposed directly above towpath in 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 the unit 16 is described as hard pale yellowish gray fine-grained dolostone **(**17.65–17.75 m) grading upward into gray thin-bedded fine-grained dolostones with molds after bivalve shells (17.75–18.00 m). In polished slabs retains fin-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: gray 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. Macrososils numerous, 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 base erosional (ravinement) locally hosts conglomerate with small dolostone and dolomarl pebbles. In top dolostone buff and 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 Soapston') of Noinsky (1899, 1924).

Dolostone: argillaceous and buff-colored, microporous, thick-bedded and grading in top to 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. Macrofossils diverse, encountered only in uppermost part: 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 *Platysomus* sp., *Acentrophorus varians* Kirkby, *Kasanichthys* sp., 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: gray, very fine-grained ("sandstone-like"), locally mottled medium to thick bedded. Nodules and secondary open-space large crystals of gypsum. From base to top: gray and yellow-mottled, weakly fissile dolostone with faintly laminated mudstone texture (0.00-0.25 m); brownish gray 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 dolomitized 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: gray, fine-grained, tight to locally vuggy, partly chertified and dedolomitized into a crystalline limestone. Base yields rare bivalves *Nuculana kasanensis* (Vern.), *Pseudomonotis (Ps.)*

permianus Masl., *Pseudobakewellia ceratophagaeformis* Noin., brachiopods *Cancrinella cancrini* (Vern.), *Cleiothyridina pectinifera* (Sow.), *Beecheria netschajewi* Grig., and branching bryozoans. The upper part (0.85–

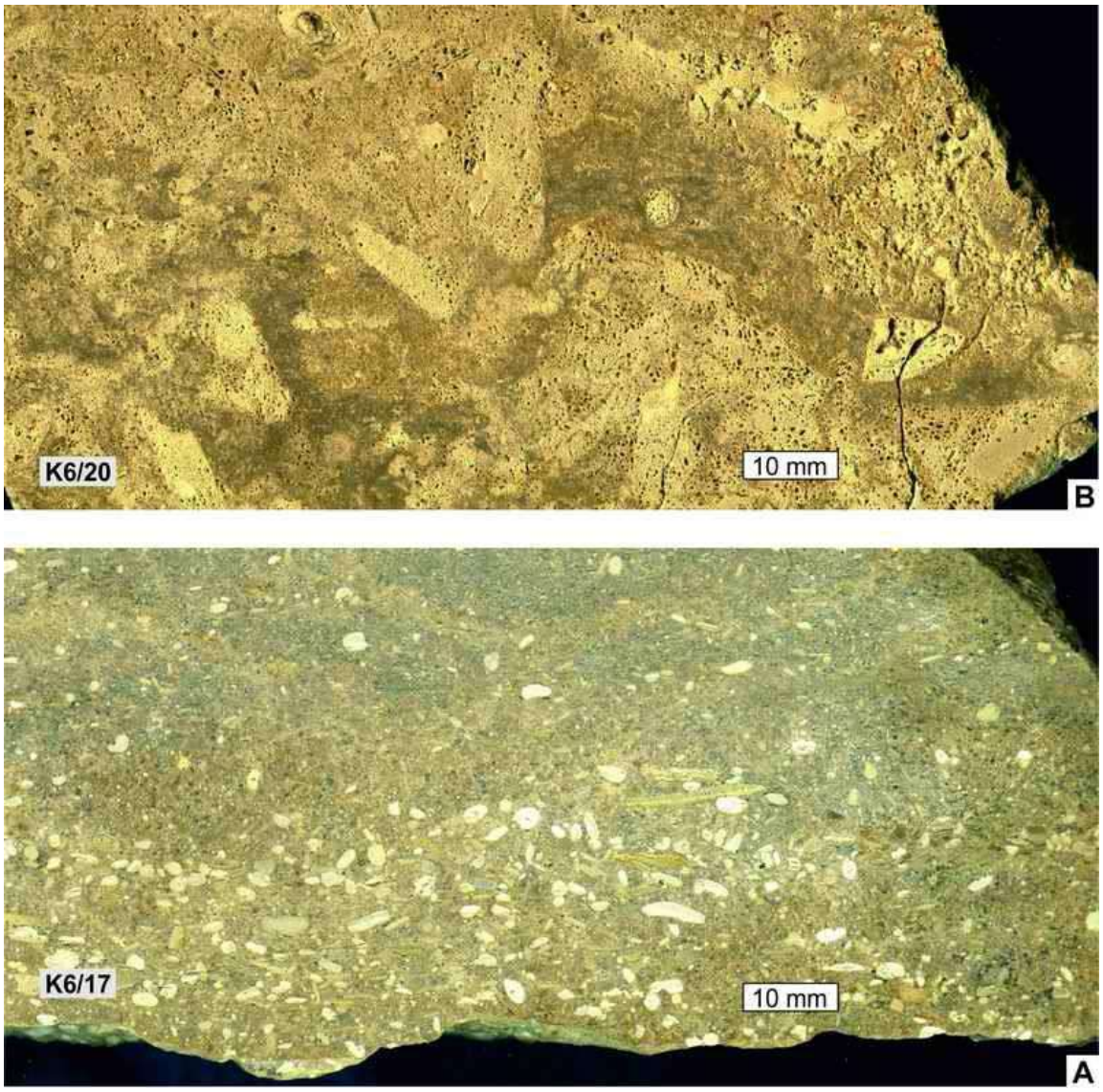
1.30 m) bears numerous ellipsoidal chert nodules (0.30 x 0.40 m) and quartz druses; the 40 cm in top is notably vuggy, with gypsum nodules.

Member E (Shikhany Member)

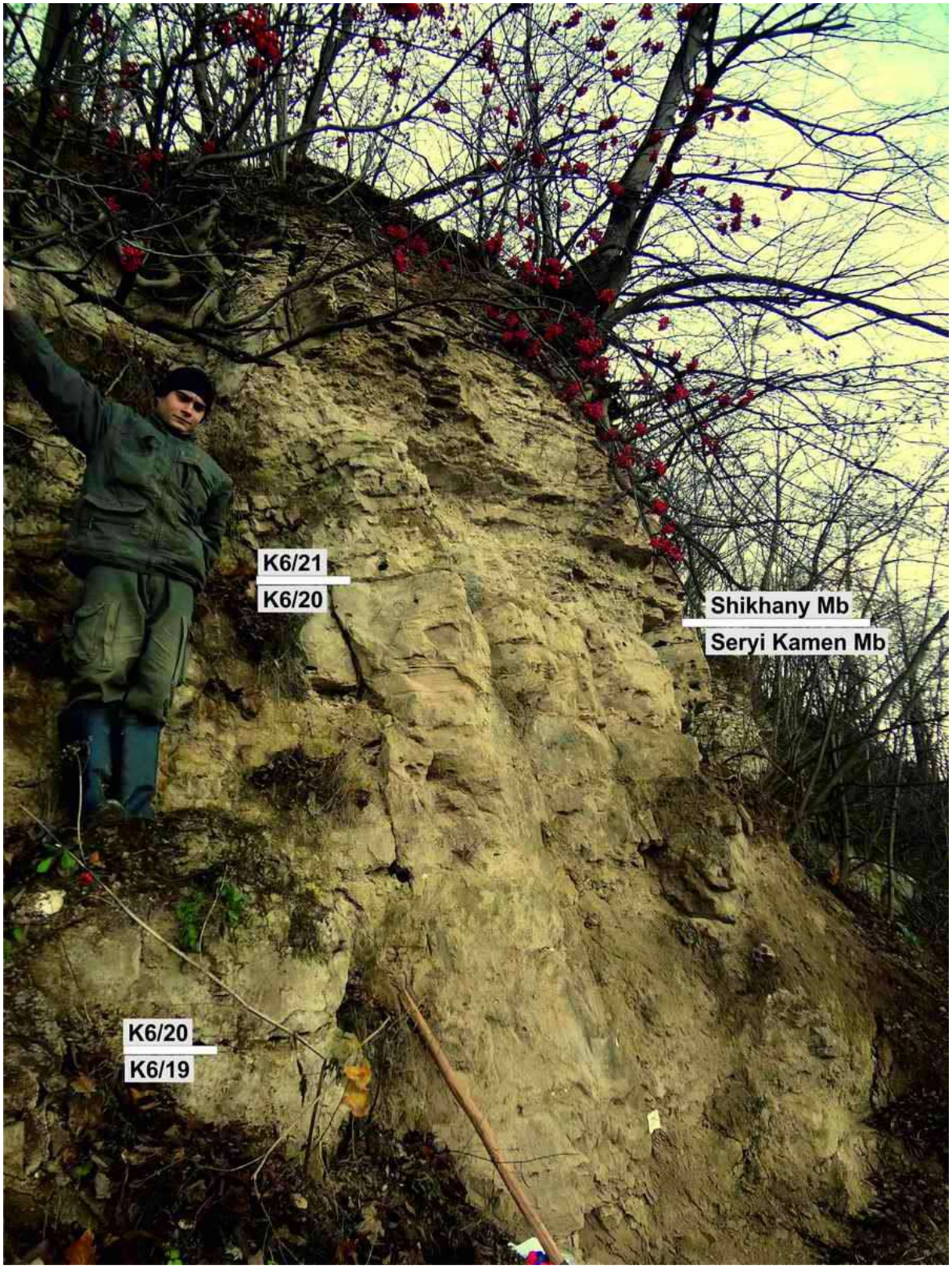
Unit K6/21 Interval 24.75-26.45 m Thickness (visible) 1.70 m

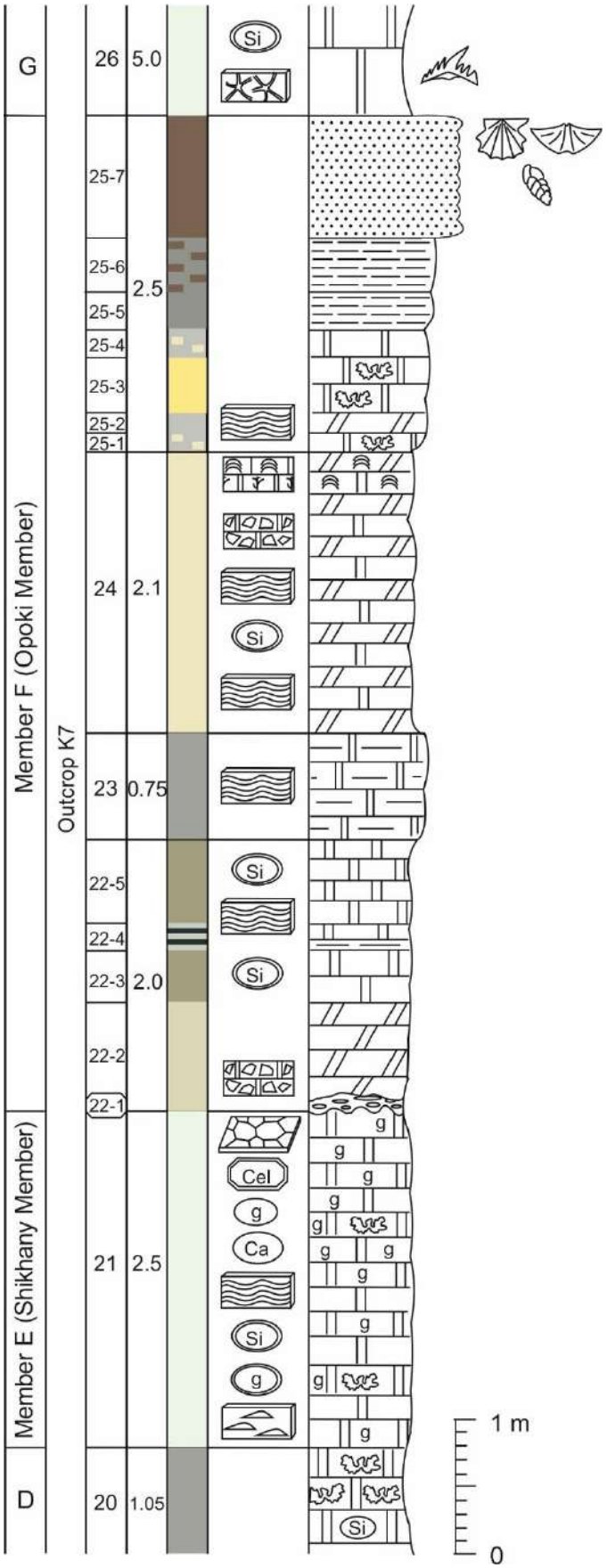
Bed no. 21 Shikhany of Noinsky (1899, 1924).

Dolostone: white to pale gray, unevenly crystalline, porous, relatively hard, with thin buckled lamination, rich in granules, nodules and flakes of gypsum (original 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 gypsum is weathered out. Gypsum nodules contain celestine crystals. Common elliptical chert nodules. 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, fully bioturbated dolostone (polished slabs)


K6/21
K6/20
Shikhany Mb
Seryi Kamen Mb
K6/20
K6/19


G
Member F (Opoki Member)
Member E (Shikhany Member)
D
Outcrop K7
26
5.0
25-7
25-6
25-5
25-4
25-3
25-2
25-1
2.5
24
2.1
23
0.75
22-5
22-4
22-3
22-2
22-1
2.0
21
2.5
20
1.05
Si
Cel
Ca
g
1 m
0

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 the Member F (Opoki Member) is overlaid by hard dolostones of the Member G (Podluzhnik ('Stone lying under the meadow') Member). Lower boundary of the unit K7/21 (the 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 the unit K6/21.

Complete thickness of Member E (Shikhany Member) varies from 2 to 4 m.

Verkhnyi Uslon Beds

Member F (Opoki ('Silica Clay') 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 disconformable, erosional. The unit can be divided in two 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 gray dolomarls forming 2-3 cm thick laminae; the dark gray 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. Polishes 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 colored. Dolostones are mostly soft, locally chertified, include 2-3 cm thick beds of harder fragile partly chertified dolostones. A 10 cm thick chertified stromatolithic dolostone in 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

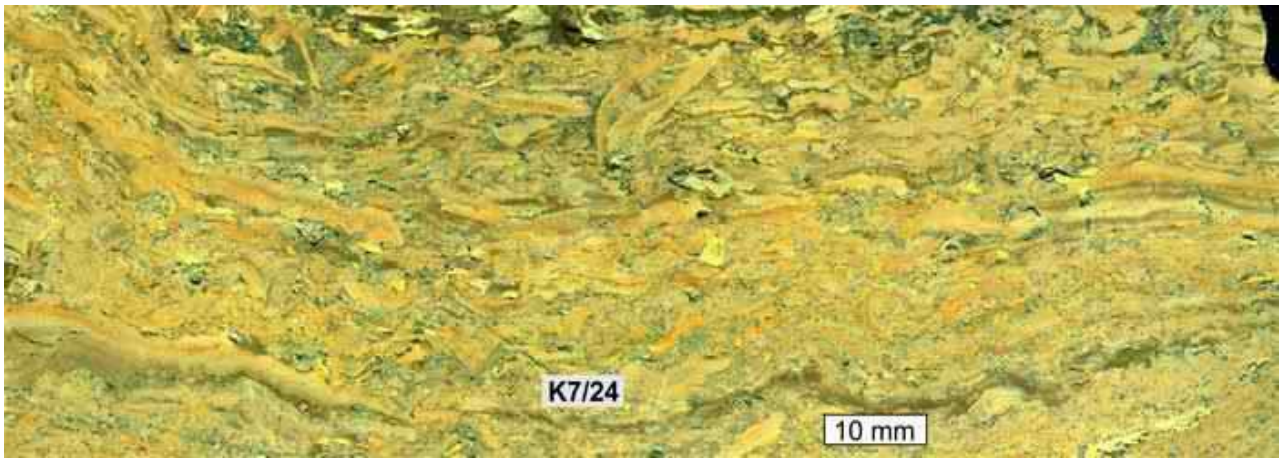
Dolostone: grey, argillaceous, very fine-grained, finely fractured, with ferruginized fracture planes, more argillaceous and grading to sandstone in top. The upper sandstone locally hosts numerous bivalve and brachiopod valves. Bivalves: *Pseudobakewellia, Pseudomonotis*. Brachiopods: *Cancrinella, Rhynchopora,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

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

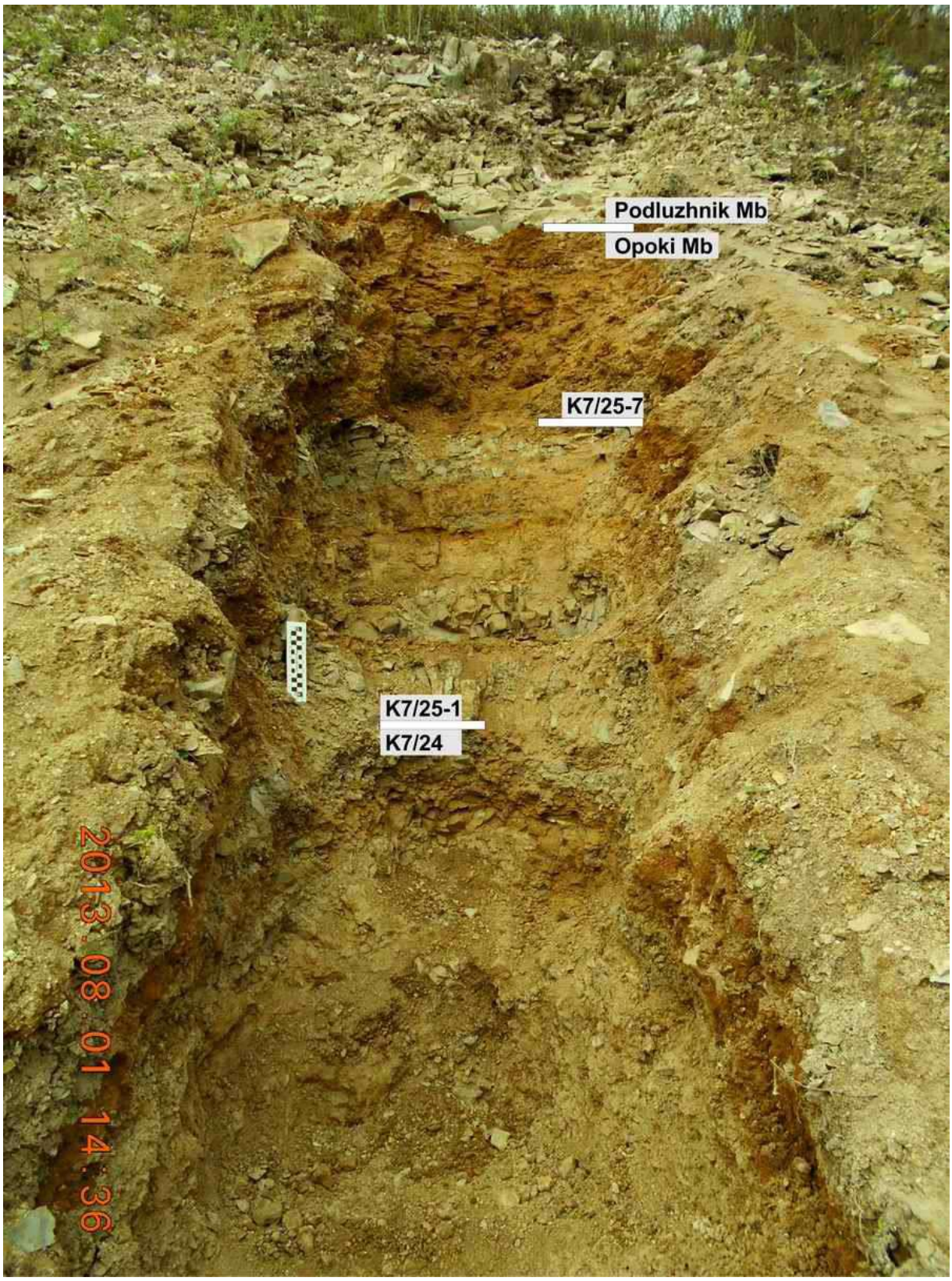
Bed K7/25-1 [0.00–0.15] Interval 32.10–32.25 m Thickness 0.15 m

Dolostone: grey-yellowish, locally vuggy.

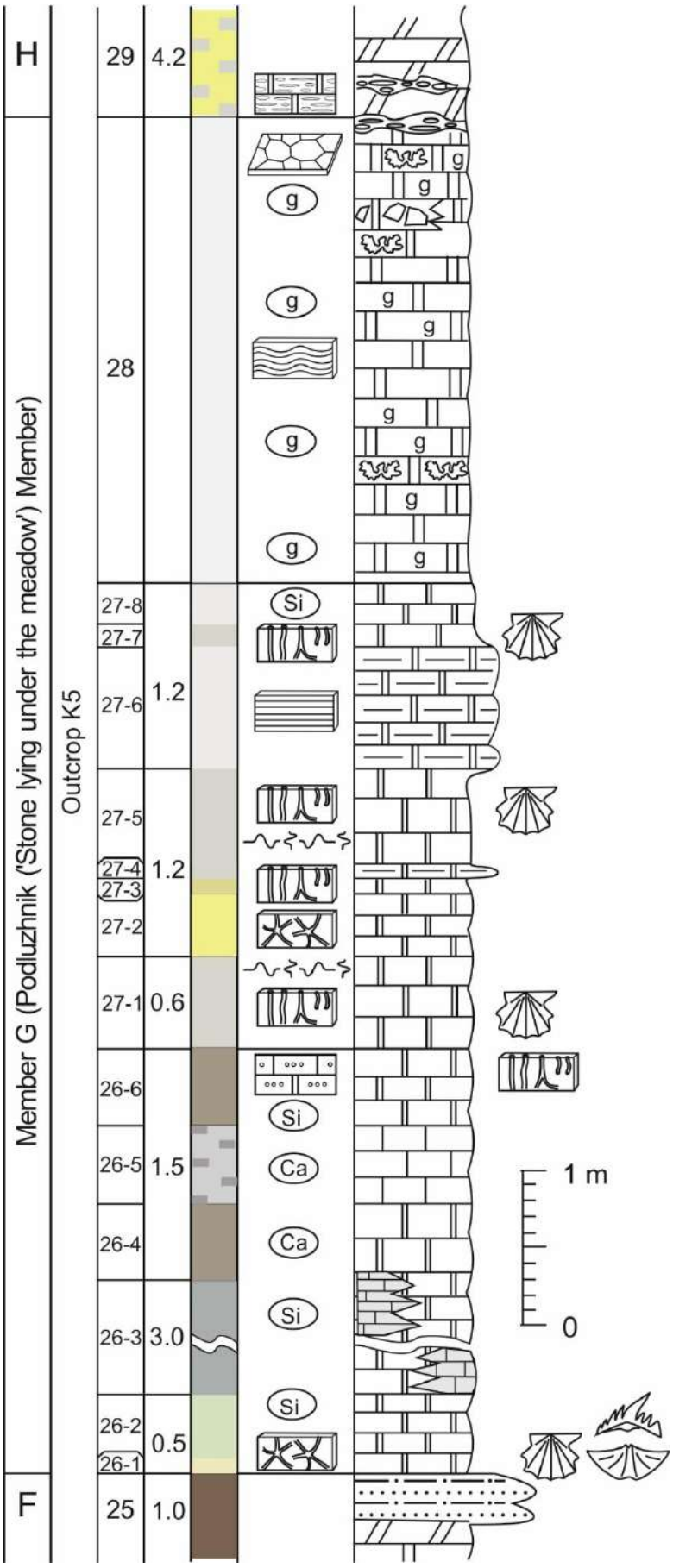
Bed K7/25-2 [0.15–0.30] Interval 32.25–32.40 m Thickness 0.15 m
Dolomarl: grey, fissile.
Bed K7/25-3 [0.30–0.70] Interval 32.40–32.80 m Thickness 0.40 m
Dolostone: bright yellow, probably sandy, with fine wavy lamination, locally vuggy and fractured.
Bed K7/25-4 [0.70–0.90] Interval 32.80–33.00 m Thickness 0.20 m
Hard recessive yellowish gray 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 gray argillaceous seams.
The unit is overlain by the moderately slumped dolostone of the Member 'Podluzhnik' (1.30 m) and the soil profile on the gully ledge. Total thickness of Member F (Opoki ('Silica Clay') 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 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 Clay’) Member) and its contact with Member G (Podluzhnik (‘Stone lying under the meadow’) Member)


Member G (Podluzhnik ('Stone lying under the meadow') Member)
Outcrop K5
29
4.2
28
27-8
27-7
27-6
1.2
27-5
27-4
27-3
1.2
27-2
27-1
0.6
26-6
26-5
1.5
26-4
26-3
3.0
26-2
26-1
0.5
25
1.0
g
Si
Ca
1 m
0

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 Cheremushka ("Bird Cherry'') Gully. Uppermost beds of Member F (Opoki ('Silica Clay') 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 is accessible in vertical cutting for approx. 10 m. Upper boundary of the unit K5/25 (Member F (Opoki)) is exposed in 78.0±3 m ASL.

Verkhnyi Uslon Beds

Member F (Opoki ('Silica Clay') Member)

Unit K5/25 Interval 33.60–34.60 m Thickness (visible) 1.00 m

Sandstone: buff, poorly lithified with gray argillaceous seams. The same as in the 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 divided in 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 recrystallized 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 gray, 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 upper part.

Unit K5/27 Interval 39.60–42.60 m Thickness 3.00 m

Dolostone: pale gray, 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 contained bivalves and probably foraminifers.

The unit can be divided in 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 in base and massive in top, alternation of calcimudstone and very fine-grained ooid grainstone; rare *Pseudomonotis* presumably in life position and vertical and shallow plunging burrows 3-5 mm in diameter.

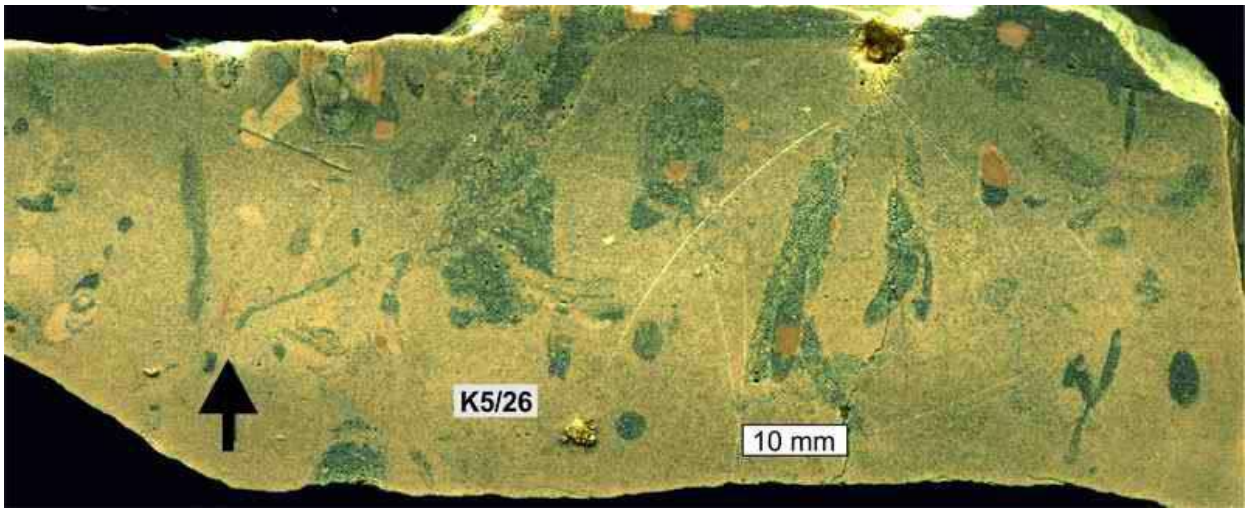
Bed K5/27-2 [0.60–1.00] Interval 40.20–40.60 m Thickness 0.40 m

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.

