The Early Permian Landscape in the Fore Urals

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When the English scientist Roderick Impey Murchison with his colleagues travelled through Russia and the Ural-region near Perm in 1841, they never expected to discover one of the most important gaps in the Earth's history. Between the Carboniferous, characterized by its huge lycopod and horsetail trees, and the Triassic, there existed another – overlooked until this moment – fifty million-year-long period, the "Permian system", as Murchinson indicated in a letter. During this time, a revolution that we can observe everywhere today took place. Insects and a special family of plants – the angiosperms or flowering plants – began their fruitful symbiosis to conquer the world. In a short period during the Paleozoic era, they generated all the features to adapt well and fit better than other plants and animals. And in no place can we experience this evolution better than in the Early Permian Fore-Urals. In two slightly time-different stages, the Artinskian and Kungurian, and two localities, Chekarda and Matvèevo. we can follow the creation of a magical world as it occurs today.

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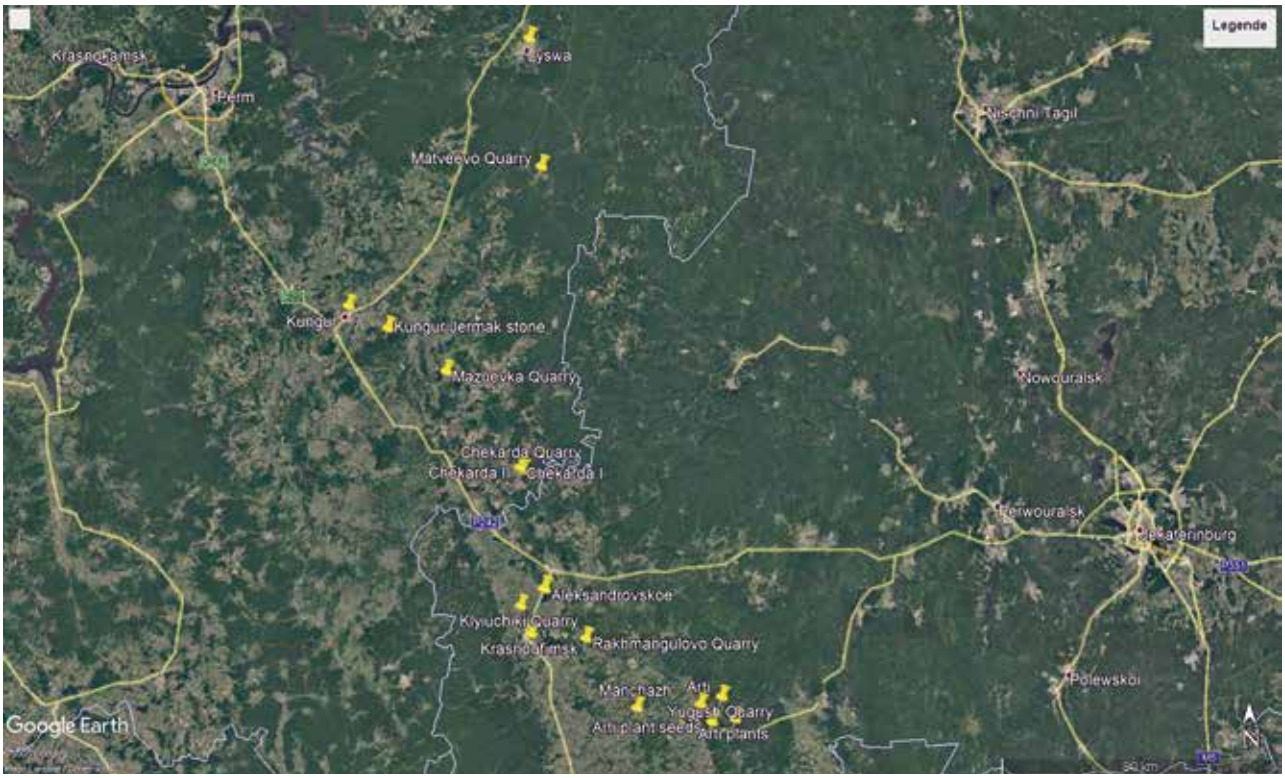


The Main Permian (Artinskian-Kungurian) Fossil-quarries in the Ekaterinenburg-Perm Area

The older Artinskian (290.1 till 283.5 Ma) fossil sites are located mostly around Arti, the Kungurian period (283.5 till 272,95 Ma), around the city of Kungur (drawing Thomas Gerasch).