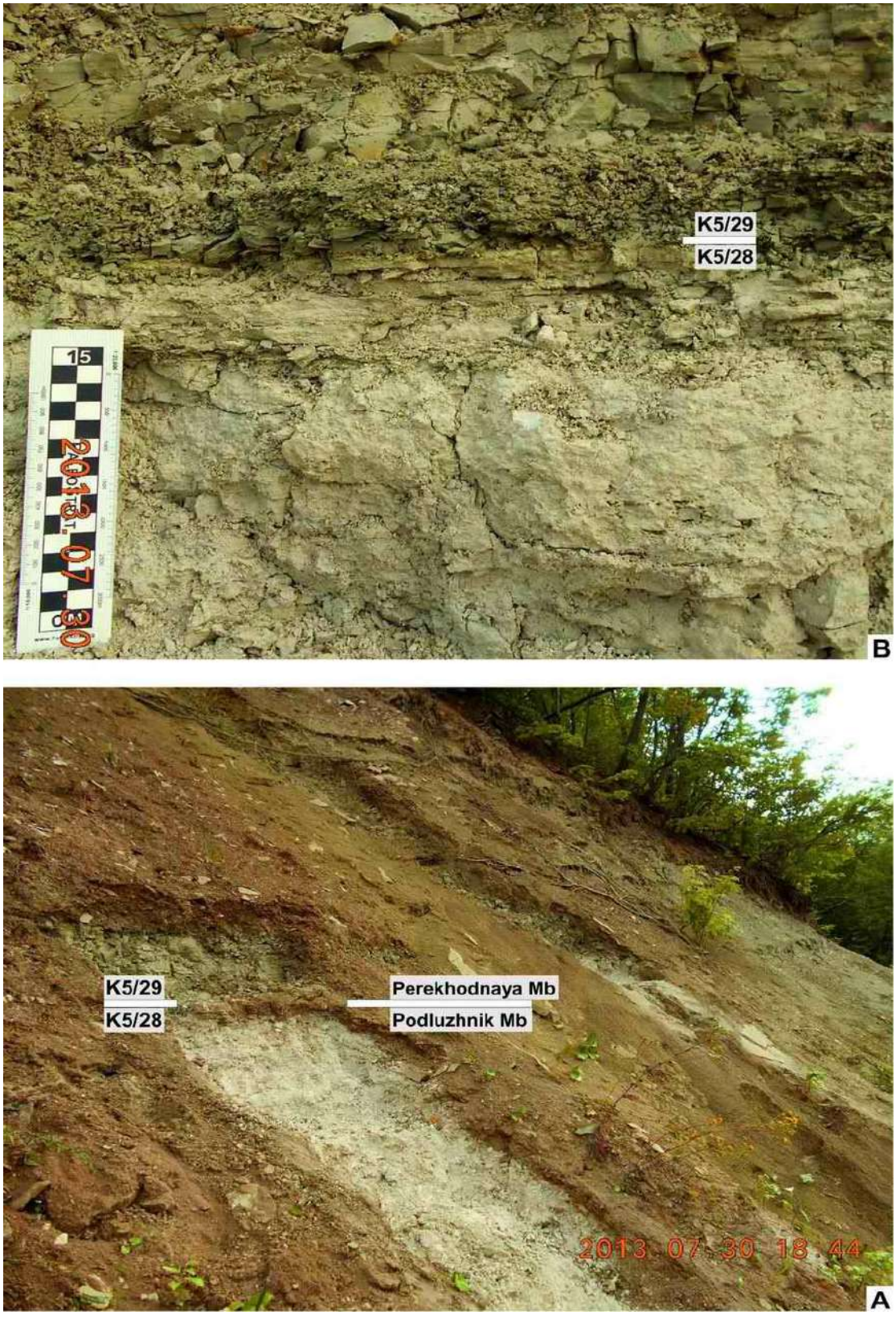
Bed K5/27-3 [1.00–1.10] Interval 40.60–40.70 m Thickness 0.10 m

Dolostone: pale yellowish grey, resistant, with rare bivalve molds and horizontal disrupted lamination.

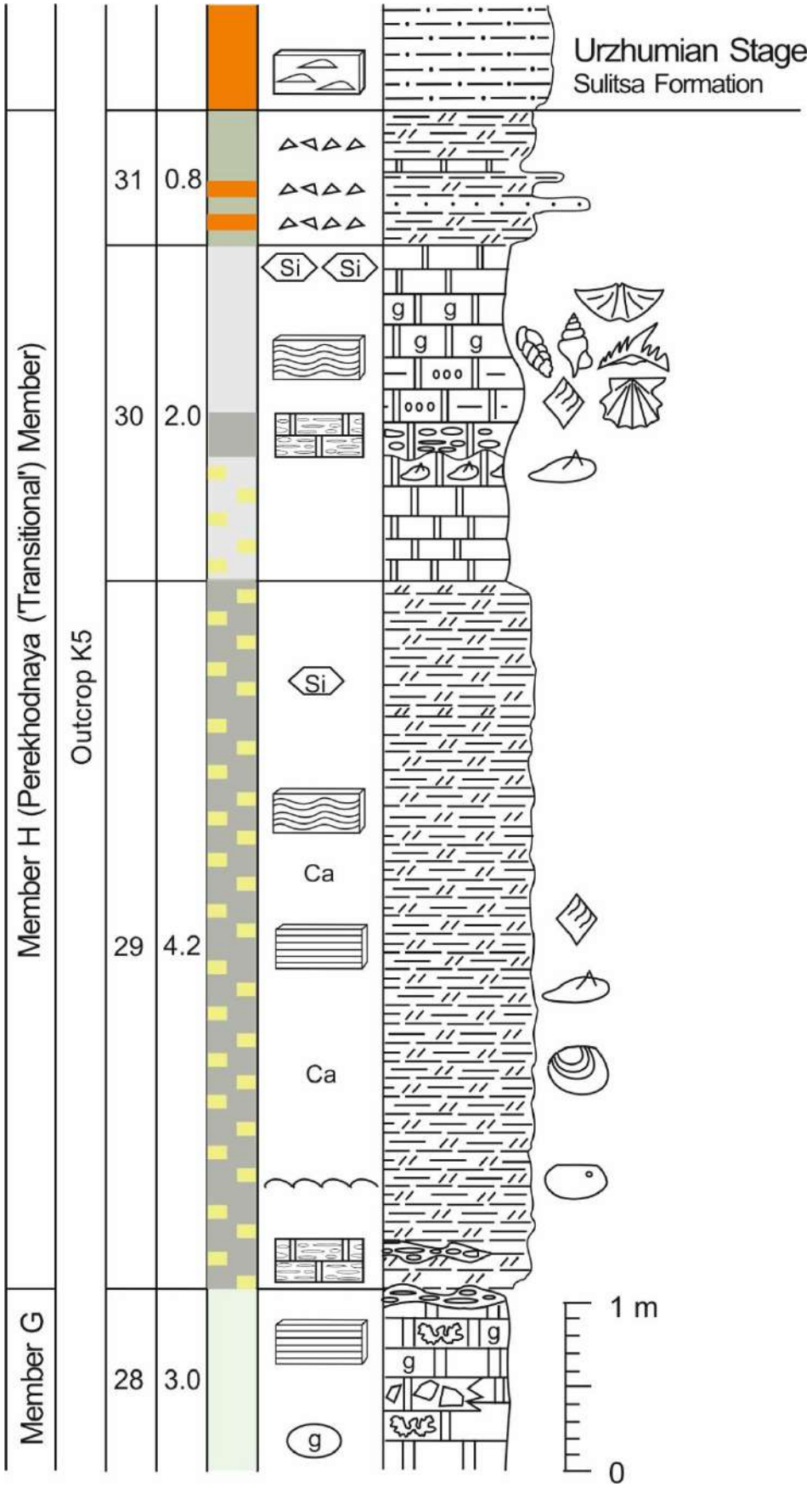
Bed K5/27-4 [1.10–1.20] Interval 40.70–40.80 m Thickness 0.10 m
Dolostone: grey, argillaceous, with thin *Scolithos* burrows penetrating from top.
Bed K5/27-5 [1.20–1.80] Interval 40.80–41.40 m Thickness 0.60 m
Dolostone: very similar to bed K5/27-1 (interval 0.00–0.60 m), with rare bivalve and brachiopod 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 gray and bluish gray 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 gray, microcrystalline, fragile, massive to microlaminated, rich in seams and nodules of white and pinkish gypsum; vuggy and locally disintegrated into powder where 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)


Urzhumian Stage
Sulitsa Formation
Member H (Perekhodnaya (Transitional") Member)
Member G
Outcrop K5
31
0.8
30
2.0
29
4.2
28
3.0
Si
Si
Si
Ca
Ca
g
g
g
g
g
g
1 m
0

Morkvashi Beds

Member H (Perekhodnaya ('Transitional') Member)

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

Dolomarl: mottled yellowish gray, microcrystalline (dolomudstone), with dolostone conglomerates in basal 10-20 cm. The upper one-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 coaly plant detritus.

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

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

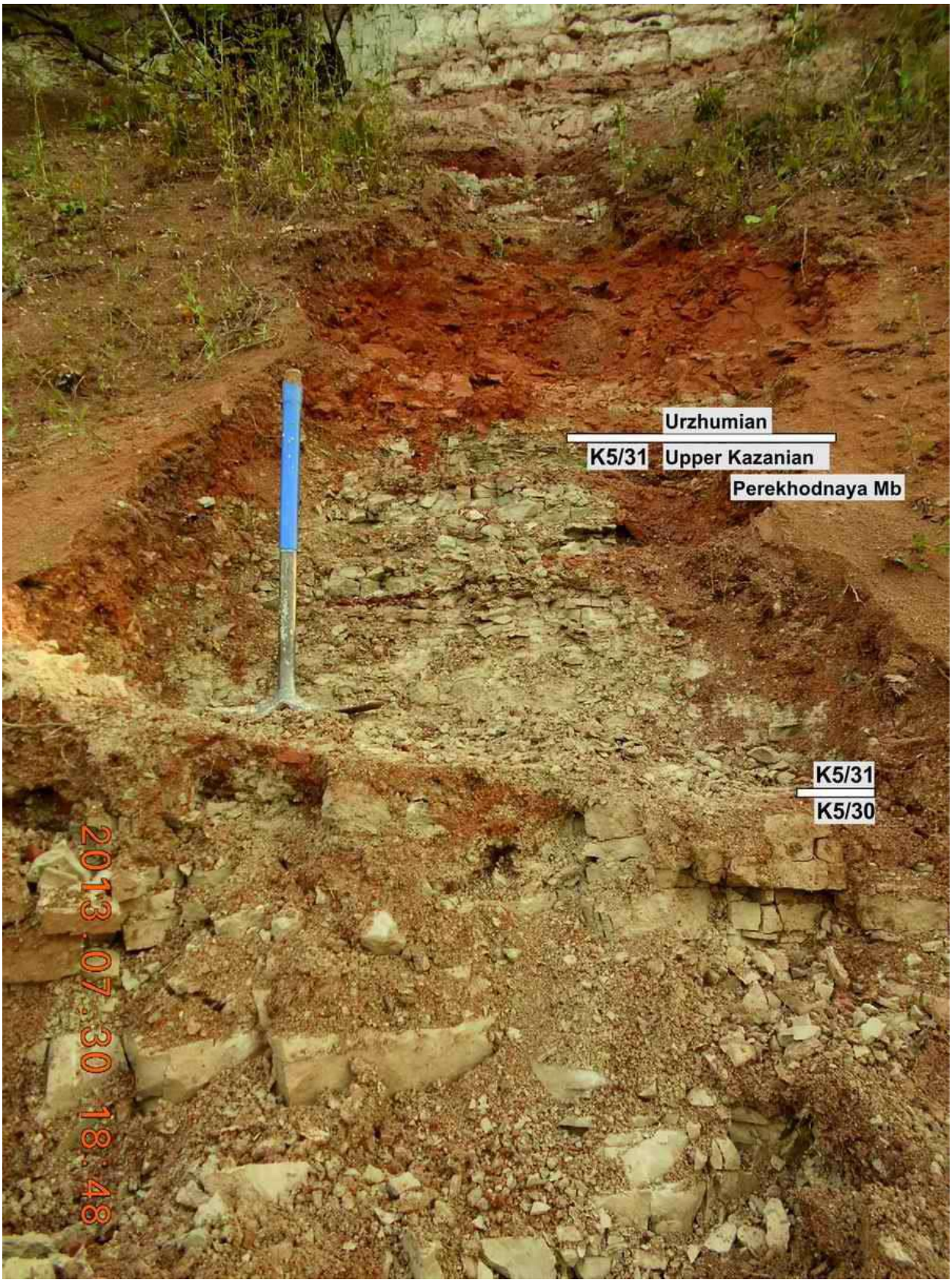
The upper part of the unit contains nests of loose chalcedony-quartz hash indicating former presence of anhydrite nodules.

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 hash horizon, there is a 5-6 cm thick packbreccia of subrounded gray-colored dolomite clasts submerged in red-colored argillaceous matrix.The top of this breccia locally shows color inversion to red clasts and gley matrix. Red-colored clasts are also encountered in the base of this breccia. The breccia is overlain by a rounded-grain intraclastic calcarenite (1-2 cm) which is in turn succeeded by the red shale and the second horizon of fine-grained argillaceous - dolomitic breccia very similar in its appearance to the lower horizon.

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

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



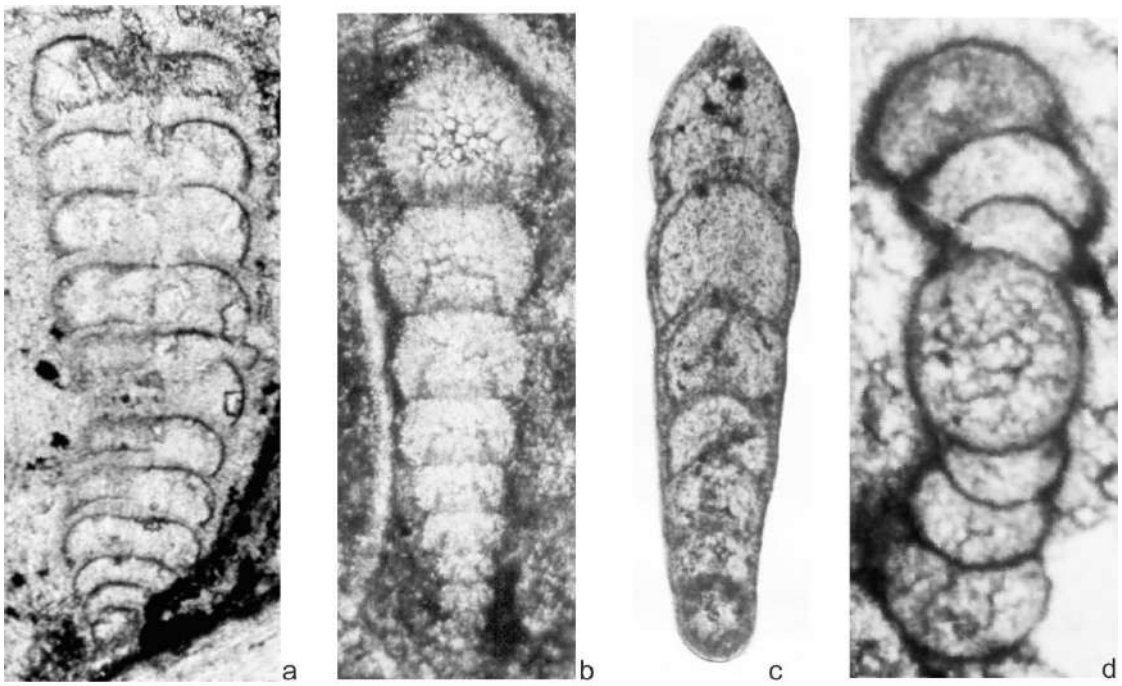
Outcrop K5. Uppermost part of the outcrop, the Kazanian/Urzhumian boundary

BIOSTRATIGRAPHY

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

Solodukho and Tikhvinskaya (1977), Esaulova (1998c, d), Chalimbadja and Silantiev (1998), Silantiev (2007), Silantiev et al. (2007), Goetz and Silantiev (2014) and other colleagues 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 readily traced in this outcrop. The fossil assemblage is more diverse because of the facial 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 in 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.*

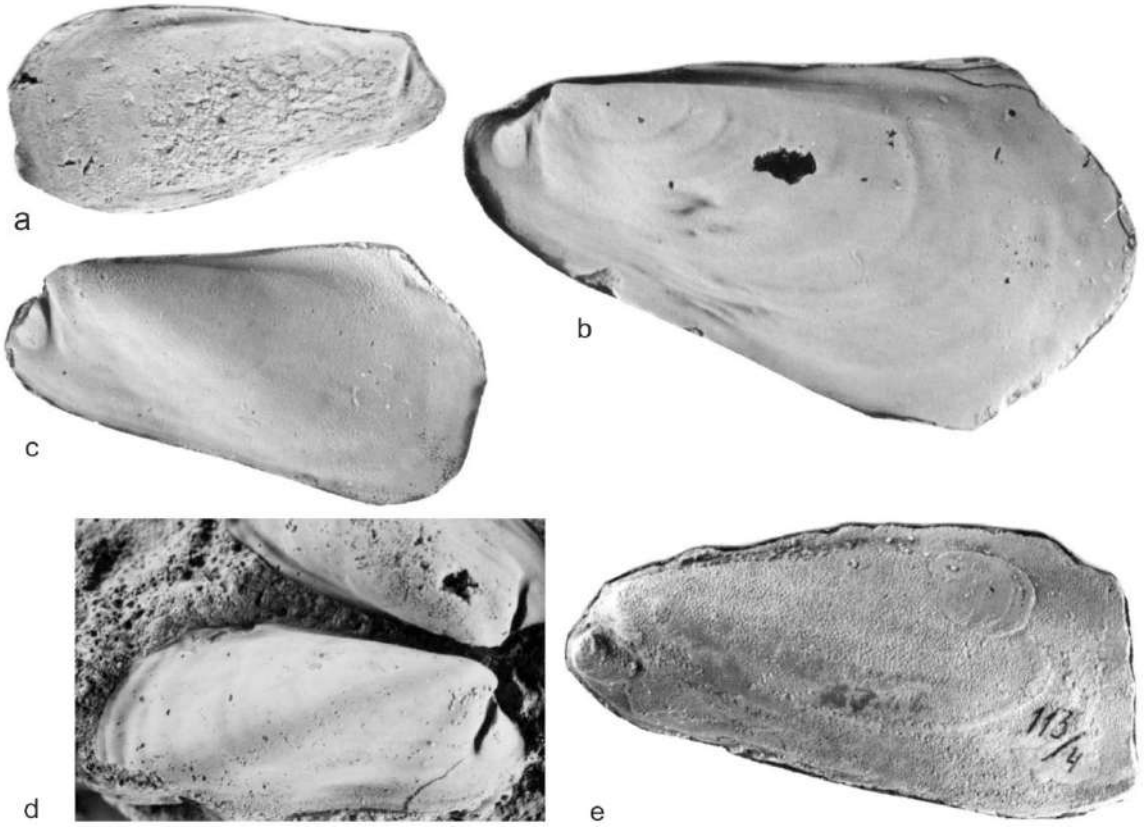


Foraminifers from The Kazanian reference section

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 in the section, in Member B, *Aulosteges* do not occur. Fossils are represented by molds and imprints of small-sized *Cancrinella*, *Beecheria*, *Stenoscysma*, *Rhynchopora*, and by many bivalves (mainly *Pseudomonotis* and *Schizodus).* These strata also yield the bryozoans *Pseudobatostomella decora* Moroz. and broken colonies of *Fenestella permutula* Moroz. Bed no. 9 Chetyre Rubtsa ('Four Seams') of Noinsky (1899, 1924) contain conodonts *Stepanovites mey*eni Kozur et Movsch. In the very top of the Beds fossils are absent.

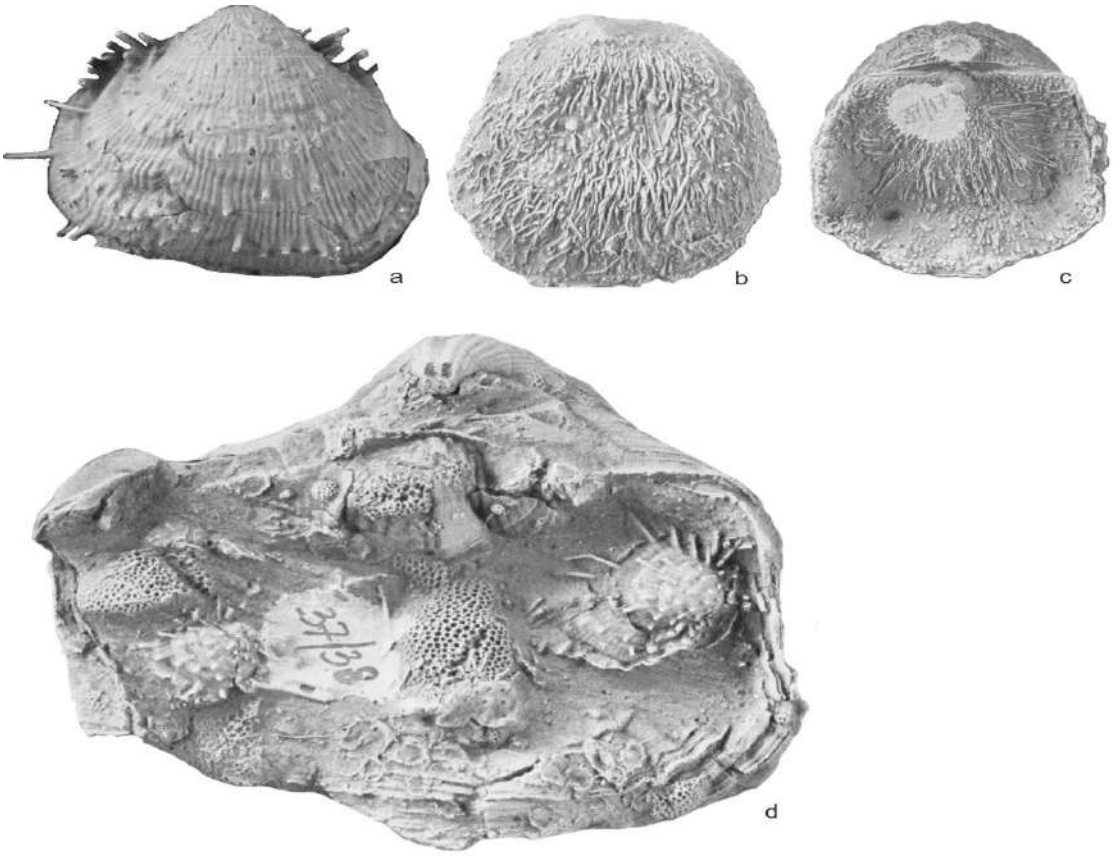
Pechishchi Beds. These Beds comprise three Members (Member C (Podboi Member), Member D (Seryi Kamen ('Grey Stone') Member), and Member E (Shikhany Member)). The index fossils for these beds are *Lingula* ex gr. *media* Tscherd. *Nodosaria krotovi* Tscherd., *Conularia hollebeni* Gein., *Fistulipora dybowsky* 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: *Hemigordius pussila* Gein., *Rhomhotrypella 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 upward in the section up to the Morkvashi Beds. These fossils are unevenly spread 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 scanty remains of *Cancrinella, Cleiothyridina, Beecheria, Pseudomonotis,* and *Pseudobakewellia.*

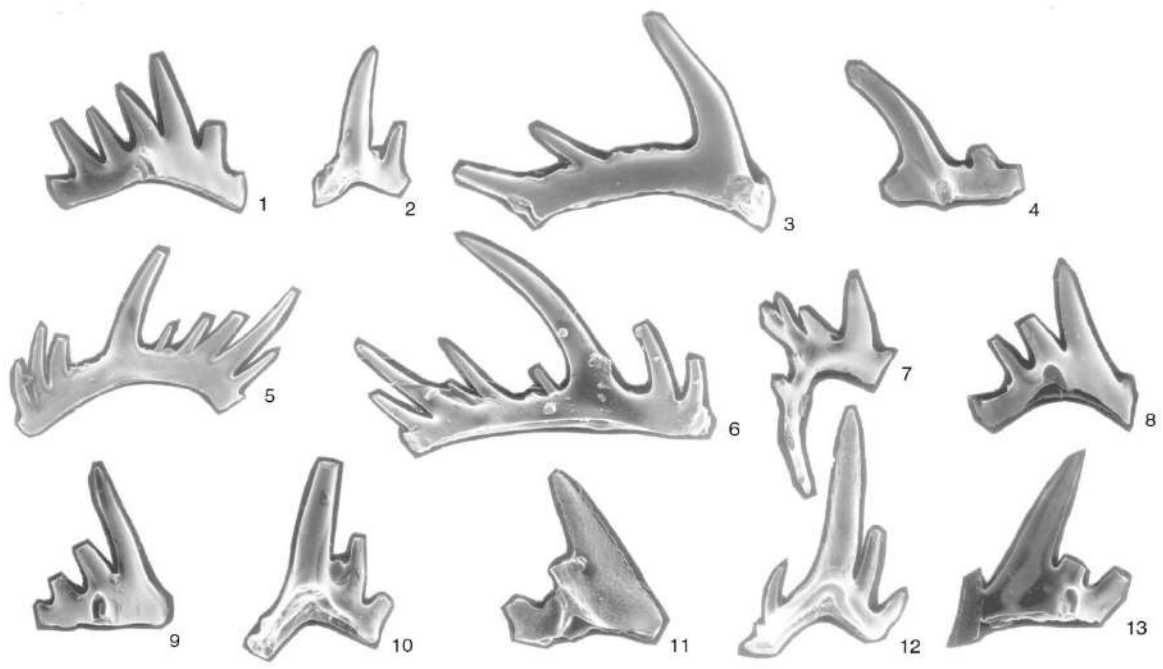
The Member «Shikhany» which is largely gypseous contains virtually no fossils.



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 Russian Empire in 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

Verkh nyi Uslon Beds. These beds are composed of two Members (Member F (Opoki (‘Silica Clay’) Member) and Member G (Podluzhnik (‘Stone lying under the meadow’) Member). The lower Member, Member F (Opoki (‘Silica Clay’) Member), contains scanty fossils, whereas the Member G (Podluzhnik (‘Stone lying under the meadow’) Member) contains (especially in its lower part) many fossils: 10 foraminiferal taxa, 13 bryozoan taxa, 10 brachiopod taxa, 40 bivalve taxa, 24 gastropod taxa, althogether 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* (?) *permiana* King, *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.) firstly appear in these beds and continue to the Morkvashi Beds.

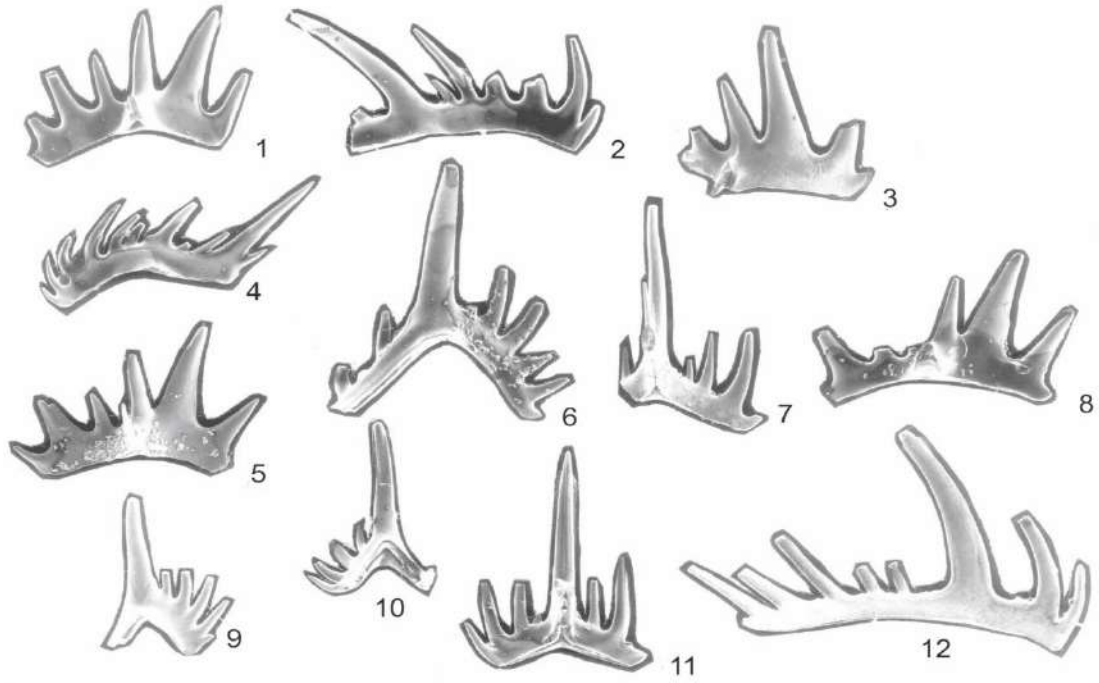


Conodonts *Kamagnathus khalimbadzhae* Chernykh, 2001

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

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, brachiopods *Cancrinella, Rhynchopora, Stenoscysma,* and *Beecheria,* bivalves *Nuculopsis, Nuculana, Schizodus, Pseudobakewellia, Netschajewia,* etc., gastropods *Bayelia, Goniasma,* and *Loxonema,* conodonts *Kamagnathus volgensis* Chern. Generally, the marine fauna of this assemblage is impoverished.

The cyclic structure of the Upper Kazanian indicates the pulsated 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 medium shelf and then by the shallow-sea, and lagoonal.



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

Fishes

The fish microremains are found in the Kamyshlinskian Regional Stage, Early Kazanian of locality Pechischi. 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 the Kazanian of Russia and Roadian of Texas, USA but is firstly described from the Late Pennsylvanian of Brazil (Ivanov, 2011).

Palynology

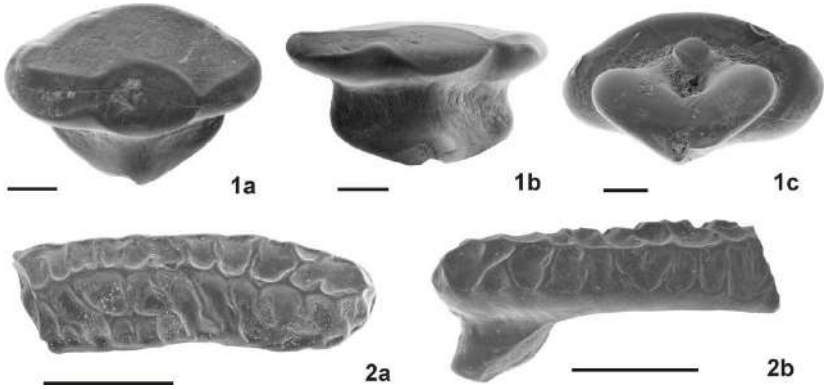
Palynostratigraphy

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 Middle Permian stages of Russia and those of the Canadian Arctic and other circumpolar regions (southern Barents Sea, Mangerud 1994; Greenland, Balme 1980), hindering interregional correlation. It was concluded that the recognized differences are most likely the result of variations in the parent flora related to different palaeoclimatic conditions.

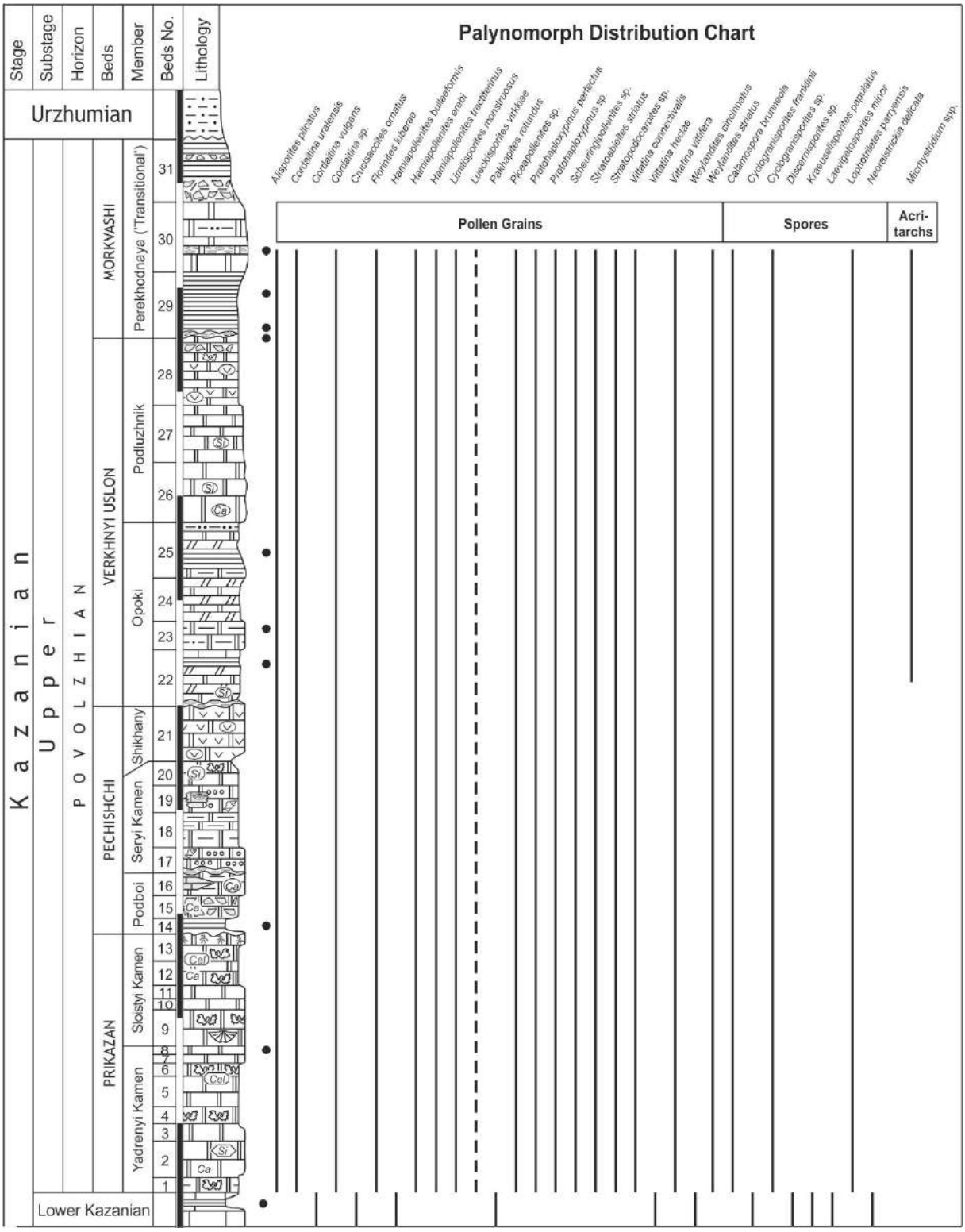
In 2014 we focus on the Kazanian stage with new palynological data from the latest Early Kazanian and entire Late Kazanian (Povolzhian), exposed in a section near the village of Pechishchi. The palynomorph assemblage is dominated by pollen grains and a major change in composition occurs at the Lower-Upper 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 *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 an Early Kazanian age, assemblage 3 and 4 indicating a Late Kazanian age). This dataset shows a general dominance of bisaccate, striate pollen grains and an increase of this pollen group is observed upsection. Spores are rare elements in the entire succession.

Chondrichthyan teeth from the locality Pechischi. 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.

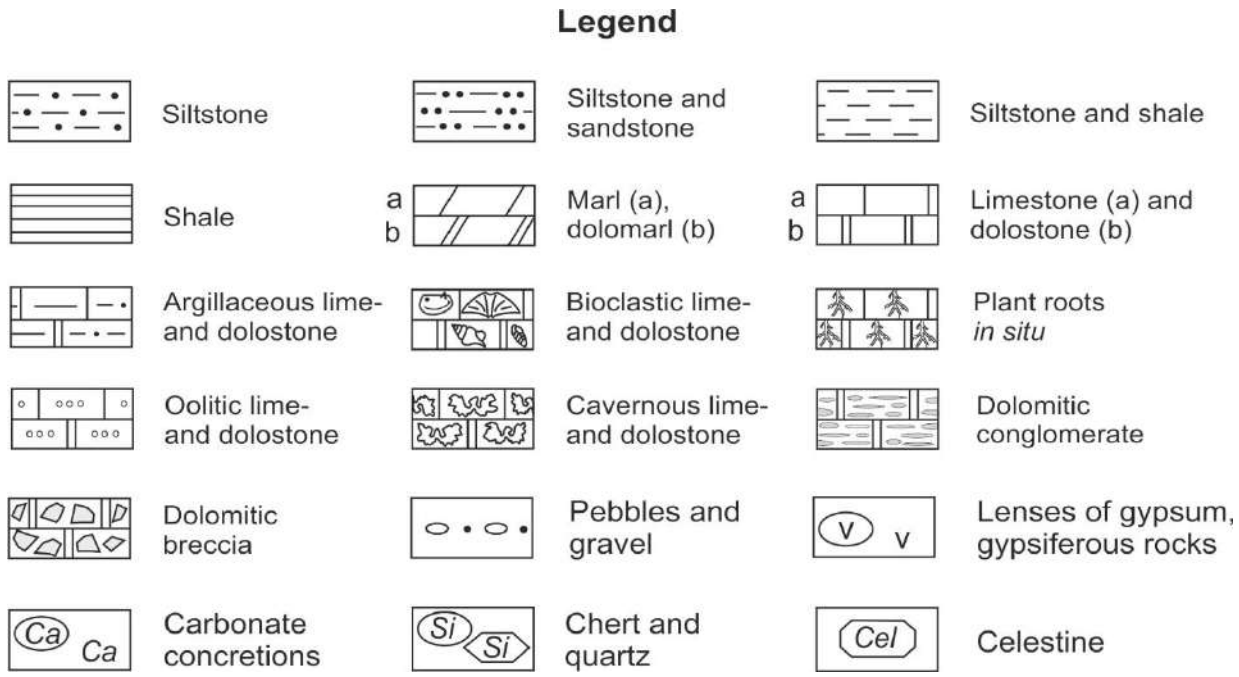


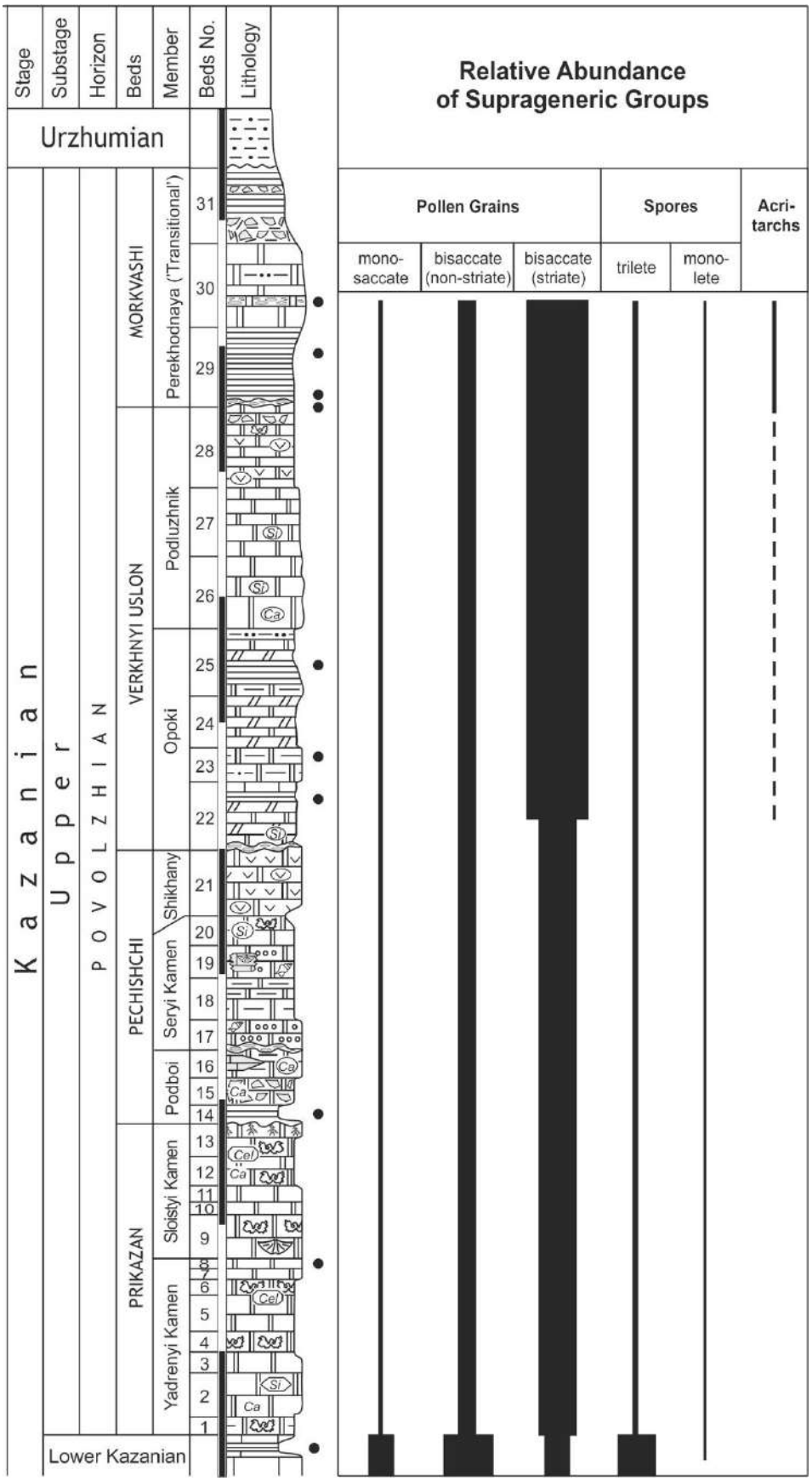
Palynomorph distribution chart of the Pechishchi section. The total thickness of the studied interval is about 50 m, scale bars 5 m each. Sample horizons are marked by black dots

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 an increase within the Kazanian was 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 recognized, 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 upsection 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 are 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.





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

Palaeoenvironment, palaeoclimate and depositional model

The study area is part of the eastern flank of the 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 studied 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 is dominated by terrestrial particles (pollen grains, spores) including phytoclasts of different size and shape, and different preservation states (opaque, translucent). The high amount of phytoclasts indicates a lush vegetation of the eastern hinterland.

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 characterized by intense erosion due to weathering. The climate was hot and dry (arid). There were hardly river systems developed. Minor soil-forming processes and only sparse vegetation are assumed. Faunal elements are rare, only small vertebrates were present 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 present 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 the ridges separating the 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.

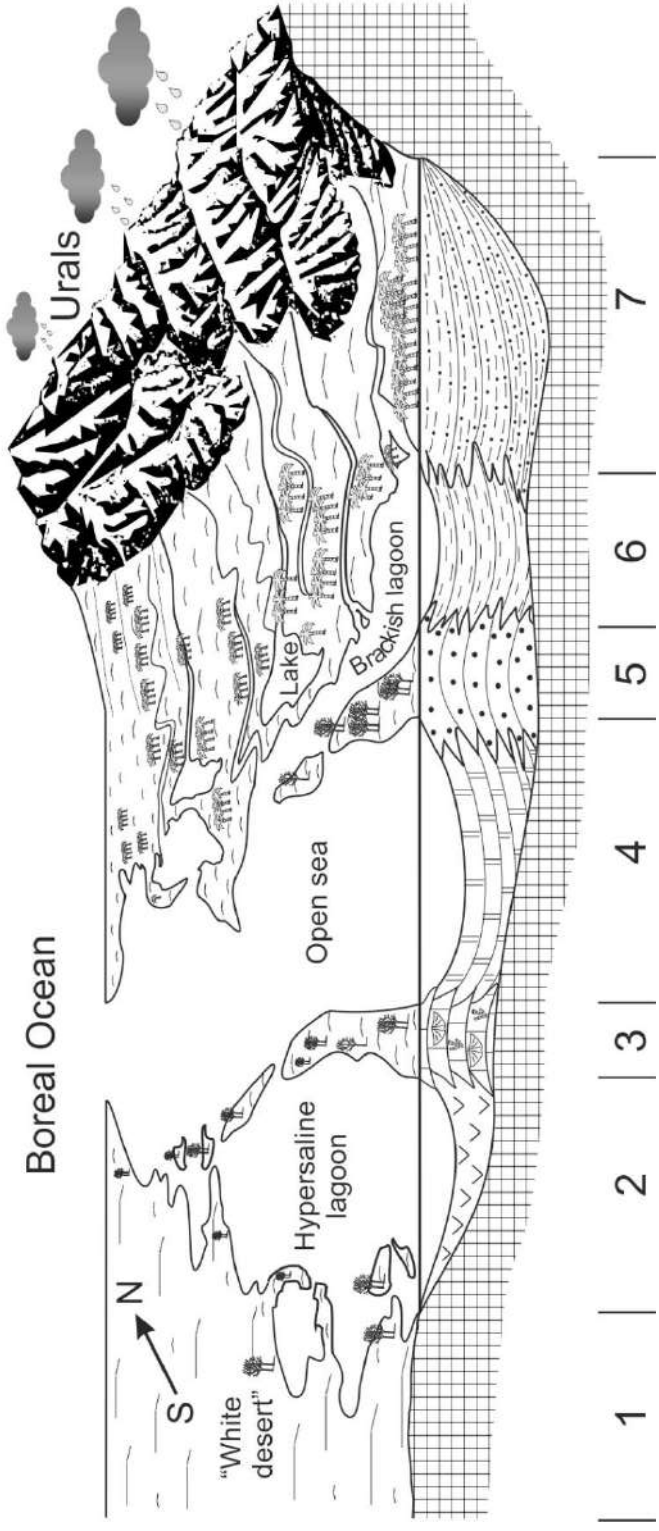
5. *Bars and barrier islands*. These large ribbon-like sand bodies were elongated parallel to the coast, separating the open sea from the brackish lagoons. Due to humid climate conditions, the vegetation is diverse and lush. Invertebrates include various shallow-water forms of brachiopods and bivalves. The dominant lithologies are sandstones with wave ripple marks and oolitic limestones; the latter characterize 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 characterized by varying desalination. In some lagoons, clay and organic-rich sediments were accumulated; other lagoons contain mainly carbonate sediment. This depositional zone is characterized 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, clays with thin layering, and numerous thin seams of coal. Limestones are often bituminous in 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 characterized 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 characterized by lush vegetation. Localities of fossil flora (including wood fragments in fluvial sandstones) are known from deposits which had 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.

PARASTRATOTYPE OF THE URZHUMIAN REGIONAL STAGE IN THE CHEREMUSHKA (“BIRD CHERRY’’) GULLY

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 in 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.

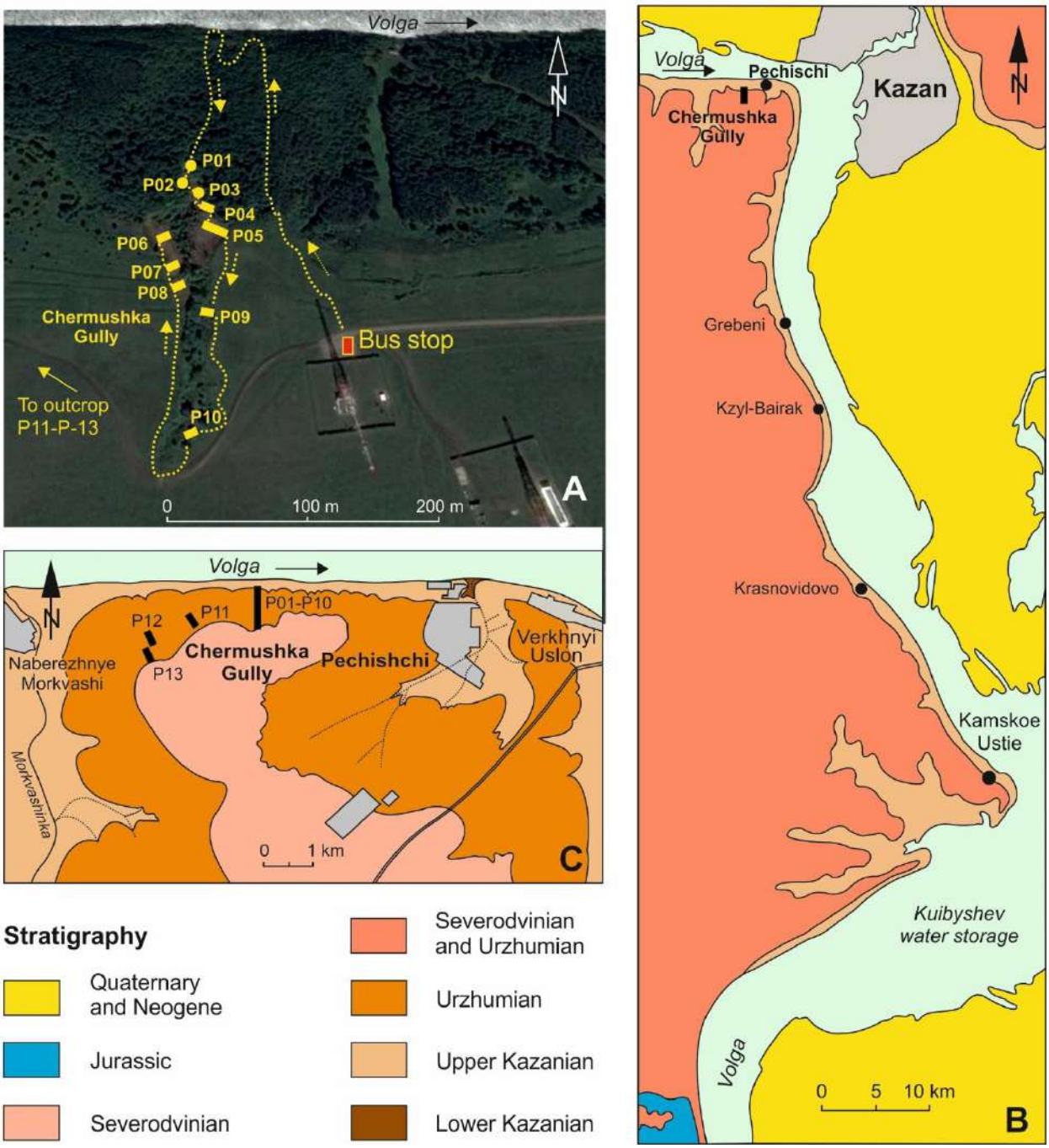
The second group walks down to the bank of the Volga River and then hike up the gully examining the Upper Kazanian to Urzhumian succession. Fragments of the Seryi Kamen’ (“Grey Stone”), Shikhany, Opoki, Podluzhnik, and the Kazanian-Urzhumian boundary beds are exposed on both sides of the gully. Then 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) (Fig. Cher1 A–C) (Fig. Cher1 A–C).

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 (1998) 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.

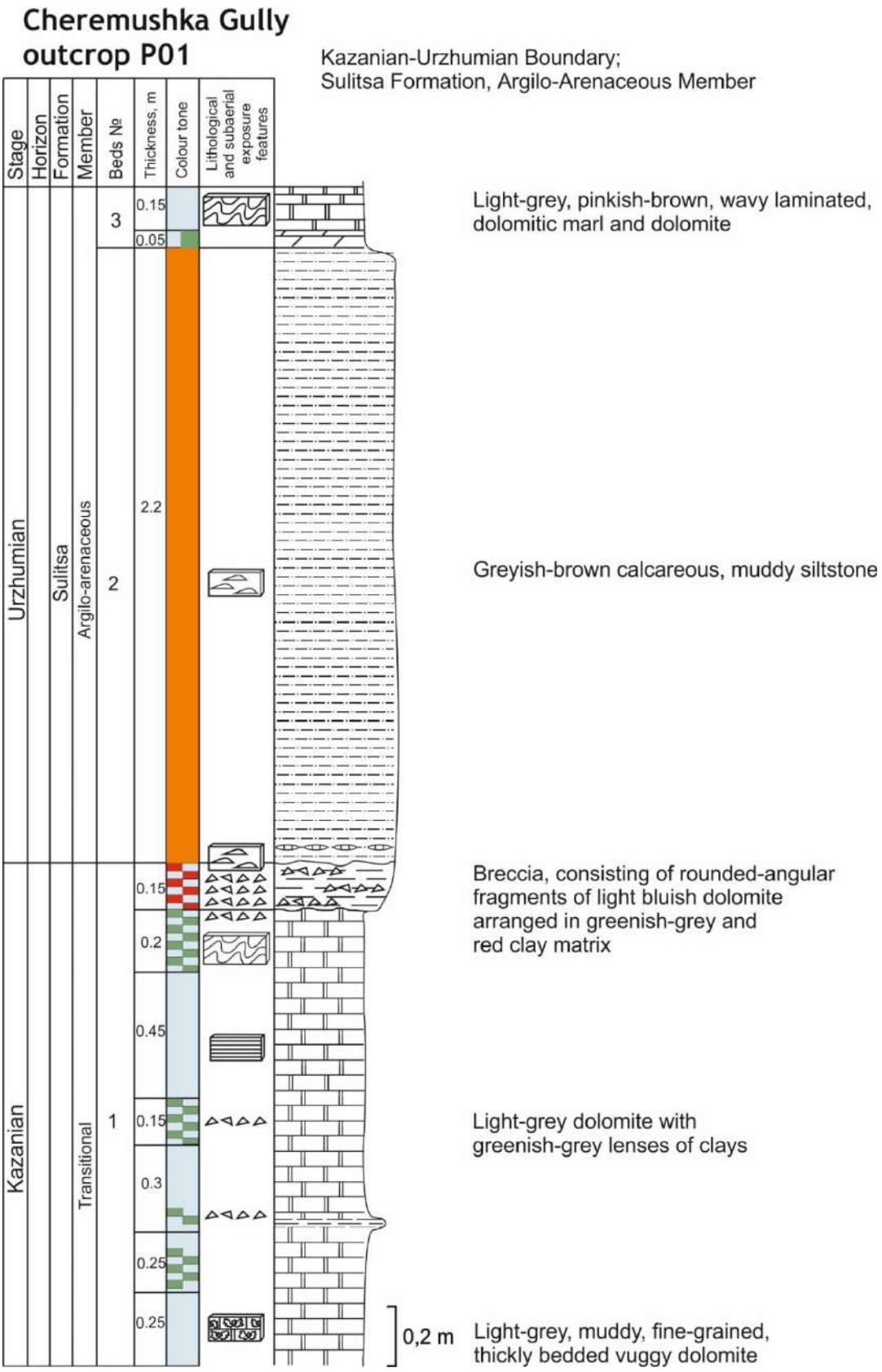
In 2013-2015, the parastratotype of the Urzhumian regional stage was studied again by the Laboratory of Stratigraphy, Kazan Federal university (Silantiev et al., 2014; Bulanov et al., 2014, Goetz, Silantiev, 2015; Mouraviev et al., 2015, etc).

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



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

Upward 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, Argilo-Arenaceous Member
Stage
Horizon
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Urzhumian
Kazanian
Sulitsa
Argilo-arenaceous
Transitional
3
2
1
0.15
0.05
2.2
0.15
0.2
0.45
0.15
0.3
0.25
0.25
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 clay matrix
Light-grey dolomite with greenish-grey lenses of clays
0,2 m
Light-grey, muddy, fine-grained, thickly bedded vuggy dolomite

Outcrop P01

GPS: 55.78047 N, 048.92753 E (WGS84). Datum: right slope of 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 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) 1.75m

Dolomite: light-grey and greenish-grey, with lenses of greenish-grey clays, 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 clay matrix (in the upper part of the interval).