Introduction

In 1841, Roderick Impey Murchison (1792–1871) travelled with the French palaeontologist, Edouard de Verneuil, Estonian-Russian mining expert Alexander von Keyserling, and the Russian officer and mineralogist, Nikolai Koksharov, from Moscow to Perm. Near the small town of Vyazniki and in several other places during their exploration of the western flanks of the Ural Mountains and near the city of Perm, Murchison noticed that based on rocks and fossils, the layers must be regarded as intermediate between Carboniferous and Triassic.

In the first letter presented to the Geological Society of London in April 1842, Murchison and Verneuil gave further details about marine fossils from Kazan, Vyatka and Perm. In 1845, Murchison wrote an interesting analysis, "*On the whole, however, we confess we are disposed to view these variegated sands and marls like those of Orenbourg as a part of the Permian system.*"

From that moment on, other geologists too began to write about the "Permian system", so the last remaining gap in the geological time scale was filled. Just before Murchinson gained scientific fame for describing the Silurian system in England and Wales, he participated in understanding the Devonian time. After that he realised that this "Permian system" was widespread across the world.

Due to long-lasting political circumstances and the remoteness of the locations, we have unsatisfactory information about the different stages and fossil record from these areas. Although, the Permo-Triassic beds cover about 1.4 million square kilometres of European Russia, reaching the Ural mountain range and providing an important record of changes in terrestrial environments to marine ecosystems before, during and after the end-Permian mass extinction (Benton et al. 2010).

The Mechetlino Kungurian-Artinskian Global Section

The small village of Mechetlino (Мечетлино) in the Russian-Bashkortostan region (South-Ural, near Ufa) was instituted as an ideal place for the Global Section Stratotype and Point (GSSP), also known as Golden Spike for the boundary of the Global Artinskian-Kungurian interval. It is called so due to the occurrence of conodonts such as *Neostreptognathodus pnevi* and *Neostreptognathodus lectulus*, ammonoids such as *Clausiuraloceras mechetlense* above the Kungurian boundary and some plant remains such as *Psygmophyllum.*

The entire region from Perm till Ekaterinenburg is interesting because older Artinskian deposits change to slightly younger Kungurian sediments and the marine biota alternate within a few kilometres to terrestrial ecosystems and a plethora of plants and insects exist, which testifies to a rapid life-explosion during that time.

Left: The hamlet Arti in the Sverdlovsk Oblast, Russia, about 200kilometress southwest of Ekaterinenburg. In 1874, the Russian geologist, Alexander Karpinsky, named the Artinskian age of the Permian Period due to many outcrops in this area. **Right:** Kungur in a photo from 1900 (Kungur Museum). The Kungurian geological stage remembers this city.

The Mechetlino Artinskian-Kungurian Stage

The research team (from left: Thomas Gerasch, Nicolas Wachtler, Martin Dammann, Michael Wachtler, Thomas Perner and, the interpreter, Lyuba Novokshonova) at the Mechetlino-quarry.

Mechetlino (Мечетлино), a small village in the Russian-Bashkortostan region, was recommended as the ideal place for the Global Section Stratotype and Point (GSSP), also known as Golden Spike, for the base of the Global Artinskian-Kungurian interval. In 2017, the Mechetlino Quarry became part of the first geopark in Russia. Additional conodonts confirmed the data of V. V. Chernykh on the Artinskian–Kungurian transition. Besides *Neostreptognathodus pnevi*, the second marker (*Neostreptognathodus lectulus*) of the base-Kungurian was established. This Artinskian–Kungurian transition is characterised by a rich association of small foraminifers, ammonoids and other marine biota. The occurrence of the ammonoid *Clausiuraloceras mechetlense* above the Kungurian boundary, which changed the representative Artinskian association, supports the insertion. Also, plants, especially *Psygmophyllum* and horsetails, are recorded.