Sulitsa Formation

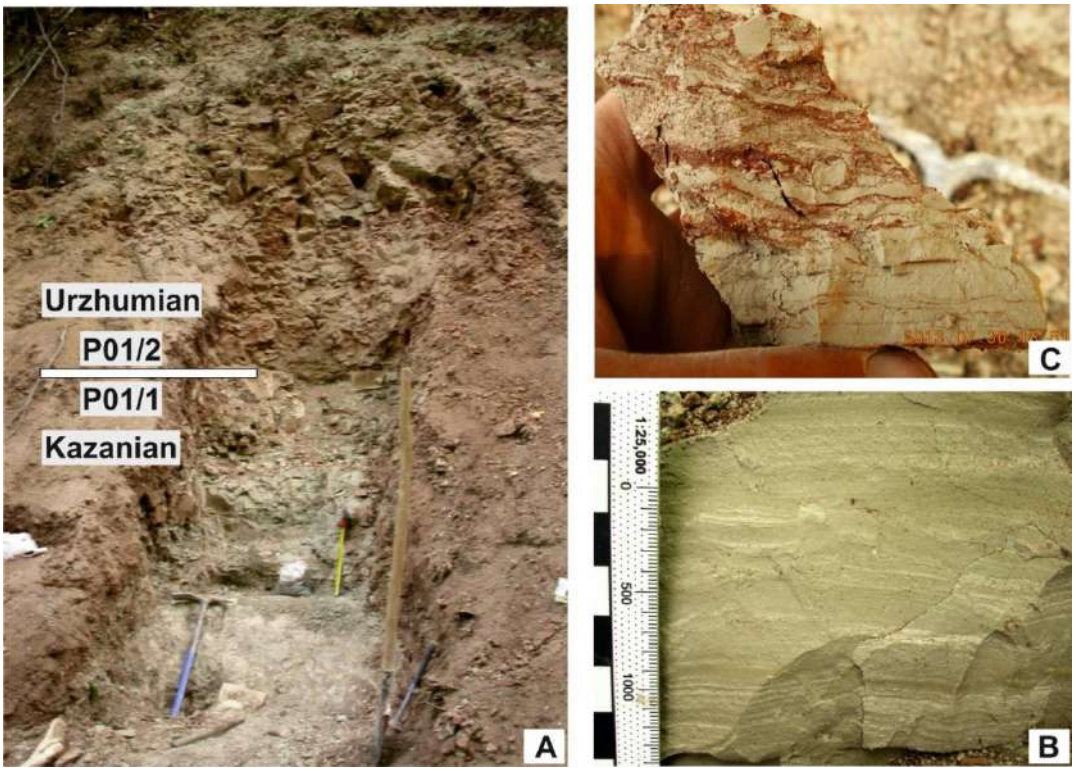
Argilo-arenaceous Member

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

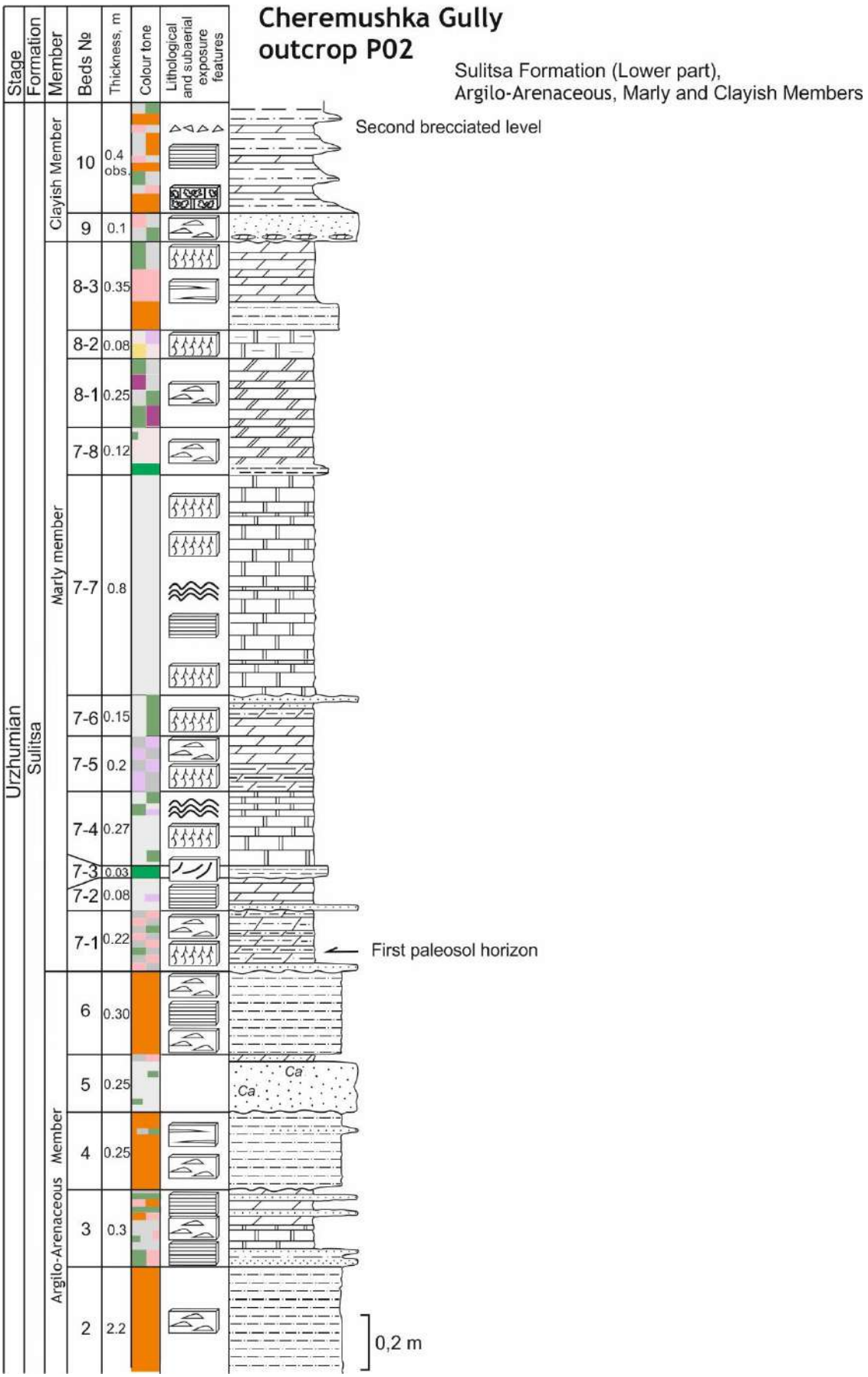
Siltstone: brownish, greyish-brown, calcareous, lenticular or wavy laminated; thin lenses of limestone gravelite at the bottom.

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),
Argilo-Arenaceous, Marly and Clayish Members
Stage
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Urzhumian
Sulitsa
Clayish Member
Marly member
Argilo-Arenaceous Member
10
0.4 obs.
9
0.1
8-3
0.35
8-2
0.08
8-1
0.25
7-8
0.12
7-7
0.8
7-6
0.15
7-5
0.2
7-4
0.27
7-3
0.03
7-2
0.08
7-1
0.22
6
0.30
5
0.25
4
0.25
3
0.3
2
2.2
Second brecciated level
First paleosol horizon
Ca
Ca
0,2 m

Outcrop P02

GPS: 55.78030 N, 048.92736 E (WGS84). Datum: left slope of 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

Argilo-arenaceous Member

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

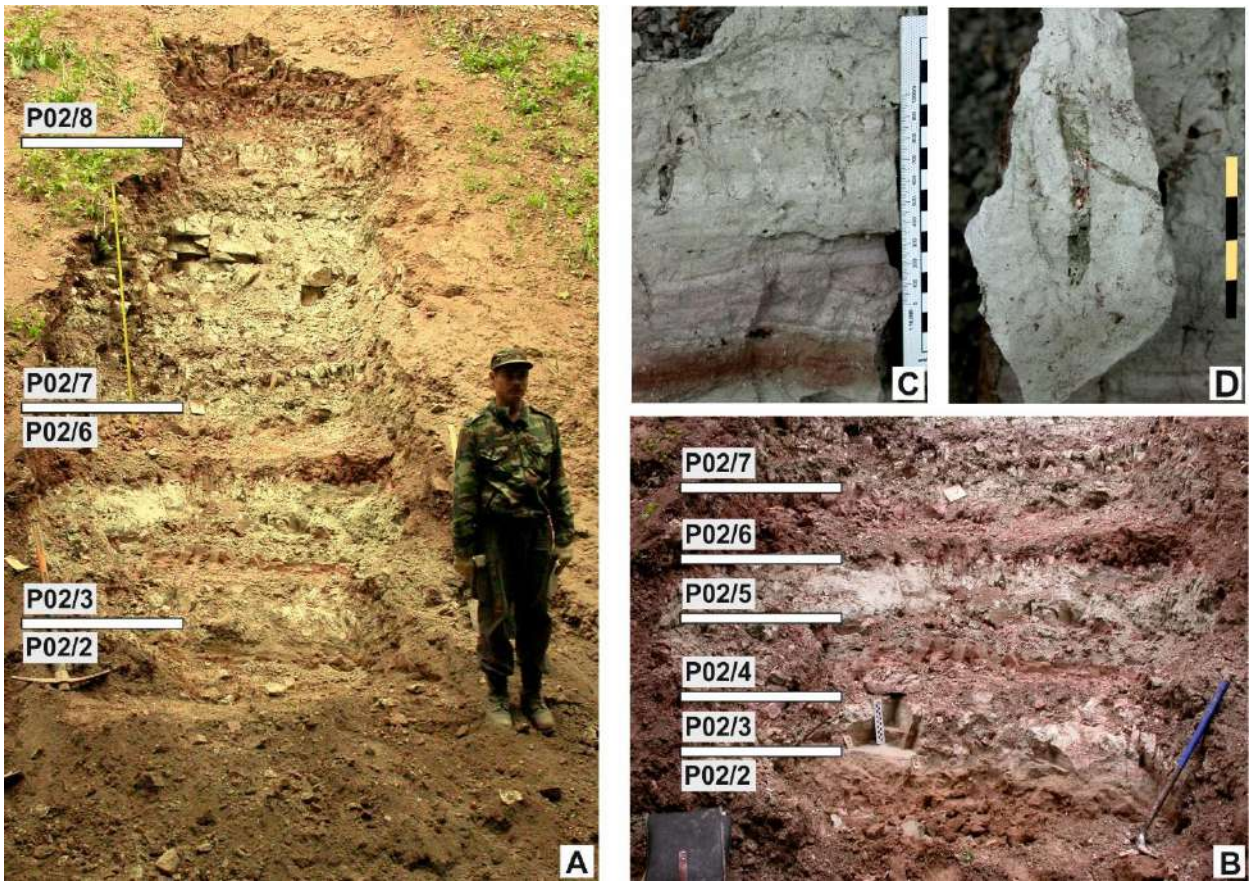
Siltstone: greyish-brown, more rarely greenish-grey, calcareous, muddy, with subordinate beds of greenish-grey sandstones and marls; various lenticular lamination.

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 clays 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 convenient 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),
Clayish and Dolomitic Members
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Sulitsa
Dolomitic Member
Clayish Member
21 0.55
20 0.45
19 0.2
17-18 1.2
16 0.25
15 0.75
14 0.25
13 0.2
12 0.2
11 0.65
10 0.55
Ca
Ca
First fish scales
Second brecciated level
0,2 m
29-31 0.45
28 0.55
27 0.55
26 0.6
25 0.1
24 0.1
23 0.8
22 0.2
21 0.55
Paleosol horizon
0,2 m

Outcrop P03

GPS: 55.78006 N, 048.92749 E (WGS84). Datum: left and right slopes of 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

Clayish Member

Packages P03/9–P03/18 Interval 7.60–11.75 m Thickness 4.15 m

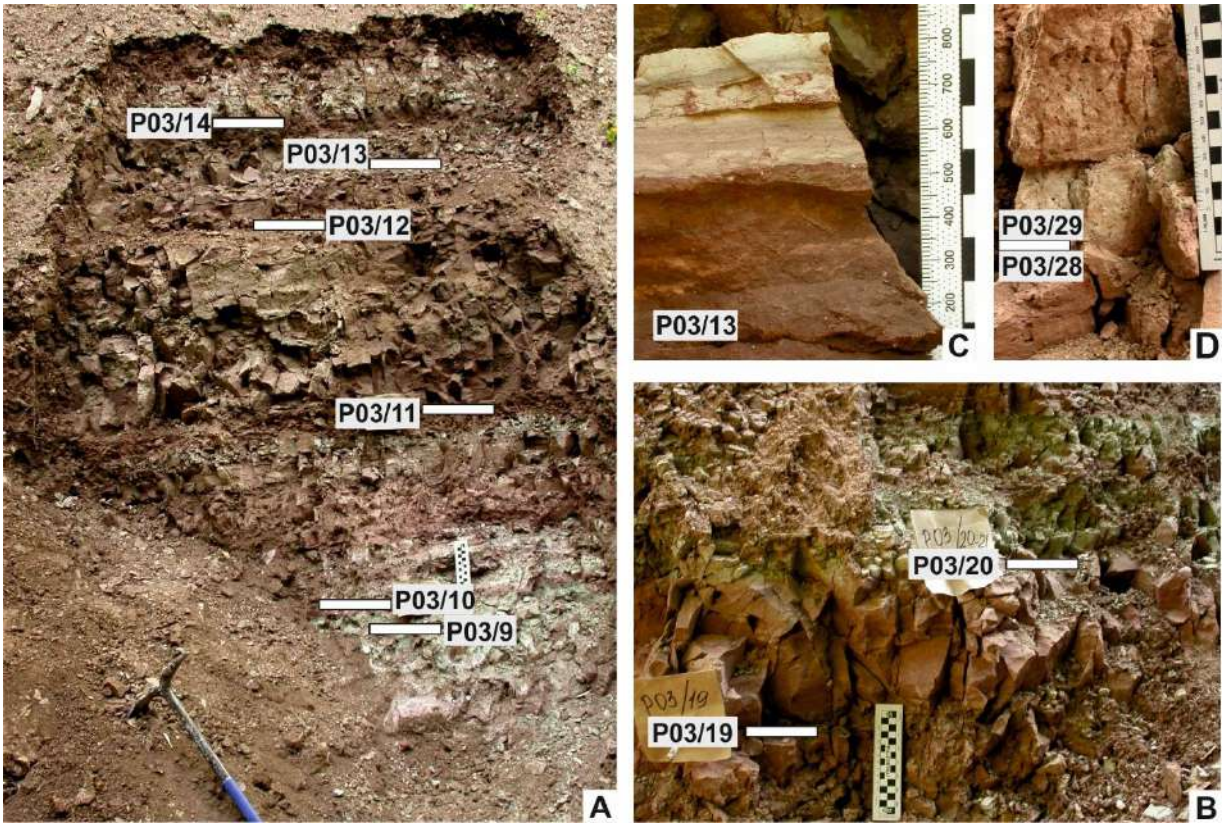
Siltstone and clay: brown, calcareous, lenticular and horizontal laminated, with thin (0.15–0.25 m) interbeds of pink and grey marl. Marl sometimes is riddled with numerous voids of plant roots *in situ*. Brecciated structure in marls and clays are identified at six thin (first cm) intervals. Clays contain rare fish scales.

Dolomitic Member

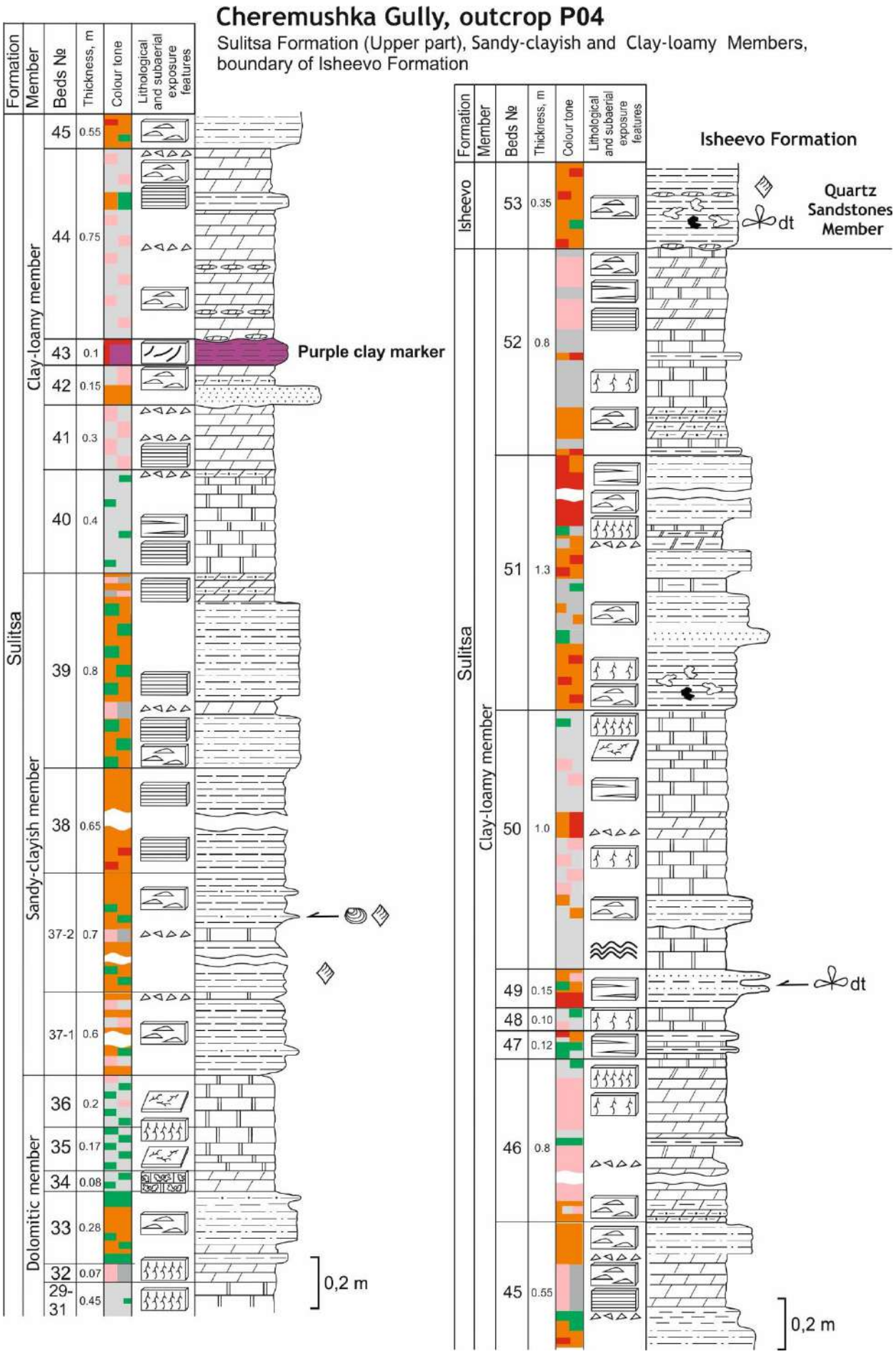
Packages P03/19–P03/31 Interval 11.75–16.30 m Thickness (visible) 4.55 m

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 clay, containing rare fish scales 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 Clayish 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-clayish and Clay-loamy Members, boundary of Isheevo Formation
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Sulitsa
Clay-loamy member
Sandy-clayish member
Dolomitic member
45 0.55
44 0.75
43 0.1
42 0.15
41 0.3
40 0.4
39 0.8
38 0.65
37-2 0.7
37-1 0.6
36 0.2
35 0.17
34 0.08
33 0.28
32 0.07
29-31 0.45
Purple clay marker
0,2 m
Isheevo Formation
Isheevo
Quartz Sandstones Member
53 0.35
52 0.8
51 1.3
50 1.0
49 0.15
48 0.10
47 0.12
46 0.8
45 0.55
dt
0,2 m

Outcrop P04

GPS: 55.77978 N, 048.92744 E (WGS84). Datum: right slope of 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 clay.

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

Sandy-clayish Member

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

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

Clay-loamy Member

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

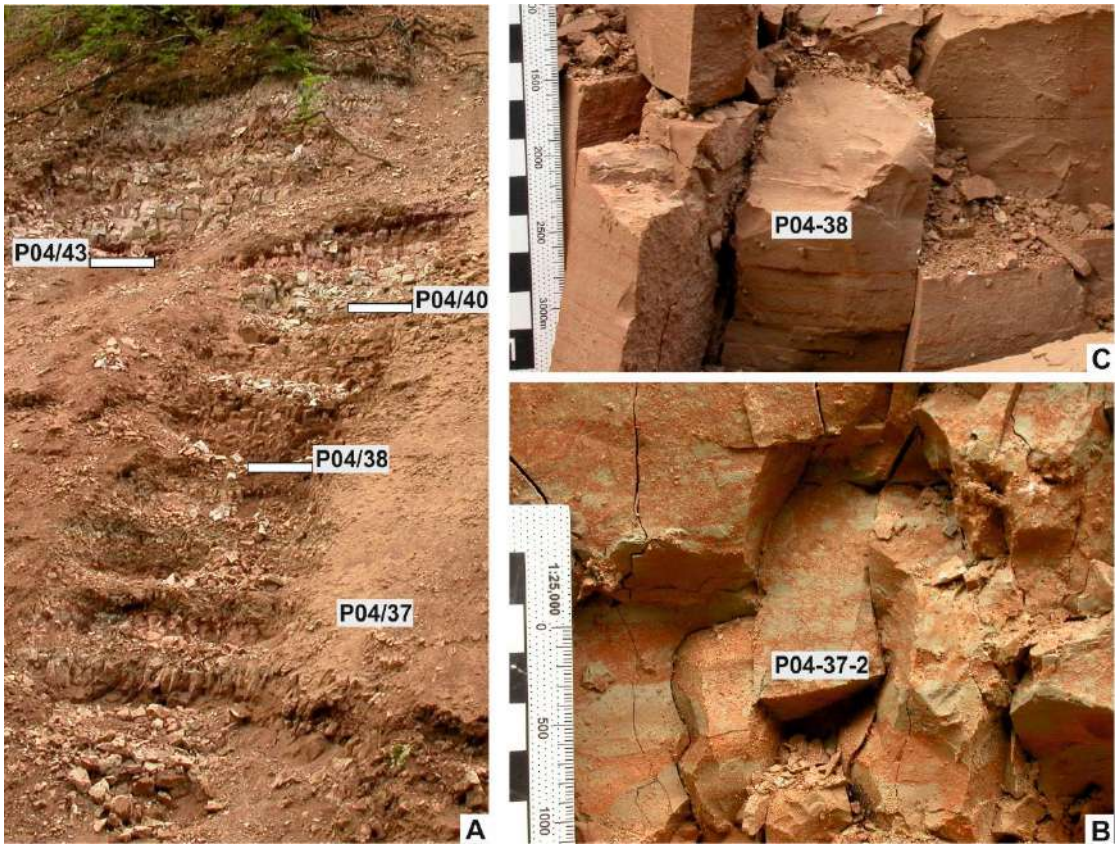
Dolomite, marl, dolomitic marl: light-grey, pinkish, greenish-grey, algal-microbial, compact, horizontal and lenticular laminated, platy, riddled with numerous voids of plant roots *in situ* and with allochthonous plant' roots on the bedding planes; several thin intervals (0.15–0.20 m) of breccias; thin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

Isheevo Formation

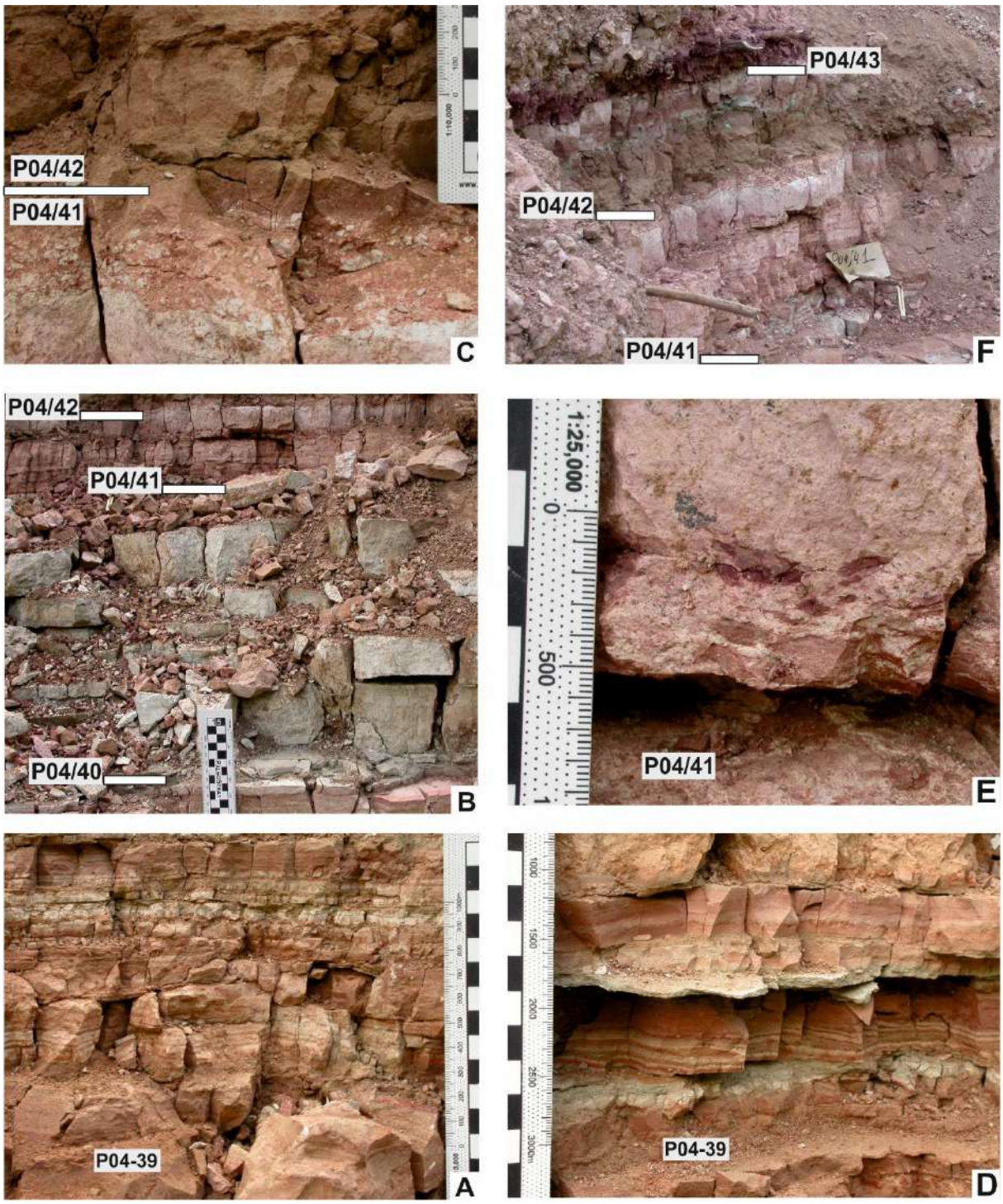
Quartz Sandstone Member

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

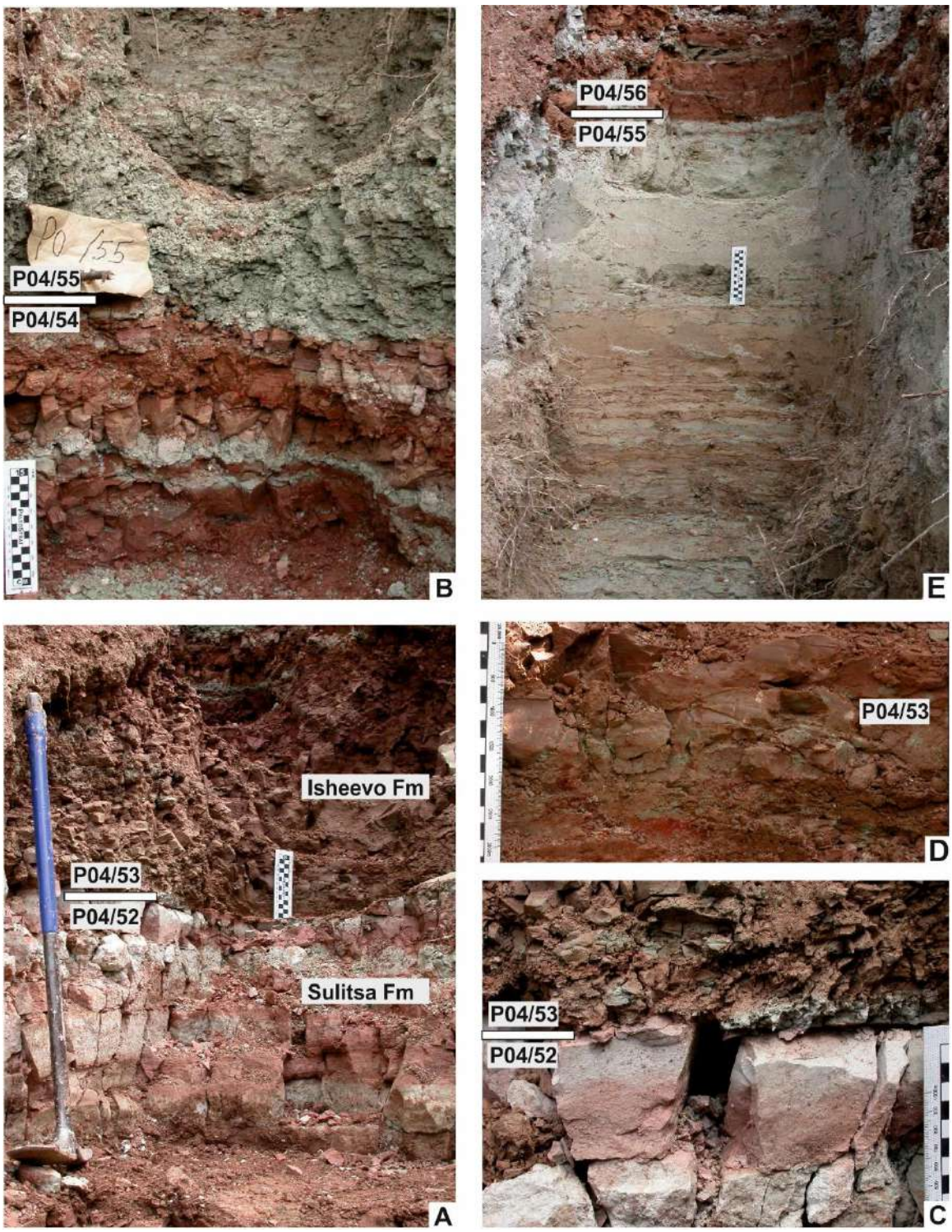
Clay: reddish-brown, with greenish-grey spots of gleization; rare fish scales and plant detritus.



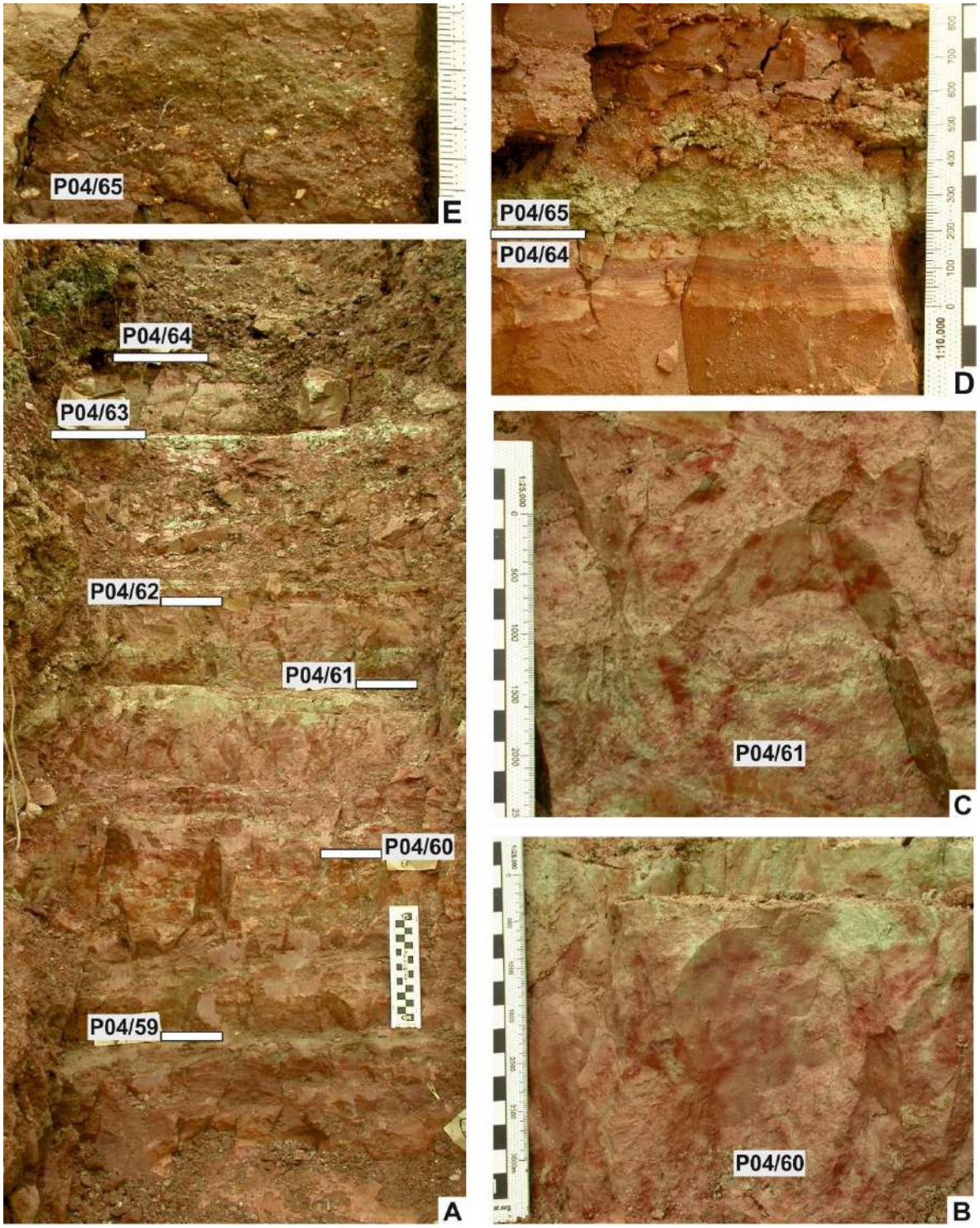
Outcrop P04. General view of the lower part of outcrop P04 (A); (B) brecciated clay of bed P04/37-2, and (C) reddish-brown clay with horizontal lamination, bed P04/38; scale bar 1 cm.



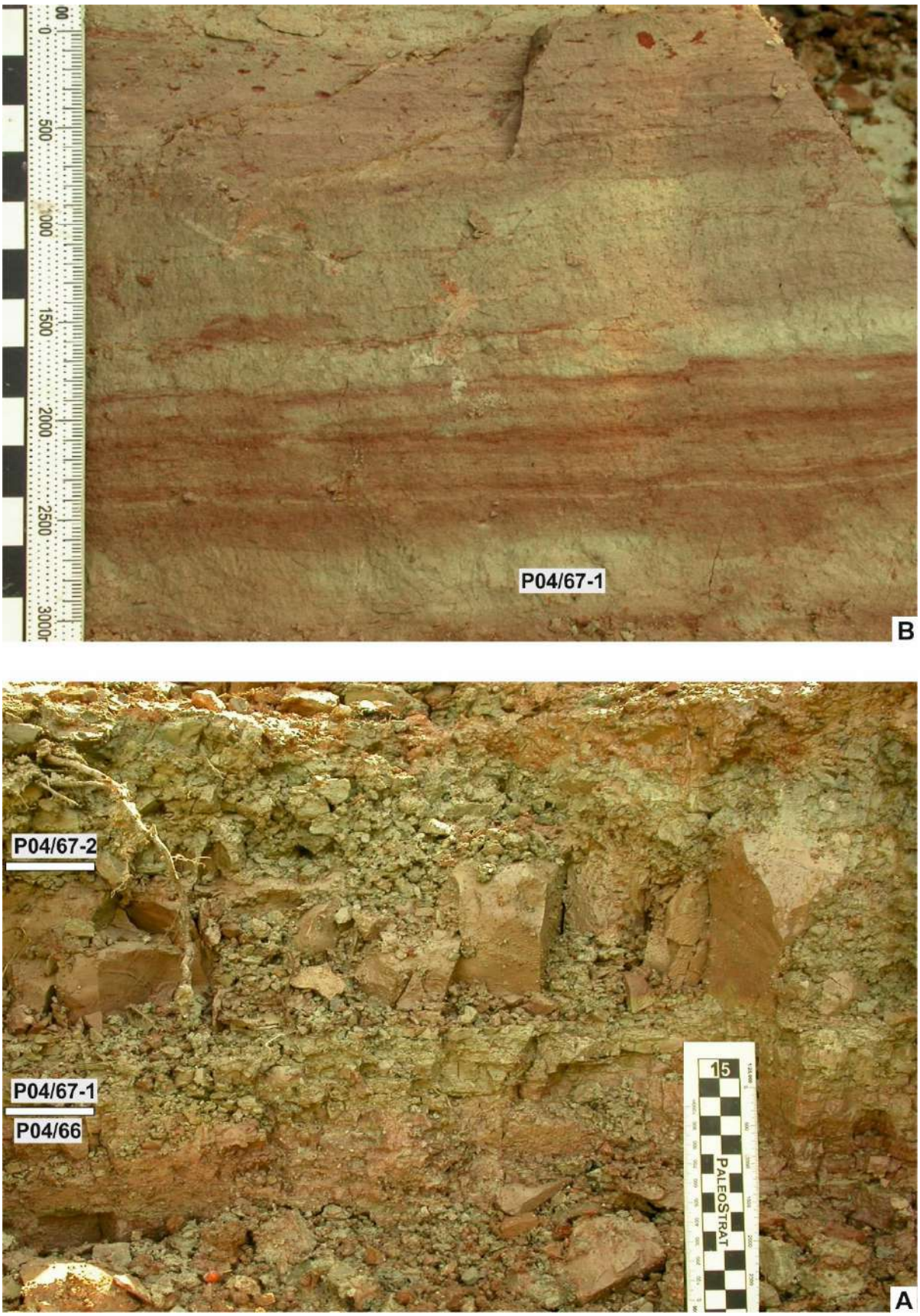
Outcrop P04. Platy speckled succession of pinkish-grey marls and light-grey dolomites, beds P04/39– P04/42 (A and B); (C) the rough surface between brecciated marl and overlaying brown sandstone, (D) the fragment of bed P04/39, thin bands of grey sandstone stress the cyclicity of succession, (E) brecciated calcareous clay from bed P04/41, and (F) the succession of Clay-loamy Member containing Purple clay marker (bed P04/43)*;* scale bar 1 cm.



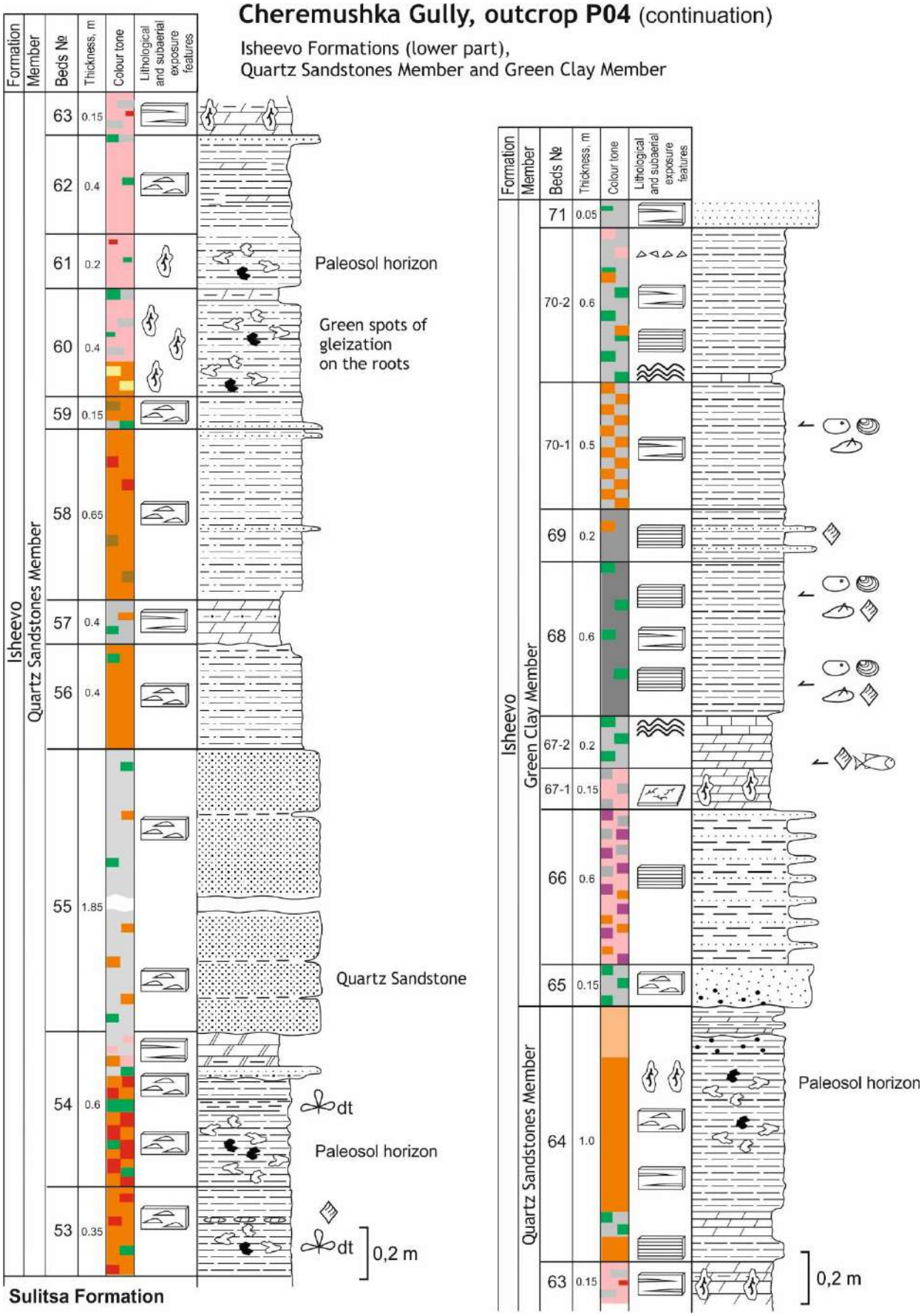
Outcrop P04. The boundary between **p**laty speckled succession (bed P04/52, Sulitsa Fm) and reddish-brown clay with greenish-grey spots of gleization (bed P04/53, Isheevo Fm) (A, C, D); (B) the rough surface between clay (bed P04/54) and overlaying greenish-grey quartz sandstone (bed P04/55), (E) the greenish-grey and brownish-grey (clayish) 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 clays with the spots of gleization (bed P04/60 and bed P04/61), (D) contact between Quartz Sandstone Member (bed P04/64, clay with brecciated lamination) and Green Clay Member (bed P04/65, basal greenish-grey sandstone)*;* scale bar 1 cm.



Outcrop P04. The fragment of the lower part of the Green Clay Member (A); (B) pinkish-green marl with lenticular lamination at the lower part of the specimen and with gleization on the allochthonous traces of plant roots (?), look like 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 Clay Member
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Isheevo
Quartz Sandstones Member
63 0.15
62 0.4
61 0.2
60 0.4
59 0.15
58 0.65
57 0.4
56 0.4
55 1.85
54 0.6
53 0.35
Paleosol horizon
Green spots of gleization on the roots
Quartz Sandstone
dt
Paleosol horizon
dt
0,2 m
Sulitsa Formation
Isheevo
Green Clay Member
Quartz Sandstones Member
71 0.05
70-2 0.6
70-1 0.5
69 0.2
68 0.6
67-2 0.2
67-1 0.15
66 0.6
65 0.15
64 1.0
63 0.15
Paleosol horizon
0,2 m

Outcrop P04 (continuation)

GPS: 55.77978 N, 048.92744 E (WGS84). Datum: right slope of 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

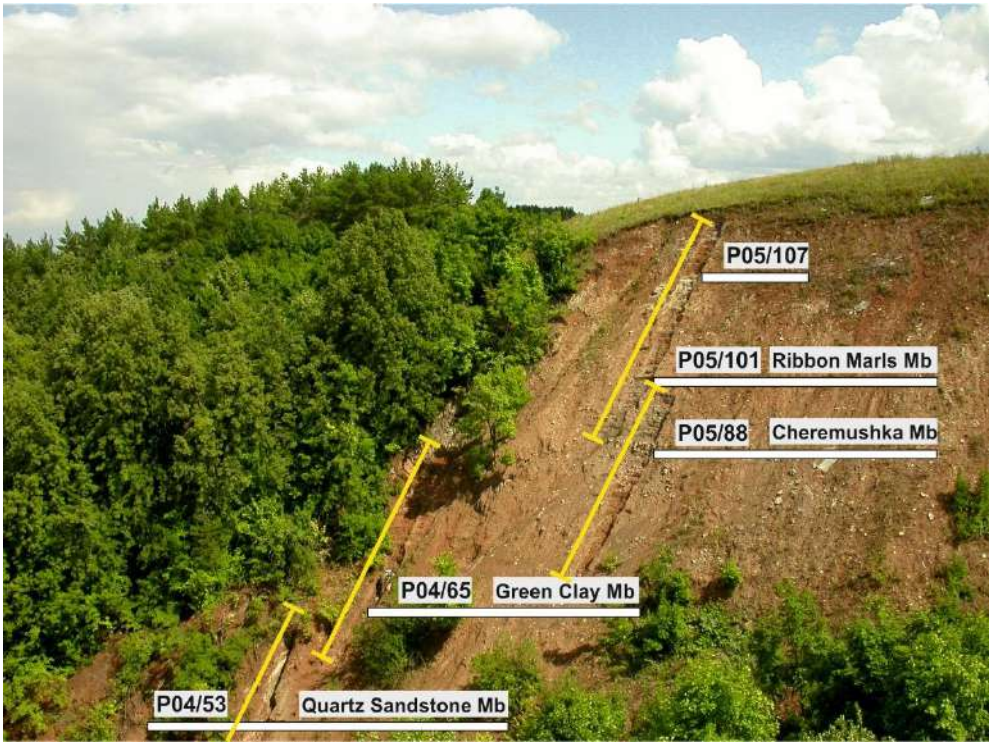
Clay, siltstone and sandstone with subordinate interbeds of marls. Clay: light-brown, yellowish, pinkish, reddish, calcareous, lenticular laminated, with greenish-grey and red spots (stains) of gleization on the vertical traces of plant roots (paleosol horizons). Sandstone (1.85 m): light-grey, yellowish-orange,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

Green Clay Member (lower part)

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

Clays: greenish-grey, brownish-grey, mudstone-like, compact, thinly horizontally laminated with ochreous stains on bedding planes. Clays contain numerous remains of bivalves, ostracodes, conchostracans, and fishes. The bivalves: *Palaeomutela wohrmani* Netsch., *P. krotowi* Netsch., *P. doratioformis* Gusev, *P. vjatkensis* Gusev, *Prilukiella subovata* (Jones), *Anadontella volgensis* Gusev; 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 layer 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 a pinkish-grey and greenish-grey marls and algal-microbial limestones (0.35 m thick) with gleization on the allochthonous traces of plant roots.

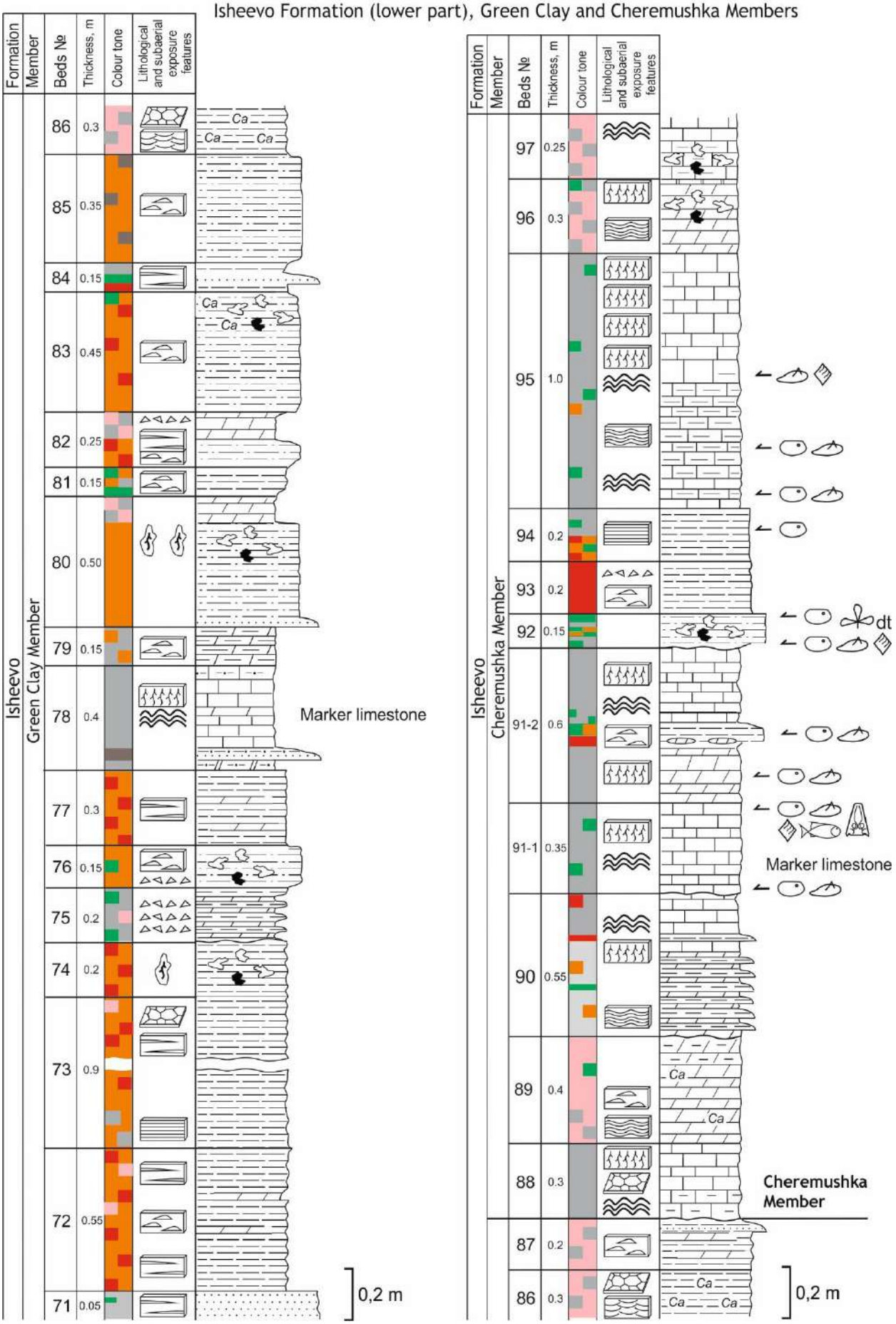
The upper part of the *Green Clay Member* is observed in outcrop P05.



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

Cheremushka Gully, outcrop P05

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



Outcrop P05

GPS: 55.77987 N, 048.92747 E (WGS84). Datum: middle part of the right slope of 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 Clay Member (upper part)

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

Clays with subordinate interbeds of marls and limestones. Clay: brownish-red, pinkish-red, with lenticular lamination and stains of bright-red and green clay.

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 clay-loamy breccias.

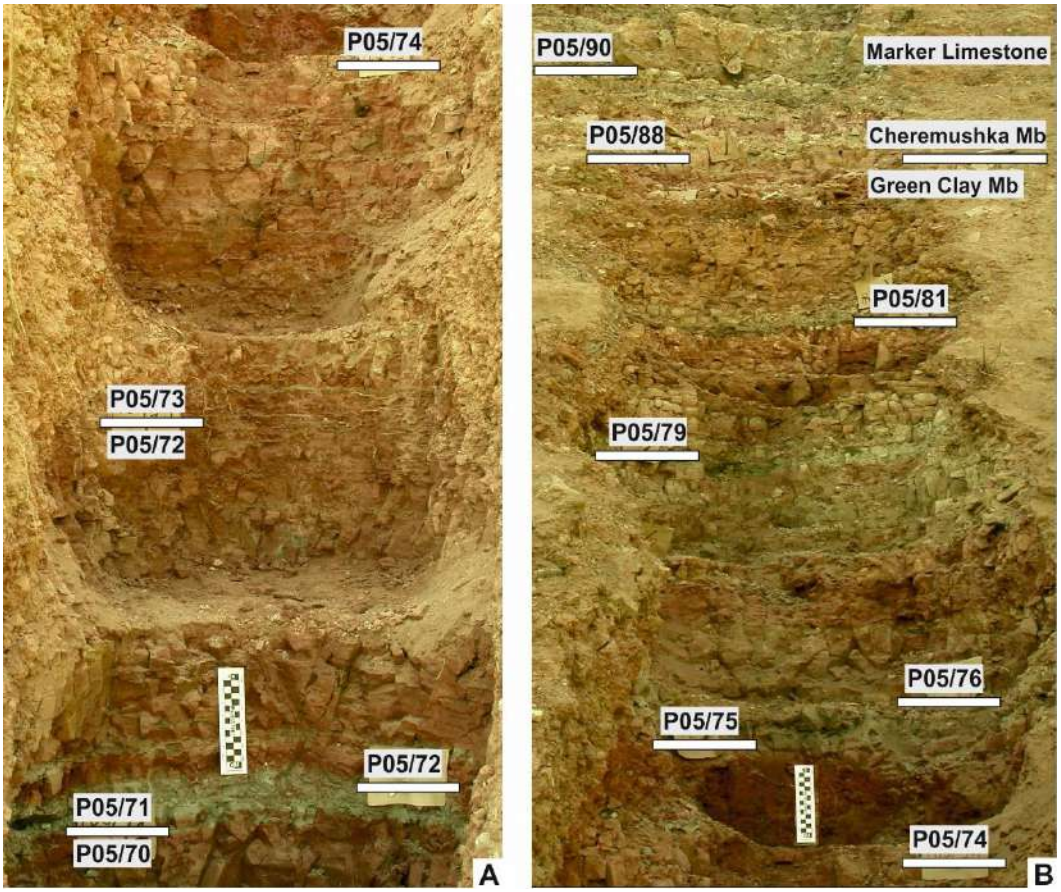
Total thickness of *Green Clay Member* is 8.25 m.

Cheremushka (clayish-carbonate) Member (lower part)

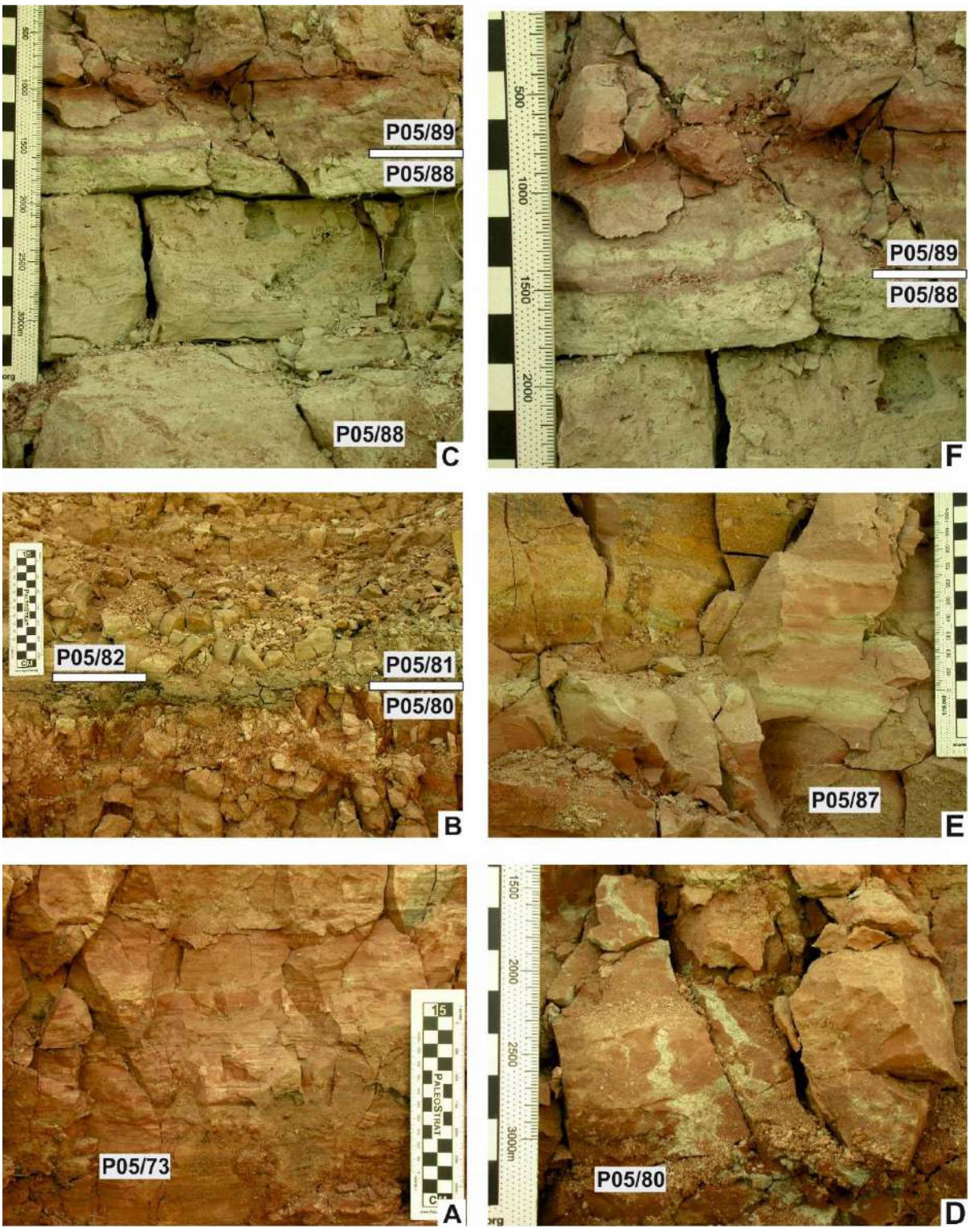
Packages P05/88–P05/97 Interval 41.15–45.45 m Thickness 4.30 m

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 clay and siltstone. Rocks contain ostracods, bivalves, fish scales, small amphibian bones and charophytes. Bivalves are represented by *Palaeomutela extensiva* Gusev, *P. wohrmani* Netsch., *P. vjatkensis* Gusev, *P. krotowi* Netsch., *P. doratioformis* Gusev, *Prilukiella subovata* (Jones), *Anadontella volgensis* Gusev, *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.) Said., *Stomochara diserta* Said., *Stm. constricta* Kis., and *Stm. lubrica* Said. Few thin intervals (0.1 m) of clay-loamy breccias and fissures of desiccation.