Artinskian Sites Around Arti

Near the hamlet, Arti (former name Artinsk) are located several interesting fossil sites, especially near the roads over outcrop layers that hold rich and variegated fossils. This is comprehensible because in the extensive Taiga, on only a few places do open rock-layers come to light. Therefore, every new road-construction project offers a treasure trove to witness the past. Some of the places hold marine ecosystems, especially Goniatitaceae (*Metacoceras artiense*), surprisingly together with the plants. Other areas are pure marine, with a richness in brachiopods, nautiloids or trilobites.

Manchazh

In the immediate vicinity of the road from Manchazh towards Ckekmash (Sverdlovsk Oblast, GPS: Latitude 56°24‘59.34“N, longitude 58°14‘57.67“E) in Artinskian deposits, a rich marine ecosystem can be found. Abundant brachiopods like *Paramarginifera clarkei, Chaoiella gruenewaldti, Spinomarginifera* sp., *Tubaria cf. genuina, Waagenoconcha, Dictyoclostus or Paeckelmanella expansa* can be discovered . Also, trilobites or parts of them can be found. Not far from this purely marine fossil site, on the street from Manchazh till Ckekmash lies an abandoned waste disposal site, (GPS: Latitude 56°24’59.34”N, longitude 58°14’57.67”E), also from the Artinskian age, where fossil plants and conifers can be found. The layers are fragmented; therefore, the recovered specimens are small-sized.

On the road from Arti to Panteleykovo (Sverdlovsk Oblast, GPS: Latitude 56°22‘37.95“N, longitude 58°35‘24.13“E), among the Artinskian sediments consisting of grainy sandstones, an interesting fossil site holds *Goniatites*, but

Alexander Petrovich Karpinsky (1847–1936), a prominent Russian geologist and mineralogist, introduced the term ‘Artinskian’ in 1874.

Artinskian stage: Road to Yugush. Goniatitaceae and horsetails

On the road to Yugush. Three-dimensionally preserved horsetails (sometimes up to 25 cm long, Coll. Wachtler) and *Goniatites* can be found (Coll. Gerasch).

On the road Manchazh to Ckekmash a rich marine biota can be discovered.

The brachiopod *Paramarginifera clarkei*

Paeckelmanella expansa and Paramarginifera

Chaoiella gruenewaldti and *Spinomarginifera* sp.

Tubaria cf. genuina sometimes described as *Reticulatia cf. praeuralensis*

Paramarginifera clarkei

Some of the brachiopods and molluscs of the quarry

this location is especially rich in three-dimensional preserved seeds. Probably the most represent *Craspedosperma bardaeanum*-acorns belonging to *Psygmophyllum expansum.* No leaves are found there, probably due to the coarse-grained sand.
Another Artinskian fossil site is located about one kilometre north-west of Yugush (GPS: Latitude 56°26‘22.16“N, longitude 58°38‘11.53“E). In the coarse-grained sand present there, some isolated plants, especially three-dimensionally preserved horsetails (sometimes up to 25 cms long), can be found together with *Goniatites*. Unfortunately, they split immediately after being recovered if not fixed with glue.

Panteleykovo-Quarry Near Arti

On the road from the hamlet Panteleykovo (Russian Пантелейково) towards Arti (Sverdlovsk Oblast, GPS: Latitude 56°22’59.47”N, longitude 58°41’41.19” E), Artinskian sediments consisting of alternating sandstones, siltstones and argillites crop out. Michael Wachtler discovered layers that held abundant and well-preserved plants, especially Psygmophyllaceae, horsetails and ferns. Due to the sandy character, the quality is not as good as that of some of the layers from Matvèevo and Chekarda, but these will be compensated by well-maintained big slabs. It is also interesting that in contrast to most of the Kungurian beds, Panteleykovo near Arti pertain to the older Artinskian stage.
The Artinskian likely existed between 290.1–283.5 million years ago (Ma). It was preceded by the Sakmarian and followed by the Kungurian. The Kungurian ended about 272.95 million years ago. Therefore, between the Artinskian fossil sites near Arti, especially the plant-rich site in Panteleykovo, and Kungurian places like Chekarda, Matvèevo and Mazuevka, a time difference of about 10 million years has been

Artinskian stage: Panteleykovo near Arti, Goniatitaceae and plant-seeds

Foto Martin Dammann

This location is rich in three-dimensionally preserved seeds like *Craspedosperma bardaeanum*-acorns and *Goniatites.*

Panteleykovo near Arti: Artinskian leaf-variation on three square metres extraction

recorded. During that period, the evolution of the flora must have been considerable. On mere 3m2 of area in the Panteleykovo-fossil site, about twenty entire leaves were recovered that can be regarded as belonging to the *Psygmophyllum expansum* species. However, their variation-range is so extensive that some can feel disposed to classify them as different species or genera. For unknown reasons, during the Early Permian period, a plant-insect explosion happened that was completed during the later Kungurian stage in large parts. Unfortunately, in the locations near Arti, the most fragile parts of the plants or insects were not preserved due to the coarse sand and therefore, the question if just winged seeds or samaras were present could not be answered satisfactorily. However, from the different types of leaf, many directions of today's angiosperms can be traced. Interestingly, the Panteleykovo-fossil site lacks mainly the characteristic bilobed and multilobed leaves known as *Psygmophyllum cuneifolium*, that generate most of the samara fruits in Matvèevo and Chekarda.
A life-explosion in the Early Permian is not a new discovery. Also, in the coeval European fossil-sites, we have recorded the similar rapid evolution, concentrated among the gymnosperms like cycads, conifers and ginkgos. However, difficulties arose when it came to attributing these to extraordinary climate changes as during that time, Europe was located near the Equator, the Early Permian Siberia in a mild boreal climate, and only the southern hemisphere suffered glaciations.

The Klyuchiki-Quarry

Some of the most suggestive places for Artinskian ocean deposits can be encountered near the small town of Krasnoufimsk (Sverdlovsk oblast), especially a quarry 1 km southeast of the village of Klyuchiki (GPS: Latitude 56°40'44.30"N, longitude 57°43'31.59"E). It pertains to the Divjinskian Formation, Sarginskian Horizon of the Artinskian Stage (Naugolnykh, 2018).
The most frequently found benthic organisms in this area are brachiopods (*Yakovlevia artiensis, Dielasma moelleri*), bivalves (*Edmondia tschernyschewiana, Aviculopecten, Pterinopecten* sp., gastropods (*Euomphalus* sp., *Worthenia* sp.) and sponges. Interesting findings are the nautiloids (*Orthoceratites siphonocentralis, Paraconularia*) and ammonoids (*Metacoceras artiense, Paragastrioceras jossae, Uraloceras suessi*). Carapaces of the proetoid trilobite *Ditomopyge artinskense* can also be found; chondrichthyan fishes (*Helicoprion bessonowi*) and shark-teeth (*Cladodus* sp.) are very rare.
Strangely, sometimes plant remains from lycopods (*Sigillanangara klyuchiki*), horsetails and some preangiosperms are found. Due to the deposition of marine biota as well as land plants, it could be established that in the Artinskian-Kungurian period, these marine lagoons constituted the shore of the huge Angara continent. Continuous elevations and subsidence of the sea lagoon gave origin to the fossilisation of a variegated land biomass and marine animals.

Researcher Thomas Perner examining the fossils. On the road from Panteleykovo towards Arti, a rich Artinskian plant-deposit crops out. Especially, beautiful *Psygmophyllum* leaves can be found here.

The Artinskian fossil site Klyuchiki near Krasnoufimsk

Shark-tooth *Cladodus* sp (Coll. Brandt)

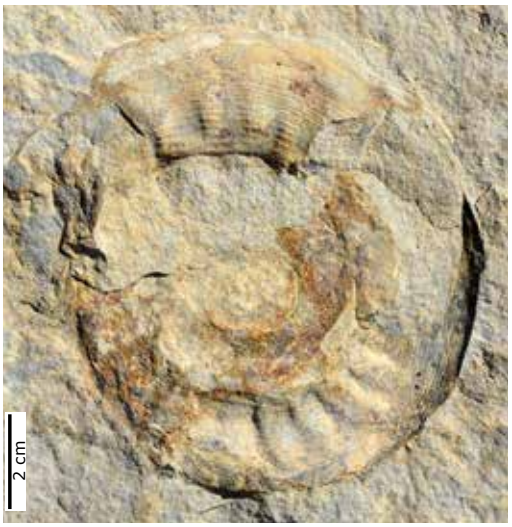
Shark-teeth *Helicoprion bessonowi* (Krasnoufimsk-Museum)