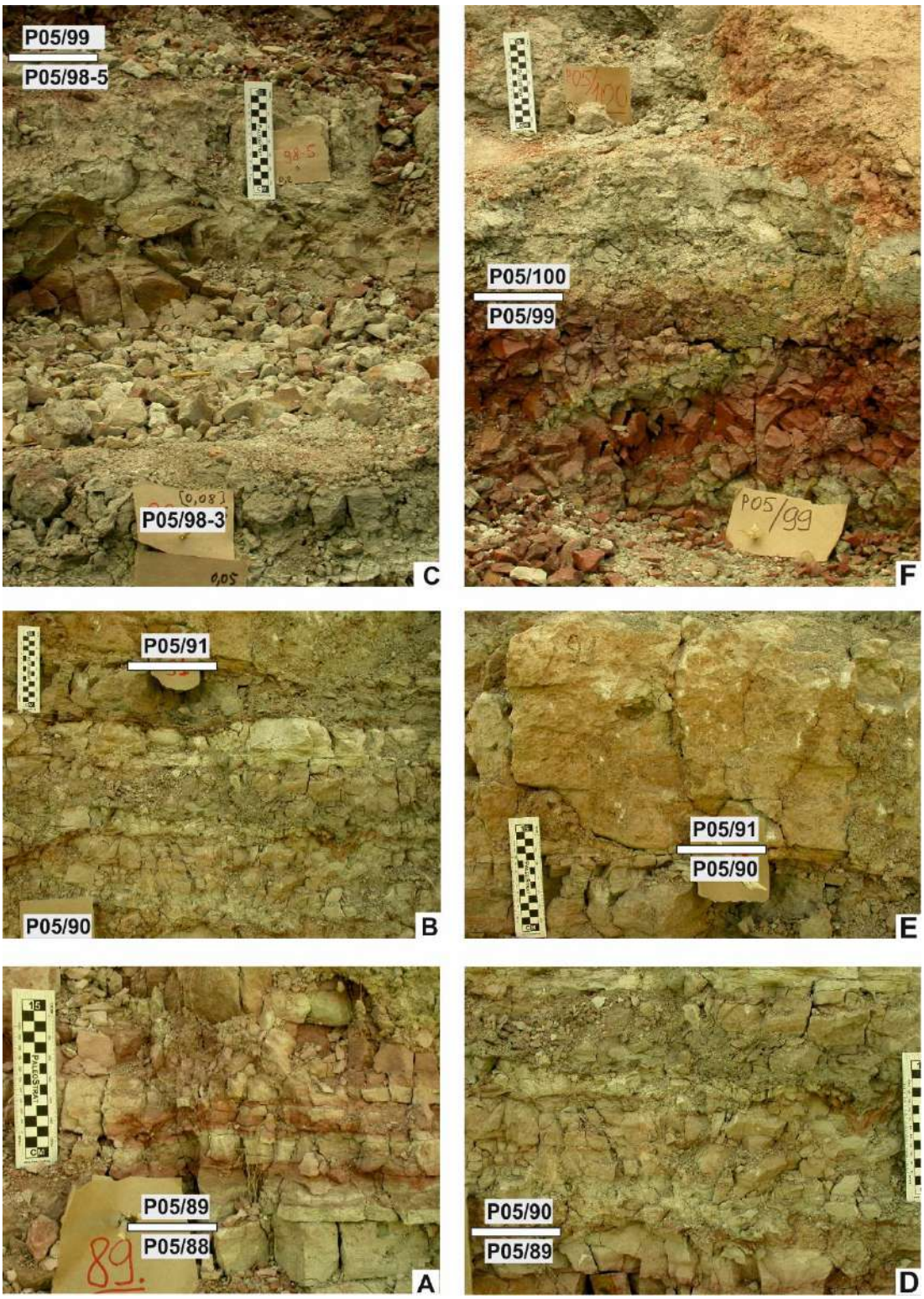
Outcrop P05. General view of the lower part of the Green Clay Member (A), (B) the upper part of the Green



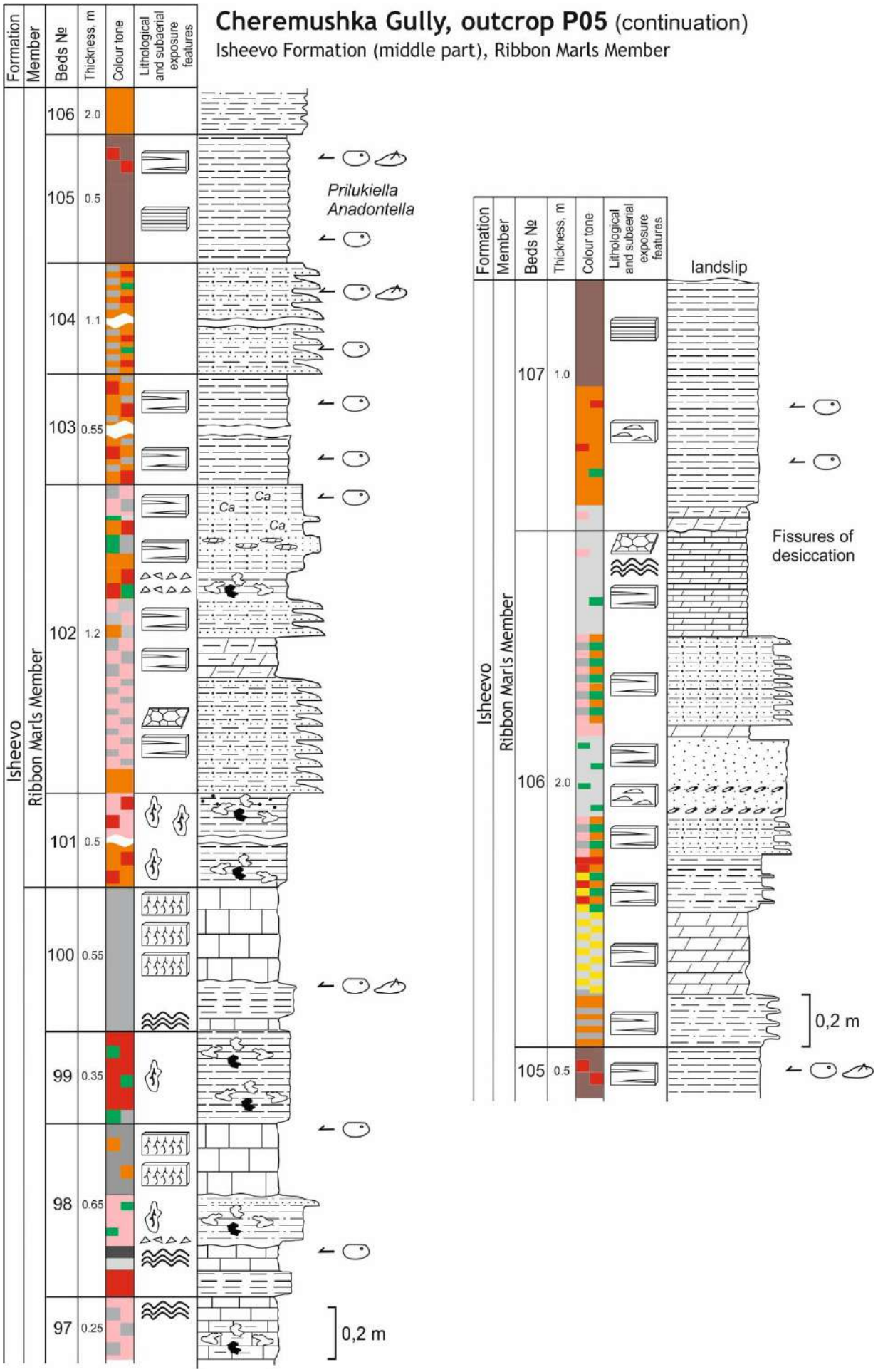
Clay Member and its contact with Cheremushka Member; scale bar 1 cm.



Outcrop P05. Typical clay of the upper part of the Green Clay Member with thin horizontal and lenticular lamination (A), (B) thin band of green clay (bed P05/81) within brownish-grey succession of siltstones, (C) platy limestones of the basal part of the Cheremushka Member, (D) clay of the upper part of the Green Clay Member with the gleization on the plant roots *in situ*, (E) the uppermost clay of the Green Clay 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 of the Cheremushka Member, the intercalation of limestone and marl with subordinate bands of greenish-grey and brownish-red clays, 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
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Isheevo
Ribbon Marls Member
106 2.0
105 0.5
104 1.1
103 0.55
102 1.2
101 0.5
100 0.55
99 0.35
98 0.65
97 0.25
Prilukiella
Anadontella
Ca
Ca
Ca
0,2 m
107 1.0
106 2.0
105 0.5
landslip
Fissures of desiccation
0,2 m

Outcrop P05 (continuation)

GPS: 55.77987 N, 048.92747 E (WGS84). Datum: middle part of the right slope of 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 (clayish-carbonate) Member (upper part)

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

Limestone and clay. 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*. Clay: red, pinkish-red, with green spots of gleization on the in situ traces of plant roots. Limestones and subjacent grey clays contain scattered remains of ostracods, small bivalves, scales of fishes, and charophytes.

Total thickness of *Cheremushka Member* is 5.85 m.

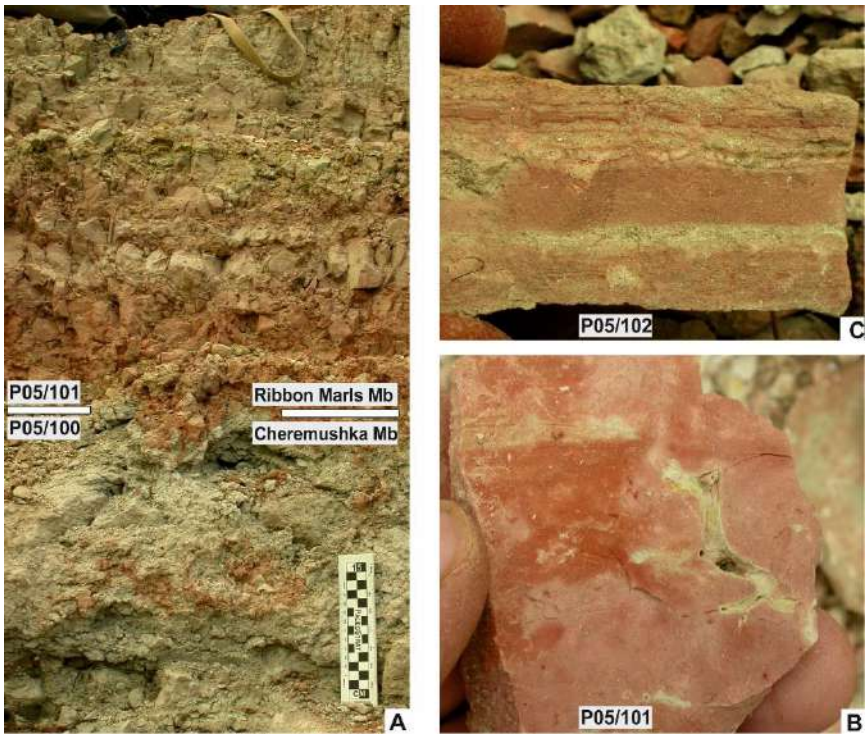
Ribbon Marls Member (lower part)

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

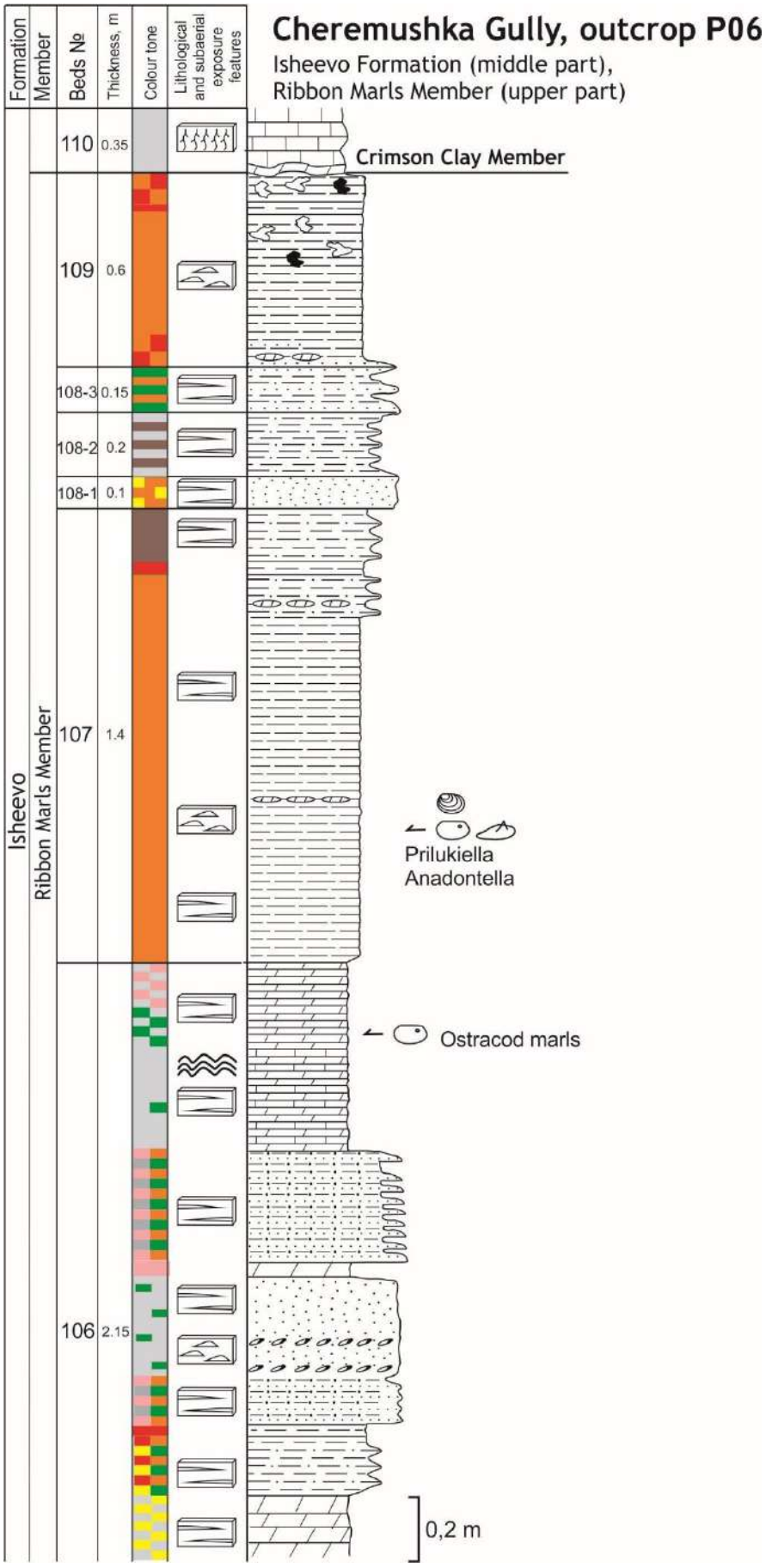
Sandy-loamy member with ribbon (banded) marls. Clays: brown, reddish-brown, pinkish, yellowish, compact, mainly thinly horizontally or lenticular laminated with laminae of greenish-grey fine-grained sandstone and brown siltstone. The middle part of the member contains several beds (each of 0.4 m) of yellowish-grey and pinkish-grey (ribbon), horizontally thinly laminated, platy marls. Clays 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* Gusev, *Palaeomutela (Palaeanodonta) cf. longissima Netsch., Anadontella volgensis* Gus., *A. uslonensis* Gus., *Prilukiella subovata* (Jones), *Pr. pugnatoria* Gus., *Pr. mirabilis* (Gus.), etc., and fish scales.

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 Clay 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 clay (bed P05/101) with the gleization on the plant roots *in situ*; (C) the intercalation of clay (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)
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Isheevo
Ribbon Marls Member
110 0.35
109 0.6
108-3 0.15
108-2 0.2
108-1 0.1
107 1.4
106 2.15
Crimson Clay Member
Prilukiella
Anadontella
Ostracod marls
0,2 m

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. Clays: 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. Clays and marls contain numerous remains of conchostracans, the ostracods, bivalves, and fish scales.

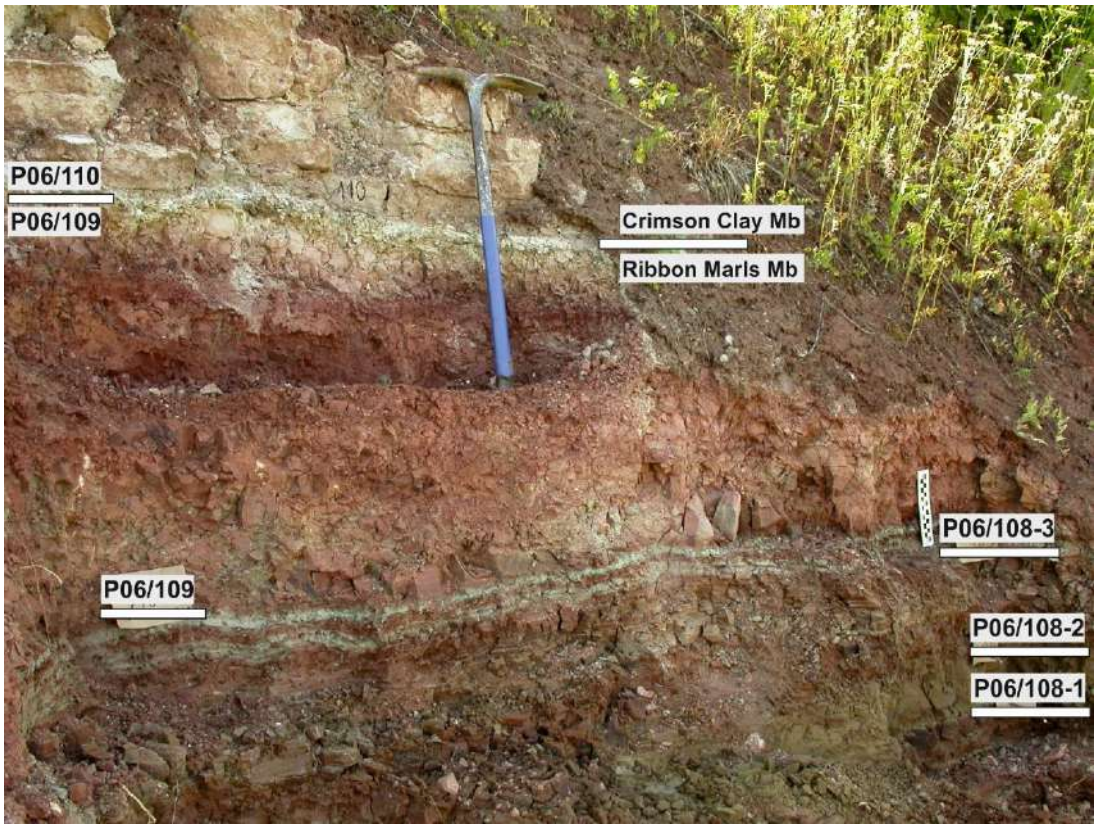
Total thickness of *Ribbon Marls Member* is 8.45 m.

Crimson Clay (clayish-carbonate) Member (basal part)

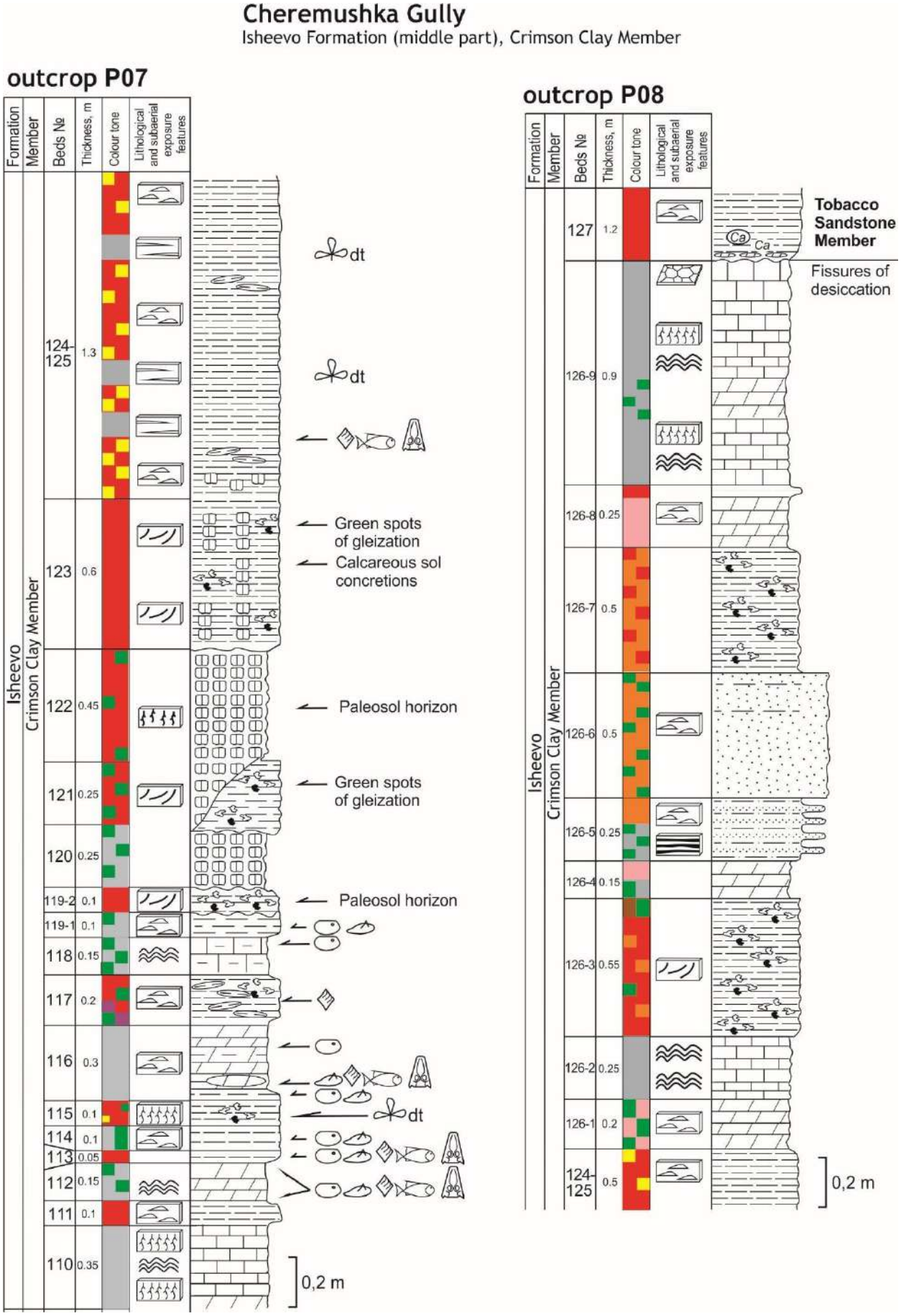
Packages P06/110 Interval 58.45–58.80 m Thickness (visible) 0.35 m

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 Clay 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 Clay Member (P05/109–P05/110).


Cheremushka Gully
Isheevo Formation (middle part), Crimson Clay Member
outcrop P07
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
Isheevo
Crimson Clay Member
124-125 1.3
123 0.6
122 0.45
121 0.25
120 0.25
119-2 0.1
119-1 0.1
118 0.15
117 0.2
116 0.3
115 0.1
114 0.1
113 0.05
112 0.15
111 0.1
110 0.35
dt
dt
Green spots of gleization
Calcareous sol concretions
Paleosol horizon
Green spots of gleization
Paleosol horizon
0,2 m
outcrop P08
127 1.2
126-9 0.9
126-8 0.25
126-7 0.5
126-6 0.5
126-5 0.25
126-4 0.15
126-3 0.55
126-2 0.25
126-1 0.2
124-125 0.5
Ca
Tobacco Sandstone Member
Fissures of desiccation
0,2 m

Outcrops P07 and P08

Outcrop P07, GPS: 55,77936 N, 048,92719 E (WGS84). Datum: upper part of the left slope of 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 slope is 161 m ASL, the bottom of the bed 110 is 155 m ASL. **Outcrop P08,** GPS: 55,77916 N, 048,92732 E (WGS84). Datum: upper part of the left slope of 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 Clay Member

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

Alteration of limestone, marl and clay 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. Clay: bright red, bright green, greenish-grey, calcareous. Clay with lenticular lamination contains numerous remains of ostracods, bivalves, fish scales and tetrapods. Clay with greenish-grey and red spots (stains) of gleization 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* Gusev, *P. wohrmani* Netsch., *P. vjatkensis* Gusev, *Prilukiella mirabilis* (Gus.), *Pr. nitida* (Gus), etc., fish scales and bones of small reptiles.