Uraloceras suessi Coll. Gerasch

Brachiopod *Yakovlevia artiensis* (Coll. Gerasch)

Nautiloids *Orthoceratites siphonocentralis*

Trilobite *Ditomopyge artinskense* (Ekaterinenburg-Museum



Paragastrioceras jossae, Coll Wachtler

The Klyuchiki-quarry near Krasnoufimsk (Sverdlovsk oblast)

Kungurian Sites around Kungur

Following the Artkinsian period is the Kungurian stage, named after the Russian city of Kungur, situated in the vicinity of Perm. It was introduced by the Russian geologist and palaeontologist, Alexandr Antonovich Stukenberg (1844–1905), in 1890. In the extended, albeit less researched, Russian fossil sites of the Fore Urals, the evolution of the plant-kingdom can be studied well. In the Kungurian era, the Angara continent kept changing between full marine environment, shore and terrestrian landscape.

The Yermak-Coral Reef Near Kungur

About 8 kms from the Kungur town on the bank the Sylva River near the Mezhevoy ravine (GPS: Latitude 57°22‘50.73“N, longitude 57° 7‘15.77“E), the famous Yermak Stone or better known as the Yermak reef

Left Klyuchiki-Quarry: A nautiloid (*Uraloceras suessi*) and a tree trunk (Coll. Wachtler). Right: Another smaller quarry is located at the hamlet Chigvintsevo, about 12 km from Krasnoufimsk. Several nautiloids were found there.

is located, which offers a good cross-cut through an Early Permian coral reef.
The location took its name from Yermak Alenin, a hero in Russian folk history, who led the Russian conquest of Siberia and won the final battle against the Islamic Khan in 1852. According to the folktale, Yermak crossed the deep canyon surrounded by mountain ridges and named the prominent hill after himself. Some parts in the vicinity are from the Artinskian age, while the others belong to the basal Kungurian age (Sylvanian formation).
The rock itself is built of a mix of algae, bryozoas, brachiopods, ostracodes, tetracoralla, crinoids, bivalves, small foraminifers, gastropods, cephalopods, trilobites, conodonts and other reef building organisms. The predominant bryozoas found here include *Polypora sargaensis, Polyporella repens, Exfenestella marie* and *Streblascopora vulgaris*. Another large group is constituted of brachiopods such as *Derbyia regularis, Krotovia pseudoaculeata, Waagenoconcha irginae, Liosotella septentrionalis, Chaoiella gruenewaltdi, Stenoscisma mutabilis, Rhynchopora variabilis, Hustedia remota, Dielasma elongata*. Typical bivalves found are *Pseudomonotis sexocostata* and *Aviculopecten elegantulis.* The corals present belong to the genera *Hexalasma hexaseptum, Amplexocarina irginae* or *Amplexocarina muralis*.

Aleksandrovskoe, Rakhmangulovo, Mazuevka

From the more recent Kungurian period, the Aleksandrovskoe section between Pridannikova and Achit, near the city of Krasnoufimsk (GPS: Latitude 56°43’10.02”N, longitude 57°49’57.61”E), the Mazuevka site near the Sylva River, about 12 kms northeast of Suksun (GPS: Latitude 57°14’38.73”N, longitude 57°27’24.50”E) and Rakhmangulovo, fairly well-preserved plants can be found. Also, the richness in *Psygmophyllum* leaves seen here is spectacular, with huge and well-preserved specimen. Mazuevka is located in the middle stream of the Sylva River in the Kishert district of the Perm region, southeast of the City of Kungur. The layers here are represented by siltstones and polymictic fine- and coarse-grained sandstones of yellow-gray or somewhat slightly greenish colour (Naugolnykh, 2013). Unfortunately, the sediments found here are not fine enough to view all the subtle parts of the plants and insects. Therefore, one cannot decide by looking at the seeds and fruits if they hold samaras or other finest appendices. The fossil site Mazuevka sometimes contains beautifully preserved *Psygmophyllum* leaves and also a rich *Rufloria* vegetation, enigmatic plants probably belonging to the first Monocots, and additionally some ferns and lycopods.

The Yermak reef near the Mezhevoy ravine, It constitutes an Early Permian lagoon and was built from corals, bryozoans and shells.

Right the frequent bryozoa *Polypora sargaensis* (Coll. Perner, Dolomythos-Museum, Italy)

Rakhmangulovo Fossil Site

It is a small quarry near the Rakhmangulovo hamlet, about 20 kms east of Krasnoufimsk and belongs to the Kungurian stage. In addition to *Psgymophyllum* leaves, enigmatic gymnosperm cones that can belong to extinct Pinus-conifers are also found (Ural Geological Museum, Ekaterinenburg).

Aleksandrovskoe Section between Pridannikova and Achit

The quarry is moderately rich in fossilised plants. The sediments are sometimes rough sandy, but the flora is variegated.

Some specimens on the main road near Aleksandrovskoe (left bank of the Zyurzya River). A flower (*Ptychocarpus distichus*, Natural history Museum, Ekaterinenburg) and a perfect twig from *Psygmophyllum cuneifolium* (Coll. Gerasch, Langenaltheim).

The World Fossil Lagerstätten Chekarda and Matvèevo

The most important sections of the Fore-Uralian Kungurian period are composed of the finest arenaceous-argillaceous deposits that crop out at Matvèevo near the Barda River and at Chekarda on the Sylva River. In the Early Permian age, shallow water lakes or lagoons were alternated by temporary streams, and this happened over several hundred thousand years. The plants were deposited not at long transport distances, but usually especially in the finest layers the remains are sparse. No marine organisms or shells were found.

Matvèevo Fossil Site

In contrast to the better-known fossil Lagerstätte at Chekarda, the outcrops at Matvéevo (Lyswa district), about 15 kms south-west of Kormovishche (GPS: Latitude 57°47’1.80”N, longitude 57°50’59.60”E), were never studied intensely. Finest-grained gray to yellow terrigenous siltstones crop out in diverse locations such as Krutaya Katushka 1, Krutaya Katushka 2, Matvéevo, Krasnaya Glinka, and Taezhnoe. Three of them – Krutaya Katushka 1, Krutaya Katushka 2 and Krasnaya Glinka – lay directly on the Barda River crossing Matvéevo (Naugolnykh, 2014). It is thought that the Matvéevo group is of the Filippovian age, meaning slightly older than the Chekarda beds, inserted as Irenian (Naugolnykh, 2014), both pertaining to the Early Permian Kungurian period.

In the thinly laminated grayish white and yellow marls and siltstones, extremely well-preserved plants can be found. Especially the higher sections near the Matvèevo village that are covered by soil and extant vegetation hold a fair amount of fossil insects in addition to the flora. Whole plants are not frequently found, but various parts such as leaves, stems, flowers and fruits can be seen. The huge number of different genera and species of plants found is interesting; the same could be said for the richness of insect families.

Mazuevka Site Near the Sylva River, Northeast of Suksun

The long outcrop yields not only huge and perfectly preserved *Psygmophyllum* foliage but also *Rufloria* leaves and ferns.

The differences between this site and the other classical fossil site Chekarda – both discovered by the amateur fossil hunter, Genrich Timofewitsch Mauer in the 1930 – are not enormous. Maybe Chekarda is a littler richer in insects, but the plant assemblages are better conserved and more variegated in Matvèevo. Bigger and detailed plant specimen can more easily be recovered in Matvèevo.

Chekarda Fossil Site

Chekarda is located about 20 kms east of Klyuchi (GPS: Latitude 57° 1’16.16” N, longitude 57°44’31.80” E). The conservation is unique, and the details of the insects and the plants, including their filigree parts, are well-maintained. The layers are composed of fine clastic sediments called Koshelevka-Formation (Irenian-horizon), a part of the Early Permian Kungurian. The sediments were deposited by shallow, not marine, rivers or are remnants of small lakes. Only isolated impressions of fishes, Diplopoda and Symphyla have been recorded (Sharov, 1999). The main outcrops are situated along the Sylva River, and the first, but small-sized, area rich in insects and well-preserved plants begins a little upstream of the Chekarda River mouth.