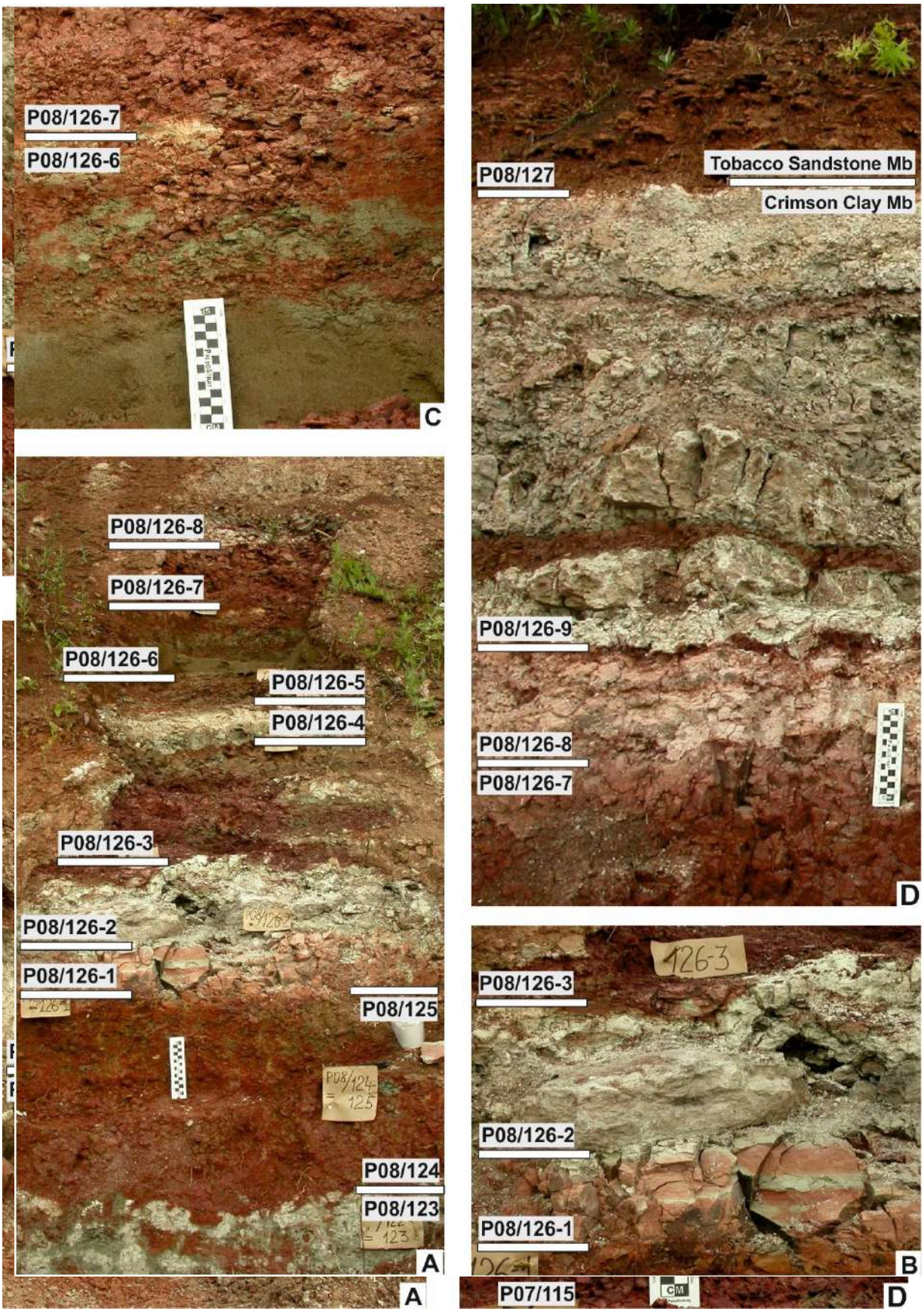
Tobacco Sandstone Member (basal part)

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 clayish laminae as well as honeycomb structure of desiccation fissures (?) are more convenient observed on the weathered surface of the package.

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

Outcrop P06. General view of the lower part of outcrop P07, the boundary between the Ribbon Marls Member and the Crimson Clay Member (P05/109–P05/110).



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

Outcrop P08. General view of the upper part of the Crimson Clay 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 clay (bed P08/126-7), and (D) uppermost algal-microbial limestone of the Crimson Clay Member (bed P08/126-9) and its boundary with the Tobacco Sandstone Member; scale bar 1 cm.

Outcrop P09

GPS: 55,77892 N, 048,92783 E (WGS84). Datum: upper part of the right slope of 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.

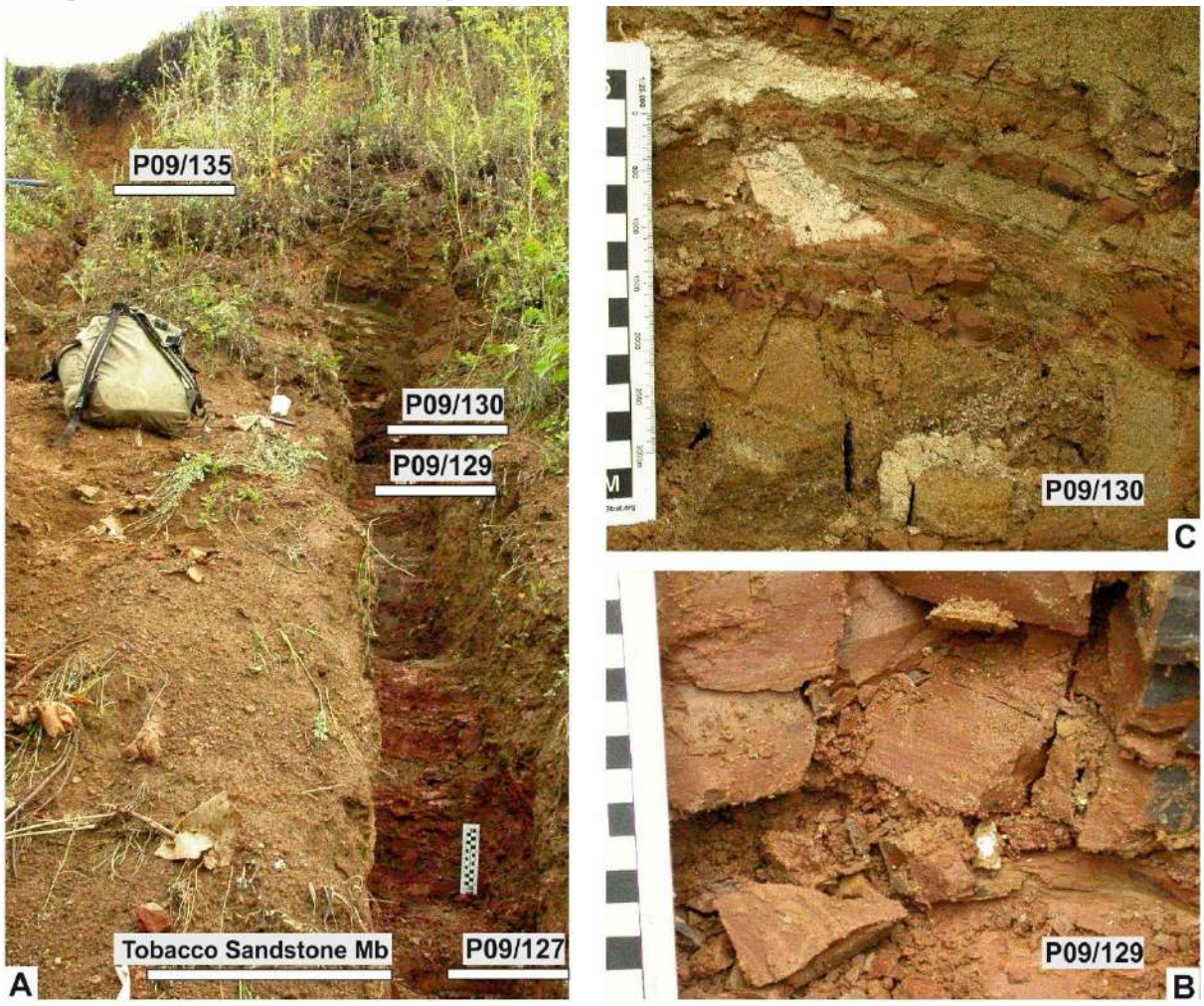
Isheevo Formation

Tobacco Sandstone Member (lower part)

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

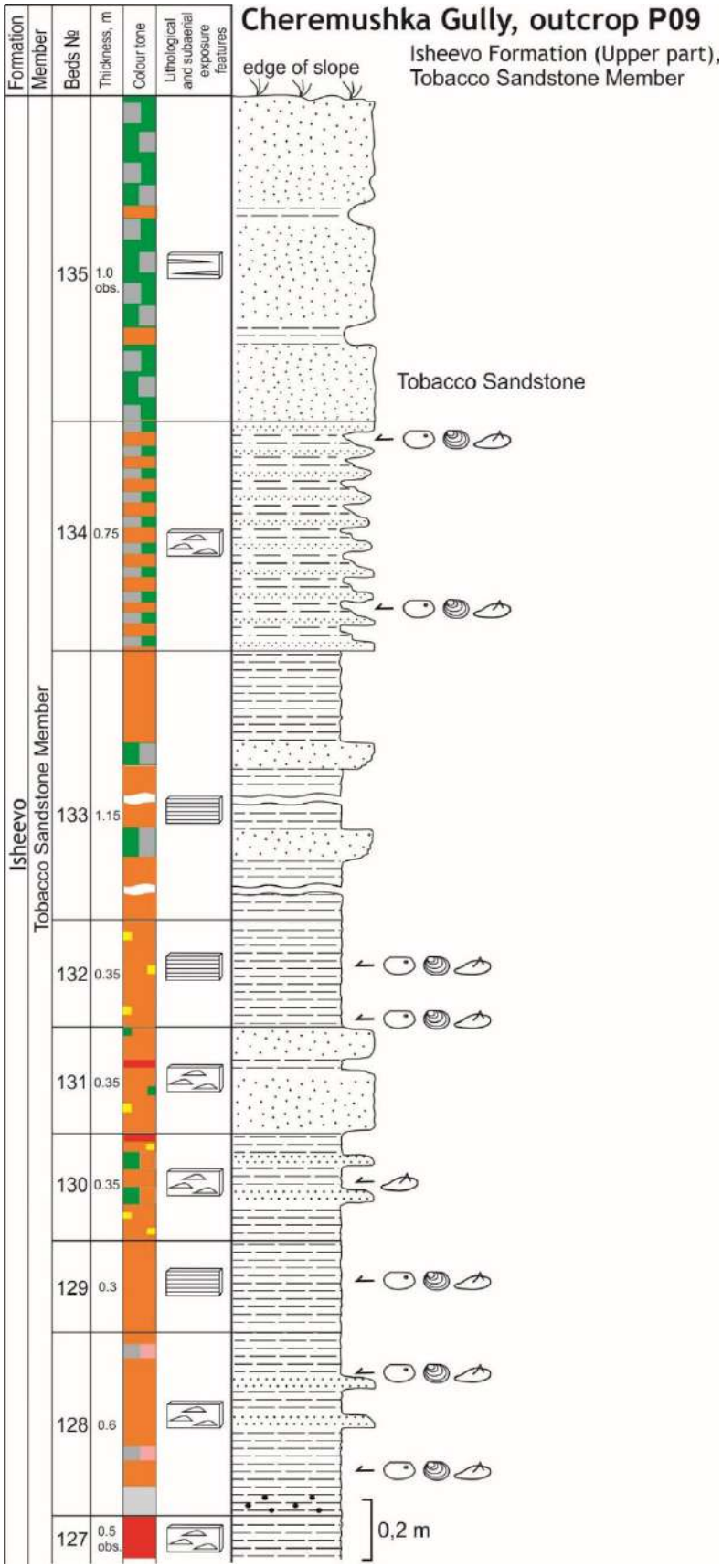
Clay and sandstone. Clay: reddish-brown (chocolate-brown), brownish-red, yellowish, compact, horizontally bedded. Sandstones: greenish-grey (tobacco) polymict, inequigranular, obliquely laminated. The clay contains many (especially right below the sandstones) remains of the bivalves *Palaeomutela (Palaeanodonta) 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.)

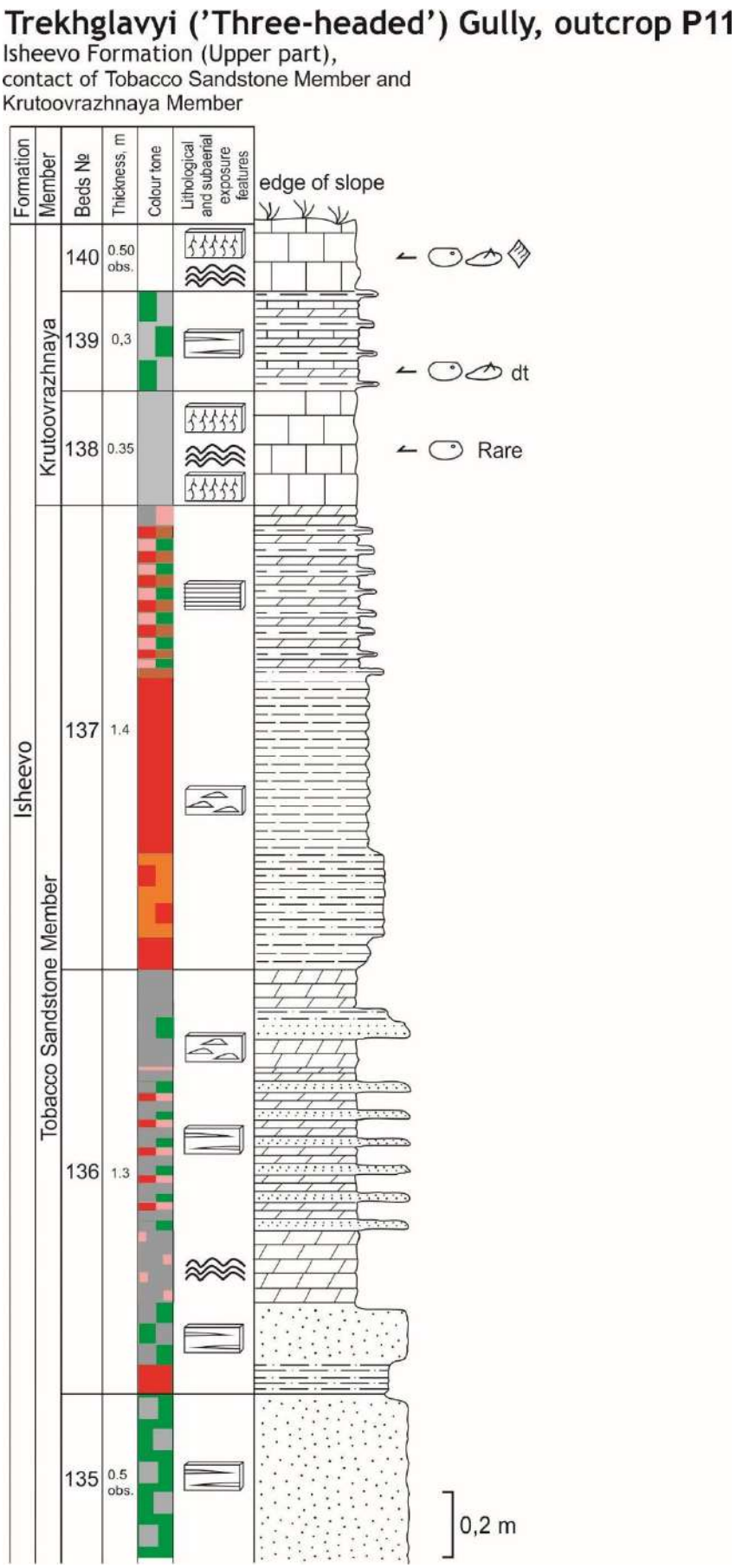
Outcrop P09. General view of the lower part of the Tobacco Sandstone Member (A), (B) reddish-brown clay



with horizontal lamination (bed P09/129), (C) greenish-grey sandstone (bed 130) with the lenses of reddish-brown clay and light-grey marls; scale bar 1 cm.

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.


Cheremushka Gully, outcrop P09
Isheevo Formation (Upper part),
Tobacco Sandstone Member
edge of slope
Tobacco Sandstone
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.
0,2 m


Trekhglavyi ('Three-headed') Gully, outcrop P11
Isheevo Formation (Upper part),
contact of Tobacco Sandstone Member and
Krutoovrazhnaya Member
Formation
Member
Beds №
Thickness, m
Colour tone
Lithological and subaerial exposure features
edge of slope
Isheevo
Krutoovrazhnaya
Tobacco Sandstone Member
140
0.50 obs.
139
0,3
138
0.35
137
1.4
136
1.3
135
0.5 obs.
dt
Rare
0,2 m

Outcrop P11

GPS: 55.77715 N, 048.91199 E (WGS84). Datum: the 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 clay. Sandstone: greenish-grey (tobacco) polymict, obliquely laminated. Clay: red, brownish-red, compact, lenticular laminated. Generally, above the sandstones, there are two marker beds of an alternation of thinly bedded variegated clays, sandstones and marls.

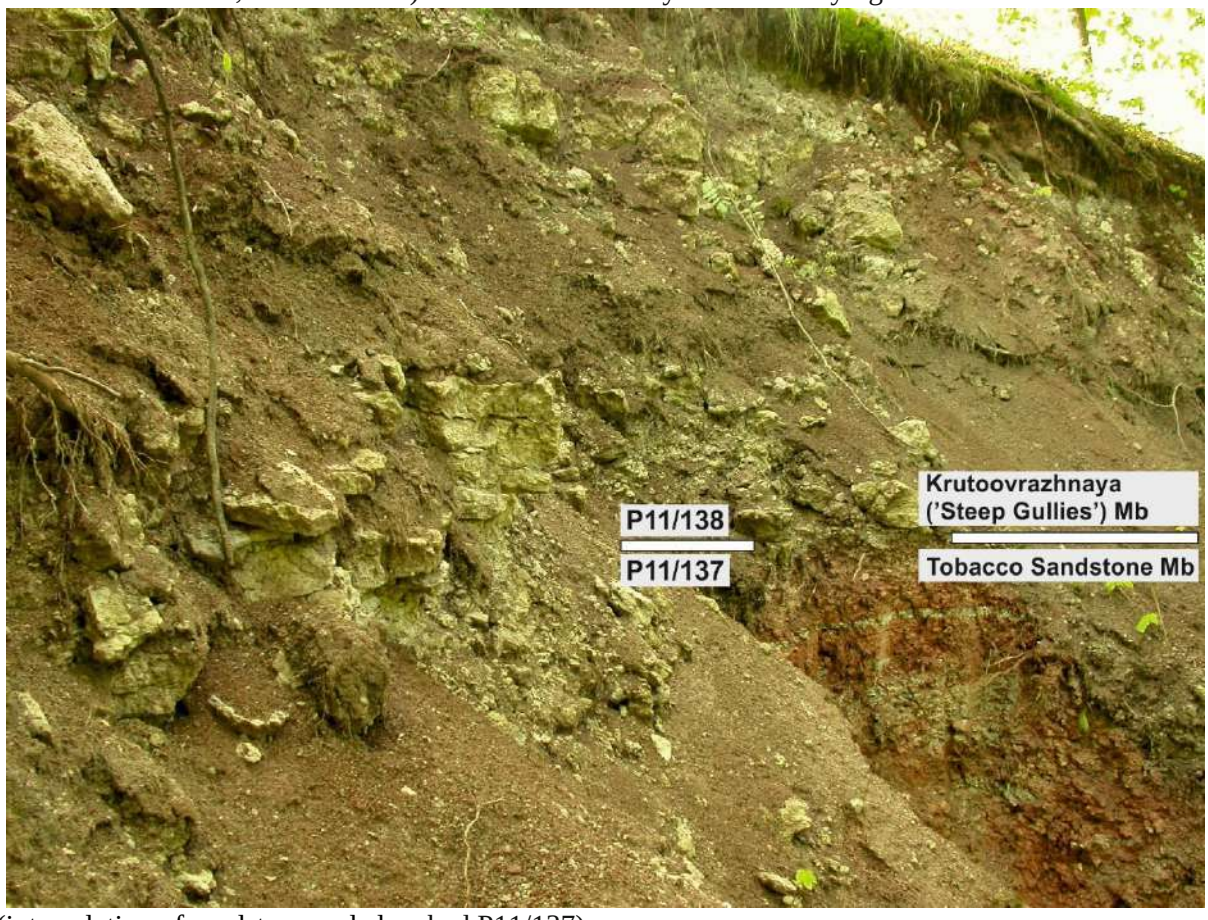
Total thickness of *Tobacco Sandstone Member* is 8.05 m.

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 clays. 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 Gusev, P. numerosa Gusev, Prilukiella* sp., fish scales, charophytes *Cuneatochara amara* Said.

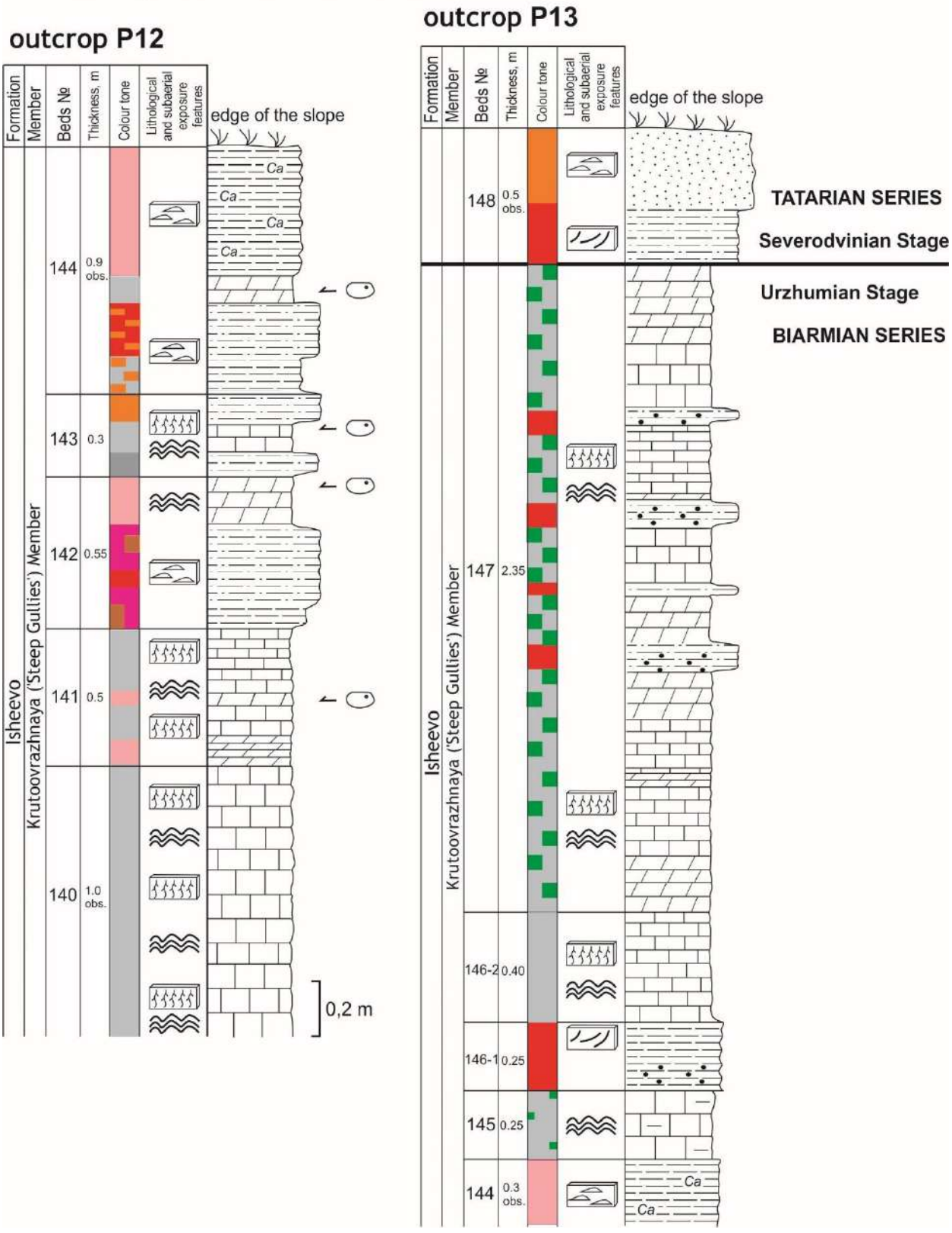
Outcrop P11. General view of the lower part of the Krutoovrazhnaya ('Steep Gullies') Member (algal-microbial limestone, bed P11/138) and of its boundary with underlying Tobacco Sandstone Member



(intercalation of sandstone and clay, 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: the 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 clay 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.

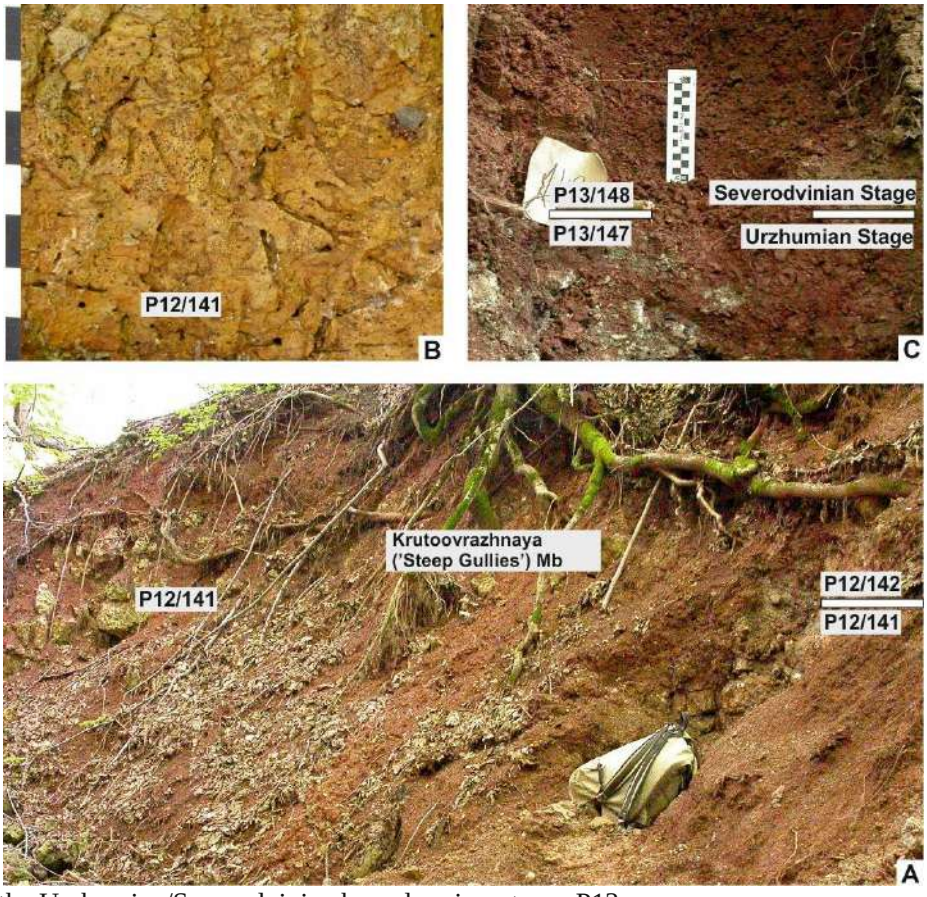
Tatarian Regional Series

Severodvinian Regional Stage

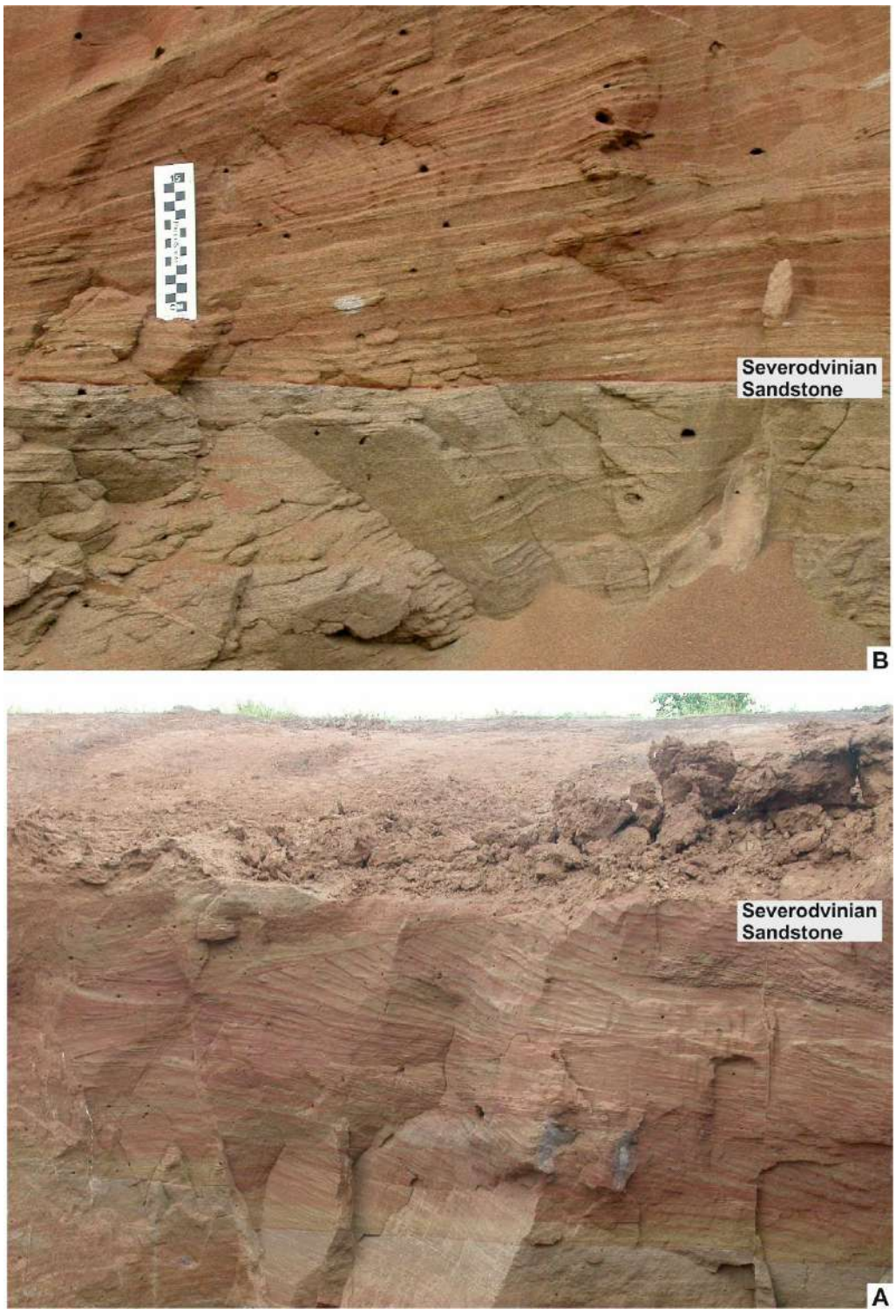
Packages P13/148 Interval 81.60–82.10 m Thickness (visible) 0.50 m

Clay and sandstone. Clay: 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 Strela (‘Arrow’) Gully.