The second fossil site comes immediately after the Chekarda River mouth and reaches a considerable length of more than one kilometre. The richest layers are found near the Chekarda River, where finest-grained grey and yellow siltstones crop out in diverse lenses (Ponomareva, 1998; Zhuzhgova et. al., 2015). After a short distance downstream, the sediments lose, for the most part, their finest mud-sediments and change to more sandy lenses. Big slabs with amaz-

The Matvèevo - fossil site

Photo: Martin Dammann

Matvèevo - Taezhnoe, the most rich sediments

Krutaya Katushka on the Barda-River upstream of Matvèevo

Photo: Thomas Gerasch

Krasnaya Glinka on the Barda River

An original specimen (*Psygmophyllum cuneifolium)* from Matvèevo (Krutaya Katushka Barda-River) collected in 1933 by Genrich Timofewitsch Mauer (1881–1940), the local historian and researcher. He moved in his free time by boat on the Sylva and Barda rivers, discovering the world fossil sites Chekarda and Matvéevo (Ural Geological Museum, Ekaterinenburg).

ing fossilised branches and fronds can be recovered from this location without problems, but the finest veins and particularities of flowers, fruits or seeds are found upstream. The research circumstances in both the places, Matvèevo and Chekarda, resemble each other: different leaves, seeds, fructifications make the process of classification difficult. It is impossible to give every slightly diverse leaf or seed a new genus or species name. In that, the Euro-American Paleozoic-Mesozoic floras are more logically to decipher; many parts of the same plant make statistical interpretations easy.

The Global Importance of the Early Permian Fossil Sites of the Fore Urals

One of the greatest problems in palaeobotany that can be resolved here is the angiospermy. Cycads, which are dominant in the European Permo-Triassic floras, were never found in the layers of the former Angara-land. From the gymnosperms, only some conifers are found, but nothing in comparison with their dominance in Euramerican floras. However, in the Fore Urals, we encountered many hermaphroditic flowers with stamen and carpel, Asteraceae-like umbels consisting of many inflorescences and frequent florets, a multitude of samaras, acorns that looks like those of maples. Additionally, aggregated fruits, umbrella-like parachutes resembling pappus, racemes, berry fruits and flowers looking like Magnolias can be found.
The problem of classifying the extraordinary multitude of plants from the Early Permian Angara-continent can only be resolved by the intense studying of their fructifications. Seeds and fruits have a greater possibility of preservation due to their hardened character

The Chekarda - fossil site

Photos: Martin Dammann

Chekarda and the first fossil site upstream of the confluence and near the horizon the second fossil site

The researcher Thomas Gerasch examining the fossils and a huge horsetail on a slab

A stone-fruit from the collection of Mauer, 1938 (Museum Ekaterinenburg) and a box of fossils (Museum Perm)

and are very specific in many plant groups. The foliage has only limited meaningfulness due to their variety even within the same plant or tree and similarity concerning many families.
Only in Chekarda and Matvèevo, we recorded at least six aggregated fruits, including Magnolia-like, and, surprisingly, their flowers. There were four different kind of spikes, typically to grasses, and fruits resembling the Campanulaceae and Phytolaccaceae. Pappus, florets and capitula from probably five different Asteraceae were present. Extensive presence of samaras from almost five different broad-leaved trees like maples, elms or ashes can be found. Moreover, we encountered four acorns or nuts, typically from oaks or hazelnuts, and two different drupes from stone fruits.
Although the flowers today, just like in the past, are small-sized, more than ten different development stages were discovered. Mostly, they have clearly defined carpels and stamen incorporated in the same plant.
Without counting the cones of the conifers, the various strobili of the horsetails and the ferns, we encountered almost 25–30 different fruits that cannot be inserted in the European Permian's usually known gymnosperm-concepts. Also, it will be impossible to find solutions in former theories, if we do not accept that the angiosperms evolved just on the Carboniferous-Permian border.
Older authors (Zalessky, 1937b, 1939; Naugolnykh, 2014) have tried to put all the remains of plants such as Peltaspermales, Callipteridales, Coniferales or Ginkgophyta from the Fore Urals in one of the known Euramerican classification systems, but such methods and procedures were not successful. The Angaran vegetation was quite different from all other known floras worldwide to be obliged to elaborate a totally new, evolving concept.

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Contributions

Thomas Gerasch, Martin Dammann, Thomas Perner, Nicolas Wachtler and Michael Wachtler made fossil specimens available. Michael Wachtler analysed the data, made the drawings, photos and wrote the paper. Thomas Perner supported the work financially.

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