BIOSTRATIGRAPHY

Non-marine ostracods

The rocks of Sulitsa Formation contain too much magnesia to have many fossils. The first ostracodes and bivalves appear only at the lower part of the Isheevo Formation, in the Green Clay Member. The species composition of the ostracod assemblage is here fairly poor (Molostovskaya, Lukin, 1998).

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. Here belong *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 presents by *Palaeodarwinula mera, P. inornatina, P.* aff. *fainae* (Bel.) and *Prasuchonella nasalis,* which are fairly common in the continental strata of the Kazanian. Assemblage of *Palaeodarwinula* and *Prasuchonella* co-occurs, but rather rarely, with *Placidea* ex gr. *lutkevichi* (Spizh.), *Permiana elongata* (Posner), and *Sinusuella ignota* (Spizh.), all three having a broad stratigraphic interval embracing almost the entire Middle and Upper Permian.

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 with the typically Urzhumian assemblage. It is one of the index species of Severodvinian *Suchonellina inornata–Prasuchonella nasalis* zone.

Non-marine bivalves

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

The brief description of these zones is giving 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 Ravine, Outcrop Ch-2001, Bed 19 (Silantiev et al., 2007). 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: *P. vjatkensis* Gusev, *P. doratioformis* Gusev, *Anadontella volgensis* (Gusev), *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

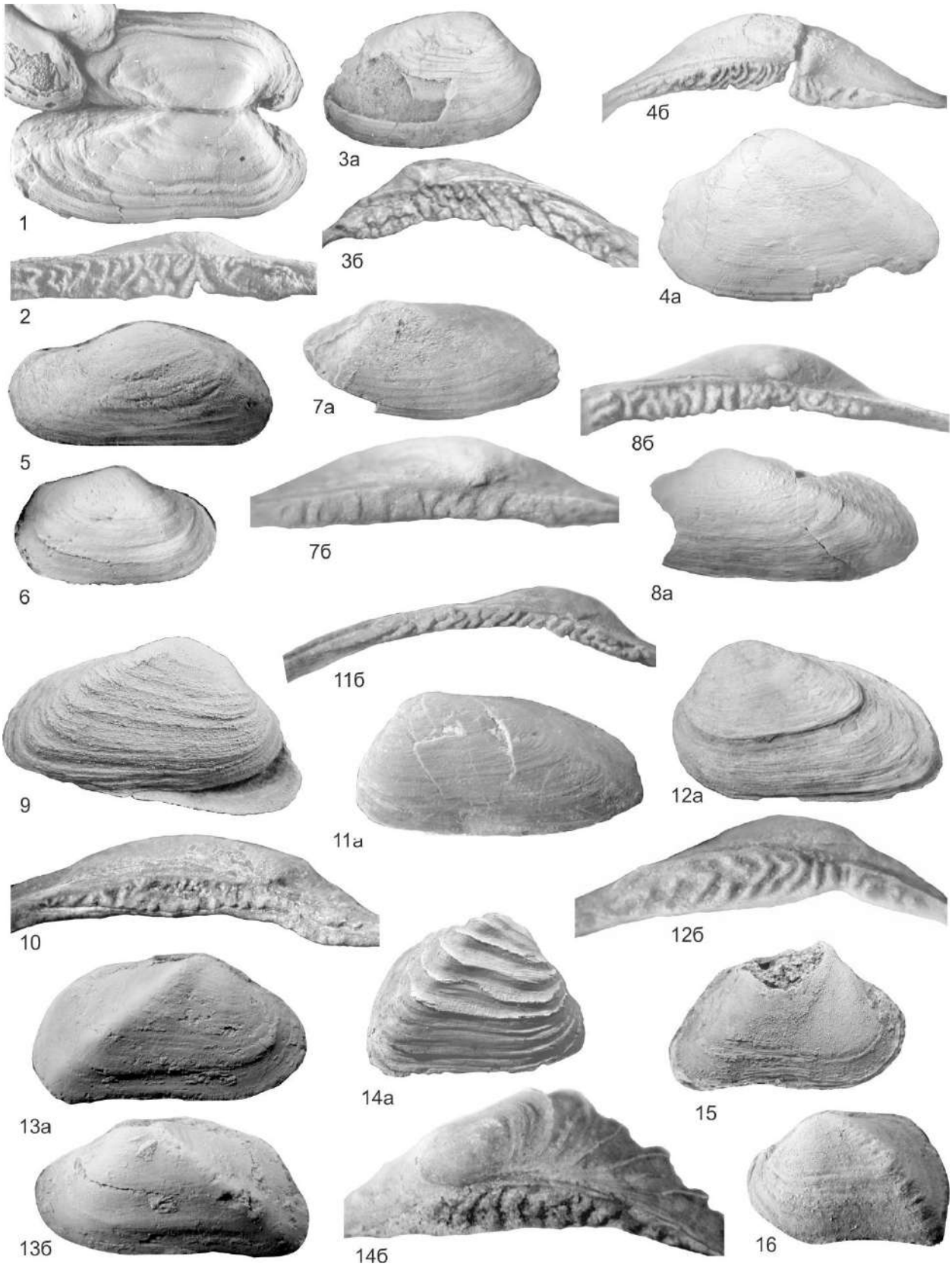
Index species: *Palaeomutela wohrmani* Netschajew, 1894. Stratotype of the zone is located on the right bank of the Volga River 1.5 km west of the settlement of Pechishchi, Cheremushka Ravine Outcrop, Green Clay Member, Bed 66. The lower and upper boundaries of the unit under consideration correspond to the first appearance levels of *P. wohrmani* Netsch. and *P. numerosa* Gusev, respectively. Characteristic bivalve species: *P. krotowi* Netsch., *P. extensiva* Gusev, *P. doratioformis* Gusev, *Anadontella uslonensis* (Gusev), *A. volgensis* (Gusev), *A. tscherdinzewi* (Gusev), *Prilukiella janischewskyi* Plotnikov, *Pr. subovata* (Jones), *Pr. nitida* Gusev, *Pr. mirabilis* Gusev, *Pr. pugnatoria* Gusev. The wohrmani Zone is documented 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 Anadontellidae and Prilukielloidea representatives 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 (Betekhtina and Tokareva, 1988). This feature allows the stratigraphic units in question to be considered as conditionally synchronous.

Palaeomutela numerosa Zone

Index species: *Palaeomutela numerosa* Gusev, 1990. Stratotype of the zone is located on the right bank of the Volga River 1.5 km west of the settlement of Pechishchi, Cheremushka Ravine Outcrop, 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* Gusev and *P. keyserlingi* Amalitzky, respectively. Characteristic bivalve species: *P. verneuili* Amal., *P. semilunulata* Amal., *P. solenoides* Amal., *P. subparallela* Amal., *P. marposadica* Gusev, *P. rectodorsala* Gusev, *P. tschuvashica* (Gusev). The zone is recorded in the Volga–Ural and Dvina–Mezen basins of the East European Platform.

Zonal species of nonmarine bivalves from the *P. umbonata* group. All specimens are stored 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 Ural region, 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, stratigraphic position the same; **(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, Monastyrskii 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**: (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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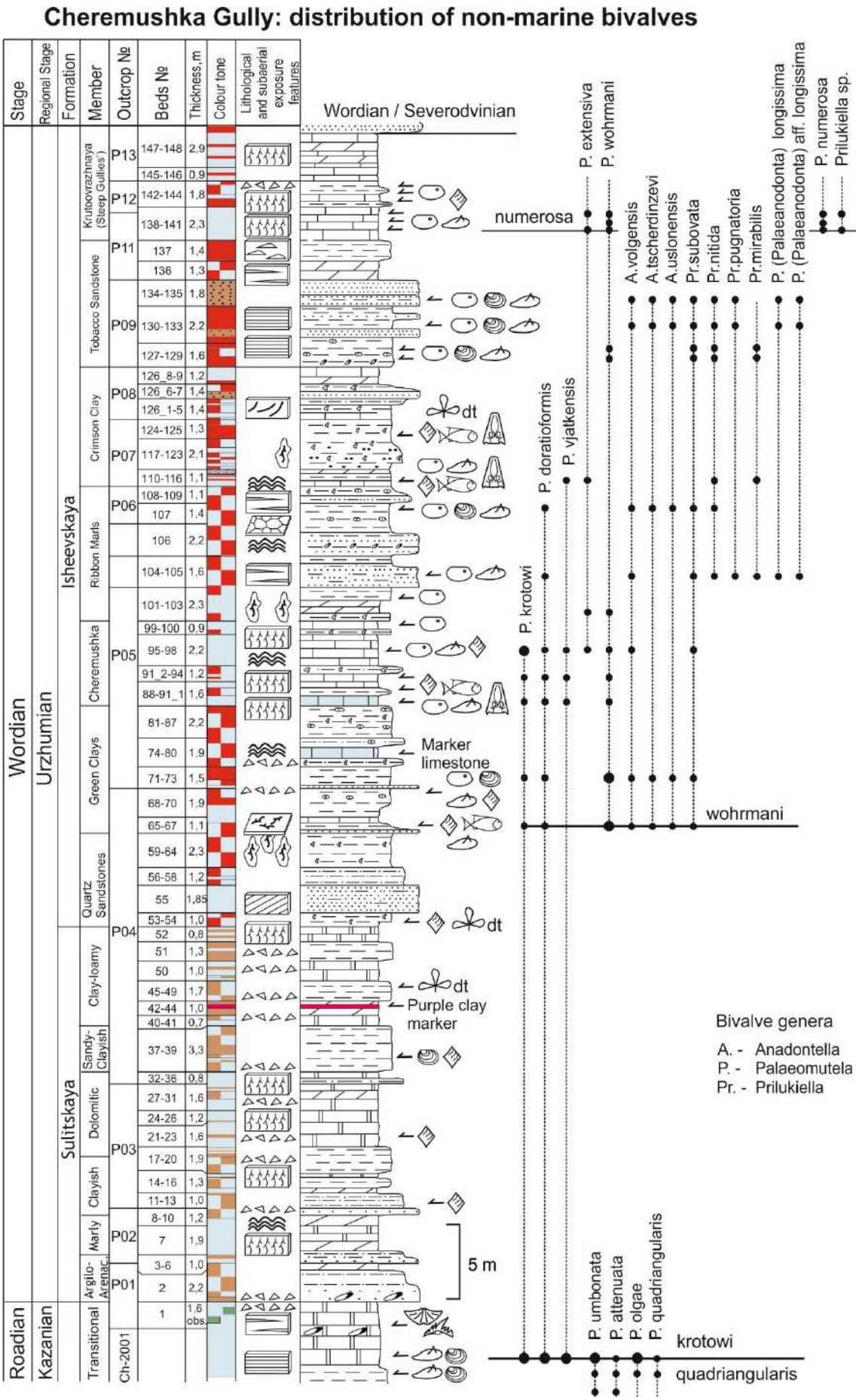

Cheremushka Gully: distribution of non-marine bivalves
Stage
Regional Stage
Formation
Member
Outcrop №
Beds №
Thickness,m
Colour tone
Lithological and subaerial exposure features
Roadian
Kazanian
Wordian
Urzhumian
Isheevskaya
Sulitskaya
Transitional
Argilo-Arenac.
Marly
Clayish
Dolomitic
Sandy-Clayish
Clay-loamy
Quartz Sandstones
Green Clays
Cheremushka
Ribbon Marls
Crimson Clay
Tobacco Sandstone
Krutoovrazhnaya (Steep Gullies)
Ch-2001
Wordian / Severodvinian
numerosa
wohrmani
krotowi
quadriangularis
Marker limestone
Purple clay marker
dt
5 m
P. extensiva
P. wohrmani
P. doratioformis
P. vjatkensis
P. krotowi
P. umbonata
P. attenuata
P. olgae
P. quadriangularis
A.volgensis
A.tscherdinzevi
A.uslonensis
Pr.subovata
Pr.nitida
Pr.pugnatoria
Pr.mirabilis
P. (Palaeanodonta) longissima
P. (Palaeanodonta) aff. longissima
P. numerosa
Prilukiella sp.
Bivalve genera
A. - Anadontella
P. - Palaeomutela
Pr. - Prilukiella

Tetrapods and fishes

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

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

The Crimson Clay Member is represented by an alternation of bacterial-algal limestones and bright speckled clays of soil and of basin origin. The limestones are, usually, riddled with numerous voids of plant roots *in situ*.

Tetrapod locality Cheremushka 1

Amphibians:

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

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

Reptiles:

Dinocephalia fam. ind. – single teeth of carnivorous 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 clay facies. The locality could be attributed to subautochthonous type due to the preservation of slightly deformed skulls and skeletons of juvenile amphibian. 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 passed the metamorphosis.

Reptiles:

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

Dinocephalia fam. ind. – single teeth of carnivorous;

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

The locality is confined to the clay gritstone which perform the basement of local alluvial lens. Locality contains a large number of individual bones of tetrapods and fish (Palaeoniscidae and Chondrichthyes) and represents typical allochthonous assemblage.

Tetrapod locality Pechishchi 1

The new locality of vertebrate fauna was founded during summer 2014 field work. It is situated 1 km south of the head of Cheremushka Ravine and is confined to the Crimson Clay Member of Urzhumian regional Stage.

In the new locality, the succession of the Crimson Clay Member has more alluvial and lacustrine character. Intervals with palaeosoils are not clearly defined. The thin bed (0.3 m) of dark grey (coal-like) lacustrine clay lies at the top of the succession and clearly differentiates this section from the reference one. The tetrapod locality is located within this clay bed as well as in the thin (0.15 m) underlying band of greenish-grey sandstone that forms the 'main amphibian bone bed'. The numerous separate bones and scales of fishes, actinopterygians and sharks, are concentrated in the thin layer of sandstone closer 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 passed the metamorphosis.

Reptiles:

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

Dinocephalia fam. ind. – single teeth of carnivorous;

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

Fishes:

Sphenacanthidae gen. et sp. nov.

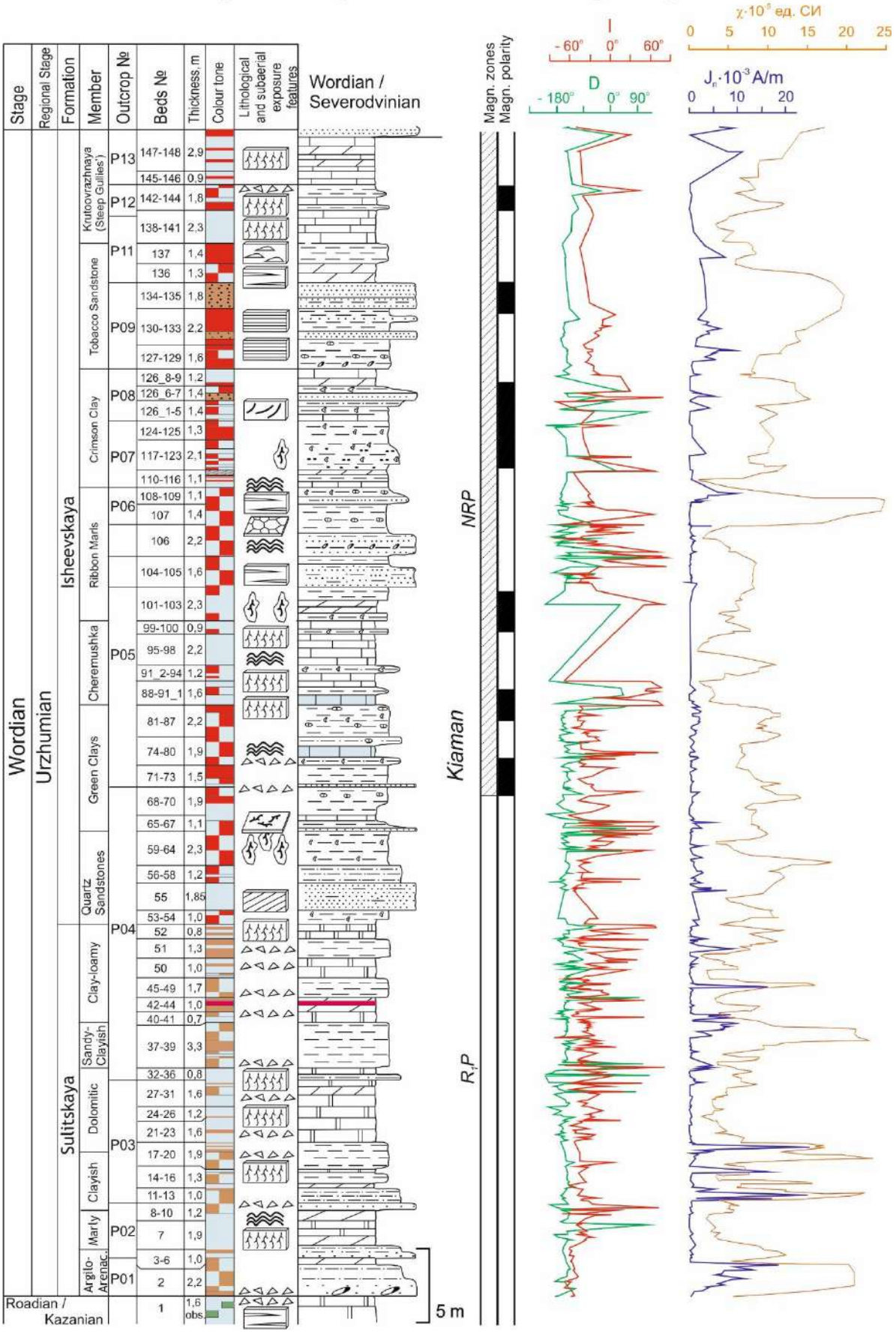
'*Lissodus*' cf. *zideki* (Johnson)

'Polyacrodus' sp. (gen. et sp. nov.; probably represented one of the Carcharhiniformes ancestor).

New locality has probably the alluvial genesis. The bones of adult temnospondyls are clearly predominated, but seymouriamorph and anthracoauromorph amphibians were not been found yet. Both carnivorous and herbivorous reptiles of different size compose the essential part of collected material.

The teeth of sharks usually are flattened and possessed the traces of abrasion at the tips that indicated the crushing adaptation of the jaw apparatus. Moreover, most of the bones including the fish scales, bear the clear traces of destruction that have preceded the burial, indicating the high energy of the water in the basin of sedimentation. There were no any bones found in articulated position, so new locality could be attributed to allochthonous type. The lithological data also confirm the alluvial genesis of the "productive" sandstone. The black clays overlain the 'main amphibian bone bed' of sandstone also contain bones of amphibians included into the flat dark-beige nodules sometimes occurring in the form of aggregations. Nodules represent either coprolite infilled by bones, either skeleton of tetrapods buried *in situ*.

Cheremushka Gully General profile with scalar magnetic parameters



Paleomagnetic studies

Paleomagnetic data of the Urzhumian Stage exposed in the Cheremushka Gully are based on 698 oriented specimens (Burov, Zharkov, Nurgaliev et al., 1997; Zharkov, 2007). Finely dispersed hematite which is responsible for the predominately reddish color of the rocks is the main carrier of NRM. Magnetization of the rocks of Sulitsa Formation is weak, and many specimens, particularly after cleaning, are measured at the limits of accuracy, with high error. Rejection of weakly magnetized specimens leads to the compact distribution of remaining 259 vectors around the direction of the reversed polarity. The Isheevo Formation, similarly to Sulitsa Formation, is characterized by substantial scatter of J_n^o directions remains after cleaning. When weakly magnetized specimens were rejected, 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 a higher value of magnetic viscosity and a relatively low value of 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 magnetized by the reversed polarity field of Kiaman Hyperzone (R_1P).

Formation / Age	N	Direction of J_n^o – ancient component of natural residual magnetization		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 NRP zone remains unclear in many aspects. Generally, the succession of the Sulitsa and the Isheevo Formations shows the dominance of reversed polarity of natural residual magnetization 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 with 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-clayish rocks. This allows the recognition of these intervals as episodes of methachronous magnetization (Zharkov, 1998).

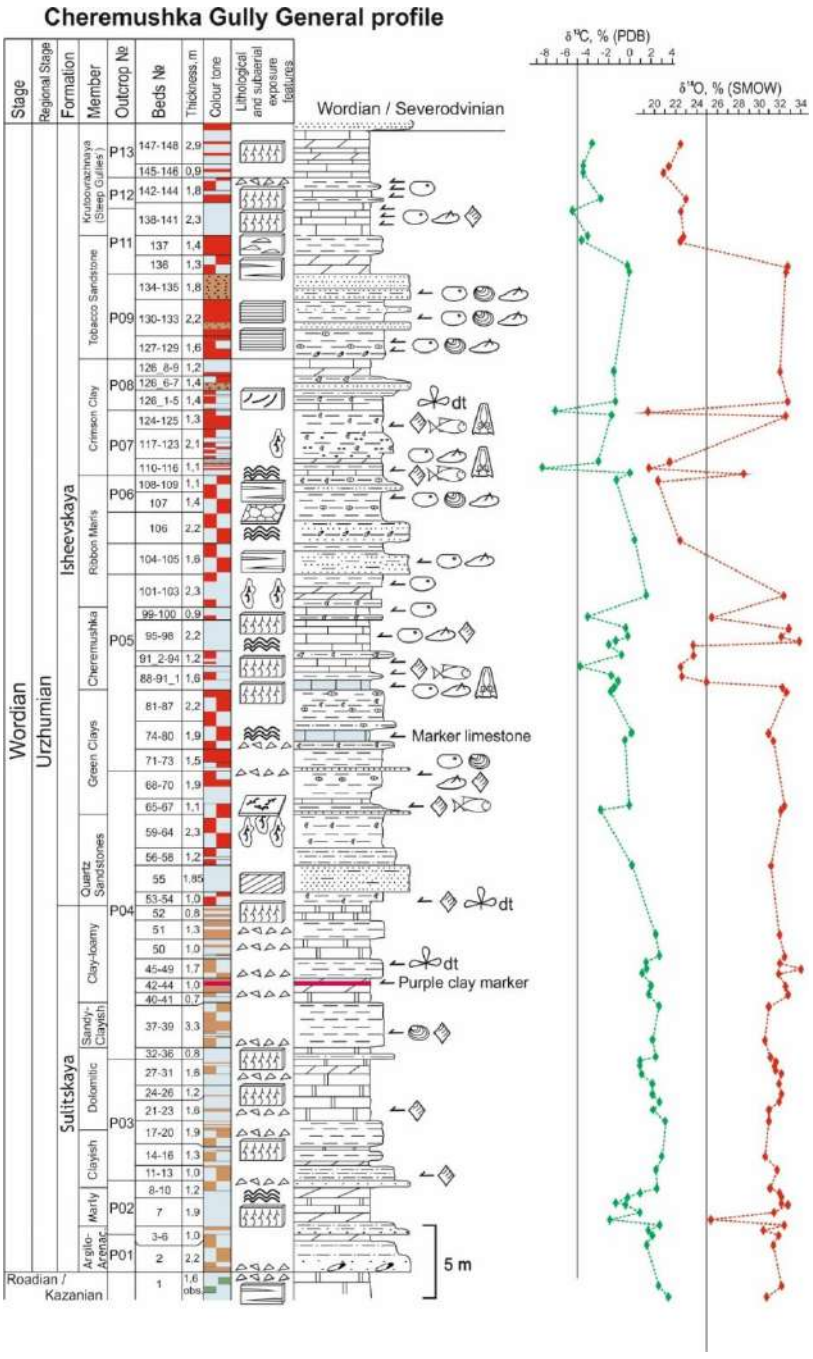
The distribution of the scalar magnetic parameters throughout the succession indicates its rhythmic structure. The changes in J_n and χ are at their most contrast in the lower rhythms. For instance, in the Argilo-arenaceous Member, at the base of the Urzhumian, the mean J_n values are 8×10^{-3} A/m, and the average χ is $21 \cdot 10^{-5}$ SI units, whereas in the overlying Marly Member these parameters are 0.39×10^{-3} A/m, and $2.1 \cdot 10^{-5}$ SI units respectively.

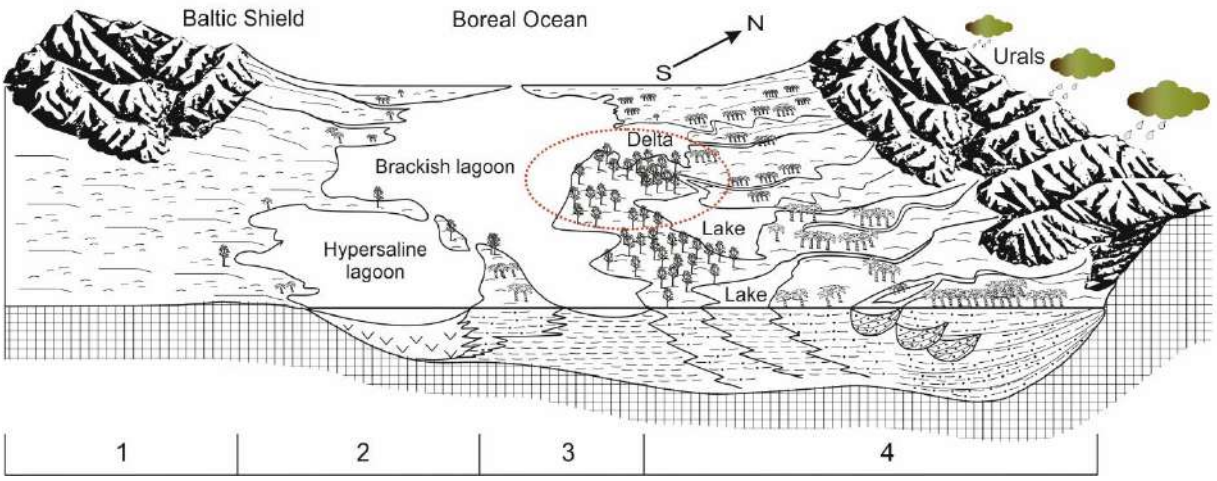
Sedimentological and geochemical data and depositional model of the Urzhumian regional Stage

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

Along the strike of the beds, the clayey breccias form a regular succession: (1) breccias, (2) silty-clay rocks with broken and subhorizontal sloping lamination, (3) silty-clay rocks with irregular undulated lamination and (4) silty-clay 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 gleization, and 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.





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

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 Clay Member respectively. Up 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 characterized 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 Clay Member respectively. Thereby, two negative excursions in the stable isotopic composition of carbon and oxygen in the Cheremushka Member and in the Crimson Clay Member are revealed. These excursions can be considered as global stratigraphic markers that suggest climate cooling and rising humidity.

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Teaching manual

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